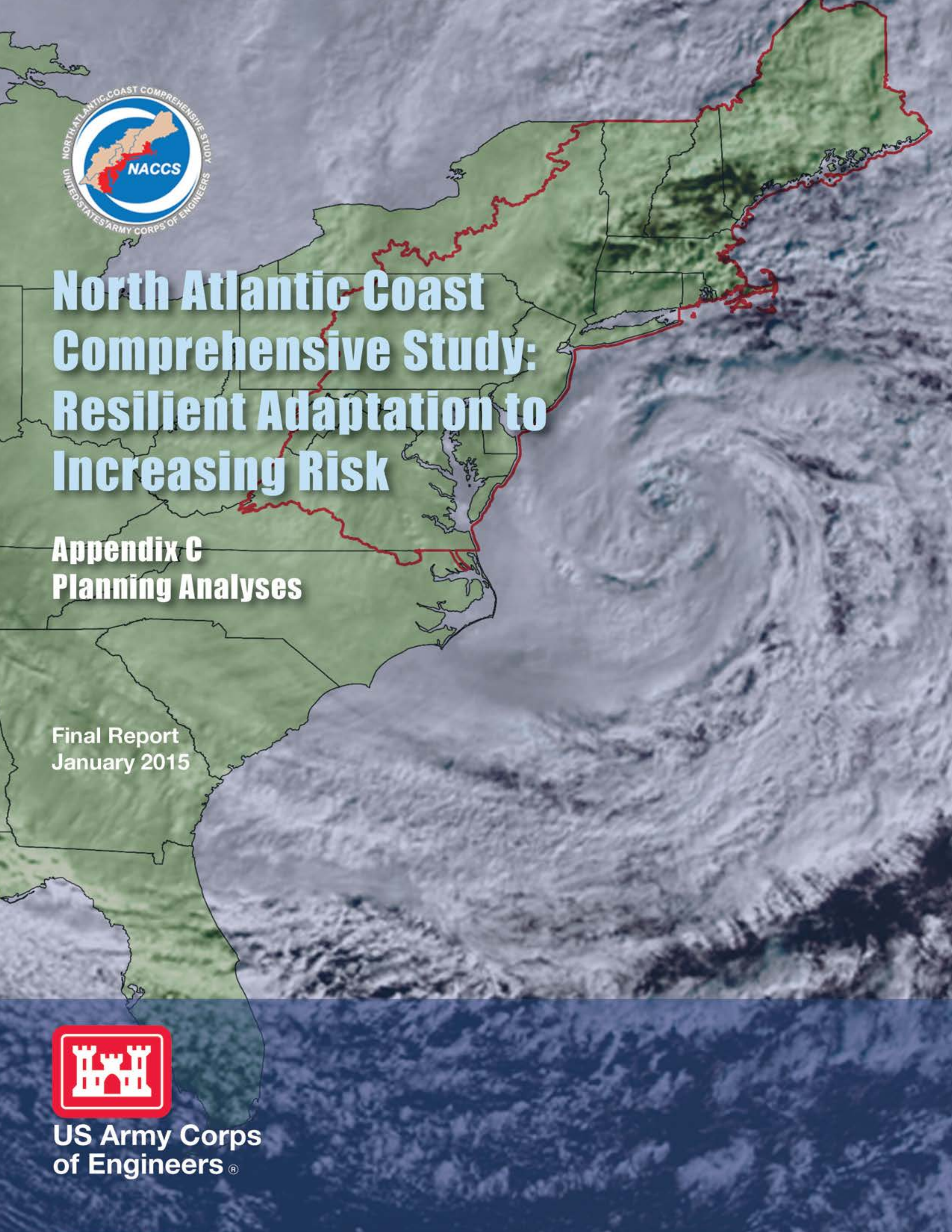

North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk

Appendix C
Planning Analyses

Final Report
January 2015

US Army Corps of Engineers®

APPENDIX C: PLANNING ANALYSES

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK

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I.1. Study Overview

On October 29, 2012, the remnants of Hurricane Sandy in the form of a post-tropical cyclone made landfall near Brigantine, NJ. Because of its tremendous size, the storm drove a catastrophic storm surge into the New Jersey and New York coastlines. As part of the extensive recovery effort, the North Atlantic Coast Comprehensive Study (NACCS) was authorized by the Disaster Relief Appropriations Act of 2013, Public Law (PL) 113-2, on January 29, 2013.

I.2. Authorization and Policy Guidance

PL 113-2, the Disaster Relief Appropriation Act of 2013, Chapter 4, authorized the U.S. Army Corps of Engineers (USACE) Investigations as follows:

> ***… using up to $20,000,000 of the funds provided herein, the Secretary shall conduct a comprehensive study to address the flood risks of vulnerable coastal populations in areas that were affected by Hurricane Sandy within the boundaries of the North Atlantic Division of the Corps.***

> "For an additional amount for ''Investigations'' for necessary expenses related to the consequences of Hurricane Sandy, $50,000,000, to remain available until expended to expedite at full Federal expense studies of flood and storm damage reduction: Provided, That using $29,500,000 of the funds provided herein, the Secretary of the Army shall expedite and complete ongoing flood and storm damage reduction studies in areas that were impacted by Hurricane Sandy in the North Atlantic Division of the United States Army Corps of Engineers: Provided further, That using up to $20,000,000 of the funds provided herein, the Secretary shall conduct a comprehensive study to address the flood risks of vulnerable coastal populations in areas that were affected by Hurricane Sandy within the boundaries of the North Atlantic Division of the Corps: Provided further, That an interim report with an assessment of authorized Corps projects for reducing flooding and storm risks in the affected area that have been constructed or are under construction, including construction cost estimates, shall be submitted to the Committees on Appropriations of the House of Representatives and the Senate not later than March 1, 2013: Provided further, That an interim report identifying any previously authorized but unconstructed Corps project and any project under study by the Corps for reducing flooding and storm damage risks in the affected area, including updated construction cost estimates, that are, or would be, consistent with the comprehensive study shall be submitted to the appropriate congressional committees by May 1, 2013: Provided further, That a final report shall be submitted to the appropriate congressional committees within 24 months of the date of enactment of this division: Provided further, That as a part of the study, the Secretary shall identify those activities warranting additional analysis by the Corps, as well as institutional and other barriers to providing protection to the affected coastal areas: Provided further, That the Secretary shall conduct the study in coordination with other Federal agencies, and State, local and Tribal officials to ensure consistency with other plans to be developed, as appropriate: Provided further, That using $500,000 of the funds provided herein, the Secretary shall conduct an evaluation of the performance of existing projects constructed by the Corps and impacted by Hurricane Sandy for the purposes of determining their effectiveness and making recommendations for improvements thereto: Provided

> further, That as a part of the study, the Secretary shall identify institutional and other barriers to providing comprehensive protection to affected coastal areas and shall provide this report to the Committees on Appropriations of the House of Representatives and the Senate within 120 days of enactment of this division: Provided further, That the amounts in this paragraph are designated by the Congress as being for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985: Provided further, That the Assistant Secretary of the Army for Civil Works shall provide a monthly report to the Committees on Appropriations of the House of Representatives and the Senate detailing the allocation and obligation of these funds, beginning not later than 60 days after enactment of this division."

The Disaster Relief Appropriations Act of 2013 also directed (USACE) to create three reports in addition to the NACCS.

- First Interim Report, to provide an assessment of authorized USACE projects for reducing flooding and storm damage risks in the affected area that have been constructed or are under construction, including construction cost estimates.
- Second Interim Report, to identify previously authorized but unconstructed USACE projects and projects under study by the USACE for reducing flooding and storm damage risks in the affected area, including updated construction cost estimates.
- U.S. Army Corps of Engineers Hurricane Sandy Coastal Projects Performance Evaluation study, to evaluate the performance of existing projects constructed by the USACE and impacted by Hurricane Sandy for the purposes of determining their effectiveness and making recommendations for improvements.

Policy guidance for the NACCS was provided by Major General Michael J. Walsh, the Deputy Commanding General, Civil and Emergency Operations of the U.S. Army Corps of Engineers (USACE, 2013):

> "The Comprehensive Study will include a framework for identifying flood and coastal flood risk reduction measures and opportunities for multi-agency action, planning level cost estimates, a summary of how sea level change and climate change might affect risk reduction strategies, identification of benefits and impacts that might be associated with different risk reduction measures, an inventory of interagency tools and resources, identification of activities and areas warranting further analysis, identification of further study and design efforts that might be warranted, and the identification of institutional and other barrier to providing comprehensive protection to affected coastal areas. …However, the comprehensive plan will not identify a 'recommended plan' nor justify projects. It is not a decision document, but a framework from which more detailed evaluations can be pursued."

The Water Resources Reform and Development Act of 2014 (Section 3026 and the Joint Explanatory Statement of the Committee of Conference) provided further clarification to USACE:

> "(a) In General – As part of the study for flood and storm damage reduction related to natural disasters to be carried out by the Secretary under title II of division A of the Disaster Relief Appropriations Act, 2013, under the heading "Department of the Army – Corps of Engineers – Civil – Investigations" (127 Stat. 5), the Secretary shall make specific project recommendations.

> (b) Consultation – In making recommendations pursuant to this section, the Secretary may consult with key stakeholders, including State, county, and city governments, and, as applicable, State and local water districts, and in the case of recommendations concerning projects that substantially affect communities served by historically Black colleges and universities, Tribal Colleges and Universities, and other minority-serving institutions, the Secretary shall consult with those colleges, universities, and institutions."

The NACCS study area encompassed 10 states and the District of Columbia. As required by Public Law 113-2 and Section 3026 of the Water Resources Reform and Development Act of 2014, stakeholder outreach included Federal and state agencies; coastal zone management teams, tribal liaisons; non-governmental organizations; industry; and academia including historically black colleges and universities, tribal colleges and universities, and other minority serving institutions. These stakeholders provided local knowledge of the study area, participated in multiple panel discussions, and assisted with website development to solicit and share information. In addition, the NACCS focus areas, which did not have USACE-partnered projects or studies in place or underway at the time of Hurricane Sandy, were identified as areas warranting further analysis by USACE. Additional information related to the NACCS focus area analyses for opportunities warranting further analysis is included in the State and District of Columbia Analyses Appendix.

I.3. Study Area

The study area is the Atlantic Ocean coastline, back bay shorelines, and estuaries within portions of the USACE North Atlantic Division. The study area (Figure I-1) includes counties that were affected by Hurricane Sandy during the October 27-31, 2012 period. "Affected" is defined as being those counties that experienced the furthest extent of Hurricane Sandy's storm surge. The overall study area is estimated to include over 31,200 miles of coastline, which was computed using the National Oceanic and Atmospheric Administration (NOAA) Environmental Sensitivity Index (ESI) shoreline data (NOAA, 2013). In addition, the Federal Emergency Management Agency (FEMA) Modeling Task Force (MOTF) Total Damage Impact Analysis layer represents a composite impact analysis that was completed in the wake of Hurricane Sandy that includes the following criteria: impacted population, supporting critical infrastructure, environmental conditions, FEMA flood insurance claims, and shoreline characteristics.

Figure I-1 provides an overview of the FEMA MOTF impact analysis symbolized using the following criteria:

- Very High (Purple): Greater Than 10,000 of County Population Exposed to Surge
- High (Red): 500 - 10,000 of County Population Exposed to Surge, or Modeled Wind Damages > $100M, or High Precipitation (>8 inches)
- Moderate (Yellow): 100 - 500 of County Population Exposed to Surge, or Modeled Wind Damages $10 - $100M, or Medium Precipitation (4 to 8 inches)
- Low (Green): No Storm Surge Impacts, or Modeled Wind Damages < $10M, or Low Precipitation (<4 inches)

Ten States and the District of Columbia are included in the Study Area (New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland and Virginia). A more detailed discussion is provided for each state in the State and District of Columbia Analyses Appendix. Maine was not included in the Framework analyses because minimal impacts from storm surge were documented as part of FEMA's post-Sandy storm impact assessments. Additionally, the USACE Hurricane Sandy Coastal Projects Performance Evaluation Study included an assessment that for the 13 USACE coastal storm risk management projects in northern Massachusetts and Maine, and it noted that Hurricane Sandy was generally less than a 20-percent annual chance event with negligible damages to project features. Based minimal impacts and the authorization language that defined the study area as areas affected by Hurricane Sandy, Maine was not included as part of the NACCS study area. Regardless, Nor'Easters primarily, but tropical storm periodically affect the Maine coastline, and stakeholders and communities could apply the Framework to address flood risk as well as utilize the various products generated as part of the NACCS effort. The Commonwealth of Pennsylvania did not actively participate in the NACCS, so correspondingly a separate chapter was not included in the State and District of Columbia Analyses Appendix.

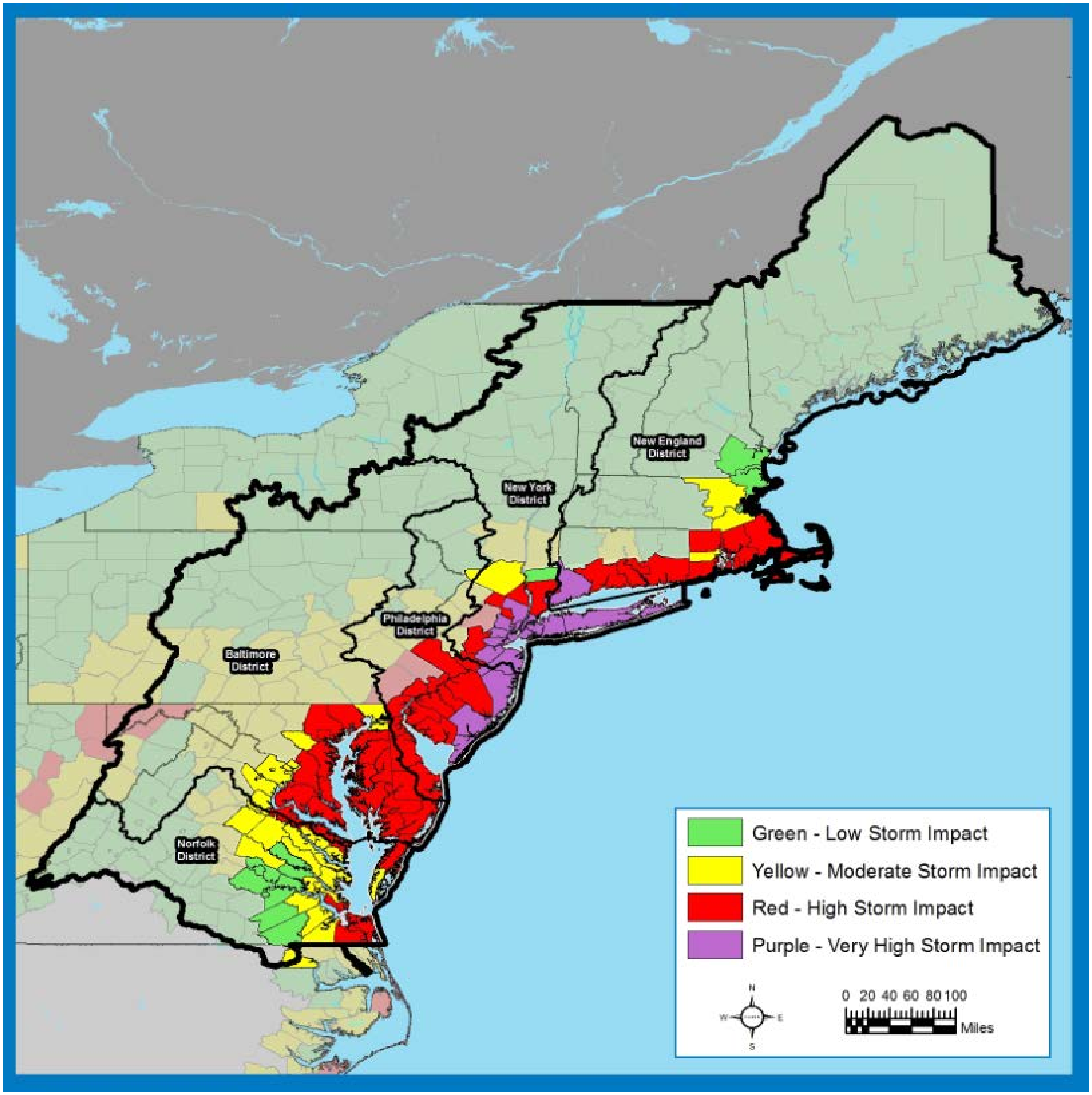


Figure I-1. Areas Impacted by Hurricane Sandy with Highlighted Counties Included in the NACCS Study Area (FEMA MOTF, 2013)

I.4. Purpose and Goals

The purpose of the North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk is to encourage action by all to implement coastal storm risk management strategies. Action is needed by all to reduce the risk from, and make the North Atlantic region more resilient to, future storms and impacts of sea level change.

Goals:

- Provide a risk management framework, consistent with the National Oceanic and Atmospheric Administration (NOAA)/USACE Infrastructure Systems Rebuilding Principles; and

- Support resilient coastal communities and robust, sustainable coastal landscape systems, considering future sea level and climate change scenarios, to manage risk to vulnerable populations, property, ecosystems, and infrastructure.

I.5. Study Approach

The NACCS is intended to be a collaborative effort undertaken with Federal, state, tribal, academia, non-governmental organizations (NGOs), and local stakeholders that utilizes the best science and engineering available to the study team. Figure I-2 shows the organizational structure of the study effort which includes the USACE North Atlantic Division's National Planning Center of Expertise for Coastal Storm Risk Management, Institute for Water Resources (IWR), and Engineering Research and Development Center (ERDC).

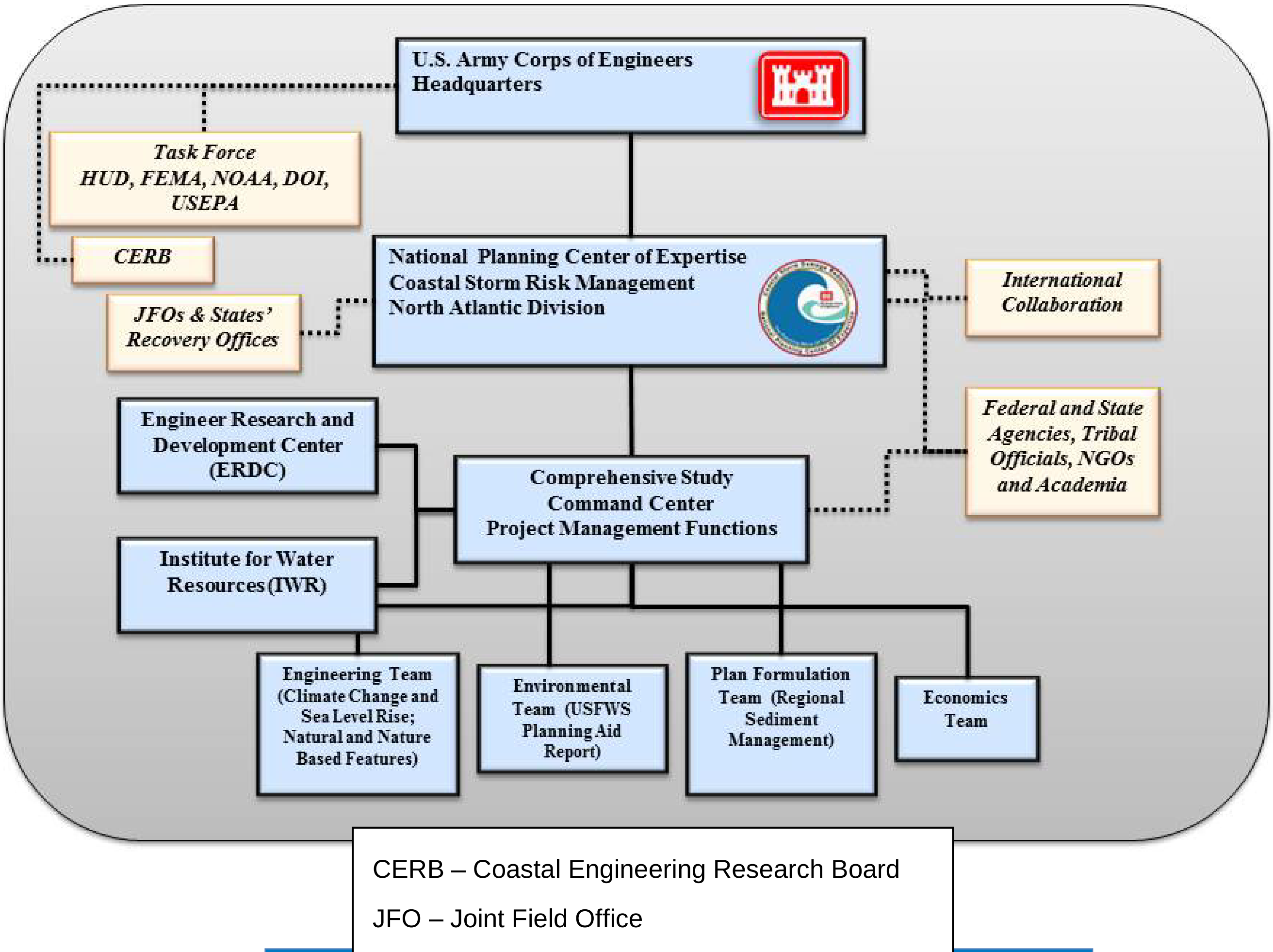


Figure I-2. NACCS Organizational Structure

In addition, there were forums for additional Federal, state, tribal, local, academia and non-governmental input to the study development and review. Those forums included a collaboration webinar series, technical working meetings, and the NACCS public website. Chapter III of the Main Report and the NACCS Collaboration Report provide additional information.

II. Coastal Storm Risk Management Framework Alignment with USACE Planning and Other Initiatives

However, given the scale of the NACCS study area, the timeframe to respond to the Congressional mandate, and policy guidance that this not be considered a typical USACE decision document, the NACCS does not include project-specific recommendations. Rather, it presents the framework that can be used by communities, states, tribes, and Federal agencies to identify risk, exposure, and vulnerability, as well as coastal storm risk management measures, to reduce risk and promote resilience. The NACCS is not a typical USACE feasibility study leading to project-specific recommendations. Additional investigation and evaluation of strategies, solutions, and plans at a smaller scale would be required for project-specific recommendations, while being considered within a systems perspective.[1]

The Framework is intended as a three-tiered analysis, which repeats the steps at each tier (Figure IV-1). Tiers 1, 2, and 3 are defined by different scales, objectives to address flood risk, and stakeholders for input and feedback into the respective evaluations. The application of the Framework as part of the NACCS presents a large-scale illustrative evaluation of risk and exposure for the North Atlantic Coast study area (Tier 1). For the NACCS Tier 1 application, national datasets were used to complete the various analyses so that the datasets would be consistent across state boundaries. Due to the scale, the datasets are likely not as refined as state or local datasets, which is why the steps of the Framework are repeated at smaller scales as part of a Tier 2 and Tier 3 assessment. Furthermore, steps 6-9 of the Framework were not completed as part of the NACCS. These steps require refined datasets and analysis as well as refined objectives and constraints to be evaluated at a smaller scale (Tier 2 and/or Tier 3) leading to the selection of a plan.

As part of Tier 2 and Tier 3, the steps presented in the Framework would be repeated and adapted to a smaller, community-specific scale, incorporating refined datasets and societal values for exposure, risk, and vulnerability assessments (Tiers 2 and 3). Conceptual Tier 2 assessments were also completed as part of the NACCS. Ten example areas, one for each state and the District of Columbia, applied the concepts of the tiered approach to the Framework at a smaller scale. However, a refined exposure and risk assessment was not completed for the Tier 2 examples. Rather, the Tier 1 exposure and risk assessments were used with only refined assumptions related to flood risk management measures. The results of the Tier 2 assessments are presented in the State and District of Columbia Analyses Appendix.

Following a Tier 2 assessment, Tier 3 would likely include a cost-to-benefit analysis leading to the selection of a plan. Additionally, the Framework can be used as a planning tool in anticipation of the next big storm and for climate change adaptation planning. Addressing long-term flood risk and vulnerability should be taken into consideration when addressing the current flood risk and vulnerability.

Table II-1 identifies how the NACC Coastal Storm Risk Management Framework aligns with the typical USACE six step planning process.

[1] For a typical USACE feasibility study leading to an agency recommendation, the USACE plan formulation process includes identifying problems and opportunities, forecasting future conditions, identifying alternatives, and evaluating and comparing alternatives leading to a recommended plan for action or implementation. This recommended plan would evaluate coastal storm risk within the context of forecasted future conditions and potential exacerbated effects of water levels from sea level change, and would include estimates of damages associated with flood inundation, waves, and erosion.

Table II-1. USACE Six Step Planning Process	
Step 1	Identify problems, needs, and opportunities through exposure and risk assessments • Hurricane Sandy impacts • Research of existing reports or plans developed by others
Step 2	Inventory existing conditions and forecast future conditions of the study area • Collect existing data • Identify planning horizon • Inventory existing plans and studies • Define and delineate planning reaches • Map inundation, exposure, and risk
Step 3	Identify management measures to address flood risk • Identify the shoreline types within the study area • Consider measures that are applicable to the shoreline types in the study area
Step 4	Evaluate measures (iterative process) • Multiplying exposure by inundation (which is referenced to some probability of that inundation level occurring) presents vulnerability • Each level includes generally more information at a smaller scale
Step 5	Compare alternative plans • No detailed investigation of alternative plans was completed due to the scale and time constraints • No detailed alignment of measures, cost estimates, economic benefits analysis, real estate requirements, hazardous, toxic, radioactive waste assessments were completed
Step 6	Select recommended plan • No site-specific recommendations will be included in the NACCS • Further investigation and evaluation of alternative plans would be required • NEPA and public involvement required to recommend an action by a Federal agency

Any subsequent investigations comparable to Tier 3 analyses conducted by USACE as part of the standard USACE Civil Works General Investigations would follow the SMART Planning Principles. SMART Planning – Specific, Measurable, Attainable, Risk-Informed, and Timely – supports the USACE Planning Modernization initiative of completing high quality feasibility studies with shorter timeframes and lower costs. In conjunction with the Planning Modernization initiative, a February 8, 2012 memorandum signed by the Deputy Commanding General for Civil and Emergency Operations directs all USACE feasibility studies to follow a 3x3x3 rule: be completed in a target goal of 18 months but no more than three years; cost no greater than $3 million; and require three levels of vertical coordination (District, Division, and HQUSACE).

The NACCS accounts for the following:

Coastal and Marine Spatial Planning. Consistent with the recommendations of the Interagency Ocean Policy Task Force recommendations, the NACCS utilized Coastal and Marine Spatial Planning (CEQ, 2010). This is a comprehensive, adaptive, integrated, ecosystem-based, and transparent spatial planning process, based on sound science, for analyzing current and anticipated uses of ocean and coastal areas. Coastal and Marine Spatial Planning identifies areas most suitable for various types or classes of activities in order to reduce conflicts among uses, reduce environmental impacts, facilitate compatible uses, and preserve critical ecosystem services to meet economic, environmental, security, and social objectives. In practical terms, Coastal and Marine Spatial Planning provides a public policy process for society to better determine how the ocean and coasts are sustainably used and protected - now and for future generations.

Climate Change Adaptation Task Force. On October 28, 2011, the Climate Change Adaptation Task Force released the 2011 Interagency Climate Change Adaptation Task Force Progress Report outlining the Federal government's progress in expanding and strengthening the nation's capacity to better understand, prepare for, and respond to extreme events and other climate change impacts. The report provided an update on actions in key areas of Federal adaptation, including: building resilience in local communities, safeguarding critical natural resources such as freshwater, and providing accessible climate information and resources to help decision makers manage climate risks. The NACCS is consistent with these actions.

Principles and Guidelines.

The Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) govern how Federal agencies evaluate proposed water resource development projects. Since 1983, the P&G have provided direction to Federal agencies when evaluating and selecting major water projects, including projects related to navigation, ecosystem restoration, and flood damage reduction. The 1983 standards used a narrow set of parameters to evaluate water investments that made it difficult for Federal agencies to support a range of important projects that communities want, or in some cases precluded support for beneficial projects. Lack of local support for P&G selected projects has often led to substantial delays, costing taxpayers and leaving communities at risk. In the Water Resources Development Act (WRDA) of 2007, Congress instructed the Secretary of the Army to develop a revised P&G (Section 2031). To promote consistency and informed decision making, in 2009, the Administration began the process of updating the P&G for Federal agencies engaged in water resources planning, including USACE, U.S. Environmental Protection Agency (EPA), U.S. Department of Agriculture, U.S. Department of the Interior, Department of Commerce, Tennessee Valley Authority, and FEMA.

The updated P&G, now referred to as the Principles, Requirements and Guidelines (PR&G), is comprised of three phases of modernization efforts: 1) Principles and Requirements; 2) Interagency Guidelines 3) Agency Specific Procedures. In March 2013, the Administration released the final set of Principles and Requirements (P&R) that lays out broad principles to guide water investments. In addition, the Administration also released, draft Interagency Guidelines, for implementing the Principles & Requirements in March 2013.

The updated P&R include a number of important changes that modernize the current approach to water resources development. They allow communities more flexibility to pursue local priorities; take a more comprehensive approach to water projects that maximizes economic, environmental, and social benefits; promote more transparent and informed decision making across the Federal Government; and ensure responsible taxpayer investment through smart front-end planning so that projects proceed more quickly, stay on budget, and perform better. Developed through interagency collaboration, the Interagency Guidelines lay out the methodology for conducting implementation studies under the new P&R. The final Guidelines will incorporate feedback from the public and stakeholders. Upon finalization of the Interagency Guidelines, each agency will update its agency specific procedures, as needed to apply the new PR&G to their agency-specific missions.

Developed by Federal agencies and incorporating extensive public comment as well as input from the National Academy of Sciences, the modernized PR&G will help accelerate project approvals, reduce costs, and support water infrastructure projects with the greatest economic, environmental and community benefits. They will also allow agencies to better consider the full range of long-term benefits of protecting communities against future storm damage, as well as promoting other locally driven priorities.

Executive Order 11988.

Executive Order (EO) 11988, issued May 24, 1977, directs Federal agencies to take action to reduce the risk of flood loss, minimize the impact of floods on human safety, health, and welfare, and to restore and preserve the natural and beneficial values served by floodplains. The intent of EO 11988 was to avoid floodplain development, reduce risk associated with floods, and restore and preserve natural floodplain services. Example actions to consider include the following: relocation; restoration and preservation of wetlands, marshes, and related natural habitat; implementation of measures that will enhance fish and wildlife values; and restoration and re-vegetation of damaged beaches and dunes.

When considering adverse impacts for a specific project, USACE would address induced new development in the floodplain or induced improvements to existing development in the floodplain that would increase potential flood damages as well as the detrimental effect of induced activities on natural floodplain services. Although the NACCS Coastal Storm Risk Management Framework will not recommend specific projects, the intent of EO 11988 is considered so that subsequent evaluations include in the decision-making process opportunities for public involvement, viable methods to reduce impacts of future development, and minimize the impacts of floods on human safety, health and welfare, and floodplain services. Additionally, natural and nature-based features (NNBF), which could be incorporated into some areas for flood risk management (likely lesser developed areas) to be considered for other uses, such as enhancing, maintaining, or restoring the natural and beneficial services of floodplains.

The effects of Hurricane Sandy and other storms have caused extensive losses and degradation of natural and beneficial values of the floodplain. Future flood losses and floodplain degradation are unacceptable and may even be increasing. Furthermore, the NACCS is an opportunity to demonstrate an exemplary and comprehensive approach to floodplain management and embed within the Coastal Storm Risk Management Framework, the direction and intent of EO 11988, which is to avoid to the extent possible the long- and short-term adverse impacts associated with the occupancy and modification of floodplains, and to avoid direct and indirect support of floodplain development wherever there is a practicable alternative. It is recognized that this will be a major challenge considering the level of existing development within the area.

Therefore, key components of the Coastal Storm Risk Management Framework consistent with EO 11988 are:

1. Ensuring rigorous compliance with EO 11988, Federal guidance and regulations, and USACE guidance, policy, and regulations when evaluating individual projects; and

2. Implementing an analysis of the effects of USACE policies and programs and the development of new or improved policies and programs to meet the intent of EO 11988.

Hurricane Sandy Rebuilding Task Force: Hurricane Sandy Rebuilding Strategy. In recognition of the rebuilding challenges facing the region, President Obama signed an Executive Order on December 7, 2012 creating the Hurricane Sandy Rebuilding Task Force, and designating the Secretary of Housing and Urban Development, Shaun Donovan, as Chair. The President charged the Task Force with identifying and working to remove obstacles to resilient rebuilding while taking into account existing and future risks and promoting the long-term sustainability of communities and ecosystems in the Sandy-affected region.

In coordination with the Hurricane Sandy Rebuilding Task Force, NACCS incorporated various elements described in the recommendations included in the Task Force's report dated August 2013. Preparing for the next big storm event, the Task Force's recommendations linked to the NACCS include promoting resilient rebuilding through innovative ideas, regionally coordinated approach to infrastructure investment, and building local governments capacity to plan for long-term rebuilding and prepare for future disasters.

Recommendation No. 4 established guidelines for the investment of the Federal funds for the recovery of the impacted region. These funds are to be used for recovery and to build back smarter and stronger with the following outcomes in mind:

1. Align the funding with local visions for rebuilding,
2. Get assistance to families, businesses, and communities efficiently and effectively with maximum accountability,
3. Coordinate the efforts of Federal, state, and local governments and ensure a region-wide approach to rebuilding, and
4. Ensure the region is rebuilt in a way that makes it more resilient – that is better able to withstand future storms and other risks posed by a changing climate.

Recommendation 22 – Develop a consistent approach to valuing the benefits of NNBF to infrastructure development and develop resources, data, and best practices to advance the broad integration of the NNBF. The work associated with NNBF as part of the NACCS provides a framework for the evaluation and implementation of NNBF such that NNBF would be included as part of a larger array of measures to achieve coastal risk reduction and resilience.

National Disaster Recovery Framework - Resilience and Sustainability

A successful recovery process promotes practices that minimize the community's risk to all hazards and strengthens its ability to withstand and recover from future disasters, which constitutes a community's resilience. A successful recovery process engages in a rigorous assessment and understanding of risks and vulnerabilities that might endanger the community or pose additional recovery challenges. The process promotes implementation of the National Infrastructure Protection Plan (NIPP) risk management framework to enhance the resilience and protection of critical infrastructure against the effects of future disasters. Resilience incorporates hazard mitigation and land use planning strategies; critical infrastructure, environmental and cultural resource protection and preservation; and sustainability practices to reconstruct the built environment, and revitalize the economic, social and natural environments.

As part of the National Disaster Recovery Framework, post-disaster recovery efforts occur at the Federal level, which integrates staff from a myriad of Federal agencies in the disaster area joint field offices (JFOs). The Federal teams work directly with state and local government representatives in order to manage the recovery effort. The New York and New Jersey JFOs prepared Federal Recovery Support Strategies. The strategies present priorities, engagements, Federal support for implementation of recovery strategic initiatives and next steps for various recovery support functions (RSFs), such as housing, infrastructure, economics, health and social series, natural and cultural resources, and community planning. USACE is the coordinating agency for the infrastructure systems RSF. The NACCS Coastal Storm Risk Reduction Framework incorporated components of the strategic engagements and initiatives in New York and New Jersey such that this information would be transferable to other areas with similar impacts from future storms.

III. Impacts of Hurricane Sandy

III.1. Physical Description of Hurricane Sandy

The NOAA Center for Operational Oceanographic Products and Services (CO-OPS) maintains a network of oceanographic and meteorological stations along the United States' coastlines to monitor air/water temperatures, water levels, winds, and barometric pressure. The National Hurricane Center (NHC) is the division of NOAA's National Weather Service (NWS) responsible for tracking and predicting tropical weather systems. Both CO-OPS and NHC have published reports that provide a comprehensive overview of the meteorological characteristics of Hurricane Sandy and its hydrological and hydraulic impacts on the East Coast of the United States. The following sections are derived from two main sources:

- Fanelli et al., January 24, 2013, *NOAA Water Level and Meteorological Data Report - Hurricane Sandy,* National Oceanic and Atmospheric Administration (NOAA)
- Eric S. Blake, Todd B. Kimberlain, Robert J. Berg, John P. Cangialosi and John L. Beven II, *Tropical Cyclone Report - Hurricane Sandy (AL182012) 22 – 29 October 2012,* National Hurricane Center, 12 February 2013

Storm Track and Timeline

Figure III-1 gives the NOAA NHC "best track" positions and storm intensities for Hurricane Sandy from October 26 through October 29, 2012. Hurricane Sandy formed approximately 320 miles south-southwest of Kingston, Jamaica on October 22, 2012. The storm then moved northward, strengthening from a tropical depression into a Category 1 hurricane by the time it passed over the Bahamas on October 26. The storm track then roughly paralleled the U.S. Atlantic coastline, with the best track position remaining 250 to 300 miles offshore between October 26 and October 29.

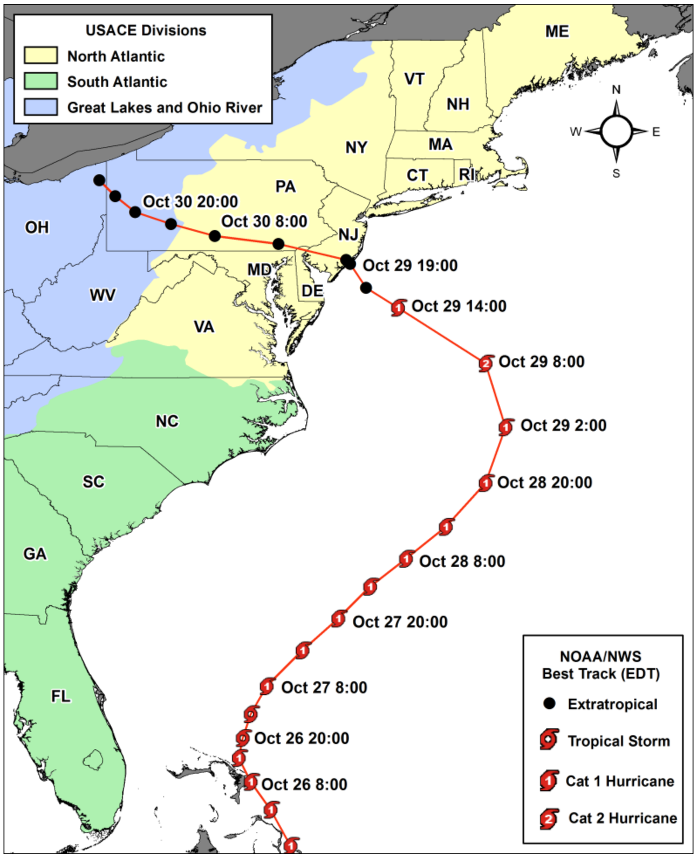


Figure III-1. Best Track Positions for Hurricane Sandy, 26 – 29 October 2012

While remaining a Category 1 hurricane, except for a period early on October 29 when the storm reached Category 2 intensity, the storm grew in size to a diameter greater than 1,000 nautical miles and became the largest diameter storm historically recorded in the Atlantic basin.

Beginning early on October 29, prevailing atmospheric effects steered Hurricane Sandy towards the mid-Atlantic coast. The storm lost hurricane status and transitioned to an extratropical storm before it made landfall at

Brigantine, NJ (near Atlantic City) around 20:00 EDT on October 29th (Figure II-2). Typically, when hurricanes leave the warm tropical waters that spawned them, they become extratropical storms, characterized by a loss of the cyclonic spinning action, while tending to spread into large storms ranging from 620 to 2,500 miles across. While the storm was technically classified as extratropical, it continued to exhibit wind speeds close to Category 1 hurricane intensity at landfall.

The storm then moved through Pennsylvania and into Canada from October 30, maintaining strong winds and dumping heavy rainfall and snow over inland areas.

Wind and Pressure Fields

The NHC estimated that Hurricane Sandy's wind speeds peaked at 115 mph prior to landfall in Cuba, making it a Category 3 hurricane at that point. As Hurricane Sandy passed over the Bahamas, the storm's maximum sustained winds decreased to tropical storm levels, and the size of the storm doubled (in terms of diameter of tropical storm force winds). The storm strengthened again as it tracked northward and maintained sustained wind speeds in the Category 1 and (briefly) Category 2 hurricane range until a few hours before landfall in New Jersey.

Hurricane Sandy is also notable for its extremely low central pressures. Based on measurements by National Ocean Service (NOS) at Atlantic City, the minimum central pressure at landfall was estimated at 945.5 millibars at 18:24 EDT October 29th, which contributed to the enormous storm surges that were experienced. This report has been noted as the lowest sea level pressure ever actually recorded north of North Carolina in the United States. Several sites across the mid-Atlantic region also recorded their all-time minimum recorded pressures during the passage of Hurricane Sandy.

Precipitation

In the United States, most of the rain from Hurricane Sandy fell south and west of the track of the center. The heaviest rainfall was reported in extreme eastern Maryland and Virginia, southern Delaware and extreme southern New Jersey, with a widespread area of 5 to 7 inches of rain[2], and a peak amount of 12.83 inches in Bellevue, Maryland. Although this rain caused rivers in the mid-Atlantic region to rise, only minor damage was reported due to this flooding. Rainfall did have some contribution, in combination with the effects of storm surge, to flooding in New York and New Jersey along the Hudson River.

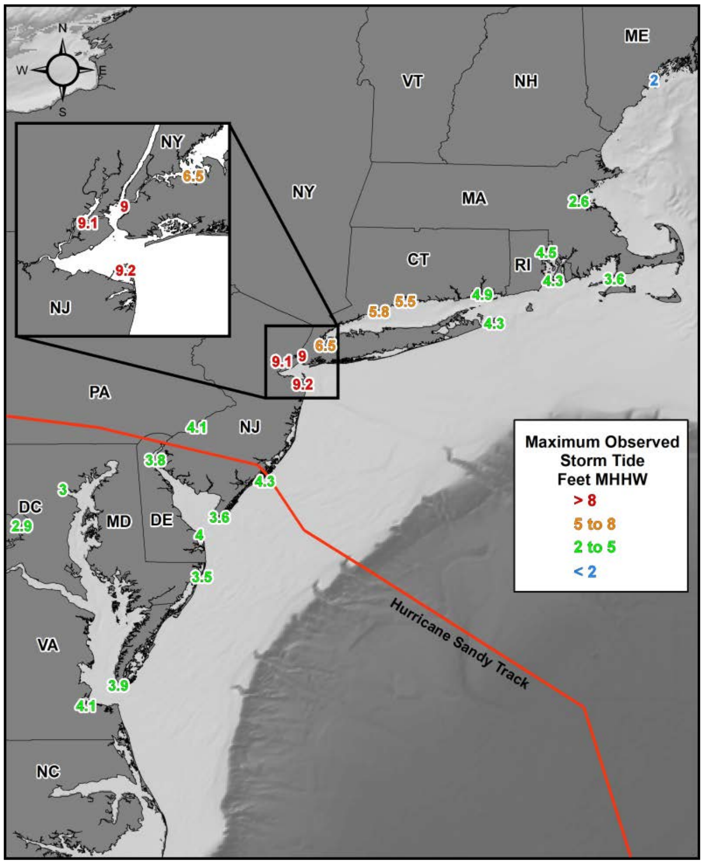


Figure III-2. Storm Tide Elevations (MHHW) Recorded at NOAA Gages

[2] See NOAA rainfall estimates at http://www.wpc.ncep.noaa.gov/tropical/rain/sandy2012filledrainwhite.gif.

Storm Tide

Several terms are used to describe water levels due to a storm. This section focuses on the storm tide that occurred during Hurricane Sandy. Storm tide is defined as the water level due to the combination of storm surge[3] and the astronomical tide. Storm tide is an elevation and is expressed in reference to a standardized vertical datum such as the North American Vertical Datum of 1988 (NAVD88) or to local tidal datums such as mean higher high water (MHHW) or mean lower low water (MLLW).

This storm tide discussion is based on data recorded by NOAA water level gages and observed high water marks collated and published by the U.S. Geological Survey (USGS) following Hurricane Sandy.

Figure III-2 shows peak storm tide elevations recorded at various active NOAA gages from Virginia to Maine. The storm tides are presented as water level elevations referenced to local MHHW at each station. Referencing the storm tide elevations to MHHW provides a sense of the inundation or depth of water above normal high tide along the shoreline.

Hurricane Sandy caused water levels to rise along the entire east coast of the United States from Florida northward to Maine. The greatest increase in water levels above those experienced in normal tide cycles occurred within New York Harbor (storm tide greater than 9 feet above MHHW) and in Long Island Sound (storm tide between 5.5 and 6.5 feet above MHHW).

In coastal areas outside the New York Harbor/Long Island Sound area, between southern Virginia and Cape Cod, Hurricane Sandy produced peak storm tides generally between 3 and 5 feet above MHHW. Storm tides less than 3 feet above MHHW were measured north of Cape Cod.

The maximum storm tides measured at Sandy Hook, NJ and The Battery, NY – both within New York Harbor – exceeded the storm tides caused by the previous storm of record at these stations (Hurricane Donna in September, 1960) by more than 4 feet. NOAA[4] estimated that the storm tide recorded at The Battery, NY exceeded a 200-year return period event or a 0.5 percent flood event. Hurricane Sandy was within 0.1 foot of equaling the record storm tide at Atlantic City, NJ. Hurricane Sandy storm tides were below the storm of record at the other NOAA gages in the study area with at least 70 years of historical data.

High Water Marks

An extensive network of water level and barometric pressure sensors deployed by USGS[5], along with over 653 post-storm surveyed High Water Marks (HWM) provide a detailed view of the relative magnitude of total water levels experienced along the mid-Atlantic and Northeast coastline. These efforts by USGS were undertaken as part of coordinated Federal emergency response as outlined by the Stafford Act under a directed mission assignment by FEMA. The peak storm tide elevations derived from the USGS data for Hurricane Sandy are shown, relative to the vertical datum NAVD88, in Figure III-3.

[3] Storm surge is the rise of water generated by the storm, over and above the predicted astronomical tide that would have occurred without the storm.

[4] See extreme water level statistics published by NOAA at http://tidesandcurrents.noaa.gov/est

[5] McCallum, B.E., Wicklein, S.M., Reiser, R.G., Busciolano, Ronald, Morrison, Jonathan, Verdi, R.J., Painter, J.A., Frantz, E.R., and Gotvald, A.J., 2013, Monitoring storm tide and flooding from Hurricane Sandy along the Atlantic coast of the United States, October 2012: U.S. Geological Survey Open-File Report 2013–1043, 42 p.

The USGS peak total water level measurements reinforce conclusions drawn from the NOAA gages which indicate that storm tide elevations were greatest in the New York Harbor and Long Island Sound area. Other areas with multiple relatively high water levels observable in Figure III-3 include Nantucket Island and Massachusetts coastlines north of Cape Cod, along the New Jersey open coast, and within the Delaware River. Isolated observed storm tides greater than 7 feet NAVD88 are shown in Delaware and southern Virginia.

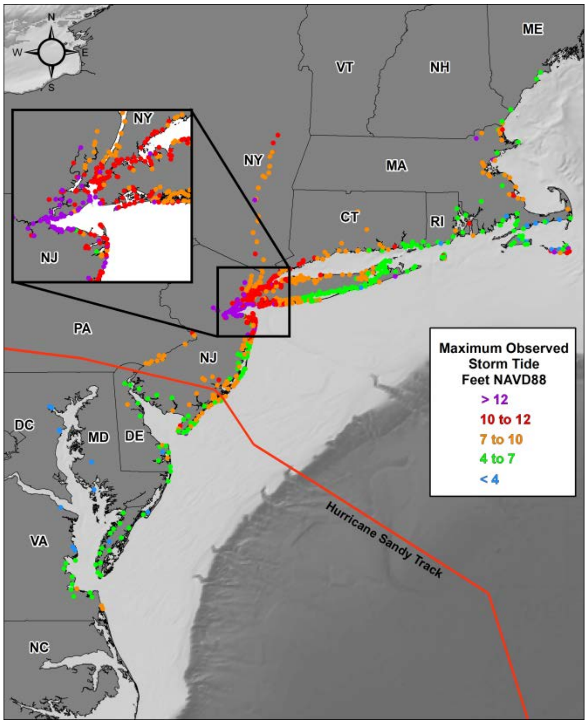


Figure III-3. USGS Peak Storm Tides from High Water Marks and Gages

Waves

In addition to high storm tides discussed above, Hurricane Sandy's wind field produced extreme, and in some locations record-breaking waves that impacted open coasts and less-sheltered areas within bays. Hurricane Sandy's unusually large diameter wind field contributed greatly to the storm's ability to generate extreme wave heights that eventually impacted the coast.

Wave heights were recorded during Hurricane Sandy by an extensive network of buoys and other instruments under the USACE Coastal Data Information Program (CDIP)[6] and NOAA's National Data Buoy Center (NDBC) umbrellas. Figure III-4 shows the significant wave height[7] at 25 buoy locations along Hurricane Sandy's track. The largest significant wave height recorded was 39.6 feet west of Bermuda (rounded to 40 feet in the figure). Wave heights from Florida to Maine ranged from 9-32 feet with typical peak wave periods of 12 to 14 seconds. Wave heights offshore of New Jersey, New York, and Rhode Island were the highest, peaking at over 30 feet.

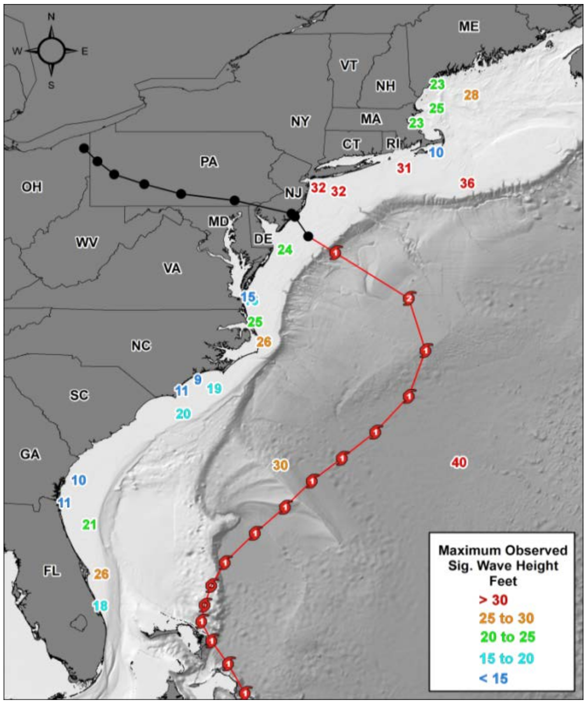


Figure III-4. Observed CDIP and NDBC Wave Heights during Hurricane Sandy

To put this in historical perspective, the 32.5 feet significant wave height measured at Long Island, NY was the largest significant wave height recorded since that buoy began operation in 1975. It exceeded the previous record of 30 feet set during a nor'easter on December 11, 1992. It is likely that many other coastal areas along Sandy's track were exposed to record or near-record wave conditions. In addition to direct wave

6 Richard J. Seymour, Corey B. Olfe, and Juliana 0. Thomas, *CDIP wave observations in Superstorm Sandy*, Shore & Beach • Vol. 80, No.4 • Fall2012.

7 Significant wave height is defined as the average height of the one third highest waves in a set interval of time.

energy impacts, wave setup contributes to total water level measurements – waves breaking near the shoreline cause a super-elevation of the water level. These effects would generally be observed as part of the surveyed HWM observations discussed with respect to total water level.

Geographical Areas Exposed to Direct Storm Impacts

East Coast states, from Florida to Maine, experienced at least some physical impact associated with Hurricane Sandy. South of Cape Hatteras, NC, the storm's direct impacts were generally limited to the elevated wave conditions associated with the storm's exceptionally large wind field. Coastal areas from Cape Hatteras northward to Cape Cod additionally experienced significantly elevated water levels, with the most extreme storm tides occurring (as noted above) in New York Harbor and Long Island Sound. According to one analysis by the FEMA MOTF, the most severe category of overall combined impacts (from wind, wave, and storm tide) occurred from southern New Jersey north to the entirety of Long Island, NY and portions of Connecticut on Long Island Sound.

Following the storm's landfall, strong winds and intense rainfall impacted Pennsylvania as the remnants of Hurricane Sandy moved through that state and into Canada. The most direct damage from Hurricane Sandy occurred from winds, waves, and storm tide flooding on the seaward waterfront in Delaware, New Jersey, New York, and Connecticut. Though not exposed to direct wave attack, developed areas on the "landward" side of barrier islands and peninsulas, or in coastal rivers, experienced high storm tides and damages from high water levels.

III.2. Summary of Hurricane Sandy Impacts

Pre-Storm Closures and Evacuations

Based on the Hurricane Sandy's track and the likelihood of it causing significant impact to the entire east coast of the United States, President Obama signed emergency declarations on October 28 for the 12 mid-Atlantic and New England states and the District of Columbia that were expected to be impacted by Hurricane Sandy, allowing them to request Federal aid and make additional preparations in advance of the storm. Flight cancellations and travel alerts on the U.S. East Coast were put in place in the mid-Atlantic and the New England areas. Over 5,000 flights scheduled for October 28 and October 29 were canceled by the afternoon of October 28 (Huffingtonpost.com, 2012). Amtrak shut down routes in the northeast on October 28, as did intra-city mass transit systems and commuters lines serving Washington, D.C., Baltimore, Philadelphia, New York, and Boston. Bridges and tunnels, including the Chesapeake Bay Bridge, the I-95 bridges over the Susquehanna River in Maryland, the Tappan Zee Bridge over the Hudson River in New York, the Brooklyn Battery Tunnel and the Holland Tunnel in New York, were closed by mid-day on October 29th.

Temporary shelters were established, and evacuations for people living in coastal and low-lying areas were ordered by the Governors of Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, and Rhode Island.

Fatalities

At least 286 direct and indirect deaths have been attributed to Hurricane Sandy across the United States, the Caribbean, and Canada, of which at least 159 deaths occurred in the United States. Of these, there were 72 deaths within the United States as a direct consequence of Sandy (e.g., wind, flood, structural collapse). At least 87 deaths were indirectly associated with Hurricane Sandy. The indirect deaths were those in which the disaster led to unsafe conditions, such as hazardous roads or disruption of usual services that contributed to the deaths. About 50 of these deaths were the result of extended power outages during cold weather, which led to deaths from hypothermia, falls in the dark by senior citizens, or carbon monoxide poisoning from improperly placed generators or cooking devices. The remaining deaths were mostly from storm cleanup efforts, including removing fallen trees, and car accidents (Blake et al., 2013).

The majority of the deaths took place in the mid-Atlantic states. New York had 48 direct fatalities, followed by 12 in New Jersey, 5 in Connecticut, 2 each in Pennsylvania and Virginia, and 1 each in New Hampshire, West Virginia, and Maryland (Centers for Disease Control and Prevention [CDC], 2013).

Storm surge was responsible for most of the U.S. deaths, with 41 of the 72 fatalities attributable to drowning. The rest of the U.S. fatalities were due to other wind-related causes, inland freshwater flooding, near-shore waves, or drowning within coastal waters. One death was reported in a U.S. territory: a man perished in a rain-swollen river near Juana Diaz, Puerto Rico. Two offshore deaths occurred about 90 miles southeast of Cape Hatteras, NC, when the H.M.S. Bounty sank - 14 other people were rescued by the U.S. Coast Guard. The median age for all deaths was 65, while the median age for deaths by drowning was 62 (CDC, 2013).

Some 32 of the 41 drowning victims were in New York. Of these, thirty of those lived in homes within New York City's (NYC) Mandatory Evacuation Zone A (Figure III-5), which are low-lying areas most vulnerable to flooding from storm surge. Twenty of those victims died in flooded homes, while the others drowned while trying to flee their homes. The other two drowning victims in New York lived in flooded areas near Evacuation Zone A (CDC, 2013).

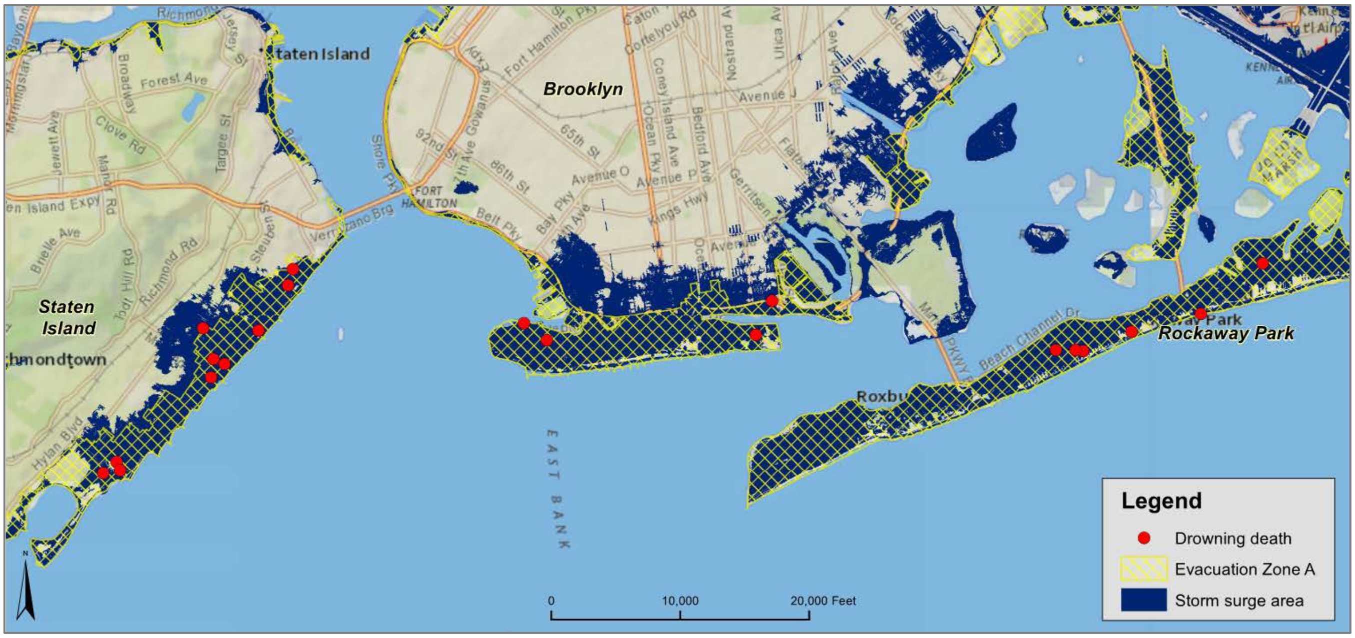


Figure III-5. Drowning Deaths Attributed to Hurricane Sandy in New York State, in Relation to the FEMA Storm Surge Area and NYC Evacuation Zone A (CDC, 2013)

Loss of Power

Following Hurricane Sandy, power outages caused by flooding or fallen trees impacted approximately 8.5 million customers, including businesses and services, across 20 states and the District of Columbia from North Carolina to Maine and as far west as Illinois and Wisconsin. An additional 150,000 outages were caused by the November 7, 2012 nor'easter that hit the region during the Hurricane Sandy recovery. Table III-1 shows the peak outages and percentage of customers for each state who suffered outages during Hurricane Sandy relative to the total number of customers in that state. For example, 65 percent of all New Jersey households and businesses lost power during Hurricane Sandy, while at least 20 percent of all customers in Connecticut, West Virginia, New York, Rhode Island, Pennsylvania, and New Hampshire lost power.

Table III-1. Peak Customer Power Outages by State (U.S. Department of Energy, 2013)

State	Peak Outages	Total Customers	Percentage of Customers without power
Connecticut	626,559	2,047,240	31%
Delaware	45,137	459,831	10%
District of Columbia	3,583	269,815	1%
Illinois	1,149	5,742,146	0%
Indiana	9,224	3,103,313	0%
Kentucky	8,379	2,234,984	0%
Maine	90,727	1,568,419	6%
Maryland	311,020	2,691,403	12%
Massachusetts	298,072	3,451,306	9%
Michigan	120,637	4,785,627	3%
New Hampshire	141,992	715,797	20%
New Jersey	2,615,291	4,031,813	65%
New York	2,097,933	9,303,419	23%
North Carolina	15,466	4,841,473	0%
Ohio	267,323	6,759,784	4%
Pennsylvania	1,267,512	6,491,718	20%
Rhode Island	116,592	498,551	23%
South Carolina		2,434,144	0%
Tennessee	2,120	3,166,486	0%
Vermont	17,959	358,678	5%
Virginia	182,811	3,684,290	5%
West Virginia	271,765	1,017,506	27%
Hurricane Subtotal	**8,511,251**	**69,657,743**	
2012 Nor'easter Outages	**150,276**		
Total	**8,661,527**		

Outages from Hurricane Sandy peaked on October 30, 2012. Three days later, utilities on average had restored power to 57 percent of the peak, and 6 days later power had been restored to 84 percent of customers throughout the affected states. Power restoration had reached more than 90 percent when the November 7 nor'easter slowed the progress of utility crews and added additional outages. Figure III-6 shows the percentage of power service restored by day since the peak State outage for four States. In the most impacted states of New York and New Jersey, power restoration to 95 percent of its customers took almost 14 days after the storm. For example, the Long Island Power Authority's (LIPA), which serves 1.1 million customers on Long Island, NY, 90 percent of whom lost power, experienced damage to 50 substations, 2,100 transformers, and 4,500 utility poles during Sandy.

Table III-2 lists the 8 nuclear power plant units that were affected by Hurricane Sandy. Some were shut as a precaution to protect equipment from the storm; others were forced to shut down or reduce power output due to reduced power demand caused by widespread utility customer outages. Due to Hurricane Sandy, three nuclear reactors totaling 2,845 megawatts (MW) of capacity were shut and five were operated at reduced rates.

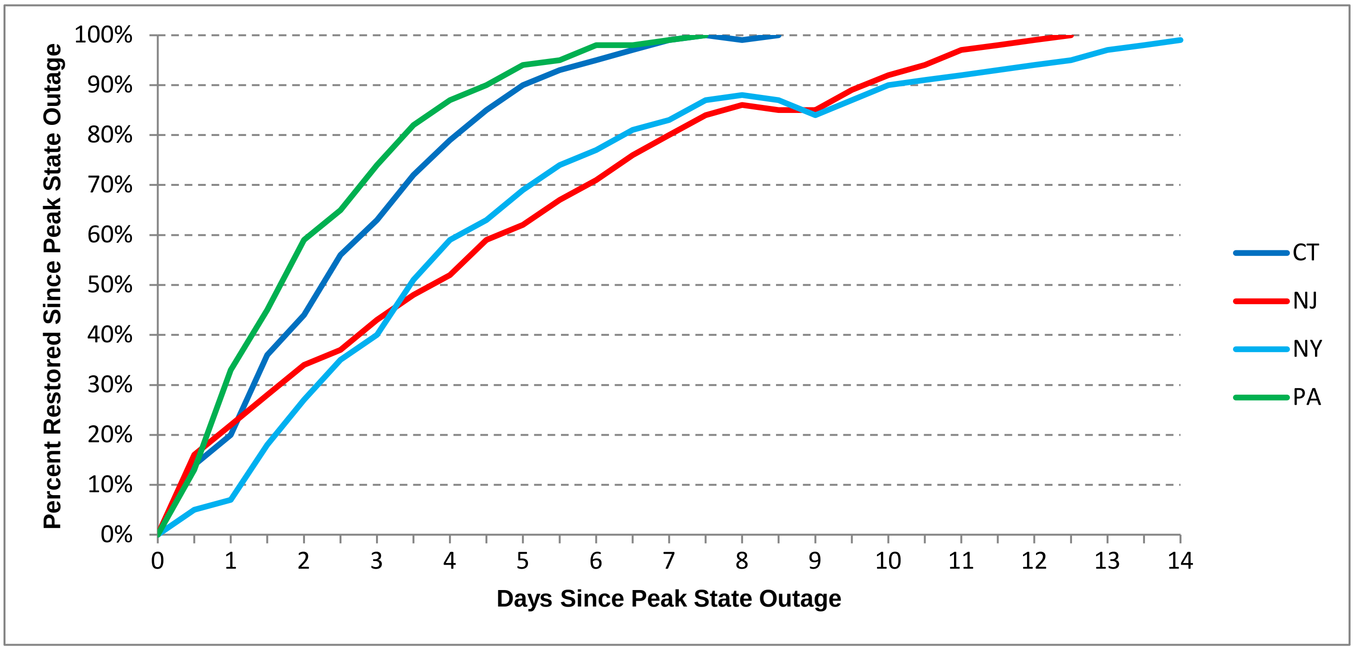


Figure III-6. Power Outage Restoration Scenario (U.S. Department of Energy, 2013)

Table III-2. Nuclear Power Plants Affected by Hurricane Sandy (U.S. Department of Energy, 2013)

Unit	State	Company	Capacity (MW)	Impact	Duration
Salem 1	NJ	PSEG	1,175	Shut	7 days
Indian Point 3	NY	Entergy	1,040	Shut	5 days
Nine Mile 1	NY	Constellation	630	Shut	13 days
Milestone 3	CT	Dominion	1,233	Reduced	5 days
Limerick 1	PA	Exelon	1,130	Reduced	2 days
Limerick 2	PA	Exelon	1,134	Reduced	4 days
Susquehanna 2	PA	PPL	1,190	Reduced	7 days
Vermont Yankee	VT	Entergy	620	Reduced	2 days

Fuel Shortages

Hurricane Sandy disrupted petroleum supply networks in the northeast due to direct effects from the storm (flooding, wind, etc.), as well as power interruptions caused by the storm. In particular, the hurricane disrupted activity in the New York Harbor area – a major distribution hub for petroleum delivery to consumer markets in New York, New Jersey, Pennsylvania, and New England. The terminals in the New York Harbor area, which have a combined storage capacity of about 70 million barrels, receive product via pipeline from refineries on the U.S. Gulf Coast, the Philadelphia area, and the two refineries located in northern New Jersey – Phillips 66 Bayway (238,000 barrels per day [b/d]) and Hess Port Reading (70,000 b/d). The terminals also receive product via tanker and barge, much of it imported from outside the United States. In addition, products from the terminals are redistributed by barge mainly to distribution terminals throughout the New York Harbor area, up the Hudson River as far as Albany, and into New England. Products also move via pipeline to Brooklyn/Queens terminals, all regional airports, and upstate New York and Pennsylvania. These distribution terminals supply gasoline, heating oil and diesel fuel to trucks for delivery to retail outlets and local distributors.

Figure III-7. Gas Station in Brooklyn After Hurricane Sandy Photo Courtesy: We Live in the City, 2012

... To ease fuel supply issues in the wake of Hurricane Sandy, the President authorized the release of fuel from the Northeast Home Heating Oil Reserve on November 5 for distribution to State, local, and Federal responders in New York and New Jersey to fuel emergency equipment and vehicles. This was the first time that a release from the reserve had taken place since its founding in 2000. Two additional releases occurred on November 12 and 25, 2012. The President also directed FEMA to purchase and deliver up to 12 million gallons of unleaded fuel and up to 10 million gallons of diesel fuel to the New York and New Jersey region to supplement private sector efforts.

> *... Petroleum supply chain disruptions and power outages caused by Hurricane Sandy led to widespread fuel outages at retail fueling stations in the NYC metropolitan area. On November 2, only one-third of gas stations sampled were operational. Long lines were widespread, sometimes stretching for miles.*

Refineries Table III-3 lists the refineries affected by Hurricane Sandy. Both Bayway and Hess Port Reading were shut down during Sandy. The Bayway refinery lost power, sustained flooding in low-lying areas and remained offline for over four weeks as operators conducted repairs and maintenance. Similarly the Hess Port Reading refinery was shut down for over three weeks. The Paulsboro, NJ; Delaware City, DE; Trainer, PA; and Philadelphia, PA refineries, with total capacity of almost 900,000 barrels per day, also had reduced outputs. In the week after Hurricane Sandy made landfall, gross inputs into East Coast refineries fell by 28 percent or 290,000 barrels per day from the week prior to landfall. Refining activity did not return to pre-storm levels until a month after Hurricane Sandy's landfill, when the Philips refinery restarted and returned to normal rates.

Table III-3. Refineries Affected by Hurricane Sandy (U.S. Department of Energy, 2013)

Refinery	State	Company	Capacity (b/d)	Impact	Duration
Linden	NJ	Phillips 66	238,000	Shut	30 days
Port Reading	NJ	Hess	70,000	Shut	24 days
Paulsboro	NJ	PBF	160,000	Reduced	4 days
Trainer	PA	Monroe Energy	185,000	Reduced	3 days
Philadelphia	PA	Philadelphia Energy Solutions	335,000	Reduced	10 days
Delaware City	DE	PBF	182,000	Reduced	4 days

Terminals Hurricane Sandy also impacted many East Coast terminals, with at least 57 terminals partially or completely closed following Sandy. In New York Harbor, inflows and outflows of petroleum products (gasoline, diesel, jet fuel and ethanol) at petroleum terminals were reduced to 65 and 61 percent of pre-storm levels, respectively during the week of November 7 to 13, 2012.

Due to the fuel shortages, fuel rationing programs were established in affected counties in New Jersey, as well as in NYC, Nassau and Suffolk Counties in order to alleviate long lines at fueling stations. NYC's fuel rationing system was extended on November 18, 2012 at which time an estimated 30 percent of the city's gas stations were still not operating. The system was lifted on November 23, 2012.

Hurricane Sandy did not have a major impact on natural gas infrastructure and supplies in the northeast, although breaks in natural gas lines caused fires in some location, resulting in the destruction of many residences. Over 100 homes in Breezy Point located on the Rockaway barrier island in NYC were destroyed by fire during Hurricane Sandy. Flooding and power outages were a concern at compressor stations along some interstate pipelines following the storm but natural gas flows were not interrupted. Natural gas utilities in areas affected by flooding, such as in Orange and Rockland Counties in New York and Pennsylvania Electric Company (PECO) in southeastern Pennsylvania, shut off service as a precaution until home inspections could be completed. New Jersey Natural Gas (NJNG) shut down part of its natural gas infrastructure serving Ocean and Monmouth Counties. As part of the shutdown, NJNG vented gas from its distribution pipelines, which allowed water to infiltrate the pipes. The damage caused by the water was severe enough that some portions of the distribution system needed to be completely rebuilt. The shutdowns affected approximately 32,000 NJNG's customers, which had significant impacts to the regional economy.

Transportation

In his testimony on December 20, 2013 before the U.S. Senate Committee on Banking, Housing, and Urban Affairs on Hurricane Sandy, Peter M. Rogoff, Administrator, Federal Transit Administration, stated that "Hurricane Sandy triggered the worst transit disaster in U.S. history. On the Tuesday morning following the storm, more than half of the nation's daily transit riders were without service". This included Amtrak service along the northeast corridor, as well as intra-city mass transit systems and commuter lines in Washington, D.C., Baltimore, Philadelphia, NYC, and Boston. About 20,000 flights were cancelled due to flooding, power outages and other storm related problems at the airports. Motorists experienced gridlock due to closures of bridges and tunnels and also due to the limited mass transit availability. The most severely impacted areas were New York and New Jersey.

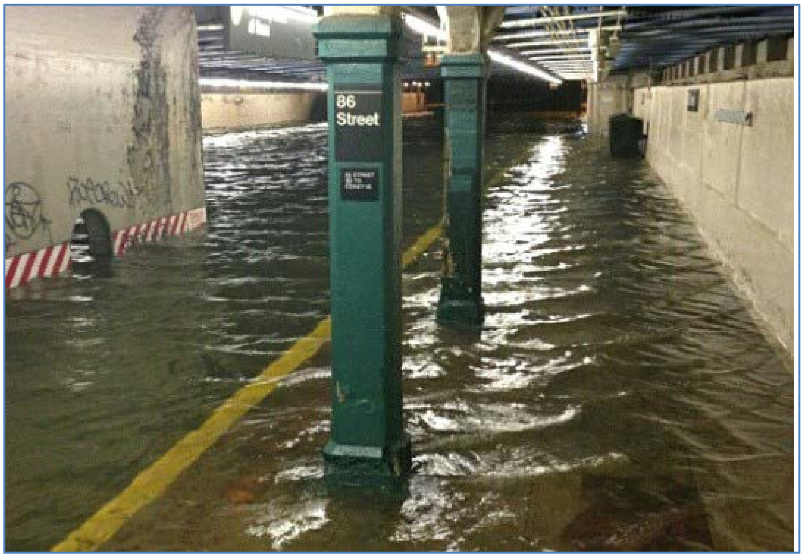


Figure III-8. Flooding at Sea Beach Line N Train Bensonhurst/Coney Island Neighborhood Subway Station, Photo Courtesy: Wzohaib/Flickr

"We experienced a level of destruction that is completely unprecedented in our 108-year history. Left in the storm's wake were eight flooded subway tunnels, two vehicular tunnels, 12 subway stations with major damage, some of them absolutely destroyed. We lost an entire bridge and a rail line serving the Rockaways and Queens, 15 miles of damaged or destroyed signaling and we had rail yards and maintenance shops under water and damaged. Damages to the subway system are estimated at $5 billion, with other transportation infrastructure damages estimated an additional $2.5 billion…." Mr Joseph Lhota, Chairman of New York's Metropolitan Transit Authority (MTA), which runs the regional network of subways, buses, commuter rail, and bridges and tunnel that are utilized by 10 million people daily, testifying on December 20, 2013, before the U.S. Senate Committee on Banking, Housing and Urban Affairs on Hurricane Sandy.

… "Much of the infrastructure maintained by the Port Authority was damaged during Hurricane Sandy. Specifically, many buildings sustained flooding, utility service disruption, and sewage failure. The Port Authority also experienced loss of rail switches and relays, destruction of security booths and fencing, damage to cranes and other cargo facilities, and channel and rail obstruction from debris, in addition to other damages.

The infrastructure damage sustained is estimated to be between $34 and $52 million in capital costs, plus an additional $5.1 million in operating costs and $1.2 million in lost revenue from port operations. From the storm itself, approximately 15,000 containers and 9,000 automobiles were lost. In addition, 57 vessels and one cruise ship were diverted from the Port of New York and New Jersey to other U.S. ports."

New York Recovers: Hurricane Sandy Federal Recovery Support Strategy – Version One, June 2013 (Curtin et al., Federal Disaster Recovery Coordination)

The MTA was effective in assessing the damage to infrastructure and instituting a cleanup plan. The subway system was severely affected by the flooding to the tunnels. The MTA used their three pump trains, and also received assistance from the "unwatering team" of USACE, to remove water from the tunnels. By November 3, 2012 approximately 80 percent of the subway system was back in operation, including the first of the

East River subway tunnels that had been flooded. By November 5, commuter rail service to the northern suburbs and Long Island had been mostly restored, with shuttle buses supplementing lines that were still out of service. By November 16, nearly all subway lines were fully operating with the exception of the R train between Brooklyn and Manhattan, and the A train between Howard Beach of the Rockaways (Kaufman et al., 2012).

Figure III-9. Boat on Rail Road Tracks near Metro North's Ossining Station, Photo Courtesy: (Reuters/MTA)

Hundreds of feet of track and the signal system along the Broad Channel Bridge that connected Howard Beach with the Rockaways were permanently damaged. To restore transit service within the Rockaway peninsula, the MTA brought subway cars on flatbed trucks and placed them on unused tracks to run a shuttle between Far Rockaway-Mott Avenue and Beach 90th Street stations. Shuttle bus service was provided between Far Rockaway and Howard Beach. Ferry service was also instituted between the Rockaways and Manhattan on November 9. With these transportation options, the Rockaways residents now had modes to return to work (Kaufman et al., 2012).

New ferry service between southeastern Staten Island and Manhattan was initiated on November 20 that provided a faster commuting option to some of the NYC's hardest-hit neighborhoods. Existing ferries also saw heavy usage. The East River Ferry which connects Midtown and Lower Manhattan with Brooklyn saw record high ridership after Hurricane Sandy until L train service resumed (Kaufman et al., 2012.

The MTA had closed all vehicular bridges and tunnels before the storm in preparation for the high winds and flooding. Although most bridges were able to re-open shortly after the storm, the Brooklyn Battery and Queens-Midtown Tunnels experienced significant flooding. The Midtown Tunnel re-opened for partial service on November 8 and full service on November 16, while the Battery Tunnel had limited service for buses until November 12.

The Port Authority of New York and New Jersey (PANYNJ) operates a wide array of services, including commuter rail (PATH trains), airports, bridges, tunnels, a major bus terminal, and the ports. The trains and tunnels are critical means of transportation for residents of New Jersey who commute into New York City. PANYNJ's tunnels, particularly the Holland Tunnel and PATH train tunnels, experienced significant flooding. This led to severe gridlock on other routes to Manhattan from New Jersey, particularly in the Lincoln Tunnel. John F. Kennedy, LaGuardia, and Newark Airports were closed during and the day after the storm, but all opened within two days of the storm. Due to serious flooding to both tunnels and rolling stock, partial PATH service began on November 6, but full service did not resume until November 20. The Holland Tunnel was reopened exclusively to buses on November 2, and then to all commuter traffic on November 7 (Kaufman et al., 2012).

New Jersey Transit (NJT), which provides both in-state and also commuter train and bus service to NYC, suffered extensive damage to its rail cars and engines, which delayed restoration of service. The agency had shut down service preemptively, and moved trains to less flood prone areas in preparation of the storm, but there was still caused significant damage. The NJT rail operations center in Kearny, NJ was flooded with 7 feet of water that damaged 74 locomotives and 294 rail cars, and several weeks passed before rail services resumed. Overall damage estimates to the NJT system are around $400 million, with estimates of total damage to the entire transit, road, and bridge system in the state reaching $2.9 billion. During the days immediately after the storm, NJT offered free park-and-rides, shuttle buses, and ferries into Manhattan to help mitigate the congestion on the open bridges and tunnels (Kaufman et al., 2012).

Wastewater Treatment Facilities

Floodwaters, massive storm runoff, wind damage, and loss of electricity combined to cause wastewater treatment plants up and down the mid-Atlantic coast to fail. These failures sent billions of gallons of raw and partially treated sewage into the region's waterways, from Virginia to Rhode Island, impacting public health and aquatic habitats.

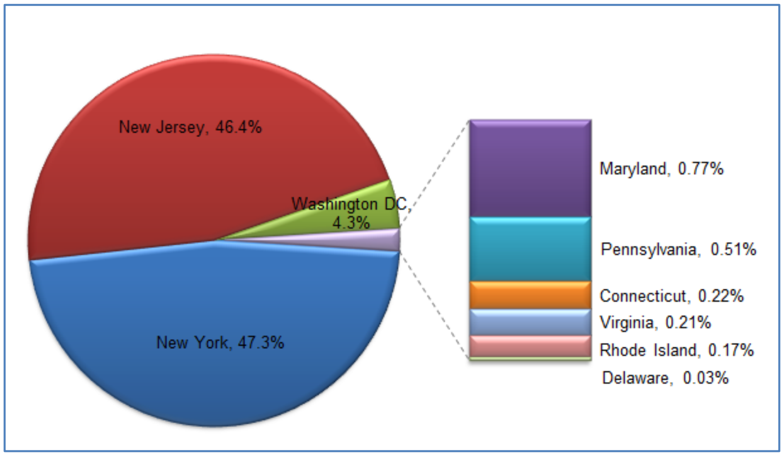


Figure III-10. Sewage Overflow from Hurricane Sandy (Climate Central, 2013)

Some treatment plants were inundated by the high water levels, leaving them flooded and incapacitated. In other cases, plants were unable to handle the extra water flow resulting from heavy rainfall and floodwater that mixed with normal sewage flow, so operators bypassed sewage around treatment plants and directly into receiving waters in order to keep the plant operating. Still, other plants lost their pumping capacity as the storm knocked out power. Data from the eight hardest hit states and the District of Columbia shows that 11 billion gallons of untreated and partially treated sewage flowed into rivers, bays, canals, and in some cases, city streets, largely as a result of the record storm surge flooding that inundated the region's major sewage treatment facilities. The States of New York and New Jersey together had 94 percent of the sewage overflow (Figure II-10) with the vast majority of that sewage flowing into the waters of NYC and northern New Jersey in the days and weeks during and after the storm (Kenward et al., 2013).

… 11 billion gallons is equal to New York's Central Park stacked 41 feet high

Following the storm, EPA and local authorities issued health advisories warning citizens to stay away from waters that were contaminated by sewage overflows and from consuming fish and shellfish from these waters.

There were also concerns that contaminated flood waters could enter groundwater aquifers, pipes, and wells that supply drinking water to much of the region. Also many drinking water utilities experienced power loss, which disrupted their ability to provide safe water. As a result, public health authorities issued dozens of "boil water" advisories for customers in many parts of New York and New Jersey. Most of the advisories were lifted within a week, but several advisories remained in effect for up to several weeks in portions of Nassau, Suffolk, Rockland and Sullivan Counties in New York, and also in Middlesex, Monmouth and Ocean Counties in New Jersey.

New York State estimates the sewage and wastewater system repair and recovery costs due to Hurricane Sandy to be about $1.9 billion. The New Jersey Department of Environmental Protection (NJDEP) plans to allocate $2.6 billion dollars to water infrastructure damaged by the storm. Of that, $342 million will go to recovery, $553 million will be spent on repairs, and the remaining $1.7 billion will be spent on building resilience into the system.

Hospitals, Schools, and Other Public Buildings

NYC metropolitan area hospitals and medical facilities were severely impacted by Hurricane Sandy. Across NYC, five acute care hospitals and one psychiatric hospital closed. This resulted in the emergency evacuation of nearly 2,000 patients. Three hospitals closed in advance of the storm, New York Downtown (Manhattan) closed after notice of a potential preemptive utility shutdown, while the Veterans Affairs New York Harbor Hospital (Manhattan) and South Beach Psychiatric Center (Staten Island) closed due to concerns about flooding. Three other hospitals—New York University's Langone Medical Center (Manhattan), Bellevue Hospital (Manhattan), and Coney Island Hospital (Brooklyn)—evacuated during or after Sandy due to the failure of multiple electrical and mechanical systems including emergency power systems.

Some hospitals narrowly escaped flood damage. For example, Metropolitan Hospital in Upper Manhattan just missed having its critical electrical systems flooded. On Staten Island University Hospital's North Campus, floodwaters came within inches of the hospital entrance. NYC hospitals incurred an estimated $1 billion in costs associated with emergency response measures taken during and immediately after Hurricane Sandy, including the costs of staff overtime, patient evacuations, and emergency repairs of equipment. It is projected that damaged hospitals will spend at least another $1 billion on repairs and mitigation. In addition, permanent revenue loss for hospitals citywide is estimated to have been nearly $70 million per week in the immediate aftermath of the storm.

Hurricane Sandy's impact on residential providers was also significant. Sixty-one nursing homes and adult care facilities were in areas impacted by power outages and/or flooding. Half of these providers continued to operate—some because they sustained minimal or no damage, others because they had effective emergency plans. However within a week of the storm, 26 facilities had to shut down, and another 5 partially evacuated, reducing citywide residential capacity by 4,600 beds and leading to the evacuation of 4,500 residents who had to be transported to other facilities or Special Medical Needs Shelters, which were staffed by personnel from the NYC Health and Hospitals

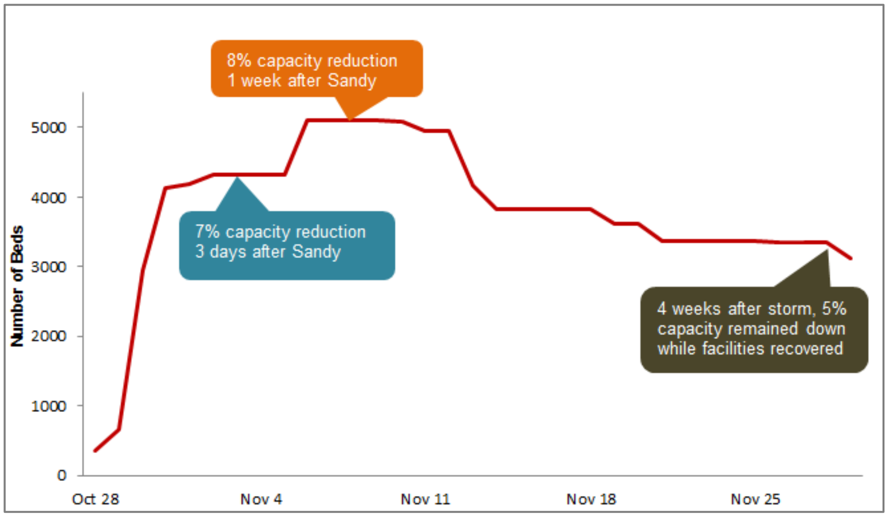


Figure III-11. NY Citywide Bed Capacity Reductions in Nursing Homes and Adult Care Facilities (NYC SIRR, 2013)

Corporation (HHC) and Disaster Medical Assistance Teams (DMAT). These closures impacted hospitals as well, preventing them from discharging patients to nursing homes, as they normally would have done. Instead, hospital beds that could have been available for new patients remained occupied by existing patients who had nowhere else to recover after treatment (Fig II-11).

Power loss was the primary cause of post-Sandy evacuations from nursing homes and adult care facilities, and many providers experienced both utility outages and damage to building electrical equipment. Even providers with generators had difficulties if those generators were located in parts of buildings that flooded or if providers had failed to secure fuel in advance. Without power, other critical systems—lights, heat, elevators, kitchens, and medical equipment—could not function. Although two nursing homes and one adult care facility evacuated patients in advance of the storm, 28 others evacuated under emergency scenarios added significantly to patient risk (though, fortunately, there was no loss of life during any Sandy-related evacuations in the city). Some evacuees were transported without medical records or proper identification, making it difficult for receiving providers to administer appropriate care or notify evacuees' families and caretakers. These disruptions caused some facilities to evacuate patients while others remained safely sheltered in place. Overall, however, these evacuations did not significantly impact the broader healthcare system because many evacuees were safely transferred to other providers. New Yorkers whose providers' facilities closed often were left without a way to see or communicate with their providers. For many without immediate medical concerns, the temporary closures may have had limited impact. However, others with pressing healthcare needs— dialysis patients or those on methadone, for instance—had to seek alternative care immediately, often from hospital emergency departments or mobile medical vans staffed by doctors and nurses from community clinics and other healthcare workers.

Similarly in New Jersey, many health care facilities were severely impacted by Hurricane Sandy, including hospitals, emergency medical providers, local health departments, homecare agencies, dialysis centers and long-term care facilities. Hospitals alone reported an initial estimated $68 million in damages. The hospitals in Hudson County were the hardest hit by the storm, with Hoboken University Medical Center and Palisades Medical Center temporarily closed. The New Jersey City Medical Center was able to remain open when the first floor was flooded by moving their patients to the second floor.

Housing and Commercial Buildings

Hurricane Sandy destroyed or damaged about 650,000 homes, including 345,000 in New Jersey and 305,000 New York. There were also severe damages to commercial buildings and businesses in New Jersey, with nearly 19,000 businesses sustaining damage of $250,000 or more, and total business losses estimated at $8.3 billion. The damage in the community of Mantoloking, NJ highlights the severity of the storm surge and waves across this region. A majority of the structures were flooded, badly damaged, or destroyed. The storm surge carved a path through the barrier island, creating two new inlets. In Seaside Heights, the iconic Casino Pier and Funtown Pier were destroyed. (Fig. III-13). Long Beach Island, a barrier island offshore of the central New Jersey coast, suffered catastrophic damage with nearly every house on the seaside shore extensively damaged. The communities of Union Beach and Sea Bright witnessed similar devastation. The storm surge also pushed water into New York Bay and up the Hudson River causing massive flooding in Jersey City. The storm surge into Raritan Bay forced water up the Raritan River that resulted in flooding in nearby Sayreville. Rescue efforts by the National Guard were required to save residents stranded in the town. About half of the city of Hoboken was flooded, and at least 20,000 of its residents were surrounded by water at the peak of the surge. The community center in Hoboken, its public works garage, four fire houses, and more than 1,700 homes were flooded, with damage in the town estimated to be well over $100 million.

In New York, the governor's office estimates that 305,000 homes were damaged or destroyed in the state, mostly caused by storm surge. Parts of the Manhattan waterfront (including the Battery), Red Hook in Brooklyn, and Long Island City in Queens were under several feet of water. Flood waters reached the corner of Canal and Hudson streets and portions of the East Village, and hundreds of buildings were flooded in Manhattan. In addition, a fire within the Breezy Point neighborhood, located at the tip of the Rockaways peninsula in Queens, destroyed at least 100 homes, with that peninsula also seeing a destructive storm surge. The devastation was widespread in Staten Island, especially along its southern shore where residences, businesses, cars and other property were heavily damaged. Whole blocks of houses were swept away by the surge in the communities of Midland, New Dorp, and Oakland Beach. Significant damage also occurred to the borough's electrical grid, rail, and ferry operations. Around 100,000 homes on Long Island were severely damaged or destroyed, primarily by storm surge and waves, with more than 2,000 homes deemed uninhabitable. On New York's 32-mile long Fire Island, the storm destroyed or washed away 90 homes, and damaged approximately 50 percent of the sand dunes. Atlantic Ocean water breached the island in three places, but about 4,000 homes survived because of the dunes. Total damages on Long Island are estimated to be over $500 million.

Figure III-13. Before and After Images of a Portion of the Coast in Mantoloking, NJ. Photo Courtesy: USGS

Figure III-12. Image of the Jet Star Rollercoaster in the Atlantic Ocean in Seaside Heights, NJ. Photo Courtesy: Getty Images

Insurance Payments

There were over 1.5 million private insurance claims filed for Sandy-related damage to homes, vehicles, boats and business. Over 90 percent of the claims have been settled with insurance companies expected to pay about $18.8 billion in claims to their policyholders.

New York and New Jersey had the largest Sandy-caused flood damages. Insurance for flood damage is usually not covered under a standard homeowners or business owner's policy, but is available through the Federal government's National Flood Insurance Program (NFIP), administered by FEMA. Through June 2013, NFIP processed over 139,000 residential claims and paid out $6.7 billion. Of these there were about 55,000 claims from New York valued at $3.3 billion, and about 71,000 claims from New Jersey valued at $3.1 billion. For commercial property, NFIP processed about 4,800 claims valued at $600 million, of which over 90 percent were for properties in New York and New Jersey. It should be noted that the actual insurance payout for flood damages represents only a percentage of the damages from the storm, since many of the homes and businesses impacted by Sandy were outside the 1 percent floodplain and did not have flood insurance policies.

Ports

The most severe impacts to port operations and infrastructure occurred at facilities operated by the Port Authority of New York & New Jersey (PANYNJ). Figure III-14 shows the numerous facilities that the PANYNJ is responsible for, including marine cargo terminals at six different locations in the metropolitan area, three cruise terminals, several tunnels and bridges, the PATH rail transit system and the Airtrain, five airports, and several industrial parks and waterfront developments. This discussion of Hurricane Sandy impacts to seaports includes only the storm's impacts on the marine terminals. Impacts to the other types of facilities are discussed elsewhere in this report section.

The seaports within PANYNJ handle many types of cargo including containers, vehicles and roll-on/roll-off, bulk and break-bulk cargo (including liquid cargo and petroleum products), and liquefied natural gas (LNG). There are also three terminals for cruise ships.

Figure III-14. Facilities Operated by Port Authority of New York and New Jersey

Immediately prior to Hurricane Sandy's landfall, all PANYNJ facilities except Stewart Airport and the Lincoln Tunnel were closed. During the storm, containers stacks were toppled and some containers were lost. Trucks, cars, and other vehicles in shipping yards – both commercial cargo and personal vehicles – were flooded and/or caught fire. It is estimated that approximately 15,000 containers and 9.000 automobiles were damaged or lost. Pier movements caused contents to shift in sheds and interior wall collapse. A barge collided with the Greenville Yard Transfer Bridge, and the bridge was ultimately demolished after post-storm inspections found it structurally deficient

At the various terminals there were significant damages to cargo handling equipment (e.g. cranes, chassis, and drayage trucks); road and rail track damage; loss of train relays and switches; flooding in buildings; damage to utilities electrical and mechanical equipment; and destruction of security fencing and guard booths.

Following the storm, the marine terminals remained closed, with the first cruise ship arriving on November 2 and the first post-storm cargo ship arriving on November 4. While the marine terminals were closed for operation, 57 vessels were diverted to other ports.

… "Of all of the ways in which Sandy interfered with the liquid fuel supply chain in the New York region, perhaps the most significant was the damage to the area's terminals …. Additionally, damage to storage tanks at several terminals resulted in spills into area waterways totaling some 460,000 gallons of fuel around the city. And, as a result of the large amount of storm-related debris in the harbor immediately following Sandy, the US Coast Guard placed restrictions on port traffic for days until the waterways were deemed safe for use. As a result, even if a terminal were otherwise able to operate, many were still, for a period, unable to dispense or receive tanker and barge shipments, reducing supply capacity by an additional 20 to 25 percent. Overall, for three days after Sandy, all fuel terminals in the New York metropolitan region were completely out of service. Even 10 days after the storm, only 79 percent were operational."
NYC SIRR: A Stronger, More Resilient New York, June 2013

Impact to Natural Resources

As discussed previously there was significant contamination within the New York and New Jersey Harbor estuary due to the storm from overflow from sewage treatment plants, and from the flooding of industrial facilities located adjacent to waterways. Nearly 460,000 gallons of diesel fuel from damaged bulk fuel tanks entered the Arthur Kill, which separates New York and New Jersey, and damaged marshes along the shores of Staten Island and New Jersey.

In their preliminary assessment report of impacts of Hurricane Sandy on coastal habitat of December 17, 2012, the American Littoral Society identified significant impacts to habitat, as well as areas where new habitat was created (American Littoral Society, 2012).

The most significant impact was beach and dune erosion that destroyed important spawning grounds for horseshoe crabs and piping plover habitat, and also lowered elevations that render the already compromised beaches vulnerable to additional impacts due to future storm surges and wave action that come with winter storms.

Saltwater inundation through breaches and overwash also seriously impacted wildlife habitat in maritime forests and fresh water marshes, including the Prime Hook National Wildlife Refuge, DE; Forsythe National Wildlife Refuge, NJ; Cheesequake State Park, NJ; the Hackensack Meadowlands, NJ, and the Jamaica Bay Wildlife Refuge, NY.

The report also identified potential impacts from Hurricane Sandy through providing opportunities for invasive species to colonize disturbed areas. One area of concern was in forests where large numbers of trees were felled that opened holes in the forest canopy for colonization by invasive species. Another concern was where extensive wrack mats are smothering intertidal and near shore habitat, such as at the Forsythe National Wildlife Refuge, NJ, where Hurricane Sandy deposited a 22 mile long wrack line at the marsh/forest interface.

Despite the destruction that occurred, the report also pointed out that in many areas natural features remained intact, including dunes, bluffs, marshes, barrier and bay islands, and reduced risk for not only wildlife habitat, but park facilities and other commercial and residential structures.

For example, at Seven Presidents Oceanfront Park in Long Branch, NJ, the combination of a wide beach, well-established dune system, and a substantial bluff reduced risk to the boardwalk and pavilion behind them. At the Bayshore Waterfront Park, which experienced a 7-foot tidal surge, the recently reconstructed dune between the upland portion of the park and Sandy Hook Bay reduced risk to the historic Cedric Wilson House. The Monmouth Marina adjacent to the park was completely destroyed by the surge and may be abandoned rather than rebuilt. When the state-of-the-art Wildwoods Convention Center was built in 2002, an expansive sand dune was put in place at the same time to serve as a natural barrier to tidal water damage. This sand dune is being cited as the reason that, despite widespread destruction in the area, the convention center was untouched by Hurricane Sandy. And, in Seaside Park, the dunes are credited with reducing risk to most of the ocean front homes standing behind them from any significant damage.

Several marsh restoration projects also fared well from the storm. Situated at the southern tip of the Cape May Peninsula, the South Cape May Meadows Preserve includes over 200 acres of critical habitat comprised of dunes, freshwater wetlands, meadows, ponds and a mile of beach. The Meadows was the subject of a major restoration project in 2004 to return the area to its more natural state to benefit wildlife and reduce flood risk for local communities.

The Meadows fared very well during the storm and achieved its goal of flood risk management. Although water from the surge reached the dunes and the beach was reshaped, the dunes remained intact, as did the salt marshes. During the storm, the City of Cape May suffered a broken storm pipe and directed the resultant overflow into the Meadows. According to resource managers in the area, the Meadows handled the additional water well.

In Jersey City, NJ, Lincoln Park covers 270 acres of recreation fields and natural areas and was the site of a major restoration project that began in 2010 and was recently completed. The projected restored 42 acres of wetland, stream and salt marsh habitat on the Hackensack River to create new habitat for birds and fish and to provide coastline support against climate change. According to resource managers who visited the site after Hurricane Sandy, the area experienced “zero damage.” Similarly, other than deposits of debris, there were no significant damages observed at five salt marsh islands in Jamaica Bay that were constructed using dredged material from the deepening of the shipping channels into New York Harbor.

Impact to Cultural Resources

Coastal flooding from hurricanes and nor’easters can cause damage to historical and other cultural resources resulting in damages to irreplaceable art, artifacts, books, and historic records (FEMA, 2005). With the widespread damages that occurred as part of Hurricane Sandy, state historical preservation offices received reports of damages to cultural resources or other structures of historical importance or designation. Additionally, damages to archaeological sites occurred as well, such as a number of documented archaeological sites associated with Native American settlements and shipwrecks (NPA, 2014a). Approximately 10-percent of the State of New Jersey’s architectural resources were impacted by Hurricane Sandy, with Ocean, Hudson, and Cape May Counties representing the areas with the largest percentages of impacted cultural resources (NPS, 2013). Other damages occurred throughout the NACCS study area that resulted in the National Park Service obligating funds to the Historic Preservation Fund for recovery activities in areas of the States of Connecticut, Delaware, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Virginia, and the

District of Columbia as well as the Narragansett Indian Tribe, Mashantucket (Western) Pequot Tribal Nation, Mohegan Tribe, and Wampanoag Tribe of Hay Head (NPS, 2014b).

IV. Existing Conditions/Post-Sandy Conditions

IV.1. Overview

For the purposes of this report, the existing conditions are the conditions immediately after the landfall of Hurricane Sandy. This existing conditions analysis includes government and agency response, shoreline characteristics, population, supporting critical infrastructure, environmental conditions, and existing shoreline flood risk management projects that were vulnerable to coastal flood risk associated with Hurricane Sandy.

This analysis helped to identify coastal risk reduction and resilience opportunities. The following information is a summary of existing conditions within the study area after Hurricane Sandy. A more detailed analysis for each state can be found in the State and District of Columbia Analyses Appendix.

Key government and agency responses included:

FEMA and SBA

Following Sandy, FEMA coordinated major response and recovery efforts by Federal, state, and local government agencies and NGOs, to repair, replace and restore critical infrastructure under the National Disaster Recovery Framework.

As of July 2013, FEMA and the Small Business Administration (SBA) had helped more than 270,000 individuals or households and 3,900 businesses through $3.8 billion in SBA recovery loans and FEMA individual assistance.

Information from flood insurance claims and the public assistance/individual assistance programs are a component of assessing the existing/post-Sandy conditions.

Disaster Relief Appropriations Act

In January 29, 2013, Congress passed the Disaster Relief Appropriations Act (PL 113-2] that provided approximately $50 billion in funding to support rebuilding in the region. Included were $15 billion to U.S. Department of Housing and Urban Development (HUD) for Community Development Block Grant (CDBG) Disaster Relief.

Infrastructure Systems Rebuilding Principles

USACE and NOAA collaborated to identify tenets to ensure a unified strategy for the agencies' respective activities in restoring the coast following the impact of Hurricane Sandy. The NACCS incorporates these principles into its overall scope and results.

IV.2. General Discussion of the Study Area

Shoreline Characteristics

There are 10 shoreline types in the study area, which were aggregated using the NOAA Environmental Sensitivity Index Shoreline Classification (NOAA, n.d.). These 10 shorelines identified in the Framework include the following: rocky shorelines (exposed), rocky shorelines (sheltered), beaches (exposed), manmade structures (exposed), manmade structures (sheltered), scarps (exposed), scarps (sheltered), vegetated high banks (sheltered), vegetated low banks (sheltered), and wetlands/marshes/swamps (sheltered). Each of the shoreline types responds differently to coastal storms, sea level change and adaptive management; therefore, these are important considerations in identifying coastal storm risk management measures.

Population

The affected population within the study area for the existing condition is provided in Figure IV-1. Affected population totals are offered by state and then by county in the embedded table on the figure.

Infrastructure

The count of affected infrastructure within the study area which characterizes the existing condition is provided in Figure IV-2 based on information from the Homeland Security Infrastructure Program (HSIP) Gold database[8]. Numbers of affected infrastructure are offered by state and then by county in the embedded table on the figure. Table IV-1 offers a list of data layers that were used in the development of the affected infrastructure map.

[8] https://www.hifldwg.org/public/HSIP%20Gold%20Freedom%20One%20Pager_July%202012.pdf

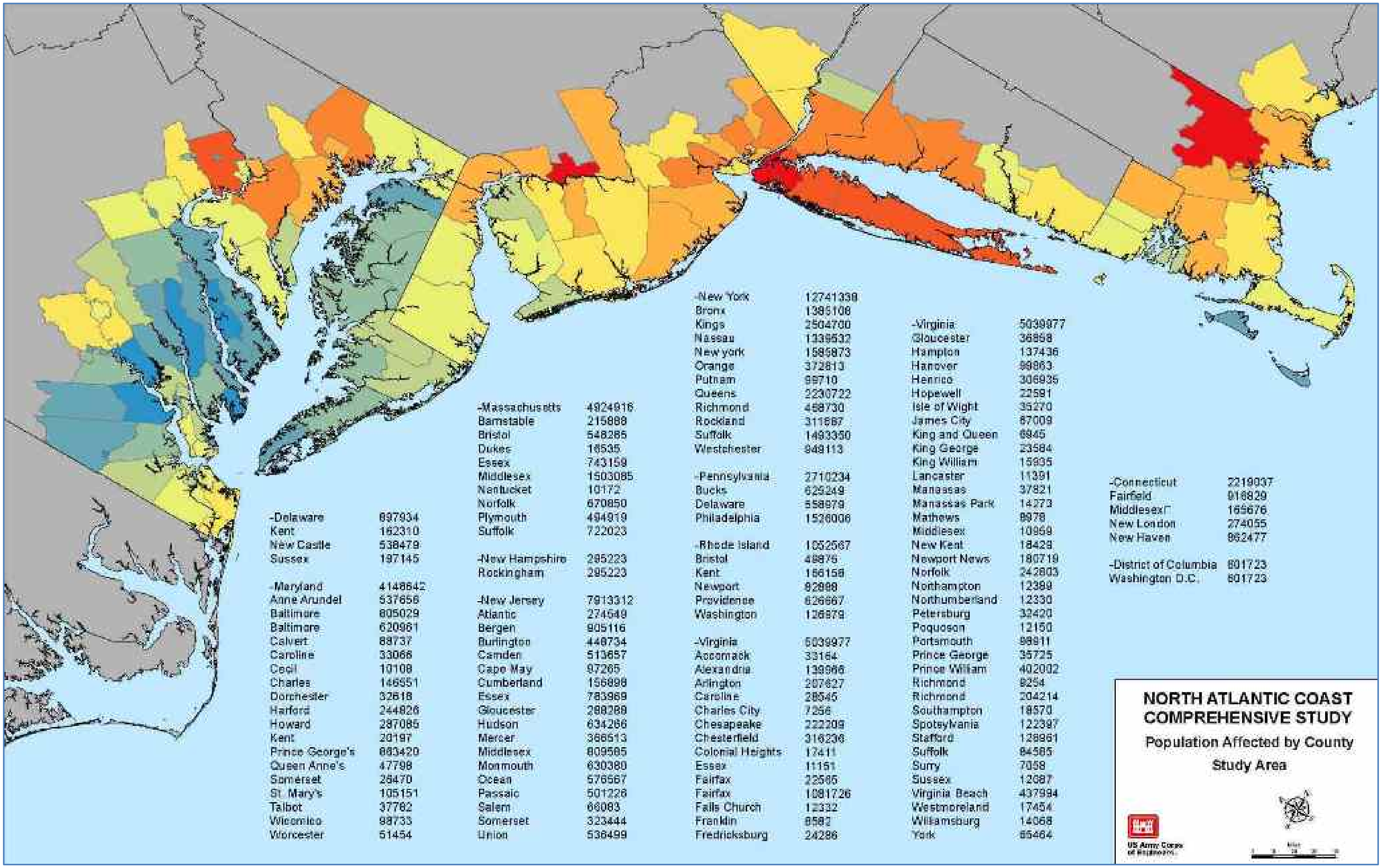


***Figure IV-1**. Affected Populations by County within the NACCS Study Area.*

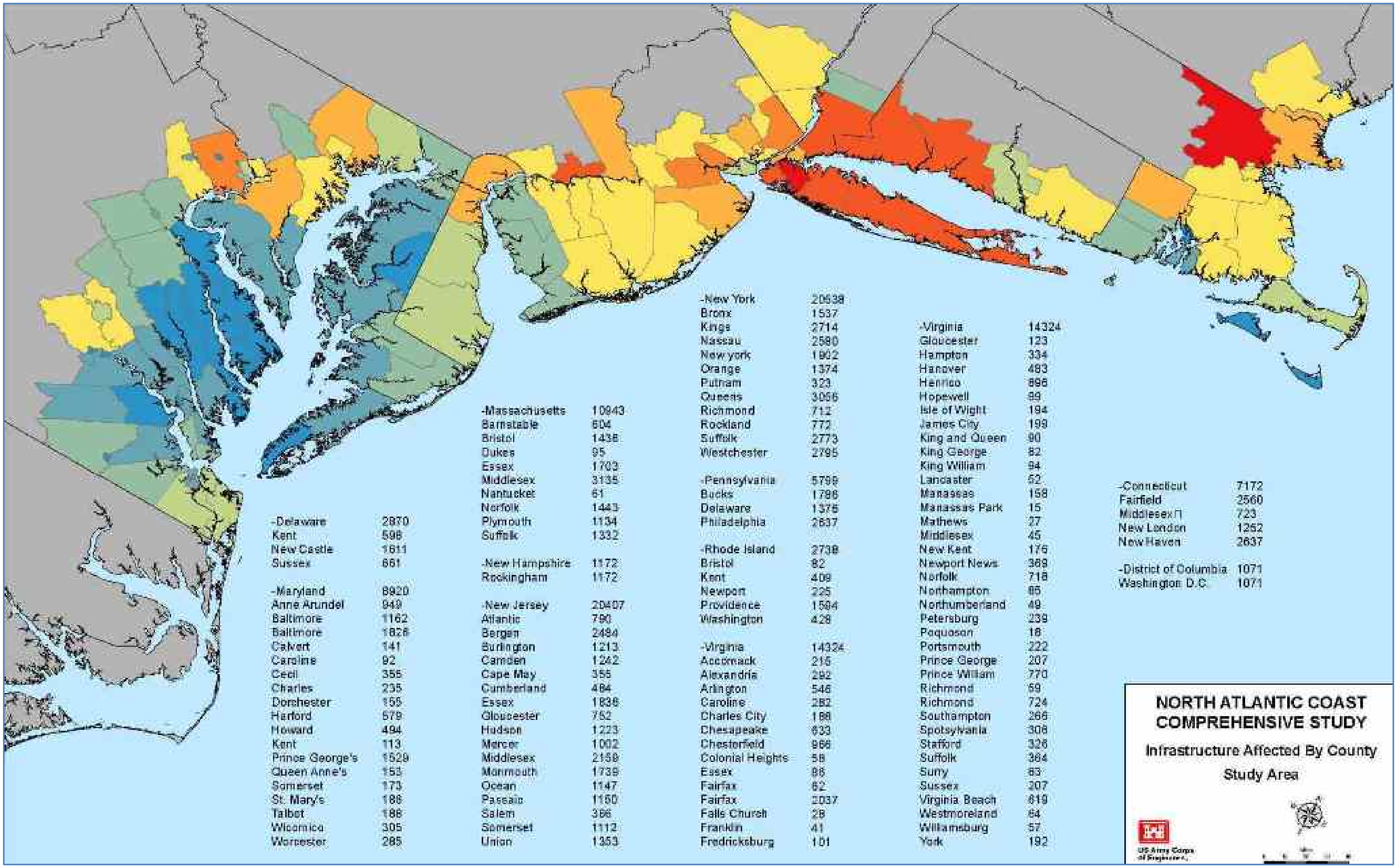


Figure IV-2. Affected Infrastructure by County within the NACCS Study Area (Based on HSIP Gold Database)

Table IV-1. Infrastructure Data Layers

Critical Infrastructure Data Layer	Natural Gas Processing Plants	Road and Railroad Bridges
Cellular Towers	Natural Gas Receipt and Delivery Points	Road and Railroad Tunnels
Communication Centers	Natural Gas Storage Facilities	Service Providers
Electric Generating Units	Nuclear Power Plants	State Emergency Operation Centers
Electric Power Generation Plants	Nursing Homes	Substations
EMS	Oil & Natural Gas Interconnects	Urgent Care Facilities
Energy Distribution Control Facilities	Oil and Natural Gas Platforms	Wastewater pump stations
Ferry	Oil Refineries	Wastewater Treatment Plants
Fire Stations	Petroleum Pumping Stations	Water Treatment Facilities
Gas Stations	Pharmacies	Critical Infrastructure Linear Data Layer
Historic Sites	POL Terminals / Storage Facilities / Tank Farms	Hurricane Evacuation Routes
Hospitals	Ports	Transmission Lines
Intermodal Terminal Facilities	Private Schools	Railroad
Law Enforcement Location	Public Schools	Pipeline Distribution System
Local Emergency Operation Centers	Railroad Bridges	Canal
National Shelter System	Railroad Stations	Channel
Natural Gas (LNG) Import Terminals	Railroad Tunnels	Oil and Natural Gas Pipelines
Natural Gas compressor Stations	Railroad Yards	Ferry Route
Natural Gas Import/Export Points	Receiving Hospitals	

Environmental Conditions

The North Atlantic Coast comprises a vast and rich coastal ecosystem which includes: barrier islands; beaches and dunes; salt, brackish, and freshwater marshes; tidal mud flats and maritime forests; rocky shorelines; submerged aquatic vegetation; oyster and rock reefs, shallow bays and bay islands; terrestrial uplands, floodplains, and riparian zones. These habitats contain a remarkable array of biodiversity and are recognized as an important ecological resource for migratory birds including waterfowl, wading birds, shorebirds, and other species that depend upon these areas during their lifetime.

Significant habitats along the coast include coastal wetlands, waterbird islands, and Essential Fish Habitat (EFH). Some area beaches provide critical habitat for horseshoe crab spawning, other areas support threatened and endangered species such as least and common Terns. Additionally, the entire study area is part of the Atlantic Flyway which is home to 32 priority bird species.

Coastal habitats and their dependent species are discussed in more detail in the NACCS Environmental and Cultural Resources Report, which includes a planning aid report as an attachment prepared by the U.S. Fish and Wildlife Service (USFWS) (USACE, 2014).

IV.3. Existing Flood Risk Management Projects

Sources of information which assisted in the inventorying of USACE projects include:

- First and Second Interim Reports
- Hurricane Sandy Coastal Projects Performance Evaluation Study
- The Coastal Systems Portfolio Initiative (CSPI) Technical Review Document (TRD): A Technical Review of Coastal Projects: Storm Risk Management, Navigation, and Ecosystem Restoration for the Nation's Coastline (Spring, 2012),
- USACE coastal flood risk management and navigation project and study location maps, and;
- Existing state coastal flood risk management, navigation, and shoreline stabilization project maps.

In addition to coastal flood risk management projects, navigation, ecosystem restoration, and economic development efforts were included if they were made known to the study team and were related to coastal resilience or represented significant social and economic investments in our coastlines. An inventory of existing USACE coastal storm risk management and navigation projects are presented for the study area in Figure IV-3 and Table IV-2. These are based upon the Disaster Relief Appropriations Act of 2013, PL 113-2 First and Second Interim Reports, and the CSPI TRD. In addition, as part of PL 113-2, other Federal agencies received appropriations for various purposes within the agencies' mission areas in response to Hurricane Sandy. A more detailed discussion of USACE projects, other Federal projects and programs, as well as relevant state agency information is provided for the respective states in the State and District of Columbia Analyses Appendix.

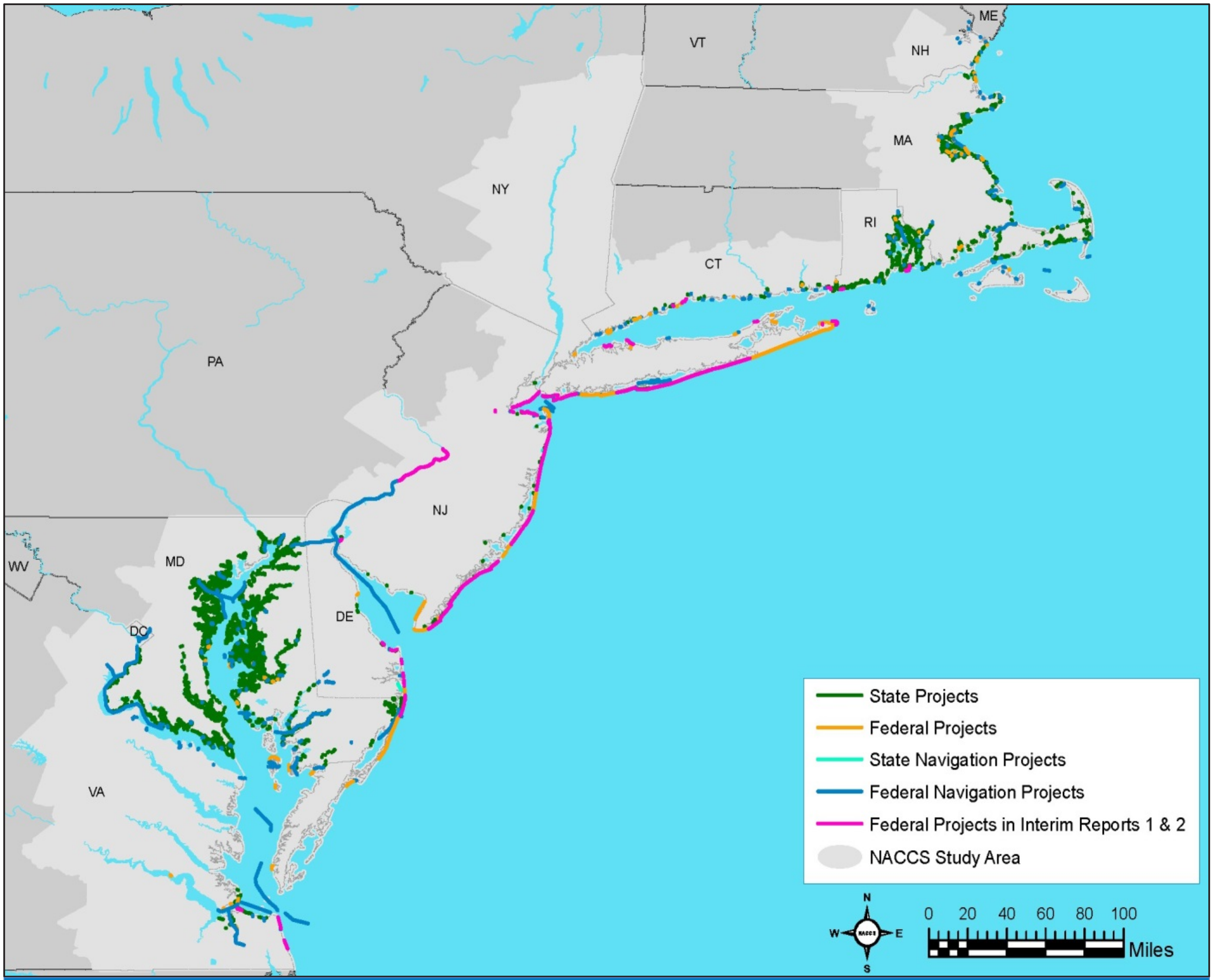


Figure IV-3. Existing/Post-Sandy Federal (USACE) and State Coastal Projects

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)						
PROJECT	**Constructed Projects (From First Interim Report)**	**Projects Under Construction (From First Interim Report)**	**Authorized but Unconstructed Projects (From Second Interim Report)**	**Projects Under Study with High Probability of Implementation (From Second Interim Report)**	**Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)**	**Navigation Projects**
NH						
Bellamy River, NH						X
Cocheco River, NH						X
Exeter River, NH						X
Hampton Beach, Hampton, NH	X					
Hampton Harbor, NH						X
Lamprey River, NH						X
Little Harbor, NH						X
Portsmouth Harbor and Piscataqua River, NH						X
Rye Harbor, NH						X
Wallis Sands State Beach, Rye, NH	X					
MA						
Andrews River, MA						X
Aunt Lydia's Cove, MA						X
Beverly Harbor, MA						X
Bluffs Community Center, Swansea, MA					Constructed	
Boston Harbor, MA						X
Buttermilk Bay Channel, MA						X
Canapitsit Channel, MA						X
Cape Cod Canal, MA						X
Charles River Dam, Boston, MA (Cat 1 Protection)					Constructed	
Chatham (Stage) Harbor, MA						X
Clark Point Beach, New Bedford, MA					Constructed	
Cohasset Harbor, MA						X
Cross Rip Shoals, MA						X
Cuttyhunk Harbor, MA						X
Dorchester Bay, MA						X
Duxbury Harbor, MA						X

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)						
PROJECT	**Constructed Projects (From First Interim Report)**	**Projects Under Construction (From First Interim Report)**	**Authorized but Unconstructed Projects (From Second Interim Report)**	**Projects Under Study with High Probability of Implementation (From Second Interim Report)**	**Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)**	**Navigation Projects**
Edgartown Harbor, MA						X
Essex River, MA						X
Fall River, MA						X
Falmouth Harbor, MA						X
Gloucester Harbor and Annisquam River, MA						X
Green Harbor, MA						X
Hingham Harbor, MA						X
Hyannis Harbor, MA						X
Ipswich River, MA						X
Island Ave, Quincy, MA					Constructed	
Kingston Harbor, MA						X
Lagoon Pond, MA						X
Little Harbor at Woods Hole, MA						X
Lynn Harbor, MA						X
Menemsha Creek, MA						X
Mystic River, MA						X
Nantasket Beach, Hull, MA					Project Under Study - High Probability of Construction	
Nantucket Harbor of Refuge, MA						X
New Bedford Hurricane Barrier, MA (Cat 3 Protection)					Constructed	
Newburyport Harbor, MA						X
North Scituate Beach, Scituate, MA					Constructed	
Oak Bluffs Town Beach, Martha's Vineyard, MA					Constructed	
Pigeon Cove Harbor, MA						X
Plum Island Beach, Newbury, MA					Constructed	
Plymouth Harbor, MA						X
Point Shirley, Winthrop, MA					Constructed	
Pollock Rip Shoals, MA						X

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)

PROJECT	Constructed Projects (From First Interim Report)	Projects Under Construction (From First Interim Report)	Authorized but Unconstructed Projects (From Second Interim Report)	Projects Under Study with High Probability of Implementation (From Second Interim Report)	Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)	Navigation Projects
Provincetown Harbor, MA						X
Quincy Shore Beach, Quincy, MA					Constructed	
Revere Beach, MA					Constructed	
Rockport Harbor, MA						X
Roughans Point, Revere, MA					Constructed	
Salem Harbor, MA						X
Salisbury Beach, MA					Constructed	
Saugus River, MA						X
Scituate Harbor, MA						X
Sesuit Harbor, MA						X
Taunton River, MA						X
Town River Bay, Quincy, MA					Constructed	
Vineyard Haven Harbor, MA						X
Wareham Harbor, MA						X
Wellfleet Harbor, MA						X
Wessagusset Beach, Weymouth, MA					Constructed	
Westport Harbor, MA						X
Weymouth Fore & Town Rivers, MA						X
Winthrop Beach, MA					Constructed	
Winthrop Harbor, MA						X
Woods Hole Channel, MA						X
RI						
Apponaug Cove, RI						X
Block Island (Harbor of Refuge), RI						X
Bullocks Point Cove, RI						X
Cliff Walk, Newport, RI	X					
Fox Point Hurricane Barrier, Providence, RI (Cat 3 Protection)					Constructed	
Great Salt Pond, RI						X

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)						
PROJECT	**Constructed Projects (From First Interim Report)**	**Projects Under Construction (From First Interim Report)**	**Authorized but Unconstructed Projects (From Second Interim Report)**	**Projects Under Study with High Probability of Implementation (From Second Interim Report)**	**Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)**	**Navigation Projects**
Greenwich Bay, RI						X
Misquamicut Beach, Westerly, RI	X					
Newport Harbor, RI						X
Oakland Beach, Warwick, RI					Constructed	
Pawcatuck River, Little Narragansett Bay and Watch Hill Cove, RI						X
Pawtuxet Cove, RI						X
Point Judith Pond and Harbor of Refuge						X
Potowomut River, RI						X
Providence River and Harbor, RI						X
Sakonnet Harbor, RI						X
Sakonnet River, RI						X
Seekonk River, RI						X
Warwick Cove, RI						X
Wickford Harbor, RI						X
CT						
Branford Harbor, CT						X
Bridgeport Port V Facility, Bridgeport, CT	X					
Bridgeport Harbor, CT						X
Clinton Harbor, CT						X
Connecticut River below Hartford, Saybrook Shoals (entrance), CT						X
Duck Island Harbor, CT						X
Five Mile River Harbor, CT						X
Greenwich Harbor, CT						X
Guildford Harbor, CT						X
Gulf Beach, Milford, CT	X					
Gulf Street, Milford, CT					Constructed	
Housatonic River, CT						X

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)

PROJECT	Constructed Projects (From First Interim Report)	Projects Under Construction (From First Interim Report)	Authorized but Unconstructed Projects (From Second Interim Report)	Projects Under Study with High Probability of Implementation (From Second Interim Report)	Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)	Navigation Projects
Mianus River, CT						X
Middle Beach, Madison, CT					Constructed	
Milford Harbor, CT						X
Mystic River, CT						X
New Haven Harbor, CT						X
New London Harbor, CT						X
New London Hurricane Barrier, CT (Cat 1 Protection)					Constructed	
Niantic Bay and Harbor, CT						X
Norwalk Harbor, CT						X
Patchogue River, CT						X
Pawcatuck Hurricane Barrier, CT (Cat 2 Protection)					Constructed	
Point Beach, Milford, CT					Constructed	
Prospect Beach, West Haven, CT	X					
Sea Bluff Beach, West Haven, CT	X					
Sherwood Island State Beach, Westport, CT					Constructed	
Southport Beach, Fairfield, CT					Constructed	
Southport Harbor, CT						X
Stamford Harbor, CT						X
Stamford Hurricane Barrier, CT (Cat 2 Protection)					Constructed	
Stonington Harbor, CT						X
Stony Creek, CT						X
West Point Harbor, CT						X
Westcott Cove, CT						X
Westport Harbor & Saugutuck River, CT						X
Woodmont Beach, Milford, CT	X					
NY						
Ambrose Channel, NY						X
Asharoken, NY (CAP S 103)					Constructed	

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)

PROJECT	Constructed Projects (From First Interim Report)	Projects Under Construction (From First Interim Report)	Authorized but Unconstructed Projects (From Second Interim Report)	Projects Under Study with High Probability of Implementation (From Second Interim Report)	Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)	Navigation Projects
Atlantic Coast of Long Island, Fire Island Inlet to Montauk Point, NY (FIMP)			X			
Atlantic Coast of Long Island, Fire Island to Montauk Point, NY (FIMP): West of Shinnecock Inlet Interim #		X				
Atlantic Coast of Long Island, Fire Island to Montauk Point, NY (FIMP): Westhampton Interim #					Constructed	
Atlantic Coast of Long Island, Fire Island to Montauk Point, NY (FIMP): Fire Island to Moriches Inlet Interim #			X			
Atlantic Coast of Long Island, Fire Island to Montauk Point, NY (FIMP): Downtown Montauk Interim #			X			
Atlantic Coast of Long Island: Jones Inlet to Rockaway Inlet (Long Beach, NY)			X			
Atlantic Coast of New York City, East Rockaway Inlet to Rockaway Inlet, NY (Rockaway), NY #	X		X			
Atlantic Coast of New York City, Rockaway Inlet to Norton Point, NY (Coney Island) #			X			
East Rockaway Inlet, NY						X
Fire Island and Shores Westerly to Jones Inlet, NY (Gilgo Beach), NY	X					
Fire Island Inlet, NY						X
Great South Bay, NY						X
Hashamomuck Cove, NY				X		
Jamaica Bay, Marine Park and Plumb Beach, NY *					Unconstructed	
Jamaica Bay, NY Federal Navigation Channel						X
Jones Inlet, NY						X
Lake Montauk Harbor, NY					Unconstructed	
Lake Montauk Harbor, NY						X
Long Island Intracoastal, NY						X
Mattituck Inlet, NY						X

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)						
PROJECT	**Constructed Projects (From First Interim Report)**	**Projects Under Construction (From First Interim Report)**	**Authorized but Unconstructed Projects (From Second Interim Report)**	**Projects Under Study with High Probability of Implementation (From Second Interim Report)**	**Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)**	**Navigation Projects**
Mattituck Inlet, NY (CAP S 111)					Constructed	
Montauk Point, NY#			X			
Moriches Inlet						X
Oakwood Beach, NY	X					
Orchard Beach, NY					Constructed	
Orient Harbor, NY State Road 25, NY (CAP S 14)					Constructed	
Point Lookout/Jones Inlet, NY (CAP S 204)					Constructed	
Plumb Beach, NY (CAP S 204)					Constructed	
Shelter Island, NY					Constructed	
Village of Northport, Northport Harbor, NY (CAP S 14)					Constructed	
NJ						
Cheesequake Creek, NJ						X
Joseph G. Minish Waterfront Park and Historic Area, NJ #			X			
Passaic Main Stem, NJ			X			
Passaic River Tidal Protection Area, NJ #			X			
Port Monmouth, NJ #			X			
Raritan Bay and Sandy Hook Bay: Keansburg, East Keansburg, and Laurence Harbor	X					
Sandy Hook Bay, NJ (Atlantic Highlands)						X
Sandy Hook Channel, NJ						X
Sandy Hook to Barnegat Inlet, NJ (Elberon to Loch Arbour) #			X			
Sandy Hook to Barnegat Inlet, NJ (Sea Bright to Ocean Township and Asbury Park to Manasquan) #		X				
Shrewsbury River, NJ						X
Shoal Harbor and Compton Creek, NJ						X
Shark River Inlet, NJ						X
South River, Raritan River Basin, NJ #			X			
Union Beach, NJ #			X			

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)

PROJECT	Constructed Projects (From First Interim Report)	Projects Under Construction (From First Interim Report)	Authorized but Unconstructed Projects (From Second Interim Report)	Projects Under Study with High Probability of Implementation (From Second Interim Report)	Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)	Navigation Projects
Absecon Inlet						X
Barnegat Inlet						X
Barnegat Inlet to Little Egg Harbor Inlet #			X			
Brigantine Inlet to Great Egg Harbor Inlet, NJ-(Absecon) #	X		X			
Brigantine Inlet to Great Egg Harbor Inlet, NJ (Brigantine Island)	X					
Cape May Inlet						X
Cape May Inlet to Lower Township, NJ	X					
Delaware Bay Coastline, Oakwood Beach, NJ #			X			
Delaware Bay Coastline, Reeds Beach and Pierces Point, NJ *					Unconstructed	
Delaware Bay Coastline, Villas and Vicinity NJ *					Unconstructed	
Delaware River: Philadelphia to the Sea O&M						X
Delaware River: Philadelphia to Trenton O&M						X
Great Egg Harbor Inlet to Peck Beach, NJ	X					
Great Egg Harbor Inlet to Townsends Inlet, NJ #			X			
Hereford Inlet to Cape May Inlet, NJ				X		
Lower Cape May Meadows/Cape May Point, NJ *					Constructed	
Manasquan Inlet, NJ						X
Manasquan Inlet to Barnegat Inlet, NJ #			X			
Townsends Inlet to Cape May Inlet, NJ	X					
Salem River, NJ						X
DE						
Delaware Bay Coastline, Broadkill Beach, DE #			X			
Delaware Bay Coastline, Port Mahon, DE *					Unconstructed	
Delaware Bay Coastline, Roosevelt Inlet to Lewes Beach, DE	X					
Delaware Coast from Cape Henlopen to Fenwick Island, Bethany Beach to South Bethany Beach, DE	X					

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)

PROJECT	Constructed Projects (From First Interim Report)	Projects Under Construction (From First Interim Report)	Authorized but Unconstructed Projects (From Second Interim Report)	Projects Under Study with High Probability of Implementation (From Second Interim Report)	Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)	Navigation Projects
Delaware Coast from Cape Henlopen to Fenwick Island, Fenwick Island, DE	X					
Delaware Coast from Cape Henlopen to Fenwick Island, Rehoboth Beach and Dewey, DE	X					
Delaware Coast Protection - Indian River Inlet - Sand Bypass, DE	X					
Delaware River: Philadelphia to the Sea O&M						X
Delaware River: Philadelphia to Trenton O&M						X
Chesapeake and Delaware Canal, DE						X
Wilmington, Harbor, DE						X
Roosevelt Inlet/Lewes and Rehoboth Canal, DE						X
Broadkill River, DE						X
Murderkill River Inlet, DE						X
Mispillion River Inlet, DE						X
Indian River Inlet						X
MD						
Assateauge Island Restoration Short-Term and Long-Term Nourishment, MD						
Atlantic Coast of Maryland, MD	X					
Atlantic Coast of Maryland, MD		X				
Chesapeake Bay Environmental Restoration and Protection Program, MD, VA, PA, NY, WV, and DC (AKA Chesapeake Bay Section 510) - (NORTH BEACH ONLY)						
Smith Island Environmental Restoration, Maryland			X			
Oxford, MD, Shoreline Protection					X	
Black Walnut Point, Tilghman Island, MD					X	
Taylors Island, Dorchester County, MD					X	
North Beach Park, MD					X	
Baltimore Harbor, MD						X
Fishing Creek, MD						X

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)						
PROJECT	**Constructed Projects (From First Interim Report)**	**Projects Under Construction (From First Interim Report)**	**Authorized but Unconstructed Projects (From Second Interim Report)**	**Projects Under Study with High Probability of Implementation (From Second Interim Report)**	**Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)**	**Navigation Projects**
Fishing Bay, MD						X
Duck Point Cove, MD						X
Crisfield Harbor, MD						X
Corsica River, MD						X
Claiborne Harbor, MD						X
Choptank River, MD						X
Chester River, MD						X
Cambridge Harbor, MD						X
Broad Creek, MD						X
Breton Bay, MD						X
Black Walnut Harbor, MD						X
Baltimore Harbor, MD						X
Back Creek, MD						X
Annapolis Harbor and Spa Creek, MD						X
Anacostia River, MD						X
Northeast River, MD						X
Neavitt Harbor, MD						X
Neale Sound, MD						X
Nanticoke River at Nanticoke, MD						X
Nanticoke River at Bivalve, MD						X
Nan Cove, MD						X
Muddy Hook Tyler Cove, MD						X
Middle River, MD						X
Madison Bay, MD						X
Lowes Wharf, MD						X
Lower Thorofare, MD						X
Little Creek, MD						X
Knapps Narrows, MD						X
Island Creek, MD						X

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)

PROJECT	Constructed Projects (From First Interim Report)	Projects Under Construction (From First Interim Report)	Authorized but Unconstructed Projects (From Second Interim Report)	Projects Under Study with High Probability of Implementation (From Second Interim Report)	Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)	Navigation Projects
Honga River, MD						X
Herring Creek						X
Herring Bay Rockhold Creek, MD						X
Goose Creek, MD						X
Rock Hall Harbor, MD						X
Queenstown Harbor, MD						X
Pocomoke River, MD						X
Parish Creek, MD						X
Ocean City, MD						X
Susquehanna River Above and Below Havre De Grace, MD						X
St. Peters Creek, MD						X
St. Michaels Harbor, MD						X
St. Jerome Creek, MD						X
St. George Creek, MD						X
St. Catherine Sound, MD						X
Smith Island, MD						X
Smith Creek, MD						X
Slaughter Creek, MD						X
Rhodes Point to Tylerton, MD						X
Shallow Creek, MD						X
Shad Landing, MD						X
Wicomico River, MD						X
Upper Thorofare, MD						X
Tred Avon River, MD						X
Town Creek, MD						X
Tilghman Island, MD						X
Warwick River, MD						X
Kent Narrow, MD						X
Potomac River, MD						X

Table IV-2. NACCS USACE Existing Projects (CSDR and NAV)						
PROJECT	**Constructed Projects (From First Interim Report)**	**Projects Under Construction (From First Interim Report)**	**Authorized but Unconstructed Projects (From Second Interim Report)**	**Projects Under Study with High Probability of Implementation (From Second Interim Report)**	**Projects not included in PL 113-2 Disaster Relief Appropriations Act, 2013 (First and Second Interim Reports)**	**Navigation Projects**
Washington, Harbor, MD						X
Anacostia River Basin, MD						X
Washington, DC and Vicinity					X	
Potomac River- North Side of Washington, Channel						X
Potomac River Below Washington, DC						X
VA						
Anderson Park Shore Protection, VA					Constructed	
Cape Charles Shore Protection, VA					Constructed	
Cape Henry Channel, VA						X
Chesapeake Bay Shoreline, Hampton VA					Constructed	
Chincoteague Inlet, VA						X
Hampton Institute Shore Protection, VA					Constructed	
Jamestown Island Seawall, Jamestown Island, VA					Constructed	
Little Creek Inlet, VA						X
Lynnhaven Inlet, VA						X
Norfolk Floodwall, VA					Constructed	
Norfolk Harbor - Atlantic Channel, VA						X
Norfolk Harbor - Norfolk Harbor Channel, VA						X
Rudee Inlet, VA						X
Sandbridge, VA	X					
Saxis Island Shore Protection, VA					Constructed	
Tangier Island Shore Protection, VA	X					
Thimble Shoal Channel, VA						X
Virginia Beach Hurricane Protection, VA	X					
Virginia Beach Hurricane Protection, VA		X				
Wallops Island Shore Protection					Constructed	
Willoughby Channel, VA						X
Willoughby Spit and Vicinity, Norfolk, VA #			X			

 # Project identified as a General or Hurricane Sandy Limited Reevaluation Report (HSGRR/HSLRR) in PL 113-2, Disaster Relief Appropriations Act

** Ecosystem restoration project with CSRM benefits*

Jamaica Bay Natural/Nature-Based Features will be evaluated for coastal storm risk management in the Rockaway-Jamaica Bay

General Re-evaluation Report effort. Jamaica Bay sites that are screened from the Rockaway-Jamaica Bay General Re-evaluation Report would be advanced via the regular Civil Works program and be included in the Hudson Raritan Estuary Feasibility Study.

Projects under study may be constructed with Public Law 113-2 funds if the Office of the Assistant Secretary of the Army (Civil Works) determines the recommended project is technically feasible, economically justified, and environmentally acceptable and if there are sufficient Public Law 113-2 funds to complete initial construction of the project.

[3] For projects with high probability of implementation, the estimate of 5 years to complete construction is acceptable for regional planning purposes.

CAP = Continuing Authorities Program

Of the existing USACE projects identified in Table IV-2, some projects are currently undergoing a process to reevaluate the scope and purpose of the project. The Hurricane Sandy Coastal Projects Performance Evaluation Study includes the evaluation of projects' performance during Hurricane Sandy. Information contained in that report along with elements of the NACCS Coastal Flood Risk Management Framework have informed the separate and parallel formulation effort for those projects, including addressing risk and uncertainty, combinations of measures and projected performance, as well as the projects' economic analyses. Furthermore, this process could include an evaluation of other measures as part of the existing projects for purposes beyond the original intent and scope of the project. The NACCS Framework considers an array of solutions to effectively address flood risk and promote resilience as part of the coastal system. There is an opportunity for USACE and other agencies to consider navigation, ecosystem restoration, and flood risk management as multi-purpose projects utilizing a systems approach.

However, the USACE authorized but unconstructed (ABU) projects presented in the Second Interim Report included a design for a flood risk management project as part of a recommended plan in the USACE decision document authorized by Congress. Within the scope and scale of the project design, modifications to incorporate features to address resilience, sea level change, and adaptation would be considered as part of subsequent plans and specifications for the project. Technical products and advancements (i.e., modeling, NNBF, analysis of benefits), as a result of NACCS, may be used during the design and implementation phases to align the projects with the Framework and future adaptation, inasmuch as the existing congressional authority allows.

A summary of the existing condition for each state is provided and is based on the aforementioned inventory of resources. A detailed discussion of each state's existing condition including a list of specific projects and mapping is provided in the State and District of Columbia Analyses Appendix. Additional project reliability information on a project by project basis is presented in the CSPI Report for the majority of USACE coastal storm risk management projects in the USACE North Atlantic Division.

New Hampshire

Coastal storm risk is not managed along the Atlantic Ocean coast due to the lack of Federal coastal storm risk management projects.

Massachusetts

Only the Charles River Dam in Boston, MA and the New Bedford Hurricane Protection Barrier in New Bedford, MA provide reliable risk management against storm surge.

Rhode Island

Only the Fox Point Hurricane Protection Barrier in Providence, RI provides reliable coastal storm risk management against storm surge.

Connecticut

Only the Stamford Hurricane Protection Barrier in Stamford, CT provides reliable coastal storm risk management against storm surge.

New York

While coastal storm risk is managed along the Atlantic Ocean coast of NYC and Long Island by a number of Federal coastal storm risk management projects, additional coastal storm risk management improvements to these shorelines should be identified. In addition, portions of the Nassau County back bays are not well protected due to the limited number of coastal storm risk management projects.

New Jersey

While coastal storm risk is managed along the Atlantic Ocean coast by a number of Federal coastal storm risk management projects, the back bay and Delaware Bay coasts are not well protected due to the limited number of coastal storm risk management projects.

Delaware

While the Atlantic Ocean coast is well protected owing to a significant number of Federal coastal storm risk management projects, the back bay and Delaware Bay coasts are not well protected due to the limited number of Federal coastal storm risk management projects.

Maryland

While the Atlantic Ocean coast is well protected owing to significant coverage of Federal coastal storm risk management projects, the coastline of the coastal bays including Assawoman, Sinepuxent, and Chincoteague Bays are not well protected due to the lack of Federal coastal storm risk management projects.

Virginia

The Atlantic Ocean as well as the Chesapeake Bay coasts are not well protected due to the lack of Federal coastal storm risk management projects.

As for municipal projects, no existing municipal projects were identified as part of the existing condition except where projects were partnered with USACE.

V. Post-Sandy Landscape

V.1. Overview

Conditions in the study area are constantly changing. In contrast, many of the past decisions affecting coastal storm risk have resulted in more rigid actions that are not readily adaptable to change. The Framework seeks to provide a flexible approach that can be adapted to changing coastal conditions or societal needs. In order to do so, the likely future conditions must be forecasted to enable consideration of the range of potential alternatives. Future changes in socio-economic, environmental, cultural and related conditions will certainly alter coastal risks and resilience, likely in ways difficult to foresee. This reinforces the need for scenario planning to identify adaptable strategies to accomplish the NACCS goals.

Some of the future changes considered in the Framework are as follows:

- Relative sea level is increasing throughout the study area, and this will increase the areas exposed to storm surge and will increase the frequency of flooding.
- Shorelines are changing in response to relative sea level change (RSLC) and sediment deficits. Historic erosion patterns are likely to continue or accelerate.
- The population in the study area is increasing, and this will increase the number of people and extent of infrastructure at risk during a storm.
- The population in the study area is getting older. In addition, some segments of the population are more vulnerable to hazards than others.
- The extent and character of coastal storm risk management projects will increase. In response to the increased risk, many communities will implement projects and programs to reduce vulnerability and reduce risk to developed areas through a combination of traditional engineered storm risk management projects, nature based solutions, and strategic retreat and/or elevation of vulnerable structures.

V.2. Coastal Storm Risk Management Projects

For purposes of forecasting future scenarios, it is assumed that:

- All existing USACE coastal storm risk management projects identified in the First Interim will be both repaired to pre-Sandy conditions through the USACE Flood Control and Coastal Emergencies (FCCE) program and also returned to authorized design dimensions through funding provided under PL 113-2;
- All authorized but unconstructed USACE coastal storm risk management projects will be constructed to authorized design dimensions through funding provided under PL 113-2;
- All studies identified in the Second Interim Report with a high (>75 percent) probability of construction will be constructed to authorized design dimensions through funding provided under PL 113-2;
- Other Federal agency/NGO projects and state projects will be repaired to their pre-Sandy condition unless otherwise communicated by individual agencies.

The post-Sandy landscape identified those projects applicable to receive construction funds as a part of the Second Interim Report. They were identified based on the assumption that Federal funds are in hand and after further communication with non-Federal sponsors. Many of these projects are already underway or were in receipt of funding appropriated as part of PL 113-2. In early 2013, once the scoping, existing, and future conditions forecasts for the NACCS were being developed, the study adopted a general assumption of five years to complete construction of those projects identified in Interim Report 2. In parallel to the NACCS, the post-Sandy construction program was established. Further coordination resulted in refined schedules leading to some projects expected to be 100 percent constructed before 2018 as well as many after 2018; however, for planning regional planning purposes, the estimate of 5 years to complete construction is acceptable.

The projects included in the post-Sandy landscape are presented in the main report, Section IV - Existing Conditions/Post-Sandy Conditions. Details of the post-Sandy landscape for each state are provided in the State and District of Columbia Analyses Appendix.

V.3. Conceptual Regional Sediment Management Budget

As part of the post-Sandy assessment, USACE prepared a conceptual regional sediment budget for the NACCS study area. The conceptual regional sediment budget was developed using existing literature and databases to characterize sediment transport pathways and magnitudes, and morphologic zones of erosion and accretion. It is intended to provide in general terms information about sediment sources and sinks, as well as opportunities for strategic placement. The development of a more detailed sediment budget is fundamental to better sediment management. Further collaboration with Federal, state and other stakeholders will be necessary to identify available sediment and borrow areas, as well as placement sites. This collaboration would be part of a systems approach to identify opportunities to address risk and vulnerability in proximity to navigation and ecosystem restoration initiatives, potentially incorporated into NNBF flood risk management solutions as part of a combination measures, as sediment dredged from navigation channels is a valuable resource for placement. Identification of areas of flood risk that may be appropriate for consideration of NNBF opportunities could benefit from an optimization of dredging and placement alternatives from both Federally and state maintained navigation channels.

A conceptual sediment budget is the first step in the process to develop a more detailed sediment budget based on more rigorous data analysis and numerical modeling. Additional analyses into the footprint of navigation channels, placement and quality of dredged sediments, and developing a future sediment budget related to impacts from climate change and sea level change is required. The information associated with the NACCS conceptual regional sediment management is available at http://www.nad.usace.army.mil/CompStudy.aspx.

V.4. Evaluation of Sea Level Change

RSLC will not only inundate larger coastal areas, but will also be a driver of change in habitat and species distribution, as will other effects of climate changes such as increased sea surface temperatures. Impacts will likely include shoreline retreat from erosion and inundation, increased frequency and magnitude of storm related flooding, temperature changes, and saltwater intrusion into the estuaries and aquifers. Additionally, presence of developed shorelines behind many of these habitats will prevent barrier island overwash and migration landward in response to RSLC. Habitat changes may be structural or functional; species that depend on coastal habitats for feeding, nesting, spawning, protection, and other activities could be severely impacted if this critical habitat is converted or lost. Additional services provided by coastal habitats would be also affected.

The future conditions of coastal habitats and their dependent species are generally discussed in the NACCS Environmental and Cultural Resources Conditions Report (USACE, 2014).

V.5. Relative Sea Level Change and Forecast

The NACCS addresses sea level change in accordance with the recently-updated guidance document USACE Engineer Regulation (ER) 1100-2-8162, Incorporating Sea Level Change in Civil Works Programs (USACE, 2013). The USACE Sea Level Change ER refers to sea level change (rather than sea level rise) because it is meant to be applicable in all areas—including those locations where local relative sea levels are falling due to local/regional land uplift. In the case of the NACCS, relative sea levels are rising throughout the entire study area.

The USACE ER specifies RSLC scenarios to be used in climate change planning. The USACE Sea Level Change ER outlines the development of three RSLC scenarios: Low, Intermediate, and High. The USACE High scenario is a combination of more limited ice loss and ocean warming. The USACE Intermediate scenario is based primarily on ocean warming. The USACE Low is a linear extrapolation of the historical SLC records. All three of these USACE RSLC scenarios are evaluated in the NACCS.

In addition, the National Climate Assessment, a joint report by NOAA, U.S. Geological Service, Department of Defense Strategic Environmental Research and Development Program, and USACE, has recommended sea level change scenarios in a report entitled Global Sea Level Rise Scenarios for the US National Climate Assessment (NOAA, 2012). NOAA outlines four RSLC scenarios: Low, Intermediate Low, Intermediate High, and High. The Low and Intermediate Low NOAA scenarios are identical to the USACE Low and Intermediate, respectively. The NOAA Intermediate High falls between the USACE Intermediate and High and the NOAA High is greater than the USACE High. The NOAA and USACE scenarios incorporate the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 4 global mean sea level change predictions and are consistent with the latest IPCC Assessment Report 5 predictions. The USACE Comprehensive Evaluation of Projects with Respect to Sea Level Change provides additional information and a sea level change curve calculator for USACE and NOAA sea level change scenarios available online at http://www.corpsclimate.us/ccaceslcurves.cfm. A complete set of future sea level tables for each scenario and time is contained in the Engineering Appendix. Sea level change mapping for the respective States is presented in the State and District of Columbia Analyses Appendix. It should be noted that various federal and state agencies also have completed analyses to evaluate forecasted change in sea level, including USGS, which is completing similar analyses to USACE and NOAA. Additionally, some states have adopted regulatory policies for infrastructure projects based on similar analyses and forecasts. The State and District of Columbia Analyses Appendix includes additional information for each state's respective sea level change analyses completed.

Future Relative Sea Levels

From Virginia to Maine, NOAA has 26 water level gauge locations with tide gauge record periods of greater than 40 years. The length of record is important because it provides for a more accurate estimation of historical mean sea level change because inter-annual, decadal, and multi-decadal variations in sea level can complicate measurement of relative mean sea level over time periods shorter than 40 years. The tide gages measure water levels relative to local land elevations; therefore, the records contain the effect of both global sea level change and local sea level change due to uplift/subsidence and atmospheric conditions. Locations of these NOAA gages are shown in Figure V-1.

The future relative mean sea level was computed at four time horizons: 2018, 2068, 2100, and 2118. For the purposes of the study, construction of post-Sandy USACE projects was assumed to be completed by 2018. The year 2068 represents a 50-year post-construction period of project performance, when using the assumption that known projects would be constructed within 5 years. The year 2100 is commonly presented in the science literature around sea level change as an endpoint; few projections are provided after that time. Because USACE sea level guidance requires the consideration of a 100-year time horizon, the curves have been extrapolated beyond 2100, to 2118. However, for consistency with sea level change projections of the IPCC and other stakeholders, the presentation of USACE curves was truncated at the year 2100. The base year was set at 1992 for all calculations and corresponds to the midpoint of the current National Tidal Datum Epoch of 1983–2001. Local/regional land uplift (rise) and subsidence (fall) as well as local variations in mean sea surface elevation can contribute to higher or lower local RSLC. These local/regional variations create RSLC rates that are significantly higher than the global mean sea level change rate. Variable rates of subsidence and local sea surface elevations associated with changes in the gulfstream have been observed within the NACCS study area, particularly in MD and VA where relative sea change rise rates are the greatest. The maximum RSLC is expected to occur in Virginia and Maryland with a generally declining trend of RSLC toward the north.

Figure V-1. Location Map of NOAA Water Level Gages with Record Greater than 30 years in the NACCS Study Area

Sea Level Change Mapping

As part of the NACCS, sea level change was mapped based on four scenarios for the four planning horizons included in the study: 2018, 2068, 2100, and 2118. The first step in the process was to plot the location of gages used in the GIS. The sea level change values were then attributed in the point shapefile. Using ESRI ArcGIS, a trend surface interpolation technique, an application included in the ESRI software that creates a surface by a least-squares regression analysis of the 35 NOAA gage data points, was used to create a future sea level elevation surface grid (ESRI, 2012). In order to compute the increase in water surface elevation attributed to sea level change, the USGS 10 meter resolution National Elevation Dataset (NED) terrain dataset surface grid was subtracted from the interpolated future sea level surface grid. The results of this operation became the sea level change surface grid. If a pixel in the sea level change surface grid has a positive value, then that would indicate inundation by sea level change, with the positive value indicating the depth of inundation. Using ESRI ArcGIS, inundation polygons were created by converting the sea level change surface grid for those areas with a positive value for the sea level change surface grid (ESRI, 2012).

Forecasted Population and Density Development

Inferences related to the future population and residential development increase by 2070 were evaluated using information and datasets generated as part of the Environmental Protection Agency's (EPA's) Integrated Climate and Land Use Scenarios (ICLUS) (EPA 2009). Using these data, the percent increase or decrease in total population between the 2010 Census data and the ICLUS 2070 total population projection was derived. In most urban and suburban counties in the North Atlantic region, the total population would likely increase by 2070. The more rural areas or areas with agriculture as predominant land use, such as the lower Eastern shore of Maryland and Virginia and southern Virginia's western shore, the total population would likely decrease by 2070 (Figure V-2). With an increasing population, coastal flood risk and residual risk continue to increase in the region with an increase population density as a contributing factor.

Additionally, the ICLUS forecasted residential density development was then compared to the NACCS sea level change mapping for the USACE High Scenario. The ICLUS study also modeled land-use projections, which included a spatial allocation model to distribute housing units. For future conditions associated with residential development, ICLUS density development change from 2010 to 2070 was completed using GIS. ESRI ArcGIS software was used to create a grid of the ICLUS residential density for both years 2070 and 2010 (ESRI, 2012). By subtracting the 2010 grid from the 2070 grid, the result is an increase in the development density. The positive values were symbolized on the map and compared to the NACCS sea level change mapping to indicate the general areas of potential residential development that would be at risk to impacts from sea level change inundation. The State and District of Columbia Analyses Appendix presents the USACE High scenario inundation and the forecasted increase in residential development derived from EPA's ICLUS data.

It should be noted that the ICLUS residential density development was computed at a national level scale, and was compared to a smaller scale as part of the NACCS study area, which could potentially introduce changes in the resolution of the outputs. Some of the residential density increases are in areas of open space as designated by the ICLUS model input parameters, but in reality would not be developable, such as a cemetery for example. In addition, local planning considerations to account for sea level change that may prohibit development in the future in areas along the coast likely were also not able to be incorporated to adjust the model outputs. More refined analyses at a smaller scale, similar to the NACCS tiered approach, would be appropriate to account for changes in resolution of the data outputs. As for discussion of likely future impacts with respect to sea level change on environmental and cultural resources, the NACCS Environmental and Cultural Resources Conditions Report presents a summary of each state's (and District of Columbia) information on existing coastal and cultural resource characteristics, habitat impacts from Hurricane Sandy, and future environmental conditions in a bulleted list of details and provided in a state-specific chapter. This approach was selected to facilitate state-level use of the final document, for study and project reports, and National Environmental Policy Act (NEPA) documentation by others, whereby interested parties are able to easily locate and review applicable information, and reproduce only that portion which specifically pertains to their interests.

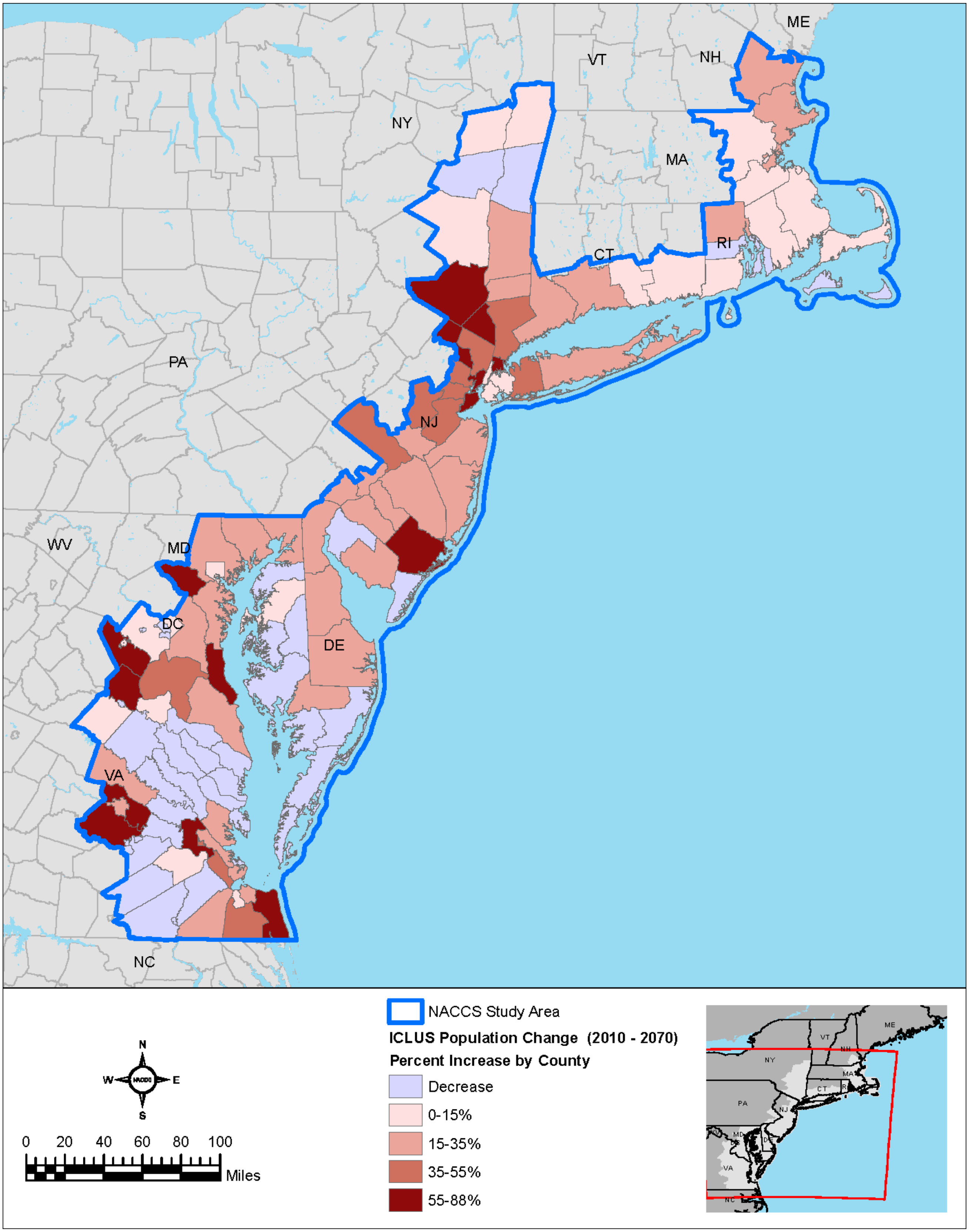


Figure V-2. Population Percent Increase 2010-2070

V.6. Extreme Water Levels

Coastal flooding is primarily caused by rainfall, storm surge, and waves. For the northeastern U.S. Atlantic coastline, tides can have a significant influence on the degree of flooding. For the region from Virginia to Maine, both tropical cyclones (hurricanes) and extratropical storms (nor'easters) have caused significant coastal flooding.

The NACCS is quantifying existing and future storm conditions for use in assessing risk and measures to increase resilience from coastal flooding. Potential future climate change will be included in the analysis. Rigorous regional statistical analysis and detailed high-fidelity numerical hydrodynamic modeling is being conducted for the North Atlantic Coast region to quantify coastal storm wave, wind, and water level extremes. These results will be available in January 2015 at http://www.nad.usace.army.mil/CompStudy.aspx.

As part of the Framework, the extent of coastal flood hazard was completed by using readily available 1 percent flood mapping from FEMA, preliminary 10 percent flood values from the ERDC extreme water level analysis, and the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) modeling conducted by NOAA. The purpose of the various inundation datasets was to be able to identify, assess, and communicate flood risk at the regional scale. The inundation mapping represents varying levels of probability and corresponds with other agencies' regulatory and planning efforts. The purpose of the 10 percent floodplain is to consider the flood risk reduction performance of various NNBF management measures with respect to storm surge. It should be noted that while NNBF may provide multiple benefits and contribute to resilient coastline and communities, some NNBF measures are not likely to offer risk reduction with respect to storm surge for extreme events. Sea level change was not accounted for as part of the 10 percent floodplain because for various NNBF management measures, such as wetlands or living shorelines, adaptive management to mean sea level conditions would be required.

SLOSH modeling of hurricane intensities is categorized by the Saffir-Simpson hurricane wind scale and includes other characteristics of hurricanes that can vary considerably along the coast, such as angle of approach to the shoreline, width and slope of the continental shelf, astronomical high tide level, and local geographic features (FEMA 2011). The SLOSH model outputs inform hurricane evacuation studies. The inundation zones identified by the SLOSH model depict areas of possible flooding from the maximum of maximum (MOM) event within the five categories of hurricanes by estimating the potential surge inundation during a high-tide landfall. Although the SLOSH inundation mapping is not referenced to a specific probability of occurrence (unlike FEMA flood mapping, which presents the 0.2-percent- and 1-percent-annual-chance flood elevation zones) nor does it include wave heights, the flooding inundation from a Category 4 hurricane making landfall during high tide represents an extremely low probability of occurrence but high-magnitude event.

The intent of the NACCS is to generate a spatially comprehensive, but first-order approximation of flooding vulnerability across the entire northeastern Atlantic coastal region. The use of the SLOSH model MOM was necessary based on the very large spatial extent of the study area and the fact that it is currently the most advanced storm surge modeling available for the entire study area. The extent of the Category 4 MOM represents the maximum storm tide levels caused by extreme hurricane scenarios across the region, and, therefore, provides a reasonable approximation of the most extreme flooding extent. The State and District of Columbia Analyses Appendix presents the SLOSH hydrodynamic modeling inundation mapping associated with Categories 1 through 4 hurricanes used for evacuation modeling.

FEMA's National Flood Insurance Program (NFIP) bases the availability of flood insurance on communities' adoption and enforcement of floodplain management ordinances relative to the base flood elevation (BFE). The BFE is the computed elevation to which floodwater is anticipated to rise during the base flood. The Base Flood is flood having a one percent chance of being equaled or exceeded in any given year and is the national standard used by the NFIP and all Federal agencies for the purposes of requiring the purchase of flood insurance and regulating new development. (http://www.fema.gov/national-flood-insurance-program/base-flood). Flood insurance and building ordinances for communities participating in the NFIP reference the BFE for new or substantial renovations or new mortgages on home sales. While flood insurance requirements and building ordinances are tied to the BFE, it is not always related to first floor elevation. For example, in V-zones presented on FEMA flood insurance rate maps, the reference to the building codes is to the lowest horizontal structural member. Local jurisdictions can adopt more stringent building codes than FEMA's minimum requirements to participate in the NFIP. Furthermore, the Hurricane Sandy Presidential Task Force established in April 2013 a Hurricane Sandy Flood Risk Reduction Standard of the 1-percent flood plus one foot for buildings, a minimum standard applicable to federally-funded recovery and rebuilding investments under P.L. 113-2, including USACE vertical infrastructure and nonstructural retrofitting projects. USACE optimizes coastal storm risk management projects to maximize economic benefits greater than or equal to the costs to construct the project. However, for the purposes of the NACCS and to use a conservative assumption, the 1 percent flood inundation mapping plus three feet, was used to evaluate structural risk management measures (including NNBF measures like beaches and dunes) as well as to generate parametric unit cost estimates for structural management measures as part of the NACCS Tier 1 evaluation.

The State and District of Columbia Analyses Appendix presents areas that are exposed to the 1 percent flood as well as the NACCS assumption of the 1 percent flood plus a 3-foot sea level change allowance. The 3-foot allowance is closely aligned with the USACE/NOAA High scenario for projected sea level change by year 2068 as well as New York City's recent recommendations (NYC SIRR 2013). The 1 percent flood inundation mapping was obtained from effective and preliminary DFIRMs available from FEMA's Map Service Center http://msc.fema.gov/portal and GeoPLATFORM http://fema.maps.arcgis.com/home/. FEMA's SHFA and the computation of the BFE includes wave heights (FEMA, n.d.). The 1 percent flood plus three feet was the SLOSH CAT2 MOM, which does not account for wave heights. The SLOSH Cat 2 (MOM) used as a surrogate, which at the study area scale was an appropriate assumption. For more refined analyses, more detailed analyses to address risk and uncertainty should be considered. The purpose of presenting the Category 4 MOM and the 1-percent-annual-chance flood plus three feet floodplain is to present a figurative example of residual risk for risk communication purposes as part of the NACCS. Subsequent and more refined analyses would more accurately define residual risk associated with various flood risk management measures accordingly.

The State and District of Columbia Analyses Appendix presents the limit of the current 10 percent floodplain (an area with a 10 percent or greater chance of being flooded in any given year). The 10 percent floodplain was delineated using the stage-frequency analyses completed for NOAA gages across the entire study area (Engineering Appendix). The purpose of the 10 percent floodplain is to consider the flood risk reduction performance of various NNBF management measures with respect to storm surge. Although NNBF may provide multiple benefits and contribute to resilient coastline and communities, some NNBF measures are not likely to offer risk reduction with respect to storm surge for extreme events. Sea level change was not accounted for as part of the 10 percent floodplain, because for various NNBF management measures, such as wetlands or living shorelines, adaptive management to mean sea level conditions would be required.

VI. Planning Reaches

The NACCS study area stretches across ten states within the northeastern United States, from the Piscataqua River on the New Hampshire border to the southern border of Virginia. Included in the study area are approximately 31,200 linear miles of shoreline and inland areas computed using the NOAA ESI shoreline dataset that are vulnerable to storm surge.

A total of 39 planning reaches were delineated to offer smaller units than State entities from which risk reduction decisions can be considered (Figure VI-1).

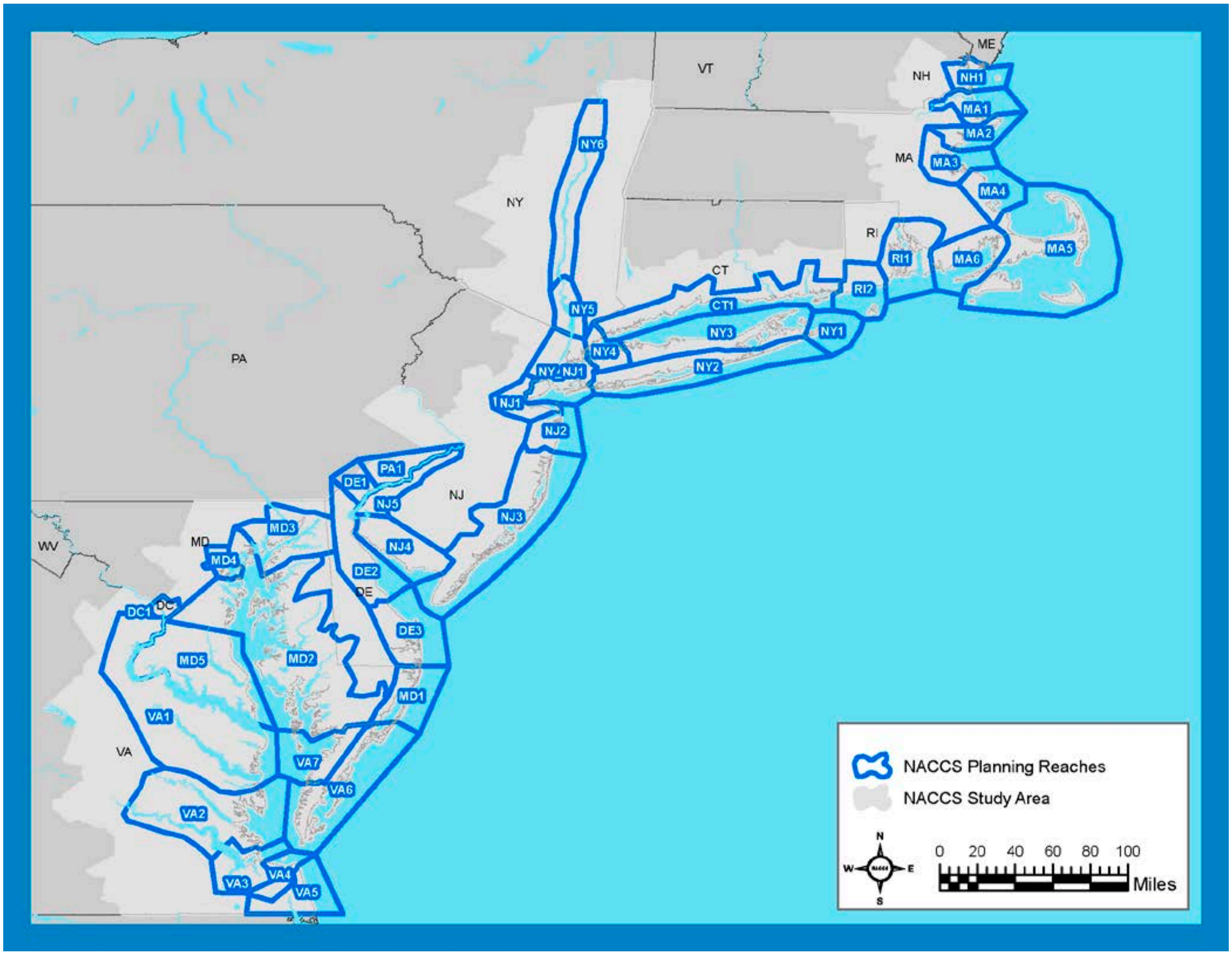


Figure VI-1. NACCS Planning Reaches

Planning reach boundaries were based upon existing natural and manmade coastal features. The general geomorphological characteristics were determined using the ten aggregated shoreline types derived from the NOAA Environmental Sensitivity Index Shoreline Classification (http://stateofthecoast.noaa.gov/shoreline/esi_categories.html) (NOAA, n.d.).

The USACE coastal storm risk management project, location, and phase was based on the Public Law 113-2, Disaster Relief Appropriations Act, 2013 First and Second Interim Reports, and the CSPI TRD, and classified as:

- Frequent: A USACE coastal storm risk management project covers greater than 60 percent of the coastline length of that particular reach;
- Occasional: A USACE coastal storm risk management project covers between 30 and 60 percent of the coastline length of that particular reach;
- Infrequent: A USACE coastal storm risk management project covers less than 30 percent of the coastline length of that particular reach.

The 1 percent floodplain is classified according to three categories, including:

- Extensive: 1 percent floodplain occurs for greater than 60 percent of the length of the coastline for that particular reach;
- Moderate: 1 percent floodplain occurs for 30 to 60 percent of the length of the coastline for that particular reach;
- Limited: 1 percent floodplain occurs for less than 30 percent of the length of the coastline for that particular reach.

These features are summarized for each planning reach by State in Table VI-1. A discussion on the characteristics of each planning reach follows Table VI-1.

Table VI-1. Planning Reach Characteristics

	Most Frequently Occurring Shoreline Type	USACE Coastal Storm Risk Management Project Coverage	Floodplain Extent
NH1	Beaches (exposed)	Infrequent	Limited
MA1	Beaches (exposed)	Infrequent	Limited
MA2	Rocky Shores (exposed)	Infrequent	Limited
MA3	Manmade Structures (exposed)	Frequent	Moderate
MA4	Manmade Structures (exposed)	Infrequent	Moderate
MA5	Scarps (exposed)	Infrequent	Limited
MA6	Manmade Structures (exposed)	Infrequent	Moderate
RI1	Manmade Structures (exposed)	Infrequent	Moderate/Extensive
RI2	Beaches (exposed)	Infrequent	Extensive
CT1	Manmade Structures (exposed)	Occasional	Moderate/Extensive
NY1	Beaches (exposed)	Infrequent	Limited
NY2	Beaches (exposed)	Frequent	Moderate/Extensive
NY3	Beaches (sheltered)	Infrequent	Moderate
NY4	Manmade Structures (sheltered)	Infrequent	Moderate
NY5	Manmade Structures (sheltered)	Infrequent	Limited
NY6	Vegetated Low Banks (sheltered)	Infrequent	Limited
NYNJ1	Manmade Structures (sheltered)	Infrequent	Moderate
NJ1	Beaches (exposed)	Frequent	Extensive
NJ2	Beaches (exposed)	Frequent	Limited
NJ3	Beaches (exposed)	Frequent	Limited
NJ4	Wetlands (sheltered)	Infrequent	Extensive
NJ5	Manmade Structures (sheltered)	Infrequent	Extensive
PA1	Manmade Structures (sheltered)	Infrequent	Limited
DE1	Manmade Structures (sheltered)	Infrequent	Limited
DE2	Wetlands (sheltered)	Infrequent	Extensive
DE3	Beaches (exposed)	Frequent	Limited
MD1	Beaches (exposed)	Frequent	Extensive
MD2	Wetlands (sheltered)	Infrequent	Extensive
MD3	Wetlands (sheltered)	Infrequent	Extensive
MD4	Manmade Structures (sheltered)	Infrequent	Limited
MD5	Beaches (sheltered)	Infrequent	Extensive
MD6	Manmade Structures (sheltered)	Infrequent	Limited
VA1	Wetlands (sheltered)	Infrequent	Extensive
VA2	Wetlands (sheltered)	Infrequent	Extensive
VA3	Manmade Structures (sheltered)	Occasional	Moderate
VA4	Beaches (sheltered)	Infrequent	Moderate
VA5	Beaches (exposed)	Frequent	Limited
VA6	Beaches (exposed)	Infrequent	Extensive
VA7	Wetlands (sheltered)	Infrequent	Extensive

New Hampshire

The New Hampshire coast includes one reach (Figure VI-2):

NH1: Beach shoreline type with some rocky headland, with infrequent USACE CSRM projects, limited floodplain extent, and includes the City of Portsmouth and Hampton Beach State Park.

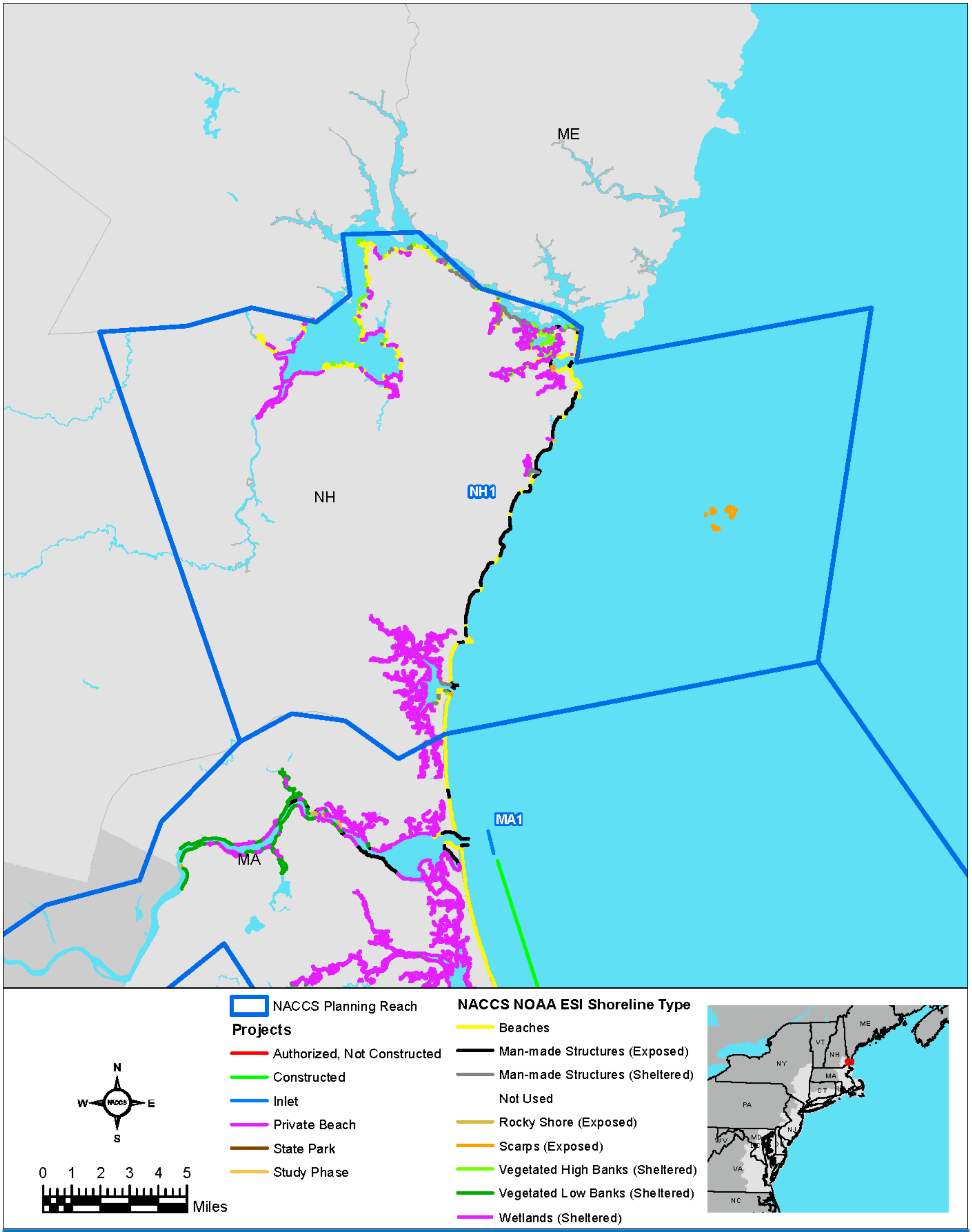


Figure VI-2. New Hampshire Planning Reach

Massachusetts

The Massachusetts coast includes six reaches (Figures VI-3 to VI-5), and is characterized on a reach by reach basis, as follows:

MA1: Beach, some rocky headland, infrequent USACE CSRM projects, limited floodplain extent. Extends from border with NH to Halibut Point State Park and includes Salisbury Beach State Reservation and the Parker River Wildlife Refuge.

MA2: Rocky headland, some beach, infrequent USACE CSRM projects, limited floodplain extent. Extends from Halibut Point State Park to Broad Sound and includes Lynn.

MA3: Urban, frequent USACE CSRM projects, moderate floodplain extent. Extends from Broad Sound to Massachusetts Bay and includes East Boston, Boston and Quincy.

MA4: Urban, some bluffs, infrequent USACE CSRM projects, moderate floodplain extent. Extends south to Plymouth.

MA5: Bluffs, some beach, infrequent USACE CSRM projects, limited floodplain extent. Includes Cape Cod shoreline, and also Nantucket and Martha's Vineyard.

MA6: Urban embayment, some beach, infrequent USACE CSRM projects, moderate floodplain extent. Includes all of Buzzard's Bay to RI border.

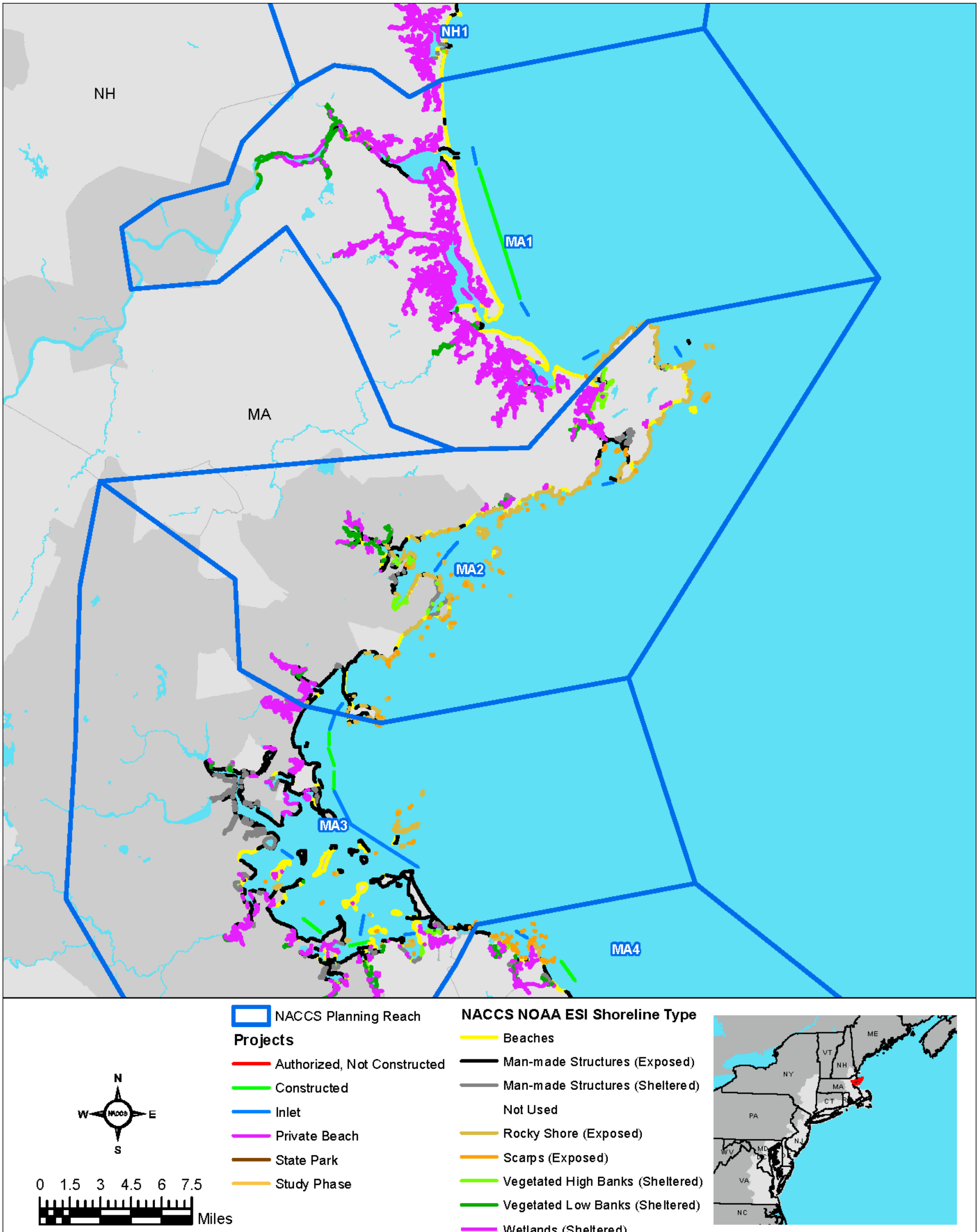


Figure VI-3. Massachusetts Planning Reaches

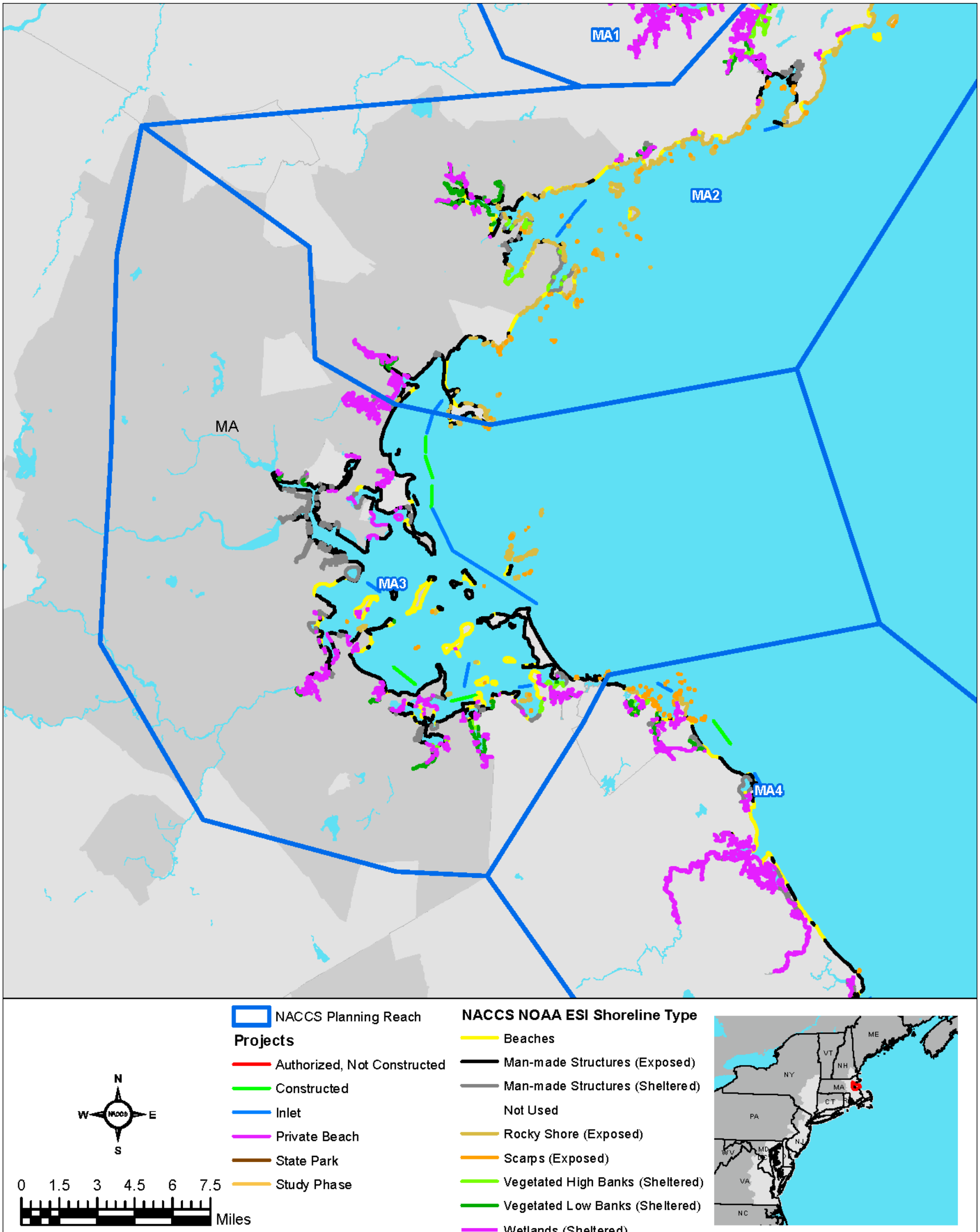


Figure VI-4. Massachusetts Planning Reaches

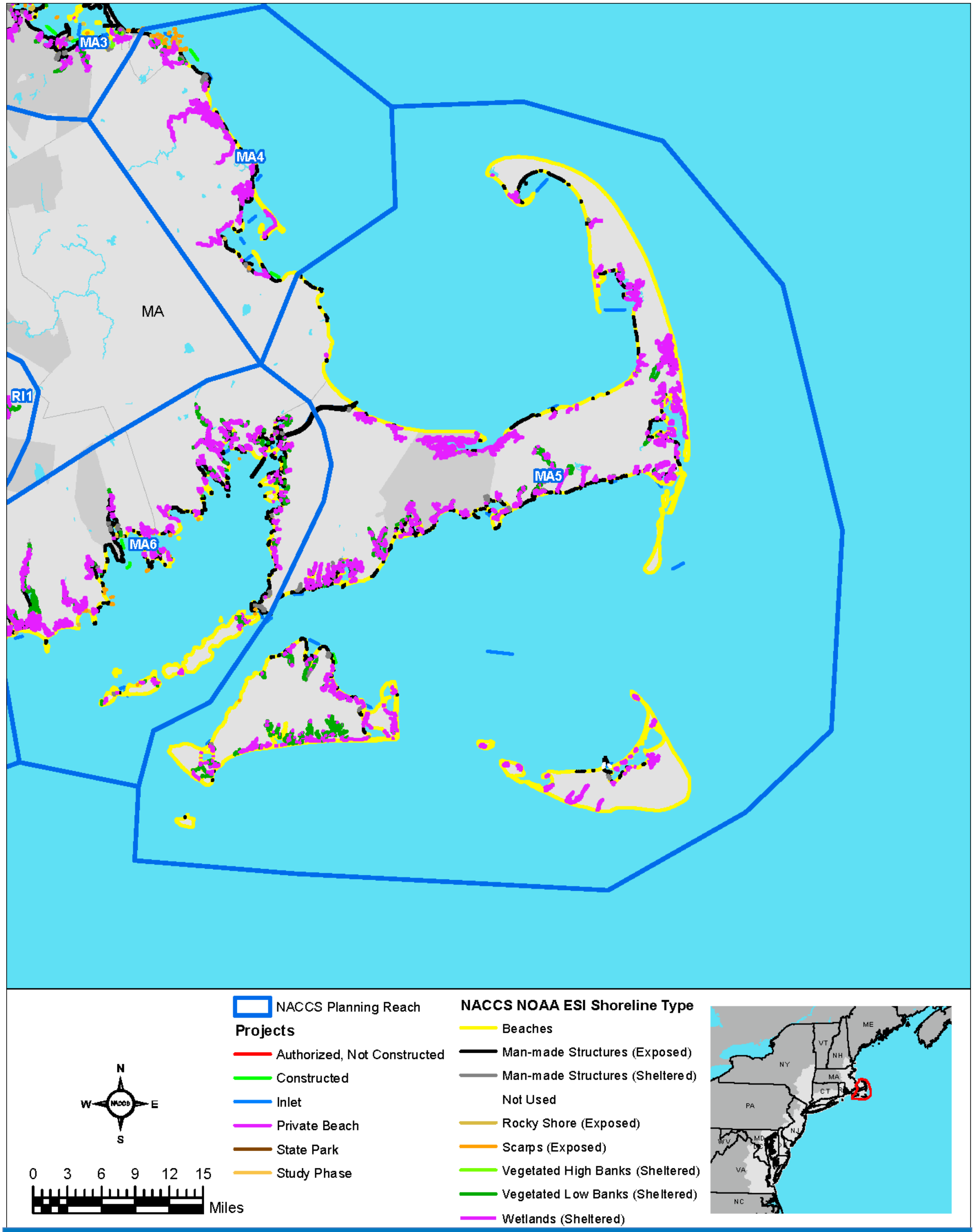


Figure VI-5. Massachusetts Planning Reaches

Rhode Island

The Rhode Island coast includes two reaches (Figure VI-6 and VI-7), including:

RI1: Urban embayment, some beach, infrequent USACE CSRM projects, moderate/extensive floodplain extent. Extends from MA border to Fisherman's Memorial State Park and includes Narragansett.

RI2: Beach, infrequent USACE CSRM projects, extensive floodplain extent. Extends from Fisherman's Memorial State Park to CT border and includes Charlestown.

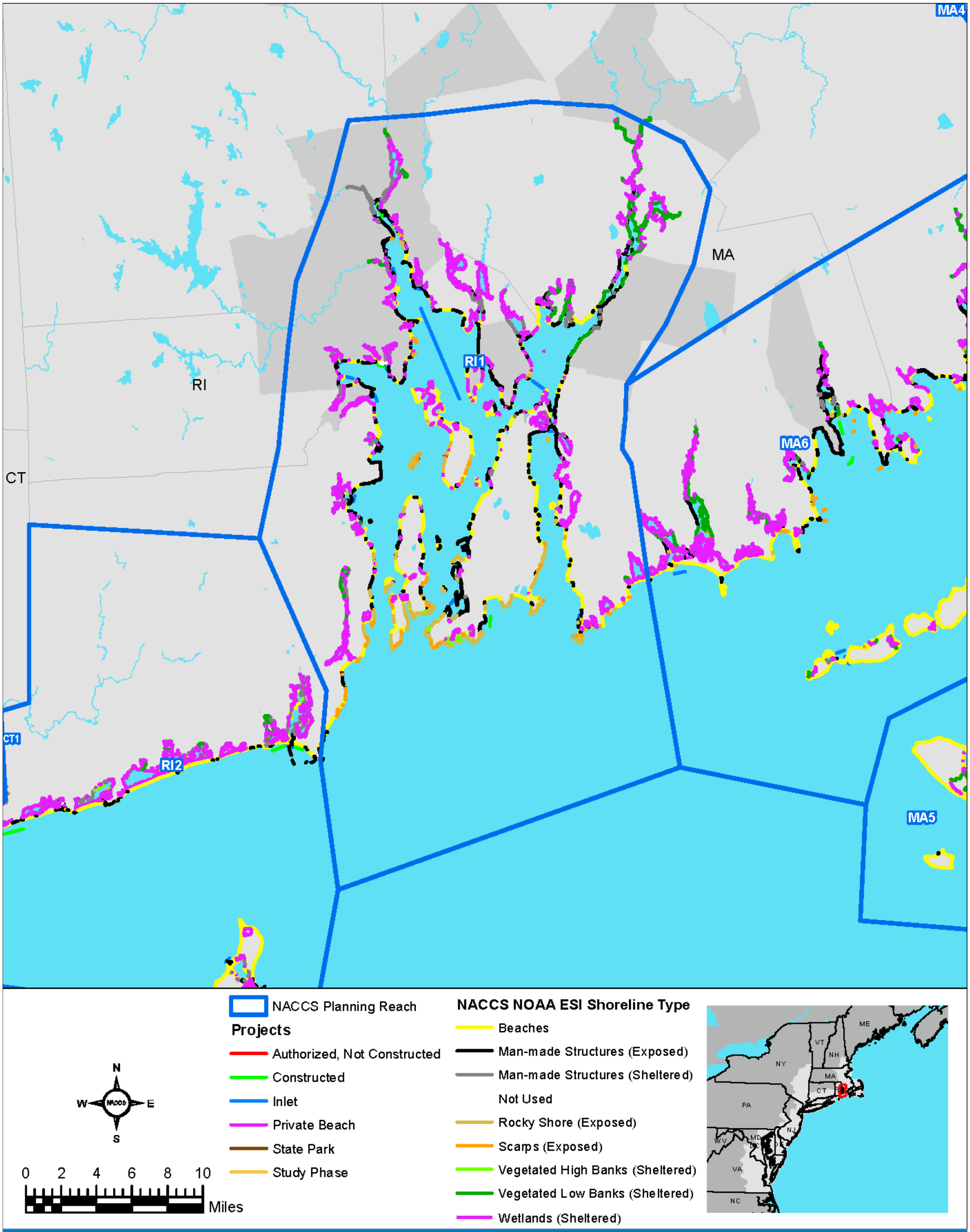


Figure VI-6. Rhode Island Planning Reaches

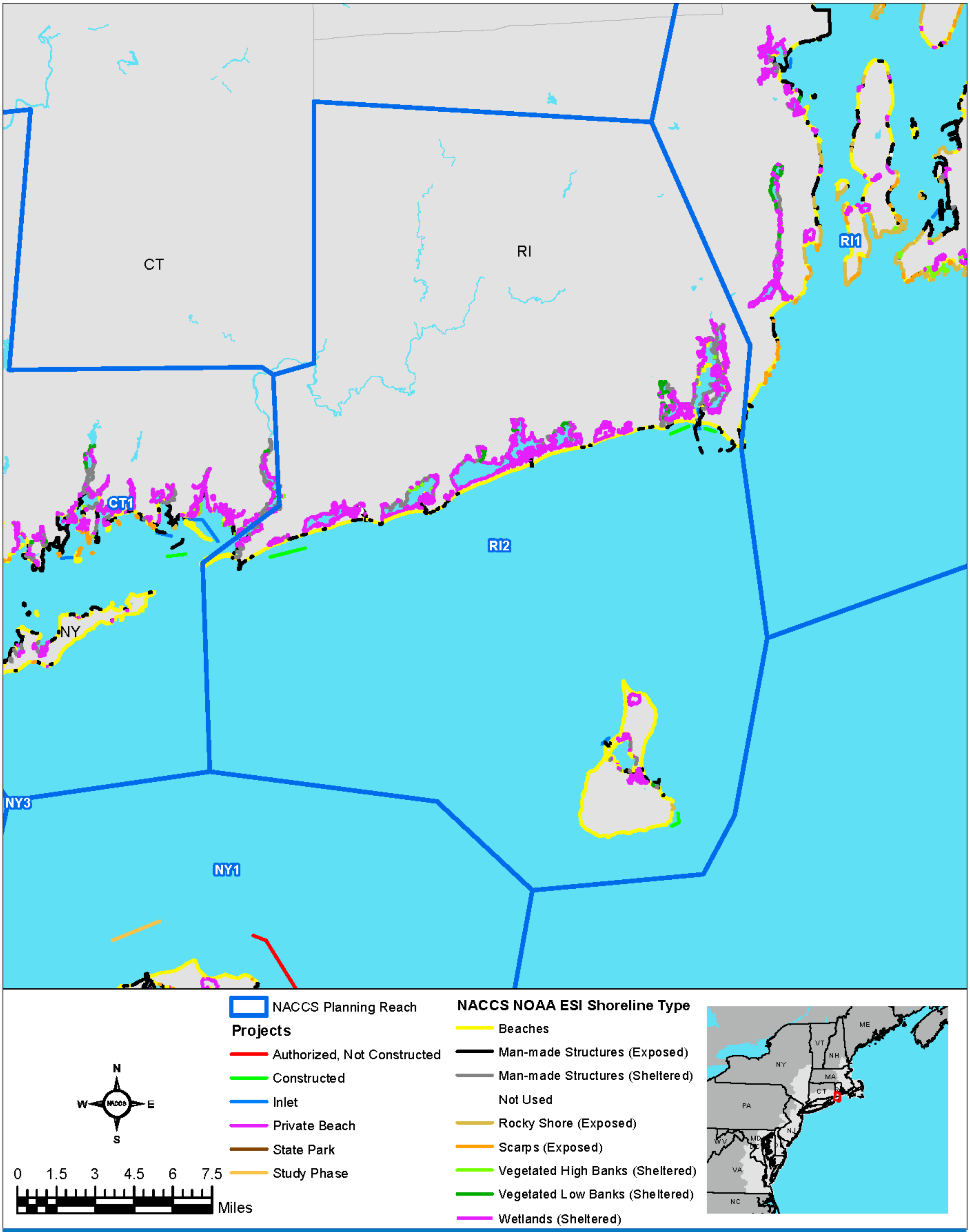


Figure VI-7. Rhode Island Planning Reaches

Connecticut

The Connecticut coast includes one reach,

CT1: Urban shoreline type with some beach, occasional USACE CSRM projects, and a moderate to extensive floodplain extent (Figure VI-8). Includes the Cities of New London, New Haven, Milford, Norwalk, and Stamford.

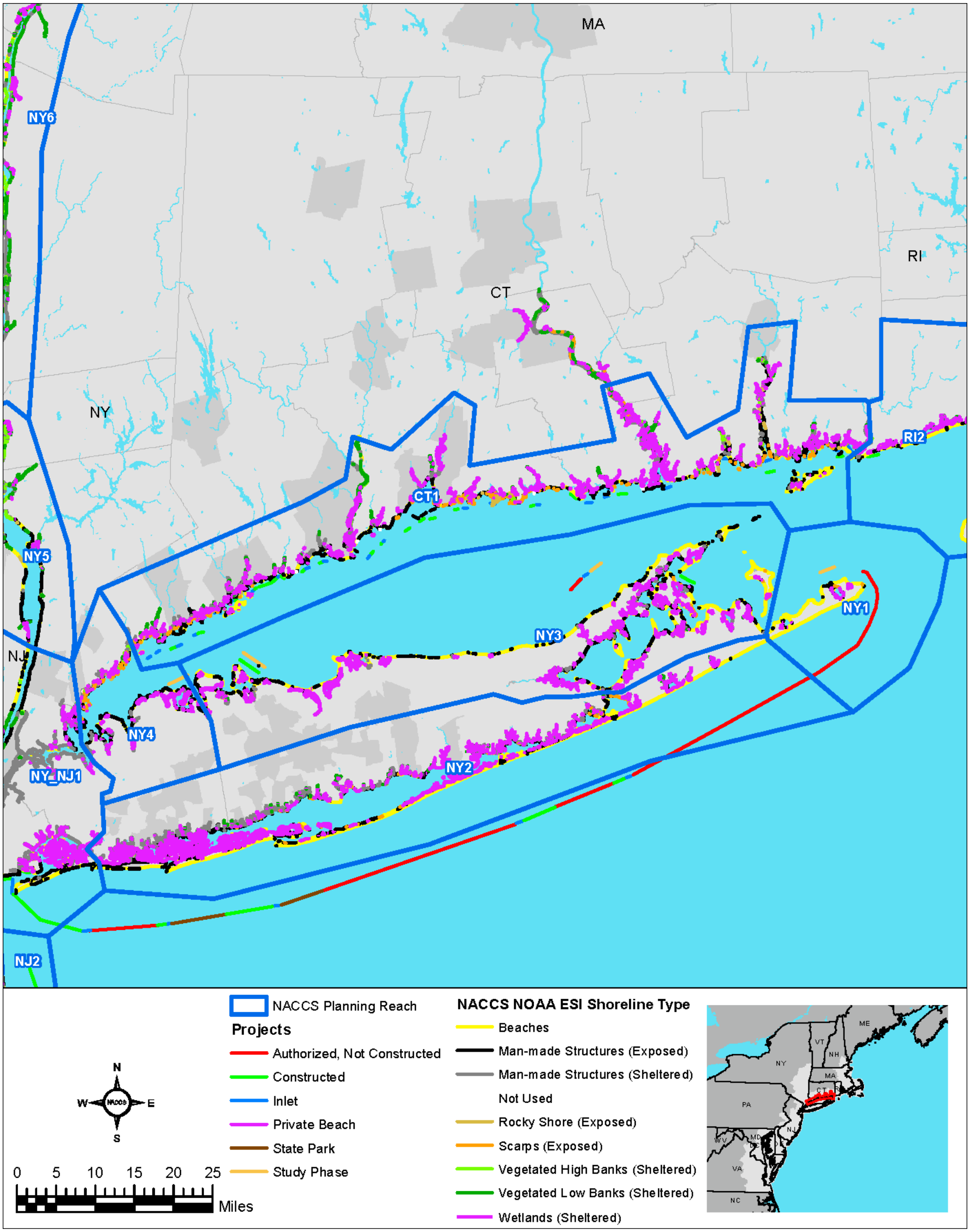


Figure VI-8. Connecticut Planning Reaches

New York

The New York coast is characterized by seven reaches (Figures VI-9 to VI-12), as follows:

NY1: Beach, some bluff, infrequent USACE CSRM projects, limited floodplain extent. Extends from Montauk Point east to Napeague State Park and includes Village of Montauk.

NY2: Beach, frequent USACE CSRM projects, moderate/extensive floodplain extent. Includes the south shore of Long Island from Napeague State Park east to Jones Inlet.

NY3: Beach, some urban, infrequent USACE CSRM projects, moderate floodplain extent. Includes Gardiners Bay, Great Peconic Bay, and north shore of Long Island along LI Sound within Suffolk County.

NY4: Urban, limited beach, infrequent USACE CSRM projects, moderate floodplain extent. Includes Nassau and Westchester Counties portions of the LI Sound

NY5: Urban, some bluff and beach, infrequent USACE CSRM projects, limited floodplain extent. Includes portions of Westchester, Putnam, Rockland, and Orange Counties, adjacent to the Hudson River.

NY6: Urban and vegetated low banks, infrequent USACE CSRM projects, limited floodplain extent. Includes portions of Columbia, Greene, Dutchess, Westchester, Ulster, Putnam, Albany, and Rensselaer Counties.

NYNJ1 (NYNJ Harbor): Urban, infrequent USACE CSRM projects, moderate floodplain extent.

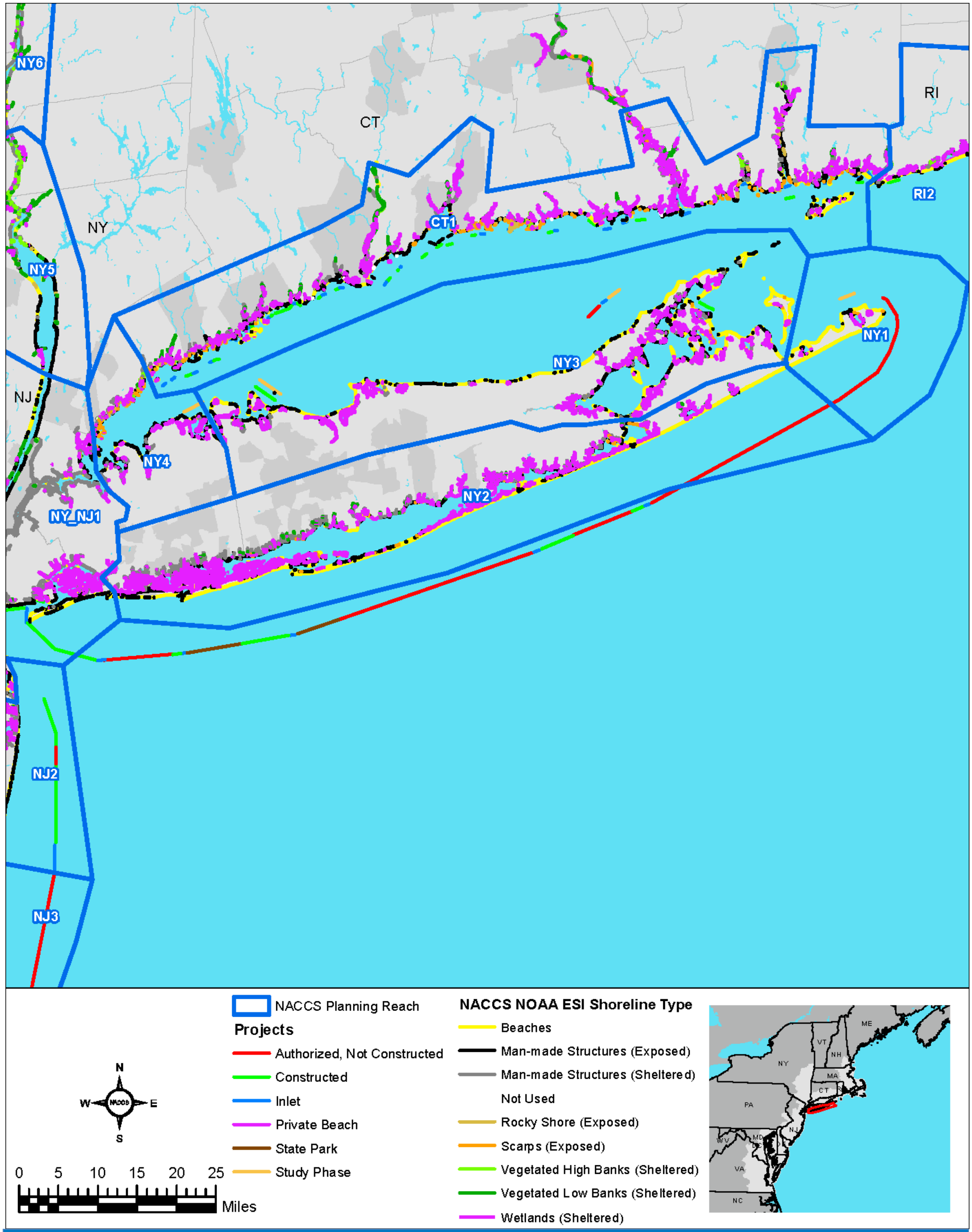


Figure VI-9. New York Planning Reaches

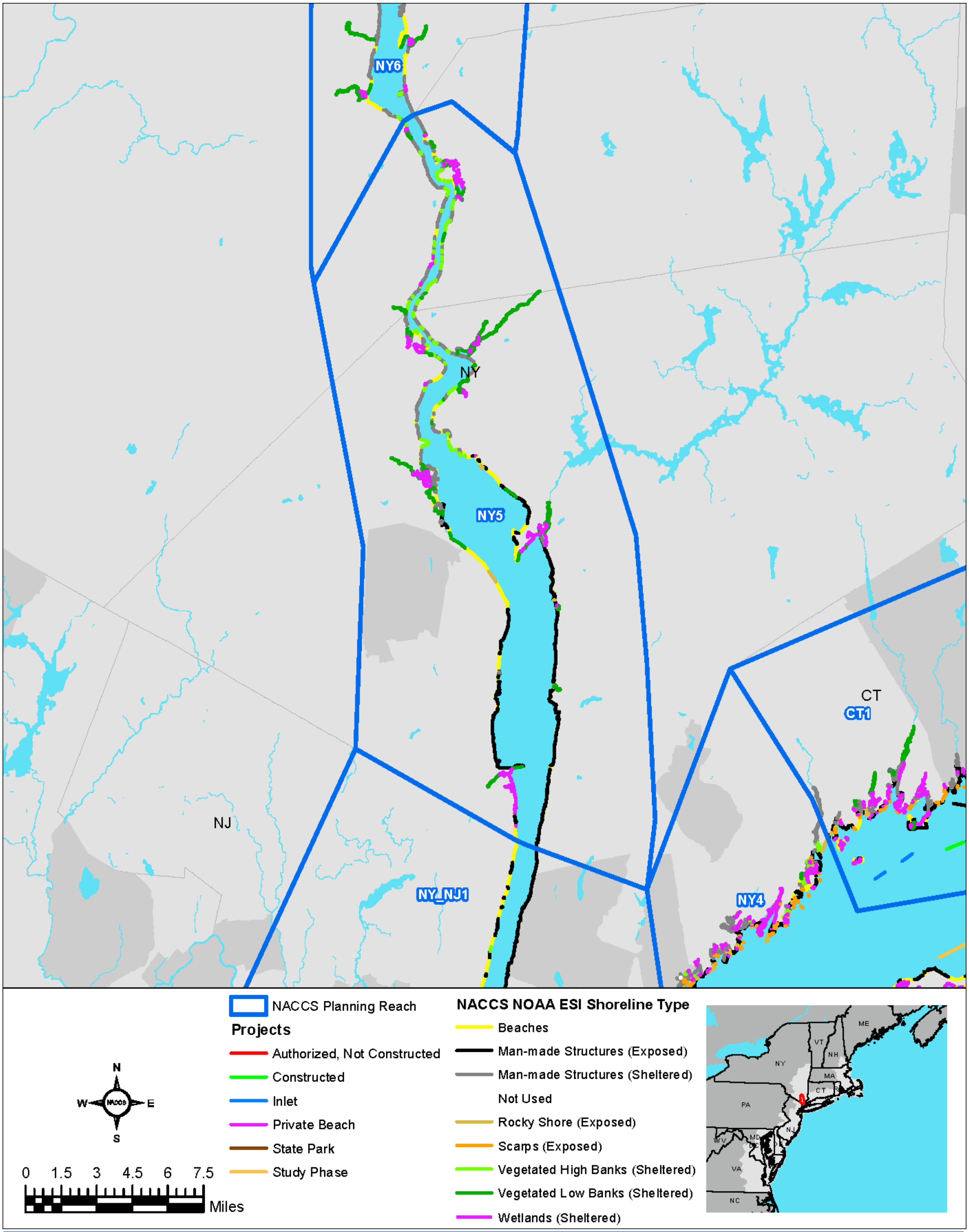


Figure VI-10. New York Planning Reaches

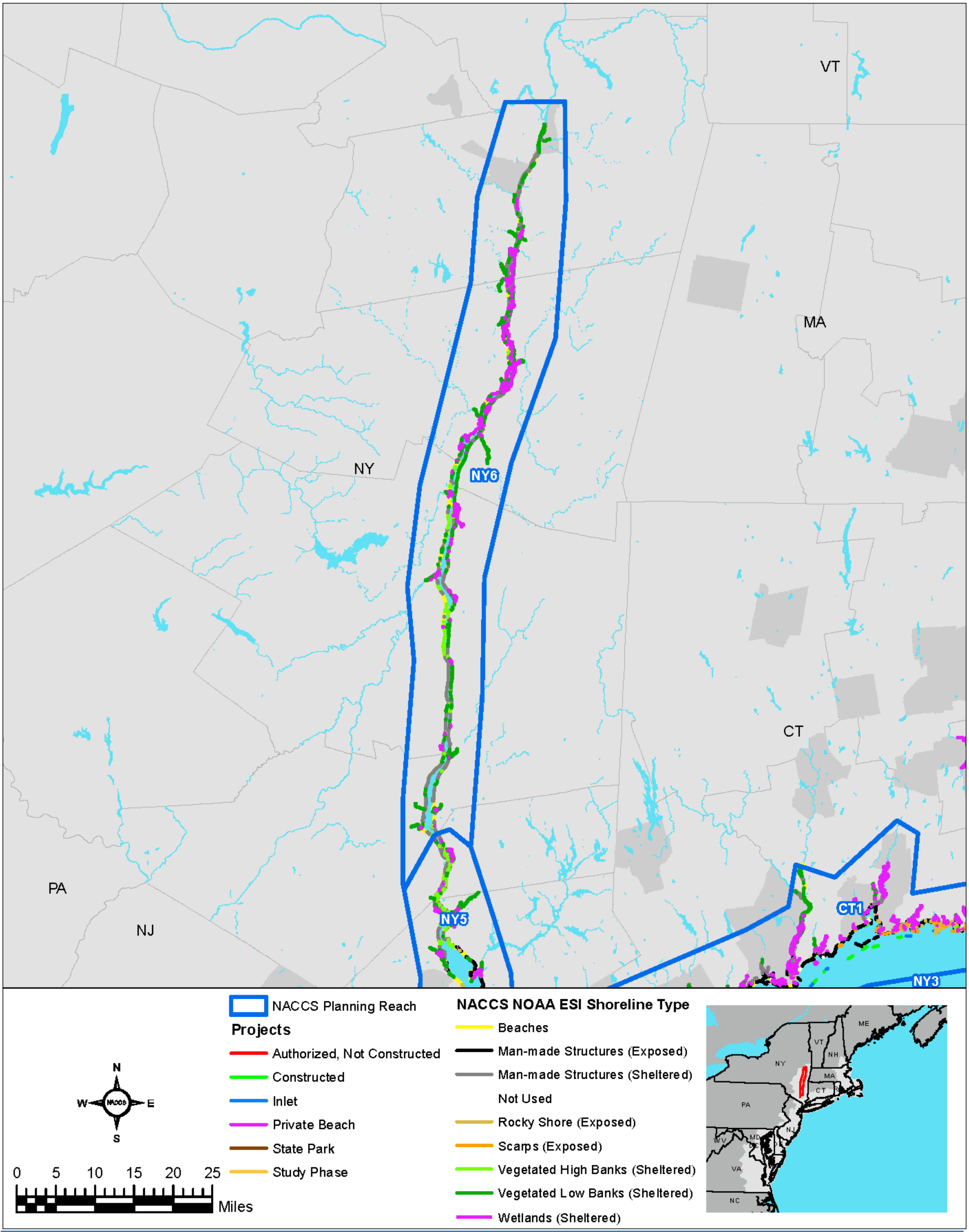


Figure VI-11. New York Planning Reaches

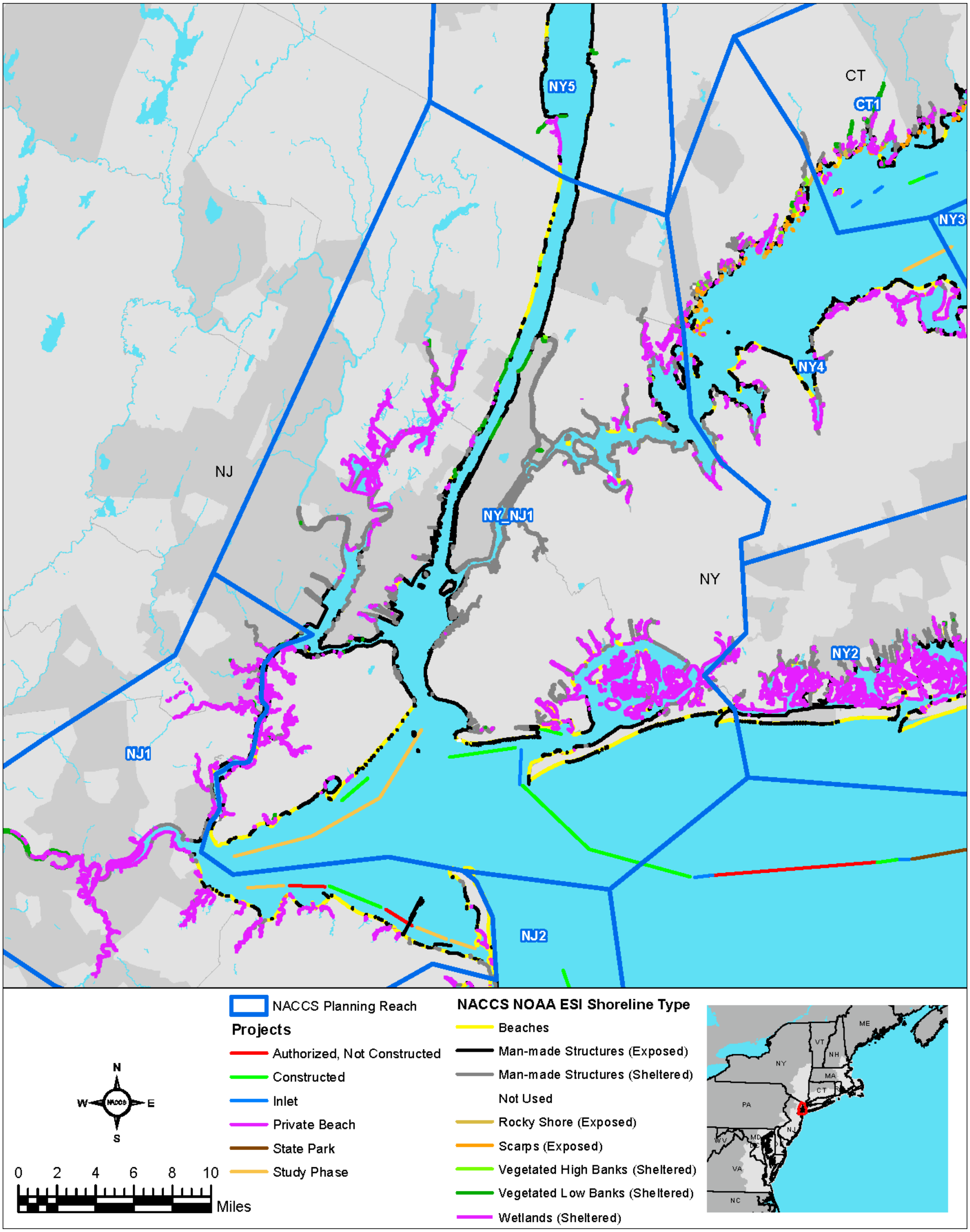


Figure VI-12. New York Planning Reaches

New Jersey

The New Jersey coast is characterized by 5 reaches (Figures VI-13 to VI-16). Characteristics of each reach are summarized in the following descriptions:

NJ1: Beach, frequent USACE CSRM projects, extensive floodplain extent. NJ1 includes areas of northeastern New Jersey, from the junction of the Kill Van Kull and Arthur Kill tidal straights south to the Raritan river mouth and east to Sandy Hook bay peninsula. Major cities/towns include Elizabeth, Edison, New Brunswick, Perth Amboy, and Sayreville.

NJ2: Beach, frequent USACE CSRM projects, limited floodplain extent. NJ2 includes the Atlantic coast of Monmouth County, extending from the eastern edge of the Sandy Hook Bay peninsula south to the Manasquan Inlet. Major cities/towns include Asbury Park and Long Branch.

NJ3: Beach, frequent USACE CSRM projects, limited floodplain extent. Extends from Barnegat Inlet to Cape May portion of Delaware Bay.

NJ4: Wetland, infrequent USACE CSRM projects, extensive floodplain extent. Includes the Delaware Bay shoreline in NJ to Pennsville Township.

NJ5: Urban, some wetlands, infrequent USACE CSRM projects, extensive floodplain extent. Includes the Delaware River shoreline in NJ to Trenton.

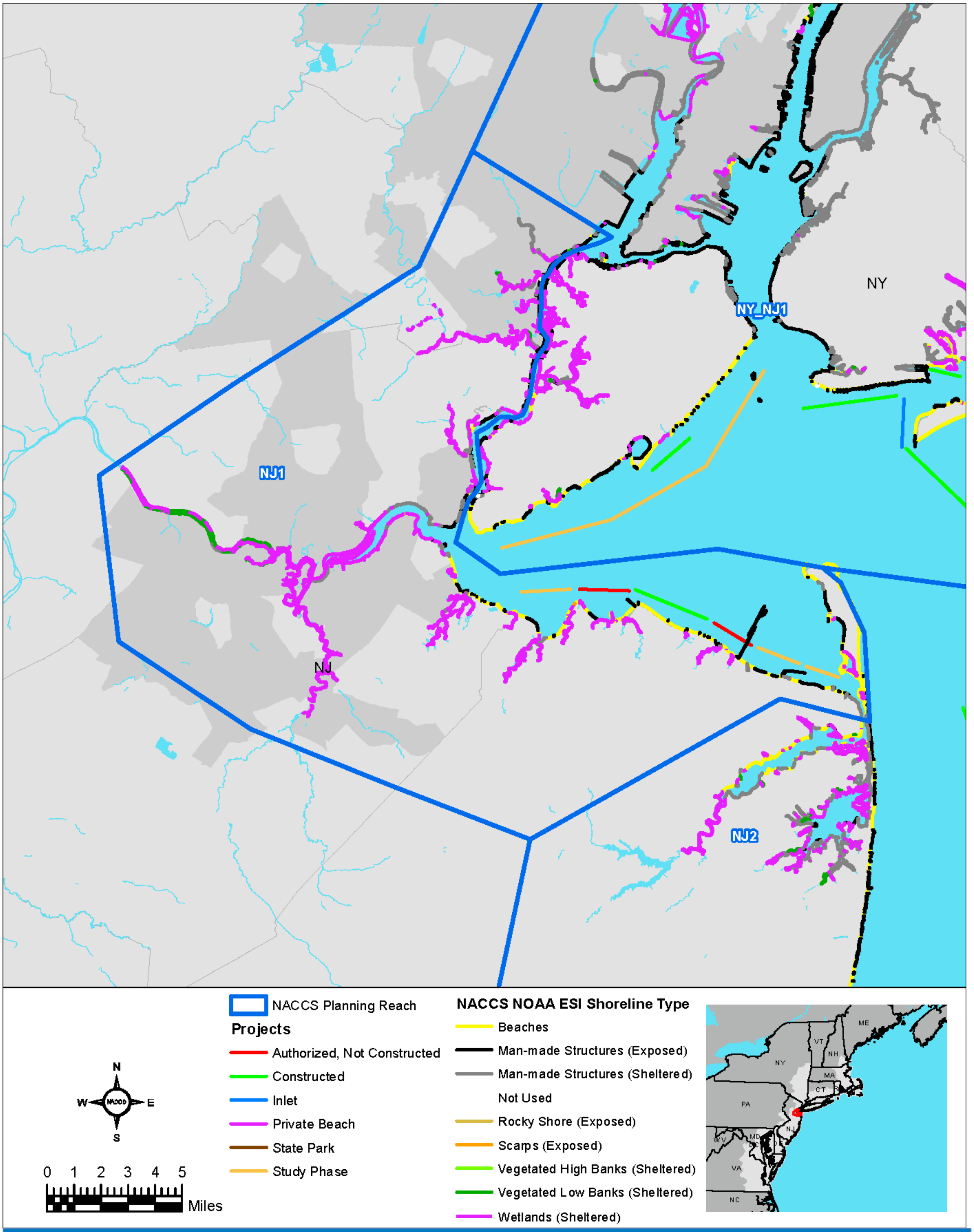


Figure VI-13. New Jersey Planning Reaches

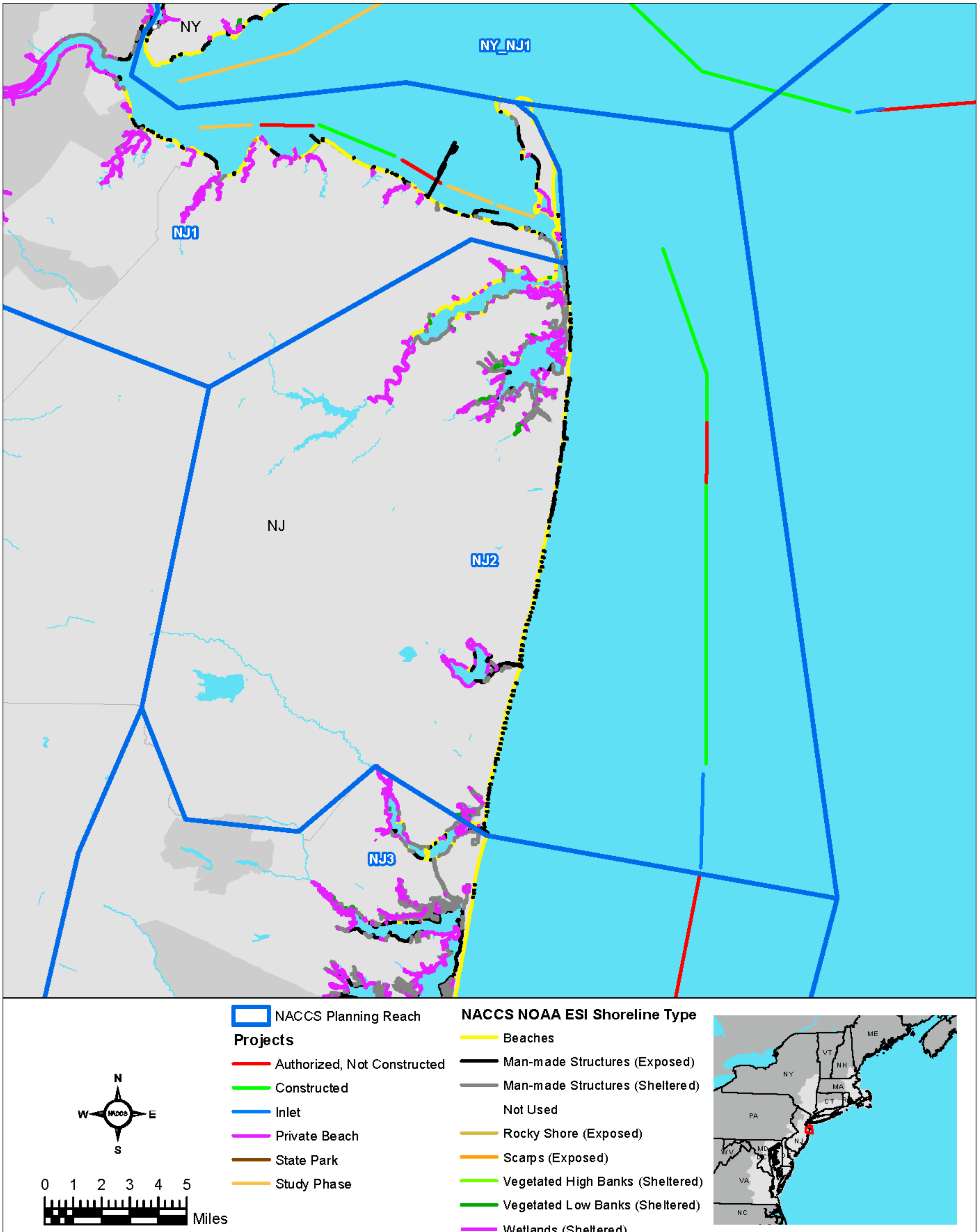


Figure VI-14. New Jersey Planning Reaches

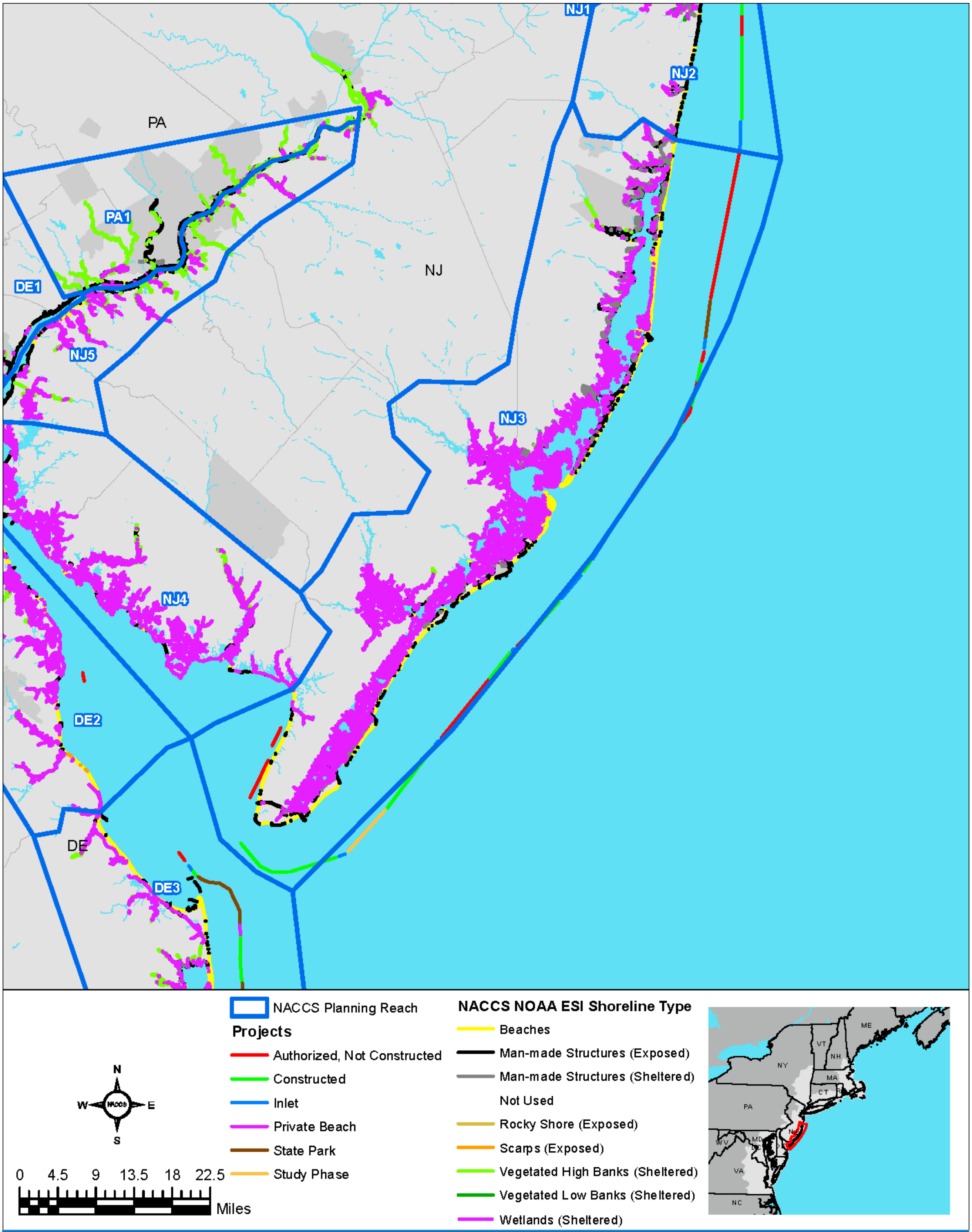


Figure VI-15. New Jersey Planning Reaches

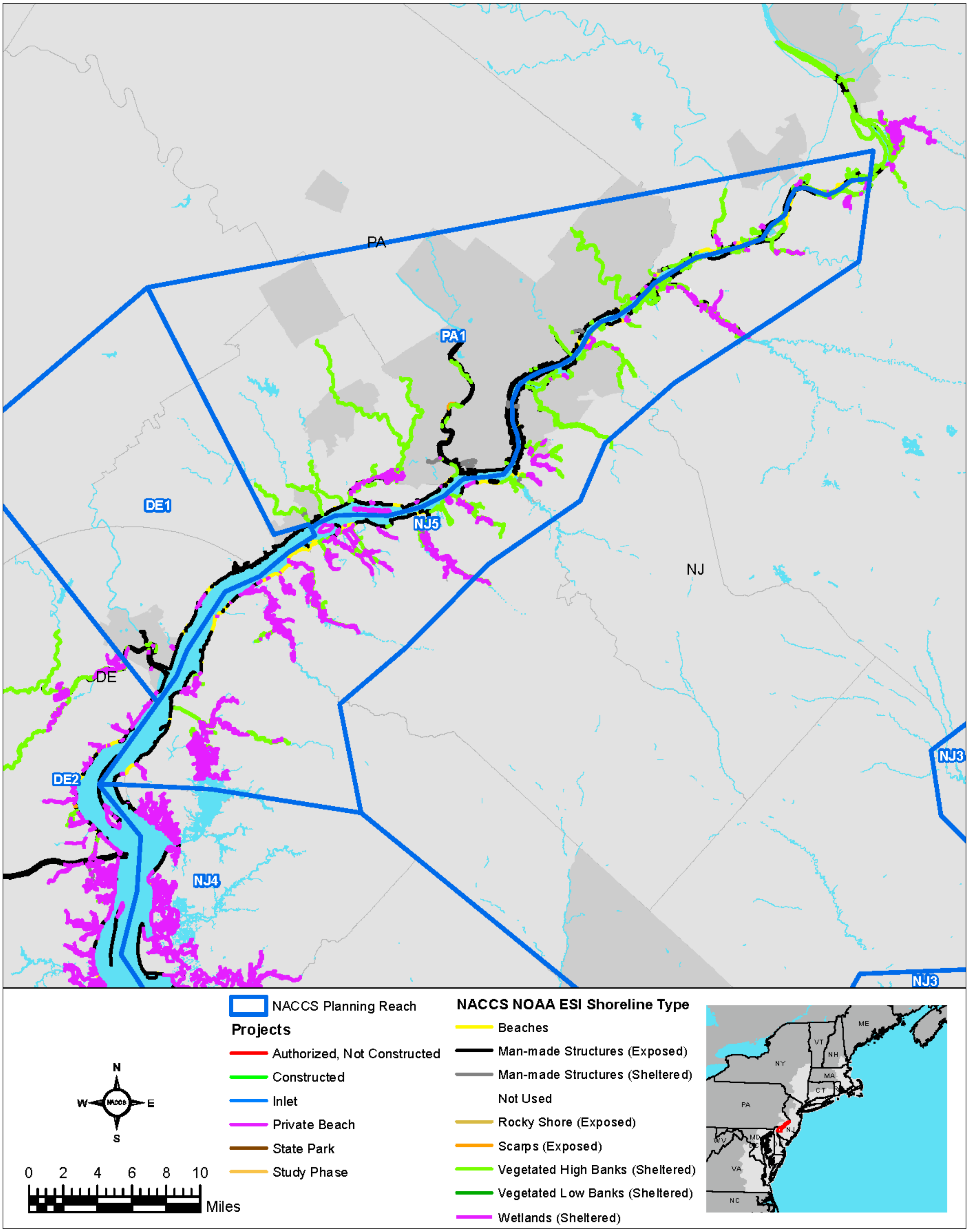


Figure VI-16. New Jersey Planning Reaches

Pennsylvania

The Pennsylvania coast includes one reach (Figure VI-17).

PA1: urban shoreline with some wetlands, infrequent USACE CSRM projects, limited floodplain extent. Includes the Delaware River from DE border to north of Philadelphia.

Delaware

The Delaware coast is characterized by three reaches (Figure VI-18). Characteristics of each reach are summarized in the following descriptions:

DE1: Urban, some wetlands, infrequent USACE CSRM projects, limited floodplain extent. Includes the Delaware River from PA border to Wilmington.

DE2: Wetland, infrequent USACE CSRM projects, extensive floodplain extent. Includes the Delaware Bay to Prime Hook State Wildlife Refuge.

DE3: Beach, frequent USACE CSRM projects, limited floodplain extent. Extends from Prime Hook State Wildlife Refuge to MD border on Atlantic Ocean. Includes Lewis, Rehoboth Beach, and Bethany Beach.

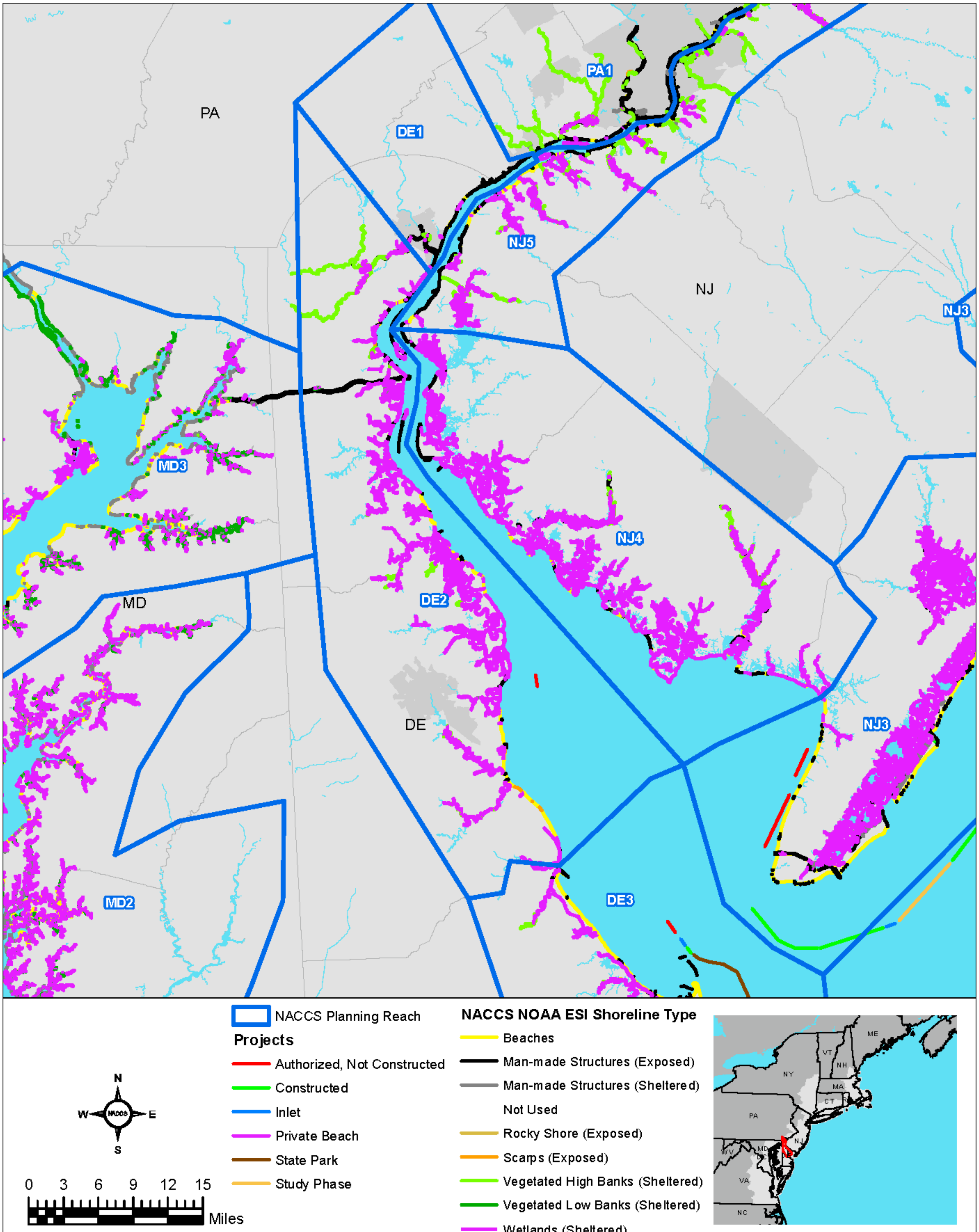


Figure VI-17. Pennsylvania Planning Reach

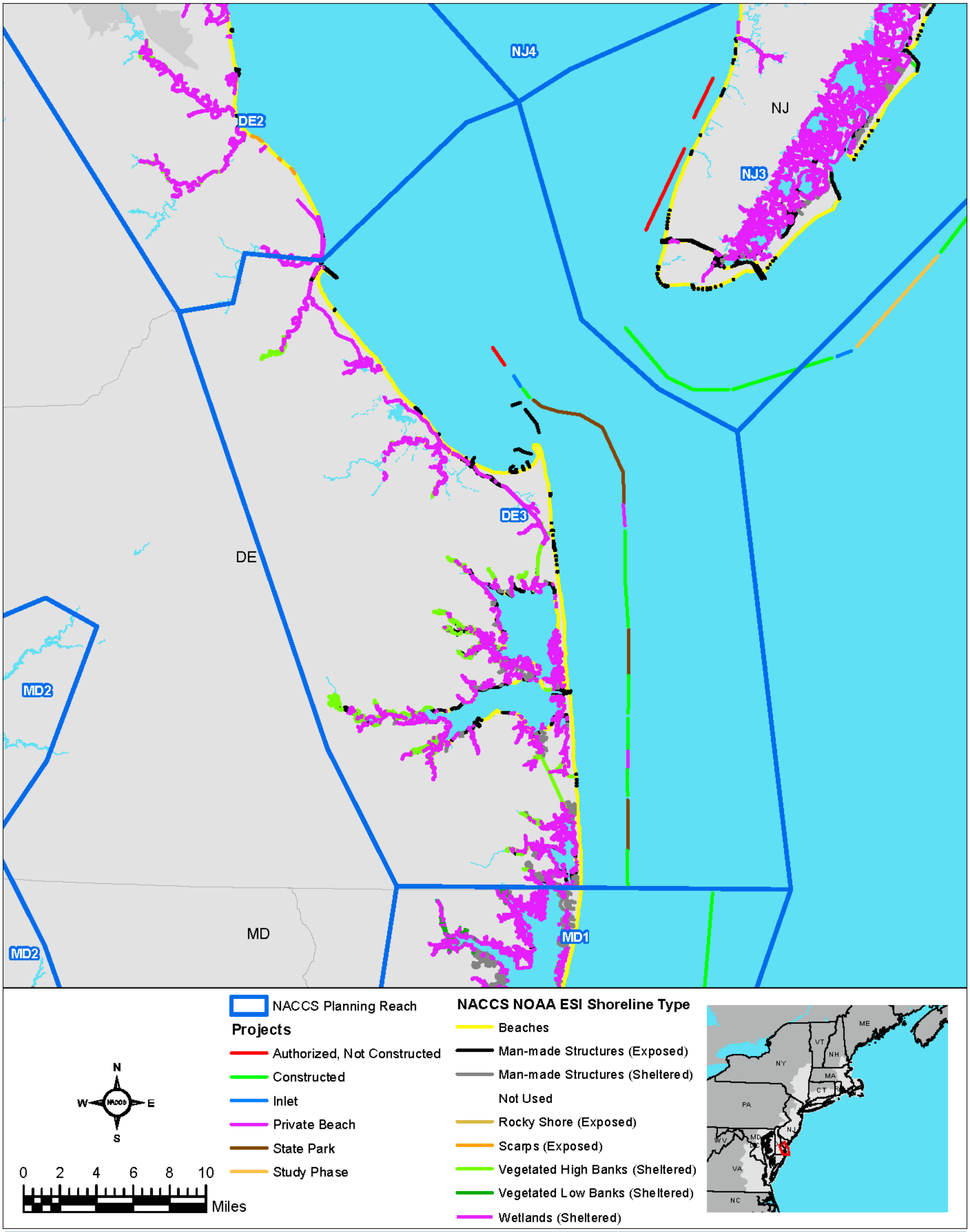


Figure VI-18. Delaware Planning Reaches

District of Columbia

DC1: Urban, infrequent USACE CSRM projects, limited floodplain extent (Figure VI-19).

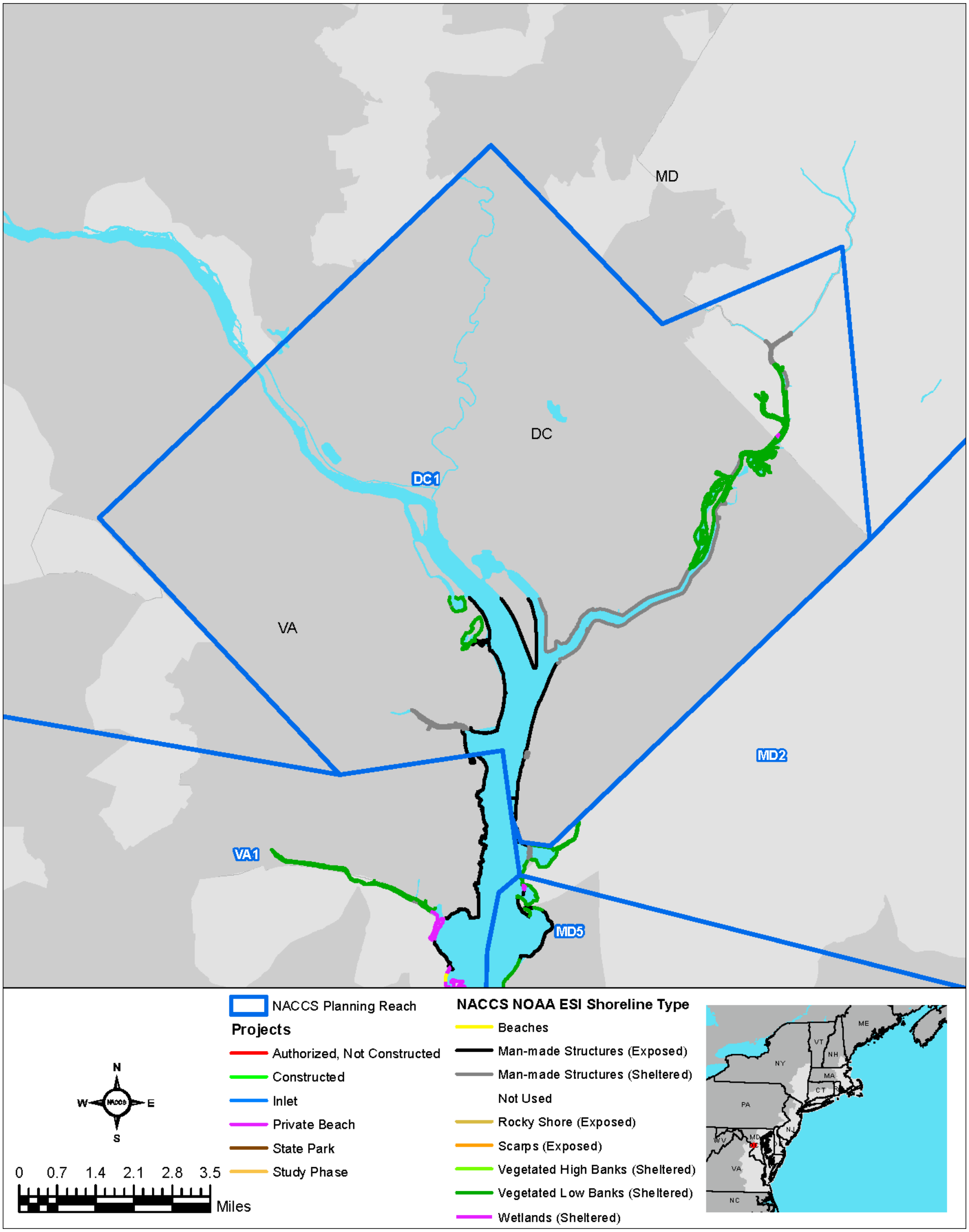


Figure VI-19. District of Columbia Planning Reach

Maryland

The Maryland coast includes five reaches (Figure VI-20 to VI-24).

MD1: Characterized by beach, frequent USACE CSRM projects, extensive floodplain extent. Includes the eastern shore of MD from DE border to VA border.

MD2: Wetland, some urban, infrequent USACE CSRM projects, extensive floodplain extent. Includes the eastern shore of MD along Chesapeake Bay to Baltimore Harbor.

MD3: Wetland/estuarine mixture, some beach and bluff, infrequent USACE CSRM projects, extensive floodplain extent. Includes the upper Chesapeake Bay to vicinity of Havre de Grace.

MD4 (Baltimore): Urban, infrequent USACE CSRM projects, limited floodplain. Includes Baltimore Harbor.

MD5: Beach, bluff, wetland, estuarine mixture, infrequent USACE CSRM projects, extensive floodplain extent. Includes the western Chesapeake Bay shoreline south of Chesapeake Beach, the Patuxent River shorelines and Potomac River shoreline within Maryland.

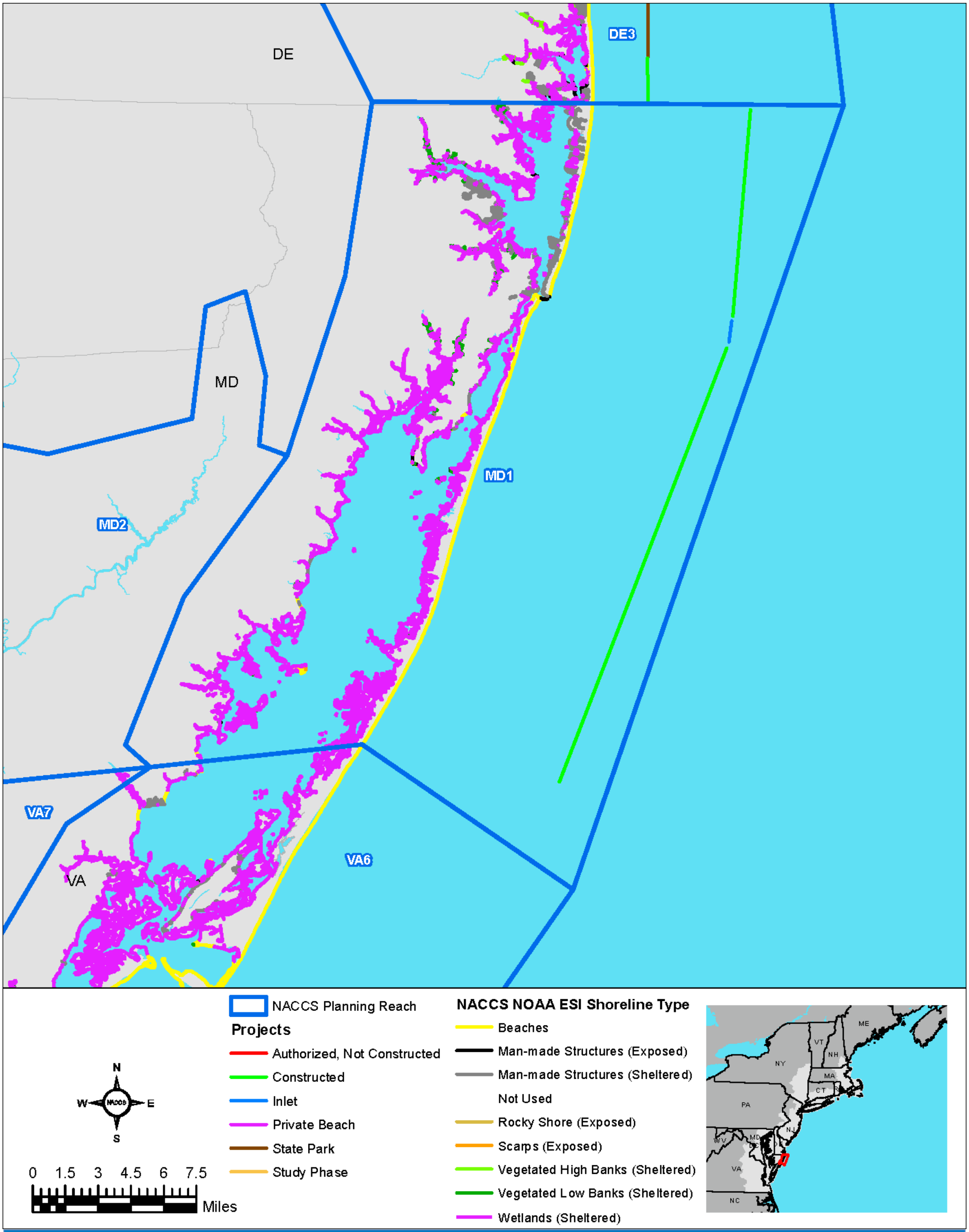


Figure VI-20.Maryland Planning Reaches

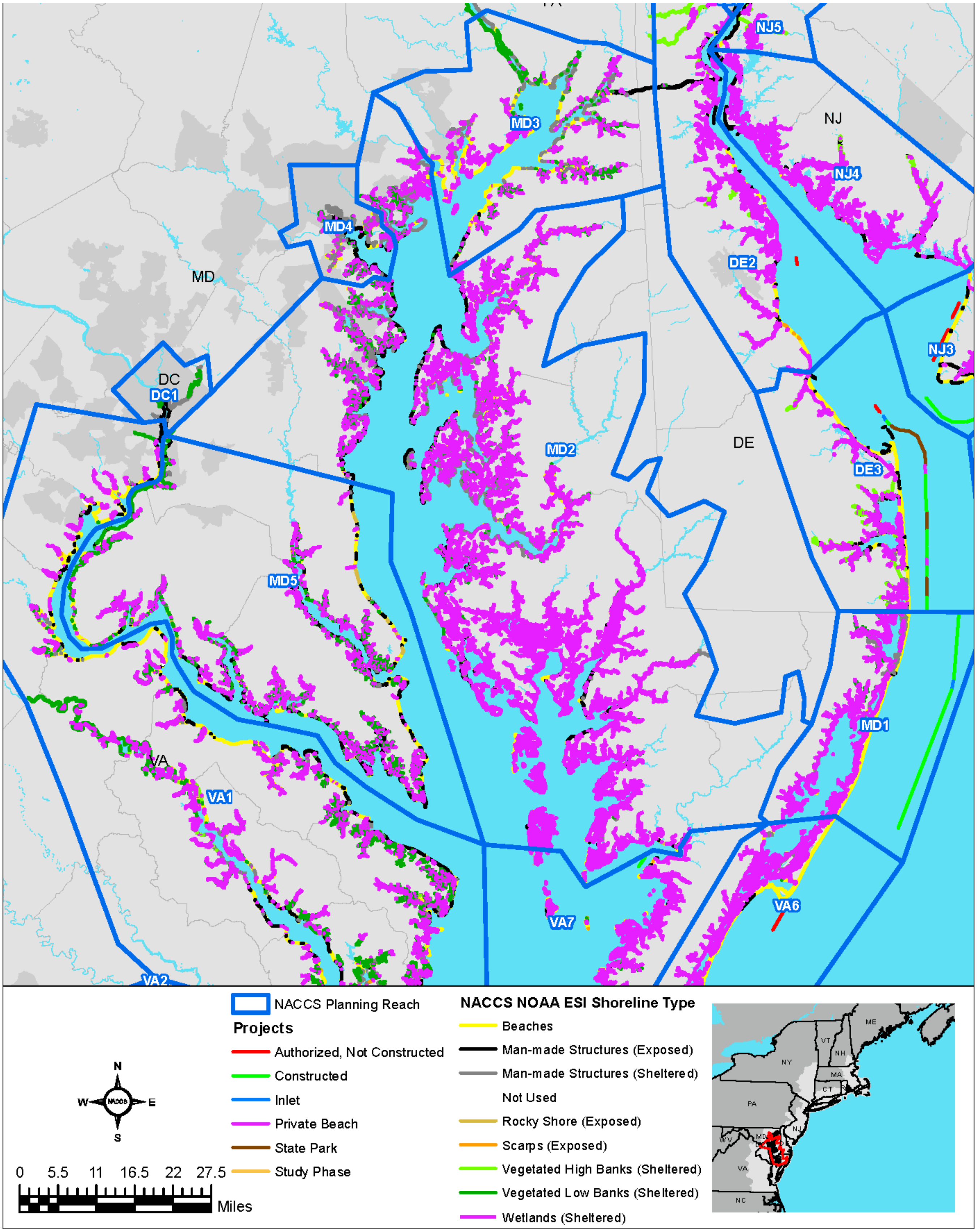


Figure VI-21. Maryland Planning Reaches

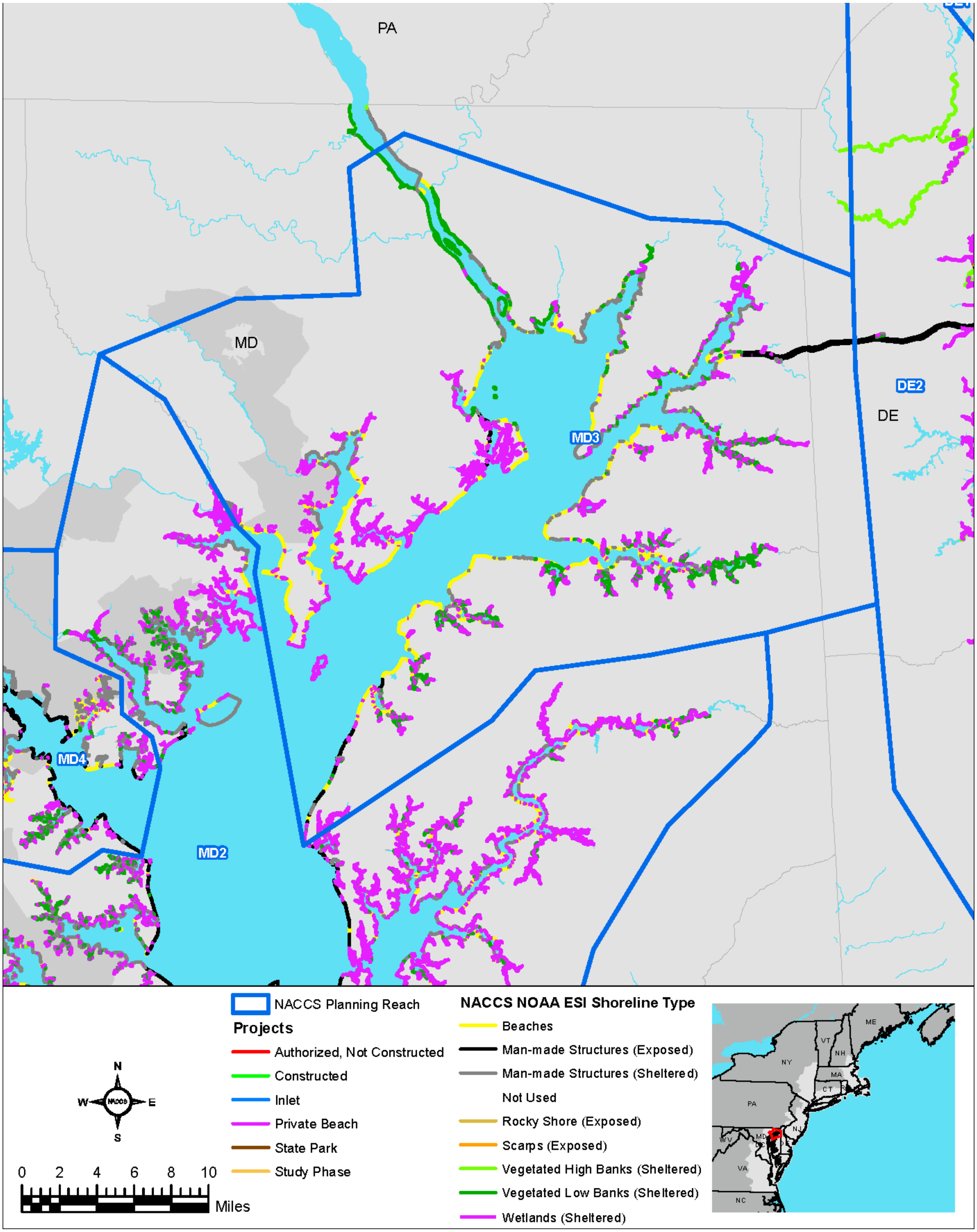


Figure VI-22. Maryland Planning Reaches

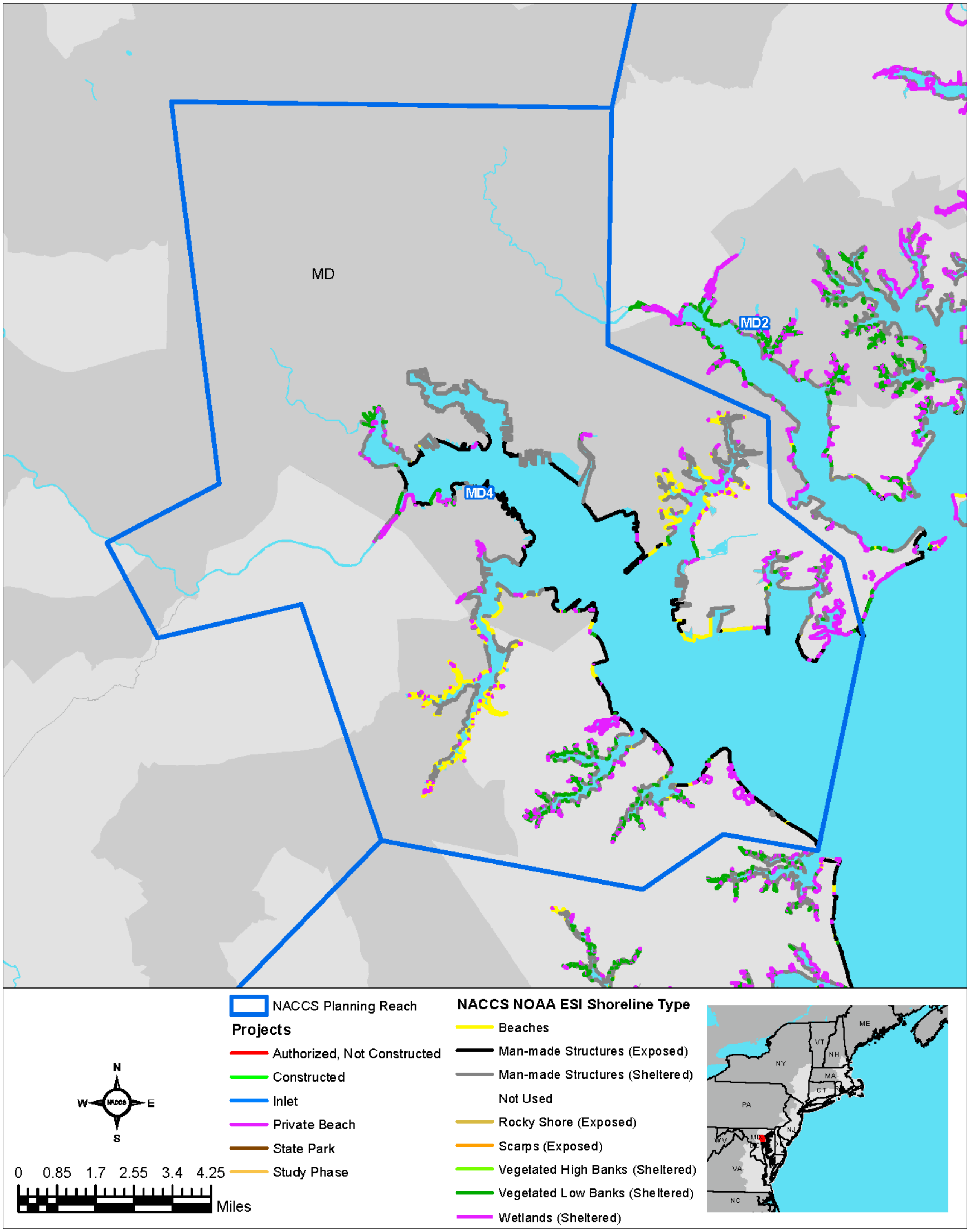


Figure VI-23. Maryland Planning Reaches

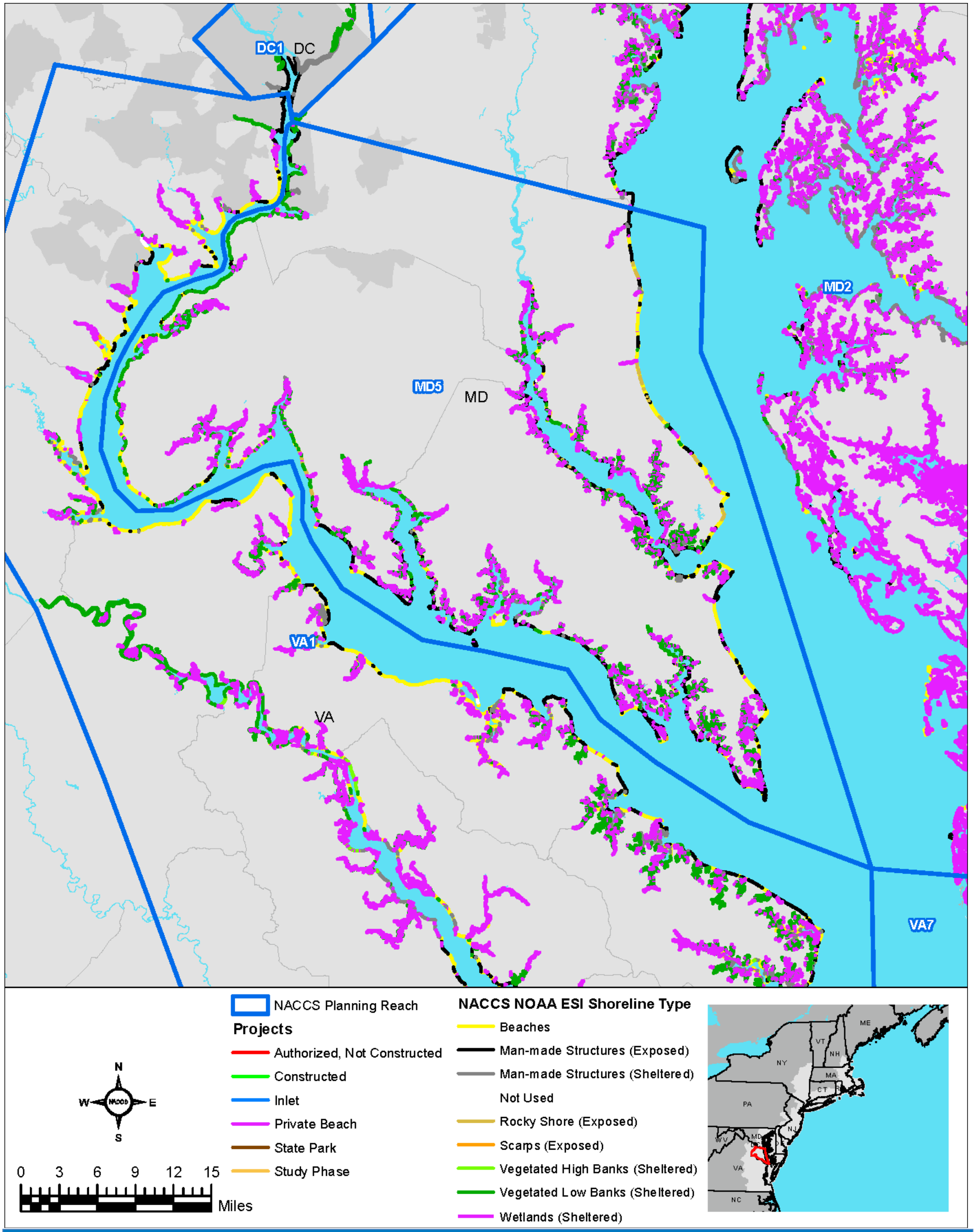


Figure VI-24Maryland Planning Reaches

Virginia

The Virginia coast includes seven reaches (Figures VI-25 to VI-27).

VA1: Wetlands and estuarine, some beaches, infrequent USACE CSRM projects, extensive floodplain extent. Includes the Potomac River shoreline within VA and Rappahannock River shorelines.

VA2: Wetlands, some beaches, infrequent USACE CSRM projects, extensive floodplain extent. Includes the western Chesapeake Bay between Rappahannock and James Rivers.

VA3: Urban, occasional USACE CSRM projects, moderate floodplain (Norfolk). Includes the James River in and upstream of Norfolk.

VA4: Beach, infrequent USACE CSRM projects, extensive floodplain extent. Includes the Chesapeake Bay portion of Virginia Beach.

VA5: Beach, frequent USACE CSRM projects, limited floodplain extent. Includes the Atlantic Ocean Coast to NC border.

VA6: Beach, infrequent USACE CSRM projects, extensive floodplain extent. Includes the eastern shore of VA along Chesapeake Bay.

VA7: Wetland, infrequent USACE CSRM projects, extensive floodplain extent. Includes the eastern shore of VA along Chesapeake Bay to MD border.

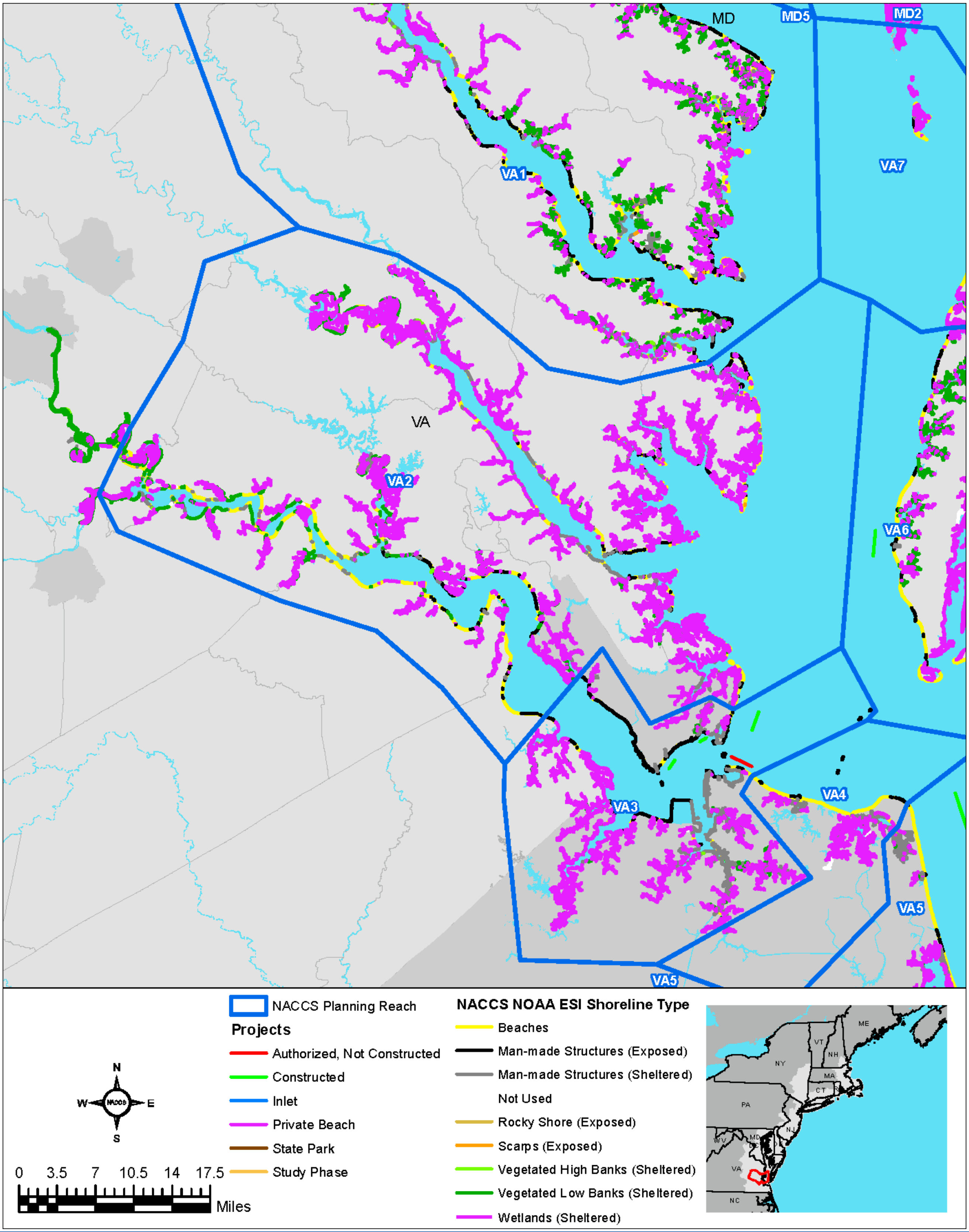


Figure VI-25. Virginia Planning Reaches

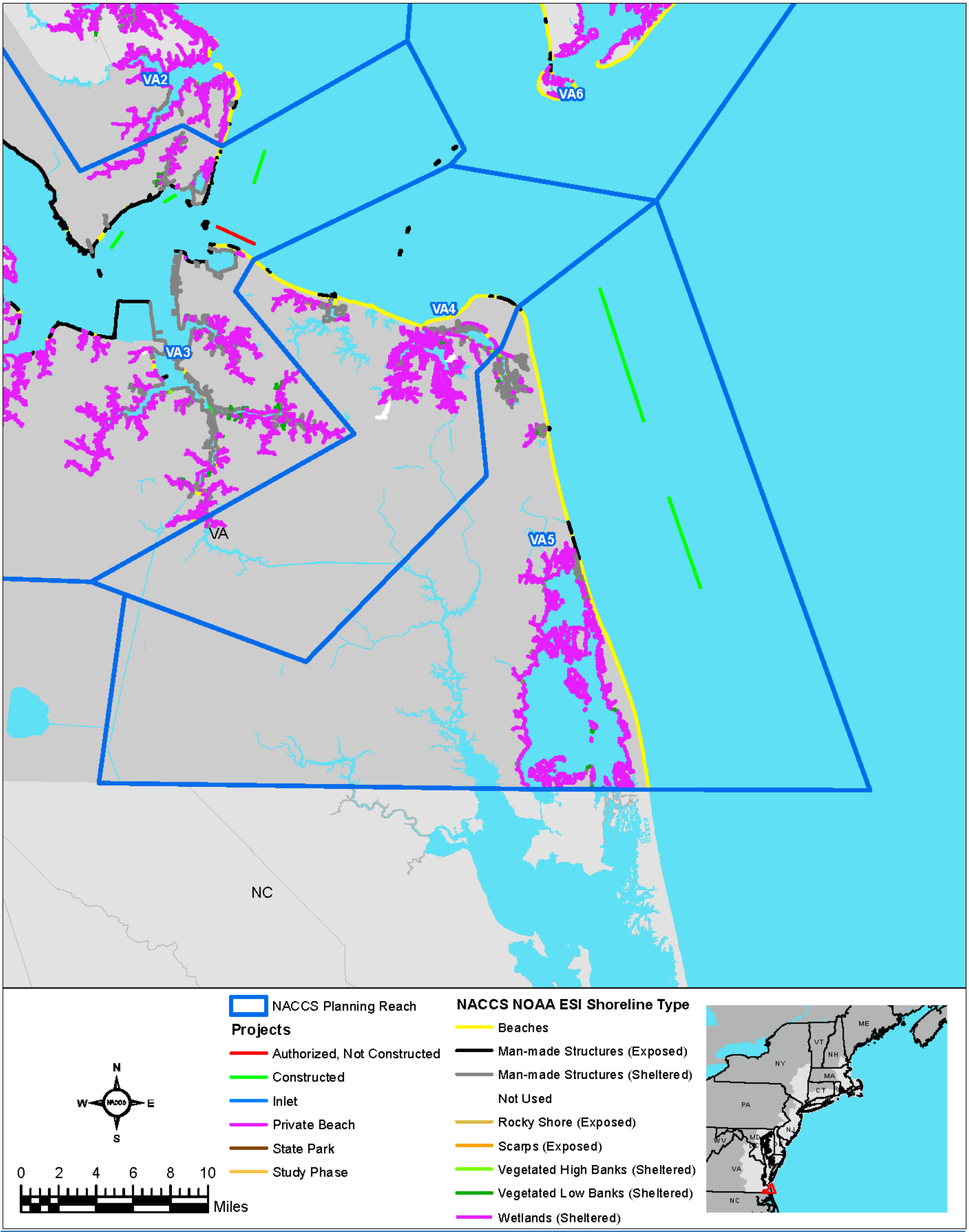


Figure VI-26.Virginia Planning Reaches

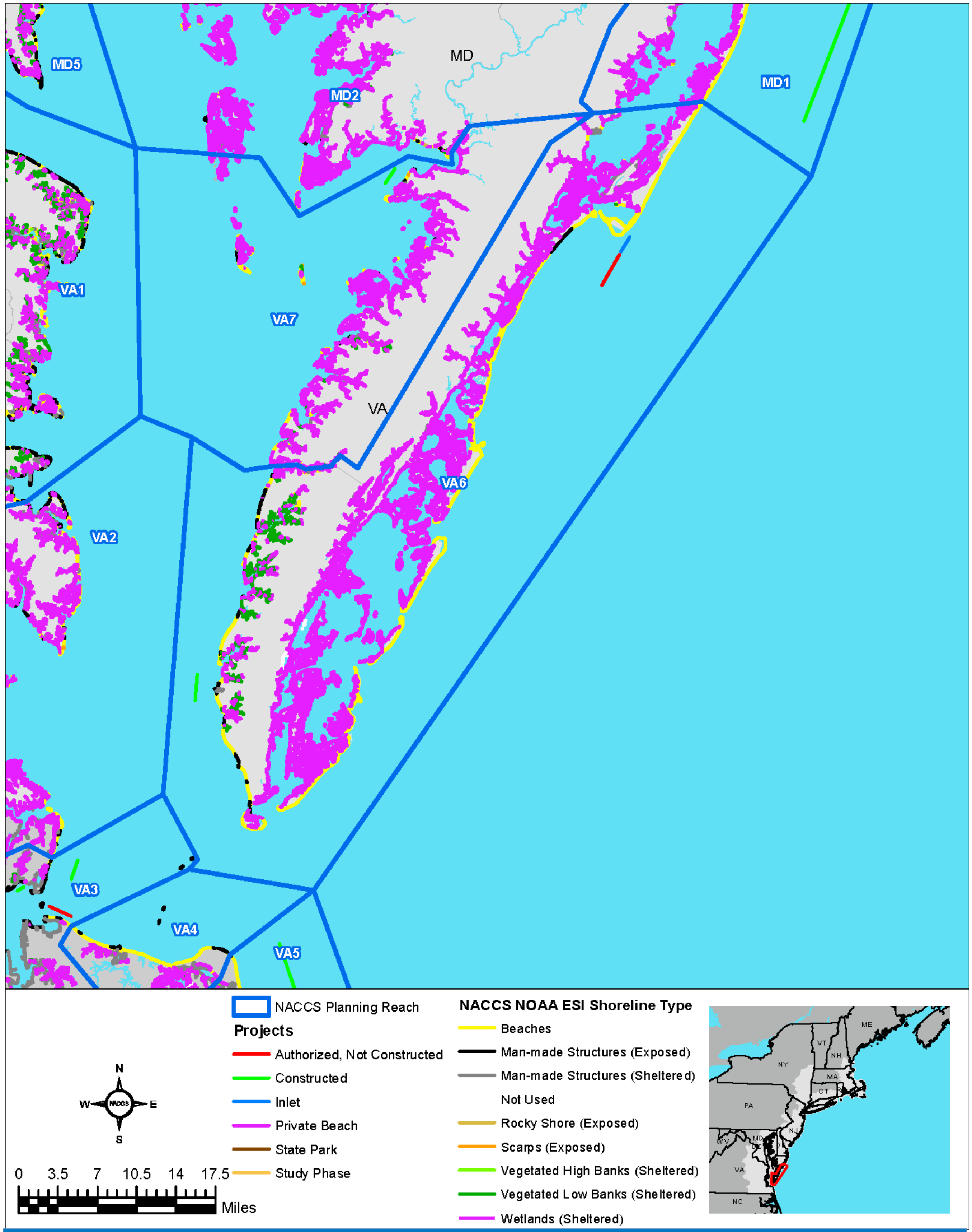


Figure VI-27Virginia Planning Reaches

VII. NACCS Exposure and Risk Assessment

VII.1. Residual Risk

Within the planning reaches, the CAT4 MOM inundation mapping area defined the areal extent to consider problems, needs and opportunities. However, it is likely that there would not be a cost-effective solution to reduce the flooding risk associated with a CAT4 MOM storm. Areas between the Category 4 MOM and 1 percent flood plus 3-foot floodplain are a figurative example of residual risk associated with flood risk management measures designed to the 1-percent level. Furthermore, the 1 percent flood is regulated by FEMA and the National Flood Insurance Program manages flood insurance using this recurrence interval. Residual risk is the flood risk that remains after all efforts to reduce the risk are completed and is the exposure to loss remaining after other known risks have been countered, factored, or eliminated. It is important to identify residual risk to account for the extreme flooding extents associated with a catastrophic event because oftentimes risk management measures do not reduce the risk associated with such an extreme event, creating a false sense of security. This concept is considered residual risk, or the flood risk to people and assets that remain after implementation of flood risk management projects and initiatives.

VII.2. NACCS Exposure Assessment

The Tier 1 assessment first required identifying the various categories to best characterize exposure. Although a myriad of factors or criteria can be used to identify exposure, the NACCS focused on the following categories and criteria, as emphasized in PL 113-2:

1. **Population Density and Infrastructure**: Population density includes identification of the number of persons within an areal extent across the study area; infrastructure includes critical infrastructure that supports the population and communities. These factors were combined to reflect overall exposure of the built environment.
2. **Social Vulnerability Characterization:** Social vulnerability characterization includes certain segments of the population that may have more difficulty preparing for and responding to coastal flood events.
3. **Environmental and Cultural Resources**: The environmental and cultural resources exposure captures important habitat and cultural resources that would be affected by storm surge, winds, and erosion.

Using the spatial data layers and weighting scheme, an exposure index was developed to characterize the relative exposure to coastal flood hazard. For each exposure category, spatial data layers were obtained to be included for evaluation of the categories' overall exposure to coastal flood hazard. The spatial layers were obtained from various sources, mostly national datasets and publicly available information although some infrastructure data included in the analysis is not publicly available due to security purposes. Using the number of features specific to the data layer included in the various spatial data layers, a weight was assigned to characterize the relative importance compared to other data layers within the category as it relates to direct and or indirect effects to population and communities during a coastal flood event.

Population Density and Infrastructure Index

The population density within the study area was identified within the planning reaches. Population density for any location was calculated to identify the extent of population exposure to the coastal flood hazard. In addition, USACE obtained the HSIP Gold 2012 geodatabase from the National Geospatial Intelligence Agency (HSIP 2012). Various data layers included in the HSIP Gold 2012 database were selected and defined as critical infrastructure that supports the population using principles associated with an engineering reconnaissance process described in the Department of the Army Field Manual (FM) 3-34.170, Engineer Reconnaissance (FM 3-34.170, 2008). The sewage, water, electricity, academics, trash, medical, safety and other considerations (SWEAT-MSO) assessment process provides immediate feedback concerning the status of the basic services necessary to sustain population. The SWEAT-MSO assessment represents a complete evaluation of both assets susceptible to direct exposure from storm damage, but also the indirect damages that would follow by identifying the assets within and support to a community. Figure VII-1 was extracted from FM 3-34.170, Appendix C (Figure VII-1. The infrastructure assessment and survey model).

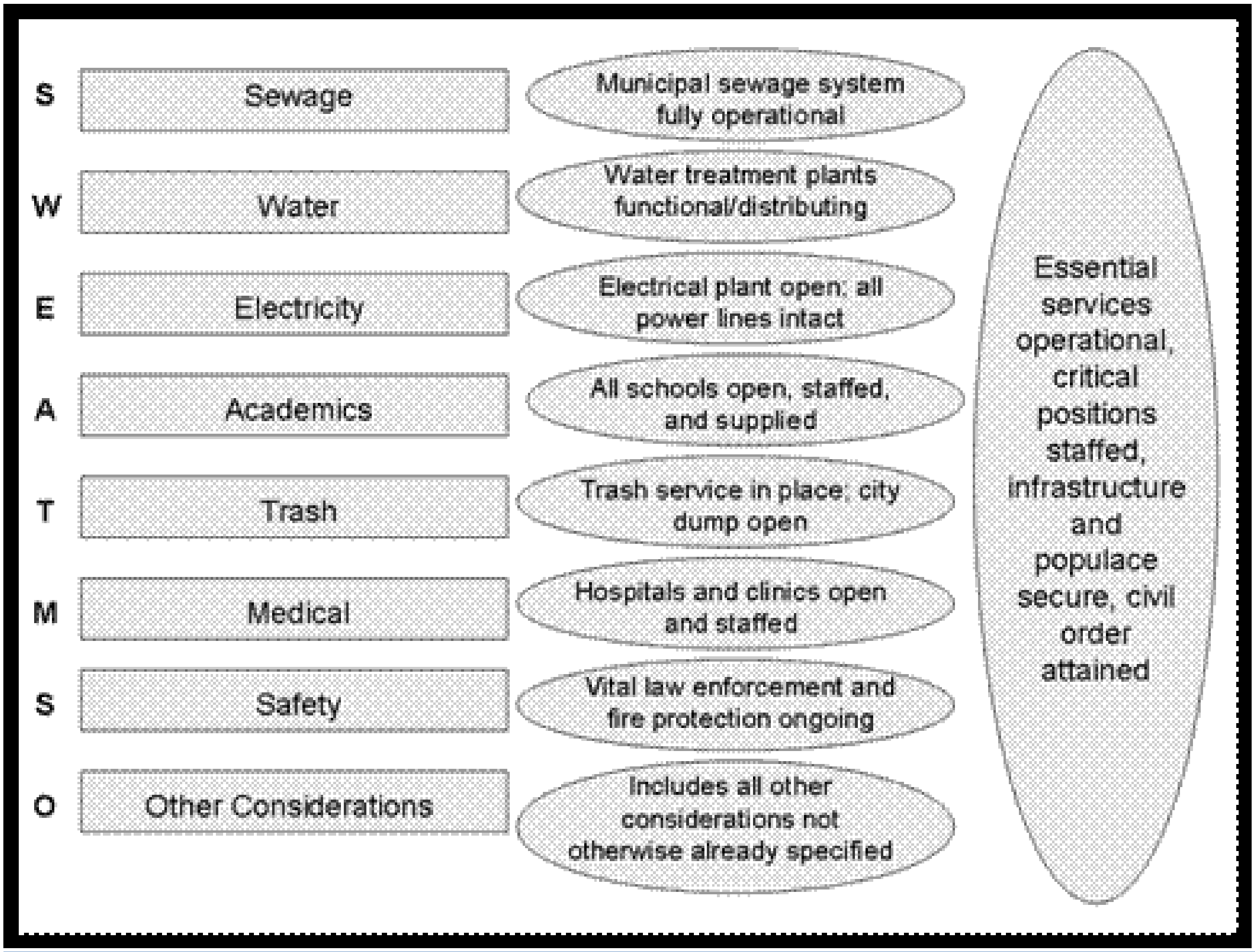


Figure VII-1 SWEAT-MSO Critical Infrastructure Assessment

Those data layers included in the HSIP Gold 2012 database that correspond to the infrastructure categories that could be considered essential services, operations, or necessary to ensure civil order were extracted for a spatial context within the CAT4 MOM inundation area. For the other considerations of the SWEAT-MSO assessment process, communications, energy (regional energy distribution network in addition to electricity), and transportation data layers were also included. Then, each layer was evaluated further as to the relative importance among the SWEAT-MSO layers by assigning a weight to the layer. The weighting for the infrastructure data layers included a range from 5 to 30 points, increasing in relative importance by 5 point increments. The range of values for population density included a range from 40 to 80 points, increasing in relative importance by 10 point increments. The layers used in the exposure categories along with the corresponding weights were discussed among both USACE staff and other flood risk management professionals from Federal and state agencies.

Environmental and Cultural Resources Index

Environmental and cultural resources were evaluated within the planning reaches. Data from national databases, such as the National Wetlands Inventory and The Nature Conservancy (TNC) Ecoregional Assessments; data provided from USFWS, including threatened and endangered species habitat and important sites for bird nesting and feeding areas; shoreline types; and historic sites and national monuments, among others were used to assess environmental and cultural resource exposure. It should be noted that properties with restricted locations, typically archaeological sites, and certain other properties were omitted from the analysis due to site sensitivity issues.

The exposure index is intended to capture important habitat, and environmental and cultural resources that would be vulnerable to storm surge, winds, and erosion. It should be noted though, that mapped areas displaying high exposure index scores may not include all critical or significant environmental or cultural resources, as indexed scores are additive; the higher the index score, the greater number of resources present at the site. Additionally, environmental data layers are typically discrete geographical characterization such that overlap of the areas is not easily incorporated into GIS datasets. With the additive feature of the index such that overlapping datasets, the index values in those areas that do overlap result in higher relative exposure where those that do not overlap result in a lower relative exposure. Impacts and recovery opportunity would vary across areas and depending on the resource affected.

Due to the lack of cultural resources information and the sensitivity of the data that was available, specific locations could not be identified. More refined datasets should be considered, among other refined objectives and constraints at a smaller scale, which the various steps of the Framework would be repeated. At that point in time, more refined information could be incorporated into the index as well as potentially a refined objective to consider cultural resources in the analysis. Future planning requirements or objectives at smaller scales for evaluation of coastal flood risk to cultural resources could include the following objectives:

1) Identify curation safe zones that would be in an area of relatively lower flood risk
2) Establish evacuation protocols for historic areas and cultural resource infrastructure that fall within areas of relatively higher risk areas in the form of partnerships with other institutions outside the impact area
3) Establish guidance for museums in areas exposed to flood peril to create reproduction pieces to replace irreplaceable artifacts
4) Establish research priorities on the tribal, state, and local level for historic sites that fall within areas exposed to flood peril that would help mitigate impacts that cannot be prevented

In addition to the NACCS Environmental and Cultural Resources Report, each state included in the NACCS study has a current State Historic Preservation Plan on file at the State Historic Preservation Office. These plans outline research priorities of the state and existing policy for research and treatment of historic properties and contextual themes. For subsequent Tier 2 or Tier 3 analyses, it would be helpful to incorporate these existing programmatic state documents into the long-term strategy of how to address increasing flood risk as a result of the effects of sea level change and climate change to historically significant structures and other cultural resources.

Social Vulnerability Characterization Index

The social vulnerability characterization was completed using the U.S. Census Bureau 2010 Census Demographic Summary Profile data (Census, 2011). The overarching goal is to quantify areas where the population is more at risk to storm impacts. After considering the Census data, it was determined that age, income, and inability to speak English were important factors in social vulnerability. The following equation including data categories available in the Census data at the tract level were used to define the social vulnerability characterization Exposure Index:

(% Population 65 and over) + (% Population under 5) + (% Population w/ Income below poverty) + (% Population Non-proficient English speakers)

The overall social vulnerability characterization exposure value was attributed to the corresponding block-group to define a spatial context for social vulnerability within the study area. Since all variables were represented as a percentage, they were already normalized and could be added together without adjustment and avoiding double counting of the actual population values. Although it would be possible for a person residing in a particular block-group to have one or more of the NACCS social vulnerability characteristics would be identified, combining the unit-less values of the percentage allows for a relative comparison of the four characteristics of the population to identify relative exposure.

1. **Percentage of people age 65 and over**: The elderly are likely to have greater difficulty in evacuating from homes and may lack the ability, stamina, or resources to bounce back after the event. Additionally, the frail elderly may be in nursing homes or hospitals, which places the burden for their safety in a flood emergency on others.
2. **Percentage of people age 5 and under:** Like the elderly, those at the other extreme of the age spectrum affect the movement out of harm's way. Parents lose time and money caring for children when daycare facilities are affected, and the very young may be more susceptible to flood-borne diseases.
3. **Percentage of all people whose income in the past 12 months is below poverty**: Poorer households are more likely to occupy risky locations and to be in housing that is older and in substandard condition. Poorer households may lack resources such as cars to evacuate in a flood emergency and have less ability to absorb losses from a flood, less access to insurance, fewer resources to provide a cushion for a long recovery period, and less access to social networks that can lobby on their behalf for assistance.
4. **Percentage of people who speak a language other than English and speak English less than very well**: New migrants that may not speak English may not be able to understand warning information or be familiar with processes for obtaining relief or recovery information, all of which increase vulnerability.

The data layers presented in Tables VII-1 through VII-4 display the criteria within each respective exposure category and its respective weighting value.

Table VII-1. Infrastructure

Critical Infrastructure Point Data Layer (HSIP 2012)	Risk Score
Airport Boundaries	15
All Places of Worship	15
Amtrak Stations	15
Bus Stations	5
Cellular Towers	10
Colleges/Universities	15
Communication Centers	15
Dams	25
Electric Generating Units	20
Electric Power Generation Plants	25
EMS	25
Energy Distribution Control Facilities	20
Ferry	5
Fire Stations	30
Gas Stations	20
Hospitals	30
Intermodal Terminal Facilities	15
Law Enforcement Location	25
Local Emergency Operation Centers	20
National Shelter System	20
Natural Gas (LNG) Import Terminals	15
Natural Gas compressor Stations	15
Natural Gas Import/Export Points	5
Natural Gas Receipt and Delivery Points	10
Natural Gas Storage Facilities	15
Nuclear Power Plants	25
Nursing Homes	25
Oil and Natural Gas Interconnects	5
Oil Refineries	20
Pier/Wharf/Quay	15
Petroleum Pumping Stations	10
Pharmacies	15

Table VII-1. Infrastructure	
Critical Infrastructure Point Data Layer (HSIP 2012)	**Risk Score**
POL Terminals / Storage Facilities / Tank Farms	15
Ports	15
Private Schools	10
Public Schools	15
Railroad Bridges	20
Railroad Stations	20
Railroad Tunnels	20
Railroad Yards	20
Receiving Hospitals	30
Road and Railroad Bridges	20
Service Providers	25
State Emergency Operation Centers	20
Substations	20
Urgent Care Facilities	20
Wastewater pump stations	30
Wastewater Treatment Plants	30
Water Treatment Facilities	30

Table VII-2. Infrastructure	
Critical Infrastructure Linear Data Layer (HSIP 2011)	**Risk Score**
Hurricane Evacuation Routes	20
Transmission Lines	20
Railroad	20
Road and Railroad Tunnels	20
Pipeline Distribution System	20
Canal	15
Channel	20
Oil and Natural Gas Pipelines	20
Ferry Route	10

Table VII-3. Population Density	
Population Density Per Acre (Census, 2011)	**Weighted Value**
0	0
0.1-12	40
13-72	50
73-193	60
194-687	70
688-3072	80

Table VII-4. Environmental and Cultural Resources	
Environmental Criteria (30 Percent)	**Weight (0-25)**
Priority Areas (USFWS 2014)	84
Coastal Barrier Islands under CBRA (USFWS 2014)	91
USFWS Refuges (USFWS 2014)	86
USFWS Protected Area (USFWS 2014)	65
USFWS Priority Areas (USFWS 2014)	91
Rare, Threatened, and Endangered Species (USFWS 2014)	89
Colonial Nesting Waterbirds (USFWS 2014)	94
The Nature Conservancy Conservation Areas (TNC 2011)	73
City, County, State and Federal Parks > 100 acres (HSIP 2012)	44
Habitat (30 Percent)	
Seagrass (TNC 2011; VIMS 2013a)	88
Estuarine Emergent Marsh (TNC 2011)	96
Forested Wetland (TNC 2011)	80
Scrub- Shrub Wetland (TNC 2011)	73
Freshwater Emergent Marsh (TNC 2011)	83
Freshwater Forested/Shrub Wetland (TNC 2011)	82
Riverine Wetlands (TNC 2011)	61
Rocky Shoreline (TNC 2011)	31
Unconsolidated Shore - mud, organic, flat (TNC 2011)	47
Unconsolidated Shore - sand, gravel, cobble (TNC 2011)	66
Cultural Resources (40 Percent)	
Coastline Buffer (1,000 feet) (water layer including, lakes, ponds, river, streams, etc.) (TNC 2011)	50
National Monuments and National Historic Landmarks (HSIP 2012)	85
Historic Sites (HSIP 2012)	75

VII.3. Exposure Mapping

Convert Index to a Spatial Grid in GIS

The NACCS could not present all of the data explicitly on a map due to security and classification of the infrastructure data. Additionally, by implementing a process to normalize the three categories, the categories could then be combined to identify a composite exposure index. Using the features in the data layers that were used to define the criteria of the exposure categories and the corresponding weighting from the criteria tables, a grid was developed at approximately 70 meters (0.00833 decimal degrees) in resolution across to allow for management processing time using ESRI's ArcGIS software program (ESRI, 2012). Once the grid was created, the various data layers that intersect the grid cell within that specific geographic area were included in the computation to define the grid cell value. The grid cell value was computed by the sum of the various scores of the various data layers for the respective index. The grids were then symbolized as green (low) to red (high) to display the relative range of exposure.

Sum and Weight Exposure Index Grids Produce a Composite Exposure Index Grid

All three of the independent exposure indices were summed together to develop one composite index that displays overall exposure (Figure VII-2). With the focus of the NACCS on reducing risk to vulnerable coastal populations and the infrastructure that supports it, the population density and infrastructure exposure index was weighted higher than the social vulnerability characterization and environmental and cultural resources indices. Population density and infrastructure was assigned a weight of 80 percent, social vulnerability characterization was assigned a weight of 10 percent, and environmental and cultural resources were assigned a weight of 10 percent. The composite index was developed to represent exposure to the system, along with an independent evaluation of exposure to the three individual categories.

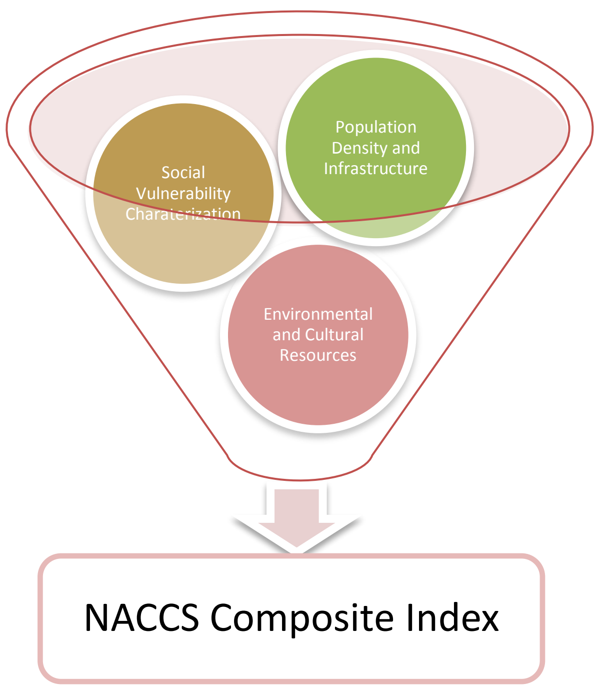


Figure VII-2. NACCS Composite Index

Narrow the Exposure Grid to the extent of the CAT4 MOM Inundation Mapping

All four exposure grids were clipped to the CAT4 MOM inundation mapping. By clipping the exposure index to the CAT4 MOM, the results present the exposure to a flood hazard of a high magnitude, low probability event in order to define residual risk within the study area.

Identify a Break in the Composite Exposure Index Data Range to Identify Exposure Areas

Using ESRI ArcGIS software, the natural breaks in the composite exposure index distribution of values in the grid were used to identify the areas of relative higher exposure (ESRI, 2012). With the identifying the relative higher areas of exposure at the study area scale, the relative areas of higher exposure were then converted to polygon features. The polygon features were necessary to compute respective shoreline types, lengths, and risk necessary to complete the Tier 1 analysis.

Aggregate Relatively Higher Exposure Areas into Risk Areas

The polygons were subsequently aggregated into larger areas of relatively higher exposure within the 39 planning reaches. The reaches were evaluated with the baseline risk areas identified by the GIS, but expanded and aggregated based on other information previously compiled, such as existing coastal storm risk management projects, recommendations from other plans, areas susceptible to sea level change, etc. As part of the reach evaluation, the USGS coastal vulnerability index was also taken into consideration, primarily to consider the effects of wave action. The USGS coastal vulnerability index takes into account geomorphology, shoreline erosion/accretion rate, coastal slope, RSLC rate, mean wave height, and mean tide range to represent a composite evaluation of the vulnerability of the coastline. The results of the evaluation of areas exposed to flood peril and flood risk in general led to the identification of NACCS risk areas. The results of this evaluation are included in the State and District of Columbia.

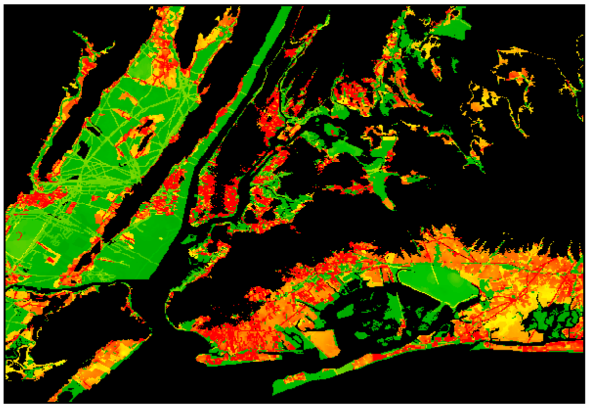
Composite Index Sensitivity Analysis

The composite index development was completed for the purposes of the NACCS Tier 1 assessment. As discussed as part of the development of the Framework, the various steps would be replicated at smaller scales using refined datasets and based on refined objectives. There are three adjustments to the development of the exposure index that would result in changes to the outputs. A sensitivity analysis was completed to evaluate the potential outputs of the index development, which could vary based on adjustments to the factors associated with the index development. Although not necessarily considered an adjustment because the index values would not change, the symbolization of the range of data values contained in the index would change the output visualization (i.e., the color ramp or the range of values included in the various segments of the color ramp).

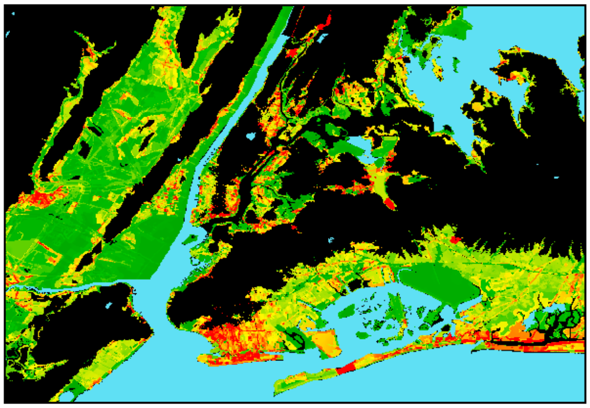
The first adjustment to the index to modify the outcome would be to change the data layers that comprise the index. The Framework acknowledges that Tier 2 and Tier 3 analyses would incorporate more refined datasets to better define and measure exposure. This would be a necessary adjustment to incorporate datasets at a finer resolution that those used as part of the NACCS Tier 1 assessment. Furthermore, as noted in the development of the environmental and cultural resources exposure index development, the data layers used in the development of the index could affect the results. Input by stakeholders could potentially identify or supplement datasets to provide finer resolution or improve assumptions.

The second adjustment to the index development that could change the results would be for users to adjust the weightings associated with each of the individual features or layers that comprise the index. Similar to data availability, input from stakeholders or a specific community could potential identify those features that would be weighted relatively higher than others due to the community-specific effects that exposure to a flood hazard would cause. At the study area scale, adjustments to the individual weightings would not result in an appreciable change in the exposure values and symbolization.

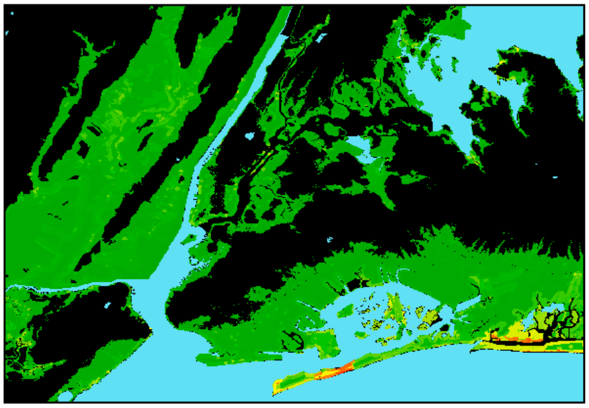
The third adjustment to the index would be the broader category weightings used in the development of the index could be adjusted to emphasize one of the three components of the composite index over another. The adjustment of the broader category weighting does result in an appreciable change in the results. To evaluate the adjustments and corresponding changes, the composite index sensitivity analysis included a comparison of the results by adjusting the 80/10/10 percent weightings of the three individual indices for the NY-NJ1 reach as a sample. The composite index was developed to demonstrate the ability to evaluate various components of the coastal system. The results of the sensitivity analysis generally show that users could refine the index to meet specific objectives. Figure VII-3 presents the results of the composite index sensitivity analysis.



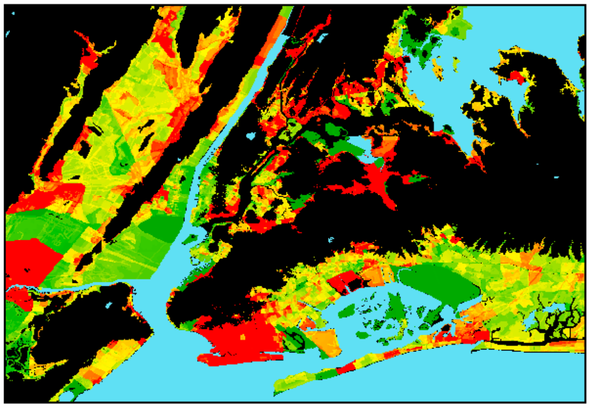
Infrastructure and Population (80%) + Social Vulnerability (10%) + Environmental and Cultural (10%)



No Weights / Equal Weights



Infrastructure and Population (10%) + Social Vulnerability (10%) + Environmental and Cultural (80%)



Infrastructure and Population (10%) + Social Vulnerability (80%) + Environmental and Cultural (10%)

Figure VII-3. Composite Index Sensitivity Analysis

VII.4. NACCS Risk Assessment

Exposure and coastal flood inundation mapping is used to identify the specific areas at risk. Once the exposure to flood peril of any area has been identified, the next step is to better define the flood risk. The Framework defines risk as a function of exposure and probability of occurrence. For each of the floodplain inundation scenarios, Category 4 MOM, 1 percent flood plus three feet, and the 10 percent flood, three bands of inundation were created. The bands correspond with the flooding source to the 10-percent inundation extent, the 10-percent to the 1-percent plus three feet extent, and the 1-percent plus three feet to the CAT4 MOM inundation extent. The 1-percent plus three feet extent was defined as the CAT2 MOM because at the study area scale there were areas that did not include FEMA 1-percent flood mapping. This process was completed for the composite exposure assessment in order to generate the new data presented as the NACCS risk assessment. The State and District of Columbia Appendix presents the results of the NACCS Risk Assessment. The data was symbolized to present areas of relatively higher risk, which based on the analysis, corresponds with the three bands that were used in the analysis. Subsequent analyses could incorporate additional bands, which would present additional variation in the range of values symbolized in the figure.

VII.5. NACCS Exposure and Risk Indices: Raster Dataset Appropriate Usage and Constraints

The NACCS exposure assessment includes constraints to note for appropriate use when applying the data contained in the NACCS geodatabase, specifically the raster files presenting the exposure and risk assessment generated as part of the Tier 1 assessment. The exposure raster files were derived using various vector spatial data, which may also include appropriate use and constraints, such as horizontal and vertical accuracy for example. When evaluating coastal flood risk as part of a Tier 2 or Tier 3 analysis at high resolution by applying the steps presented in the NACCS Framework to complete the exposure and risk assessments, the exposure grids should be recreated as part of incorporating refined datasets. When using the NACCS Tier 1 exposure and risk index raster datasets for subsequent analyses, practitioners should exercise appropriate and professional judgment in the use and interpretation of these data contained in the raster metadata.

VII.6. Vulnerability Assessment for Future Investigations and Evaluations

At a smaller scale, vulnerability is defined as a function of exposure, sensitivity, and adaptive capacity. The ERDC Use of Natural and Nature-Based Features for Coastal Resilience Report describes in detail the process to develop a detailed vulnerability analysis to incorporate the three components, including refined exposure assessment metrics, sensitivity, and adaptive capacity (Bridges et. al., 2015). The scale at which this evaluation would occur requires finer detail datasets to measure the metrics associate with each of the three components.

Once a community identifies its exposure and risk, the next step to better define the actual vulnerability to a flood event should be considered. This effort would consist of evaluation of a community's sensitivity to a flood event as well as its ability to adapt over time as conditions change. An example of sensitivity would be the number of structures elevated or floodproofed. Although a flood event would inundate structures, the sensitivity to damages may in fact be much lower because of the existing flood risk management measures.

VIII. Coastal Storm Risk Management Measures

Coastal systems provide important social, economic, and ecological benefits to the Nation. However, our coasts are vulnerable to the influence of a combination of factors, including storms, changing climate, geological processes, and the pressures of ongoing development and urbanization. The overarching strategy to increase coastal resilience and reduce vulnerability can be achieved by 1) instituting land use changes over time to adapt to impacts that increase risks; 2) accommodating potential changes such as climate variability, sea level change, etc. to preserve the natural and built environment over time; and 3) employing risk reduction measures to reduce flood damages to property and infrastructure. In addition to policy and programmatic efforts to reduce risk, the NACCS Coastal Storm Risk Management Framework builds on three common adaptation categories used by the climate adaptation communities in the US and internationally: avoid (sometimes termed retreat), accommodate, and preserve (sometimes termed "protect") (Dronkers, J. et al. 1990; USACE 2014).

NNBF, non-structural, and structural are terms used to describe the full array of measures that can be employed to provide increased coastal resilience and risk reduction (USACE, 2013). An integrated, watershed-based approach that draws together a combination of measures as part of the above strategies will reduce risk and enhance coastal resilience over the long-term (USACE, 2013). A systems approach to evaluating comprehensive flood risk is necessary to evaluate the synergistic benefits of a combination of strategies, resilience and robustness of the coastal landscape, as well as to identify and communicate residual risk. Figure VIII-1 depicts the coastal landscape considering the three strategies and various management measures. The Framework describes the process local communities and other stakeholders could use to evaluate coastal flood risk, future vulnerability with respect to sea level change, and the strategies and measures to manage existing vulnerabilities and increasing risk over time.

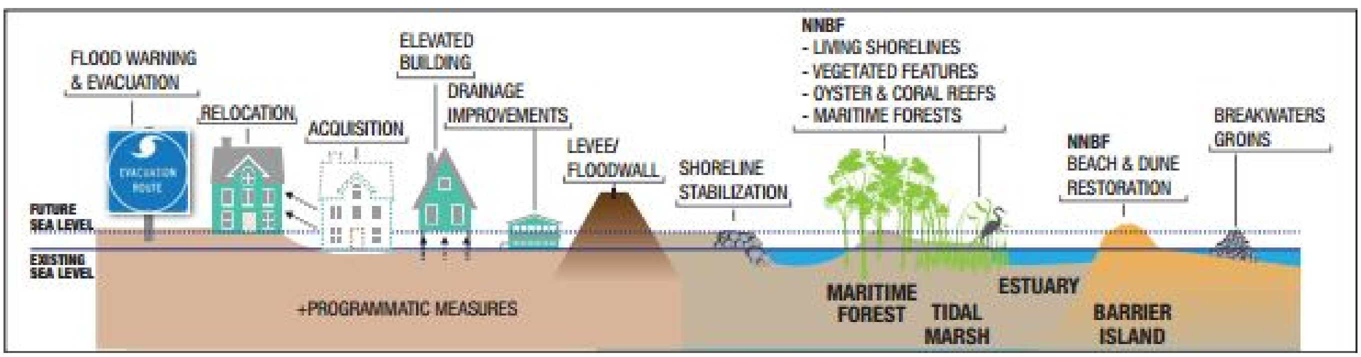


Figure VIII-1. Combinations of adaptable measures may be used to improve redundancy, robustness, and resilience associated with coastal flood risk management (not to scale)

Risk Management Measures Categorizations and Comparisons

A suite of coastal storm risk management measures was developed by taking an integrated approach that considers combinations of the full array of available measures (USACE, 2013). All of these measures were identified as potentially effective ways to reduce the vulnerability of coastal populations and increase resilience. The coastal storm risk management measures include structural, non-structural, NNBF, and programmatic measures. USACE convened a two day working meeting on June 26-27, 2013, at the Stevens Institute of Technology in Hoboken, NJ, with representatives from Federal, State, and local governments, as well as academia and private industry, to discuss the full array of potential measures. A master list of all the measures was compiled and filtered for duplication and consistency with study goals and objectives, then augmented based upon a literature review. The various measures were categorized as structural, non-structural, and NNBF in the final aggregated list. Some NNBF measures were identified for both the NNBF and structural categories because of their storm surge reduction potential. Additionally, programmatic measures were organized under the nonstructural category. Once the measures were aggregated into specific types, USACE staff evaluated the respective risk reduction capacity. Risk management measures were characterized by the degree to which they could 1) reduce coastal storm damages (through reductions in flooding, waves, or erosion), 2) produce multiple benefits, and 3) promote resilience and adaptive capacity (Table IV-4). This evaluation of the coastal storm risk management functions is based on professional experiences from previous coastal storm investigations. It was intended to present a qualitative assessment of the function, performance, utility, and resilience attributes of the various measures. Subsequent analyses could provide more refined and quantitative evaluations of the measures' risk reduction capacity. This process to compile and aggregate measures is illustrated in Table VIII-1.

Although many of the categories generally correspond to standard coastal risk management strategies, specific applications are not constrained to the usual solutions. Opportunities for innovative designs, technologies, materials, etc., should be considered when evaluating specific application of any of these measures. Furthermore, innovative combinations of standard measures are expected to be key to managing coastal risks and promote resilience. For example, shoreline stabilization measures, such as seawalls and revetments, can work effectively with beach restoration when designed to be exposed to waves only during extreme events to provide an additional line of defense without interrupting non-storm coastal processes (USACE, 2013).

Note that the actual design level associated with these measures could vary significantly depending on the specific application. At site-specific locations, design considerations of measures and corresponding assumptions will change. The values will change as assumptions change. For example, for the purposes of this study, beach restoration, alone or in combination with other structures such as groins or breakwaters, could be designed to reduce risks due to storm tides and waves to 1 percent flood level. Furthermore, USACE analyses of coastal flood risk management plans optimize net annual benefits compared to net annual costs of the plan as opposed to a specific design elevation. For general comparison and as part of the Framework evaluation of management measures, assumptions of a specific design elevation across the study area for the measure was required to compare to the corresponding the floodplain inundation scenario (10 percent flood and 1 percent flood plus 3 feet).

Table VIII-1. Storm Damage Reduction and Resilience Attributes Associated with the Full Array of Measures

Aggregated Measure Type[1]	Category[2]	Storm Damage Reduction Function			Multi-Benefits[3]	Resilience
		Flooding	Wave Attenuation	Erosion		Adaptive Capacity[4]
Acquisition (building removal) and relocation[5]	Non-STR	High	High	High	High	High
Building retrofit (e.g., floodproofing, elevating structures, relocating structures, ringwalls)	Non-STR	High	Low	Low	Low	Low
Enhanced flood warning and evacuation planning (early warning systems, emergency response systems, emergency access routes)	Non-STR	Low	None	None	Low	High
Land use management/conservation and preservation of undeveloped land, zoning and flood insurance	Non-STR	Medium	None	None	High	Medium
Deployable floodwalls	STR	Medium	None	None	None	Low
Floodwalls [6] and levees	STR	High	Low	None	Low	Low
Shoreline stabilization (seawalls, revetments, bulkheads)	STR	Low	High	High	Low	Low
Storm surge barriers	STR	High	Medium	None	Low	Low
Barrier Island preservation and beach restoration (beach fill, dune creation)	STR/NNBF	High	High	Medium	High	High
Beach restoration and breakwaters	STR/NNBF	High	High	High	High	Medium
Beach restoration and groins	STR/NNBF	High	High	High	High	Medium
Drainage improvements (e.g., channel restoration, water storage/retention features)	STR/NNBF	Medium	Low	Medium	Medium	Low
Living shorelines	STR/NNBF	Low	Medium	Medium	High	High

Aggregated Measure Type[1]	Category[2]	Storm Damage Reduction Function			Multi-Benefits[3]	Resilience
		Flooding	Wave Attenuation	Erosion		Adaptive Capacity[4]
Overwash fans (e.g., back bay tidal flats/fans)	NNBF	Low	Medium	High	Medium	High
Reefs	NNBF	Low	Medium	Medium	High	High
Submerged aquatic vegetation	NNBF	Low	Low	Low	High	Medium
Wetlands	NNBF	Low	Medium	Medium	High	High

[1] An extensive list of management measures was compiled as part of the NACCS Measures Working Meeting in June 2013. The measures presented here represent an aggregated list of the categories of measures and corresponding conceptual parametric unit cost estimates.
[2]STR = structural measure, Non-STR = nonstructural measure, and NNBF = Natural and Nature-Based Features measure. Multiple measures are listed if the aggregated measure type is made up of a combination of measures.
[3] Multi-benefits focus on socioeconomic contributions to human health and welfare above and beyond the risk reduction benefits already highlighted in this table (i.e., flooding, wave attenuation, etc.). These benefits could include increased recreational opportunities, development of fish and wildlife habitat, provisioning of clean water, production of harvestable fish or other materials, etc.
[4] Adaptive capacity is the assessment of a measure's ability to adjust through natural processes, operation and maintenance activities, or adaptive management, to preserve the measure's function.
[5] Acquisition, relocation, and buyouts do not actually prevent flooding and erosion but remove the population and associated development from its effects.
[6] The concept design identified for the floodwall category consists of a concrete structure. These structures might also require closure structures including stoplogs, miter gates, swing gates, or roller gates, which were not included in the development of the parametric unit cost estimate. A simple steel sheetpile I-wall may be more economical.

VIII.1. Applicability by Shoreline Type

In order to complete the NACCS Tier 1 assessment, the measures were further categorized based on shoreline type to generally identify a geographic location where they are best suited according to typical application opportunities, constraints, and best professional judgment. Shoreline types were derived from the NOAA Environmental Sensitivity Index Shoreline Classification dataset (http://stateof thecoast.noaa.gov/shoreline/esi_categories.html), (NOAA, n.d.). Nonstructural measures could be considered in all geographic contexts and were not specifically included in the Tier 1 assessment of management measures applicable to shoreline types for the various risk areas identified as part of the NACCS exposure and risk assessment. This categorization is summarized in Planning and State Appendices. Table VIII-2 presents the measures applicability by shoreline type.

Table VIII-2. Structural and NNBF Measure Applicability by NOAA-ESI Shoreline Type

Measures	Rocky shores (Exposed)	Rocky shores (Sheltered)	Beaches (Exposed)	Manmade structures (Exposed)	Manmade structures (Sheltered)	Scarps (Exposed)	Scarps (Sheltered)	Vegetated low banks (Sheltered)	Vegetated low banks (Sheltered)	Wetlands/Marshes/ Swamps (Sheltered)
Structural										
Storm Surge Barrier[1]										
Barrier Island Preservation and Beach Restoration (beach fill, dune creation)[2]			x							
Beach Restoration and Breakwaters[2]			x							
Beach Restoration and Groins[2]			x							
Shoreline Stabilization						x	x	x		
Deployable Floodwalls					x					
Floodwalls and Levees		x			x			x		
Drainage Improvements	x	x	x	x	x	x	x	x	x	x
Natural and Nature-Based Features										
Living Shoreline						x	x	x		x
Wetlands							x			x
Reefs	x	x				x				x
Submerged Aquatic Vegetation[3]										x
Overwash Fans[4]										
Drainage Improvements	x	x	x	x	x	x	x	x	x	x

[1] *The applicability of storm surge barriers cannot be determined based on shoreline type. It depends on other factors such as coastal geography.*
[2] *Beaches and dunes are also considered NNBF.*
[3] *Submerged aquatic vegetation is not associated with any particular shoreline type. It is initially assumed to apply to wetland shorelines.*
[4] *Overwash fans may apply to the back side of barrier islands, which are not explicitly identified in the NOAA Environmental Sensitivity Index Shoreline Classification dataset.*

Additionally, a conceptual analysis of geographic applicability of NNBF measures presented in Table VIII-3 was completed, including beach restoration, beach restoration with breakwaters/groins, living shorelines, reefs, submerged aquatic vegetation, and wetlands. The GIS operations that were used for the NNBF screening analysis are described in the ERDC NNBF Technical Report. In addition to the NOAA Environmental Sensitivity Index Shoreline Classification dataset (http://stateof thecoast.noaa.gov/shoreline/esi_categories.html) (NOAA, n.d.), other criteria that was considered was habitat type, impervious cover, water quality, and topography/bathymetry.

Table VIII-3. Structural and NNBF Measure Applicability by NOAA-ESI Shoreline Type

		Data Layers/Thresholds				
	Action/Operation	**Habitat Type**	**Urban Areas**	**Poor Water Quality**	**Shoreline Type**	**Topography/Bathymetry (ft +/- MSL)**
NNBF Measures		The Nature Conservancy Eco Regions; USFWS	Impervious Cover < 20% (Y or N)	EPA 303(d) Impaired Waterway	NOAA ESI Shoreline (NACCS aggregation)	10m DEM/NOAA bathymetry data (30m coastal relief data)
Barrier Island Preservation and Beach Restoration	NNBF Report Table 4-11 GIS Operation	Reference NNBF Report Table 4-11	N	Y	Beaches (exposed)	N/A
Breakwaters and Beach Restoration	NNBF Report Table 4-11 GIS Operation	Reference NNBF Report Table 4-11	N	Y	Beaches (exposed)	N/A
Groins and Beach Restoration	NNBF Report Table 4-11 GIS Operation	Reference NNBF Report Table 4-11	N	Y	Beaches (exposed)	N/A
Living Shoreline	NNBF Report Table 4-11 GIS Operation	Scrub-Shrub, Freshwater Emergent Wetland, Freshwater Forested/Shrub Wetland	N	Y	Scarps (exposed), Scarps (sheltered), Vegetated Low Banks (sheltered), Wetlands (Sheltered)	-1 to +2
Wetlands	NNBF Report Table 4-11 GIS Operation	Reference NNBF Report Table 4-11	Y	Y	Scarps (sheltered), Wetlands (sheltered)	0 to +2
Reefs	NNBF Report Table 4-11 GIS Operation	N/A	Y	N	Rocky Shores (exposed), Rocky Shores (sheltered), Scarps (exposed), Wetlands (sheltered)	-1 to -6
Submerged Aquatic Vegetation (SAV) Restoration	NNBF Report Table 4-11 GIS Operation	Reference NNBF Report Table 4-11	Y	N	Wetlands (sheltered)	-1 to -6

The NNBF measures presented in Table VIII-3 were evaluated using ESRI ArcGIS software to screen the relative geographic locations across the study area (ESRI, 2012). The primary features associated with the NNBF screening analysis were habitat type, shoreline type, and topography and bathymetry. The water quality components associated with the screening analysis represent areas of the study area that might impact the overall function of the respective features. The results of the NNBF screening analysis are presented in the State and District of Columbia Analyses Appendix.

VIII.2. Evaluation of Sea Level Affecting Marsh Model (SLAMM)

SLAMM "simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise" (Clough et al., 2010). Since its development in 1986, SLAMM has undergone multiple version releases (six in total) and has been broadly applied for assessing the long-term effects of sea level change on wetlands and shorelines. SLAMM is a spatially-explicit, raster-based model that applies a set of theoretical, empirical, and qualitative "rules" to capture the long-term effects of sea level change as they pertain to six key processes: inundation, salinity, saturation, accretion, erosion, and barrier island overwash (Clough and Larson 2010, Clough et al., 2010). Three of these processes (inundation, salinity, saturation) examine thresholds for switching to an alternative habitat type; the remaining three (accretion, erosion, overwash) address internal and external processes acting to maintain or degrade the current habitat type.

As part of the NACCS, USACE evaluated SLAMM to identify potential improvements for coastal marshes and wetlands affected by sea level change. The evaluation included consideration of assessing the effects of thin-layer placement of dredged materials as a potential mitigation option to reduce wetland losses due to sea level change, which could further exacerbate coastal flood risk. The purpose of this evaluation was to incorporate the opportunities for improvement of SLAMM that could be used by coastal managers. USACE staff conferred the developers of SLAMM to consider new process descriptions for the evaluation of primary productivity, the above and below ground production of organic materials, and the effectiveness of thin layer mineral placement typically associated with beneficial use of dredged materials. For those areas that could potentially utilize a combination of measures that incorporates NNBF and wetlands, particularly in back bays and estuarine conditions, the SLAMM could be utilized as part of subsequent Tier 2 and Tier 3 analyses.

VIII.3. Conceptual Designs for Risk Management Measures

Table VIII-4 summarizes the design criteria developed by the team for coastal storm risk management measures as part of the Framework. Generally, structural measures (e.g., beach restoration, levees, etc.) were assumed to be designed to the 1 percent flood elevation plus a 3-foot allowance to account for future sea level change. This 3-foot allowance is consistent with the USACE high scenario for projected sea level change by year 2068. Storm surge barriers were assumed to be designed to a higher storm tide level corresponding to a 0.2 percent flood elevation, also consistent with typical design standards, plus the same 3-foot sea level change allowance.

Table VIII-4. Criteria for Conceptual Design of NACCS Risk Reduction Measures	
Measure Type	**Criteria**
Structural (not barriers) [1]	1 percent flood elevation + 3-foot sea level change allowance
Storm Surge Barriers	0.2 percent flood elevation + 3-foot sea level change allowance
Natural and Nature-Based Features	10 percent flood elevation
Non-structural (Floodproofing and Buyouts)	1 percent flood elevation + 3-foot sea level change allowance

[1] *Beaches and dunes are also considered Natural and Nature-Based Features.*

NNBF are not typically designed to provide significant risk reduction against storm tides. In fact, most of these measures allow for the storm tide and waves to propagate over or through the nature-based feature with minimum damage to it. This characteristic is what makes nature-based measures resilient but also inherently limits their ability to reduce coastal storm risks. For the purposes of this study, all nature-based features (e.g., living shorelines, wetlands, etc.) were assumed to be designed to provide risk reduction against the 10 percent flood. This design level may be high for some specific nature-based measures and low for others depending on specific site conditions and actual design details. For the NACCS evaluations, NNBF were assumed to provide risk reduction to the current 10 percent flood without an additional sea level change allowance. The assumption is that natural or managed adaptation processes would maintain the 10 percent flood design level as sea level changes over the life of the project. Site-specific conditions and combinations of site-specific NNBF, including break offshore waves, wave energy attenuation, slow inland water transfer, etc., would change the risk reduction performance (USACE, 2013).

Buildings are typically elevated (non-structural measure) to the FEMA-mandated 1 foot above the base flood elevation (BFE). However, many coastal communities have, or are enacting, more stringent elevation requirements of up to 3 feet above the BFE as a result of the magnitude and impact of Hurricane Sandy, and the uncertainty regarding the rate of sea level change. Therefore, for the purposes of this analysis, the more conservative requirement of 3 feet above the BFE was used as the non-structural design elevation.

The Hurricane Sandy Rebuilding Task Force announced on April 4, 2013 that all Sandy-related rebuilding projects funded by PL 113-2 must meet a single uniform flood risk reduction standard (FRRS) of one foot above the best available and most recent base flood elevation (BFE) information provided by FEMA, unless local standards are more restrictive. The NACCS incorporates this FRRS as part of the 1 percent flood plus three feet.

The design criteria identified in Table VIII-4 shows the coastal storm risk reduction levels that were assigned to measures. These design criteria are suggested design levels and actual risk reduction levels may vary depending upon site specific conditions. General benefits, impacts, and other considerations associated with the management measures were identified as well. Site specific evaluations as part of Tier 2 and Tier 3 analyses would refine impacts, particularly as they relate to social and environmental impacts and especially if a decision document that requires a NEPA environmental assessment or environmental impact statement.

VIII.3.1. Parametric Unit Cost Estimates

As part of the NACCS, conceptual design and parametric cost estimates were developed for the various coastal storm risk management measures for the NACCS. Initial, representative, concept designs have been developed for each measure together with quantities and parametric unit costs (typically per linear foot of shoreline) based on a combination of available cost information for existing projects and bottom-up estimates. The latter are based on quantity takeoffs for typical design sections and representative unit costs for all construction items (e.g., excavation, fill, rock, plantings) based on historical observations. Additionally, the parametric unit cost estimates, or total opportunity costs, are the total costs of the management measures per unit (linear foot or acre) derived from construction costs (which include assumptions for design) and operation and maintenance costs. Project timeframes represent a 50-year project life, unless otherwise noted. Assumptions associated with the parametric unit costs including the basis of parametric construction costs as well as operations and maintenance costs are included in the conceptual description of the management measures.

Initial conceptual designs used to estimate quantities and costs are representative of typical conditions in the study area and do not account for reach or site-specific variations in ground level, tidal range, or storm water levels. Furthermore, real estate costs were not included in the development of the parametric unit costs because no project recommendations identifying a specific location where various real properties would be affected were made. Real estate costs are so widely variable within the NACCS study area that they would cloud the information regarding the relative cost of the engineering measures available to reduce storm damages. As part of the NACCS framework Tier 1 assessment an initial screening of potentially applicable measures for each risk area is performed considering shoreline types and the estimated reduction in vulnerability for a given cost. In the Tier 2 of the NACCS framework, the designs and associated costs were adjusted for variability in relevant design parameters, including local design water levels (e.g., FEMA BFE). In addition, future parametric cost estimates adjustments will account for regional differences in the price of materials and transportation costs within the study area, as well as real estate lands, easements, rights-of-way (LER). A brief description of the measures considered by aggregated categories provided in the following paragraphs.

VIII.4. Non-Structural Measures

As listed in Table V111-1, Non-structural measures fall into four groups: (1) Acquisition/ Removal or relocation of structures from the risk; (2)retrofit measures, (3) warning systems and evacuation procedures to alert residents and implement plans to evacuate cultural resources to increased storm risks and facilitate easier evacuation from risk-prone areas, and (4) flood insurance and Land use Management/zoning. Non-structural measures falling in the first two categories typically reduce the potential for storm damage to a structure; however, risks to the surrounding property, vehicles, and emergency access are not reduced and property owners should evacuate vulnerable properties during storm events lest they become trapped.

Figure VIII-2. Typical Elevated Shorefront Structure (Courtesy: FEMA)

VIII.4.1 Acquisition/Building Removal or Relocation

Buildings may be removed from vulnerable areas by acquisition (buy-out), subsequent demolition, and relocation of the residents. Often considered a drastic approach to storm damage reduction, property acquisition and structure removal are usually associated with frequently damaged structures. Implementation of other measures may be effective but if a structure is subject to repeated storm damage, this measure may represent the best alternative to eliminating risks to the property and residents.

Costs for structure removal are estimated to be $70,000, in addition to the property purchase price. When acquiring properties, the government typically offers fair market value for a property.

This sub-category also includes moving a structure out of the vulnerable area, either within the same property boundaries or to another property. While often a costly endeavor, it may be applicable to structures subject to severe risk, but due to available space and structure value do not warrant demolition.

Costs for this category vary significantly from region-to-region, from coastal to inland communities, by the distance a structure may be moved, etc. Unlike relocation, removal of a structure requires acquisition of the entire property, demolition of the structure, removal of debris, excavation of underground utilities (if warranted), and restoration of the site to natural conditions. Acquired properties are usually deed restricted from further development.

VIII.4.2 Building Retrofit

Building retrofit measures include dry flood proofing or elevation of a structure. Dry floodproofing involves sealing flood prone structures from water with door and window barriers, small scale rapid deployable floodwalls, ring walls, or sealants. Elevation of structures is usually limited to residential structures or small commercial buildings. Whether a structure may be elevated depends on a number of factors including the foundation type, wall type, size of the structure, condition, etc.

Costs can vary significantly depending on those factors. However, fixed costs per structure include engineering and design, administrative fees, temporary housing for inhabitants, etc. As shown in Table VIII-5, elevation of a typical 1,400 square foot structure could cost up to $195,000.

Table VIII-5. Elevation (bldg. retrofit) - Construction Quantities & Costs

	Quantity		Parametric Estimate	
Item	Number	Unit	Unit Cost	Total Cost
Elevation 8 feet	1	ea	$122,600	$122,600
Temporary rehousing	1	ea	$10,000	$10,000
Subtotal				$132,600
Contingency	25%			$33,150
Total Construction				$165,750
E&D	$10,000			$10,000
S&A	10%			$16,575
Total Estimated First Construction Cost				$192,325
Annualized First Costs				$8,200
O&M	N/A			$0
Total Estimated Annual Average Cost				$8,200

Dry floodproofing of homes is technically feasible for flood depths of up to three feet. However, this significantly limits the level of effectiveness of floodproofing in reducing vulnerability. It is important to note that FEMA generally does not endorse floodproofing of residences and there are no reductions in flood insurance premiums for floodproofed homes.

Ring walls or ring levees are most often used for large commercial/industrial structures or multi-family/apartment buildings that cannot be elevated. Figure VIII-3 shows a small ring wall constructed around a garden apartment building. Ring walls require drainage outfalls or pumps to discharge runoff collected behind the wall, and gates for access and egress.

Figure VIII-3. Typical Apartment Ringwall

Sealing a structure could cost up to $100,000 for a 1,000 square foot structure; however, damage reduction is limited to a maximum of 3 feet due to potential hydrostatic pressure on the structures. A separate, 2,000 ringwall around a vulnerable structure would cost up to $4.8 million as shown in Table VIII-6.

Table VIII-6. Ringwall (Industrial Structure) - Construction Quantities & Costs

	Quantity		Parametric Estimate	
Item	Number	Unit	Unit Cost	Total Cost
Floodproof	1	ea	$2,861,332	$2,861,332
Roller gates	3	ea	$104,000	$312,000
Subtotal				$3,173,332
Contingency	25%			$793,333
Total Construction				$3,966,665
E&D	12%			$476,000
S&A	10%			$396,666
Total Estimated First Construction Cost				$4,839,331
Annualized First Costs				$206,319
O&M	N/A			$0
Total Estimated Annual Average Cost				$206,319

VIII.4.3 Flood Warning Systems and Evacuation

Flood warning systems and evacuation planning are applicable to vulnerable areas. Despite improved tracking and forecasting techniques, the uncertainty associated with the size of a storm, the path, or its duration necessitate that warnings be issued as early as possible. Evacuation planning is imperative for areas with limited access, such barrier islands, high density housing areas, elderly population centers, cultural resources, and areas with limited transportation options.

VIII.4.4 Flood Insurance

While not often thought of as a means of addressing vulnerable areas, adequate flood insurance is closely tied to effective flood warning systems and evacuation planning for a number of reasons:

(1) Residents that are uncertain about reducing risk to their belongings may be prone to attempt to remain in vulnerable areas during storm events, creating further risk. Knowing that personal property is insured, residents may be more comfortable with evacuating vulnerable areas at the approach of a storm.

(2) Flood insurance rates and regulations directly and indirectly impact property owners' decisions to reduce risk to their property though favorable construction practices. For instance, if a property owner in a vulnerable area makes an improvement to their structure, FEMA, the administrator of the NFIP, mandates that the improvement be constructed in accordance with FEMA regulations and if the improvement is warranted to be substantial (greater than 50% of the value of the structure), the unimproved portion of the structure must be improved to meet FEMA regulations (that is, less risk-prone).

(3) Community participation in the NFIP is conditional on meeting program guidelines. Participating communities must manage development within their floodplains in accordance with FEMA standards or risk removal from the program, which risks cancellation of all flood insurance policies within the community. Therefore, proper management of development and associated risk and vulnerability helps ensure the best possible flood insurance rates. Officials can help to further reduce flood insurance rates within their communities through the NFIP's Community Rating System. Reduced premium rates will make policies more attractive to uninsured residents, resulting in more complete coverage within a vulnerable community.

(4) Communities participating in the NFIP that are proactive in promoting floodplain management, flood risk awareness, etc. may help to further reduce the insurance costs to property owners through the NFIP's Community Rating System (CRS). Under the CRS, flood insurance premium rates are discounted to reward community actions that meet the three goals of the CRS, which are: (1) reduce flood damage to insurable property; (2) strengthen and support the insurance aspects of the NFIP; and (3) encourage a comprehensive approach to floodplain management.

The CRS uses a class rating system that is similar to fire insurance rating to determine flood insurance premium reductions for residents. CRS classes are rated from 10 to 1. As a community engages in additional mitigation activities, its residents become eligible for increased NFIP policy premium discounts. Each CRS Class improvement produces a 5 percent greater discount on flood insurance premiums for properties in the SFHA, with a Class 1 community receiving the maximum 45 percent premium reduction.

VIII.5. Structural Measures

As listed in Table VIII-1, the Structural Measures include Deployable floodwalls, Floodwalls, Dikes and levees, shoreline stabilization and Storm Surge Barriers.

VIII.5.1 Deployable Floodwalls

Description

Figure VIII-4. Rapid Deployment Floodwall (Courtesy: Plainschase.com)

Rapid Deployment Floodwalls (RDFWs) are structures that are temporarily erected along the banks of a river or estuary, or in the path of floodwaters to prevent water from reaching the area behind the structure. After the storm or flood, the structures are removed. This category also includes permanently installed, deployable flood barriers that rise into position during flooding due to the buoyancy of the barrier material and hydrostatic pressure. Some systems, such as stop logs, require a permanent base or footing, while others may be deployed without a base. Structural base components contribute to the overall effectiveness and level of risk management that an RDFW can provide. Figure VIII-4 shows an example of a stop log temporary floodwall.

Temporary measures like these are particularly useful for risk management in smaller areas, and are usually considered for areas where access to the waterfront is essential to the economy or character of a community. Often, traditional floodwalls, or levees are used to reduce risk to some portions of the waterfront, with intermittent closure structures like a RDFW. RDFWs provide the same benefits as similarly sized static floodwalls or levees, but height of the structure is somewhat limited.

The successful performance of RDFWs hinges on advance flood warning. Advance warning is needed prior to deployment to facilitate transportation and assembly. Therefore, use of RDFWs is not appropriate in areas subject to flooding shortly after a rain or storm event. Stop logs must be stored close nearby, typically in a separate, dedicated facility, and must be transported to the deployment site. Because of the relatively high cost to assemble, disassemble and store the RDFW, they are not desirable in areas of frequent flooding.

The wall width, distance between stationary anchors, and the use of bracing (shown in Figure VIII-4) limit the height that a wall may be constructed to. In some areas, RDFWs may be subject to minor wave action with proper construction.

Despite the limitations due to the effective level of risk management, storage and deployment requirements, and required personnel training, RDFWs are often a welcomed solution to providing flood risk management to areas with limited available real estate for permanent structural flood risk management measures and/or with valuable viewsheds, which would be impacted by permanent structural measures. RDFWs may be appropriate for implementation on rocky coasts, beaches, estuaries/lagoons, and urban shorelines.

Generic Design

A representative typical cross-section of a RDFW includes base or anchor plates, stanchions, gasketed stop logs, and bracing, if needed. The typical wall is 8 inches thick and 6 feet in height, which is the maximum height before bracing may be required. It is assumed that the typical application is not subject to wave action. Deployment of an RDFW requires training and practice, and maintenance of static foundations or bases and the deployable logs is required to ensure easy assembly when needed.

Parametric Costs

The cost estimate for the Rapid Deployment Floodwalls is shown in Table VIII-7, which provides first construction and annualized costs including operation and maintenance (O&M) costs. The costs were developed for a wall length of one mile and reduced to provide a cost per linear foot of RDFW. First construction costs are about $5,454 per linear foot of RDFW; annualized costs based on an interest rate of 3.5% and a 50-year project life are about $247 per linear foot. Maintenance of RDFW static foundations and the deployable stop logs is required to ensure easy assembly. Annual maintenance costs are assumed to be minimal and are not significant in the overall costs.

Table VIII-7. RDFW - Construction Quantities & Costs

	Quantity		Parametric Estimate	
Item	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$200,000	$200,000
Deployable Floodwall	1	1 Mile	$10,780,000	$10,780,000
Floodwall Construction	1	1 Mile	$6,471,035	$6,471,035
Stoplog Storage	1	ea	$445,000	$445,000
Drainage Outlets	13	ea		$988,000
Subtotal Construction				$18,884,035
Contingency	25%			$4,721,009
Total Construction				$23,605,043
E&D	12%			$2,832,605
S&A	10%			$2,360,504
Total Estimated First Construction Cost				$28,798,153
Total Estimated First Construction Cost per Foot				$5,454
Annualized First Costs				$233
O&M	$2/LF + $10,000 per drainage structure			$9
O&M	Install/Dismantle Deployable Wall			$5
Total Estimated Annual Average Cost				$247

Summary: Deployable Floodwalls Benefits, Impacts and other Considerations

While deployable floodwalls can generally be rapidly deployed prior to a predicted flooding condition, considerations needs to be given to the level of risk management required, ease of deployment and recovery, cost and ground disruption during construction, and where contained water will end up going.

VIII.5.2 Floodwalls

Description

Figure VIII-5. Typical Floodwall Construction

Floodwalls are structures used to reduce risk in relatively small areas or areas with limited space for flood risk management against lower levels of flooding. They can be similar to seawalls and are usually constructed from concrete. Unlike wider, more stable levees, narrow floodwalls require significant reinforcement and anchoring construction to prevent collapse from hydrostatic pressure. The significant amounts of steel sheeting and/or reinforced concrete used in constructing a typical wall make the feature extremely heavy. Because construction in a flood prone area, such as near a river or estuary, may occur on soft organic soil, pile reinforcement may be required under the base of the wall. The combination of steel sheeting, reinforcement, concrete, and pile support make a floodwall a much more costly structural risk management measure than a similar length and height levee. A typical floodwall is shown in Figure VIII-5. These structures might also require closure structures including stoplogs, miter gates, swing gates, or roller gates, which were not included in the development of the parametric unit cost estimate. A simple steel sheetpile I-wall may be more economical.

Generic Design

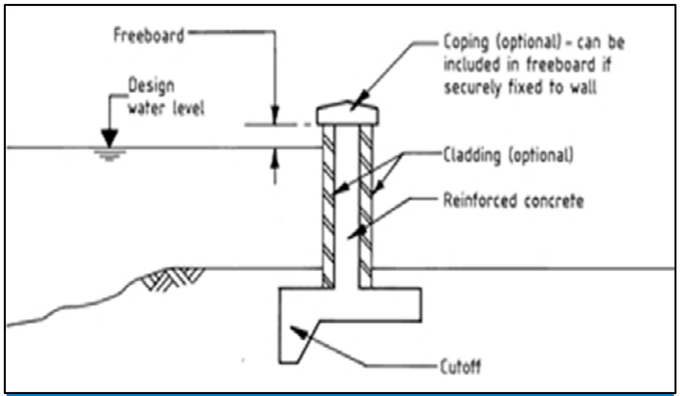


Figure VIII-6. Representative Floodwall Cross-section ("T"-wall)

A representative typical cross-section of a floodwall with a base ("T" wall, due to its shape) is shown in Figure VIII-6. Not shown in this figure are piles within the foundation. For areas where soils provide a poor foundation, the T-wall would be supported by up to 50-foot long piles every 7 feet along the wall. For areas with better foundations but still requiring piles, the wall would be supported by up to 15-foot long piles every 7 feet along the floodwall. The typical wall is 2.5 feet thick.

Parametric Unit Costs

Costs, shown in Table VIII-8 were developed for T-walls of 6 to 16 feet high. For estimating purposes, the costs are based on the weighted average between the particular wall height on a poor foundation (50-foot piles) and a good foundation (15-foot piles). The cost of drainage gates/outlet structures every 400 feet along the length of the floodwall were considered in the cost of the structures.

For a 10 foot high floodwall construction, first construction costs are about $5,335 per linear foot; annualized costs are about $237 per linear foot. Operation and maintenance actions for floodwalls were assumed to be limited to periodic inspections and clearance of debris from outlet structures.

Table VIII-8. Floodwalls- Construction Quantities & Costs

	Quantity		Parametric Estimate	
Item	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$200,000	$200,000
Floodwall Construction	1	Mile	$17,284,524	$17,284,524
Drainage Outlets	13	ea		$988,000
Subtotal Construction				$18,472,524
Contingency	25%			$4,618,131
Total Construction				$23,090,655
E&D	12%			$2,770,879
S&A	10%			$2,309,065
Total Estimated First Construction Cost				$28,170,599
Total Estimated First Construction Cost per Foot				$5,335
Annualized First Costs				$227
O&M	$2/LF + $10,000 per drainage structure			$9
Total Estimated Annual Average Cost				$237

Summary: Floodwalls Benefits, Impacts and other Considerations

Permanent floodwalls reduce risk in a specific area from high water during storm events, but are costly, can require significant require land/real estate, may impact scenic views, and may impact habitat.

Floodwall considerations include level of risk management that is required, construction and real estate acquisition costs, how to deal with contained water, and ground disruption during construction.

VIII.5.3 Levees and Dikes

Description

Levees and dikes are embankments constructed along a waterfront to prevent flooding in relatively large areas. They are typically constructed by compacting soil into a large berm that is wide at the base and tapers toward the top, as shown in Table VIII-7. Grass or some other type of non-woody vegetation is usually planted on the levee/dike to add stability to the structure. If a levee or dike is located in an erosive shoreline environment, revetments may be needed on the waterfront side to reduce impacts from erosion, or in cases of extreme conditions, the dike face may be constructed entirely of rock.

Figure VIII-7. Typical Levee Construction

Levees may be constructed in urban areas or coastal areas; however, large tracts of real estate are usually required due to the levee width and required setbacks. The height and width usually limit access to the water for recreation and commercial activities, and like floodwalls, impact the view shed of coastal properties. In some cases levees have been incorporated into trail systems and frequently include amenities such as benches, street lighting and jogging paths. Structural measures, such as floodwalls, levees and dikes tend to trap rainfall runoff associated with storms on the landward side, creating a residual flooding risk. To reduce this residual risk, gravity outlets are installed along the length of the structure. In cases where significant runoff may be trapped behind the structure, ponding areas and pump stations are required. Depending on the density of development of a vulnerable area, levees and floodwalls are often constructed as a system whereby floodwalls are interspersed between levee segments as available property space dictates. Figure VIII-8 shows a levee/floodwall system before and during Hurricane Irene flooding in 2011. The floodwall section was constructed along the line of risk management behind a large commercial structure.

Figure VIII-8. Levee and Floodwall System, Bound Brook, NJ, before and after

If properly maintained, floodwalls, levees, and dikes are highly effective methods of flood risk management. However, if the design level of risk management is exceeded, water will overtop the structure, trapping floodwater behind it and risking erosion and failure of the feature.

Generic Design

Designs and costs were developed for levees of 6 to 16 feet high. Levees on poor foundations are subject to instability and settling, and therefore, require deeper excavation prior to construction. To account for this, the parametric cost was developed based on a weighted average of levees on poor and good foundations. The costs of drainage gates/outlet structures, which are assumed to be placed every 400 feet along the length of the structure, are considered within the cost of the structures. A typical levee section is shown in Figure VIII-9.

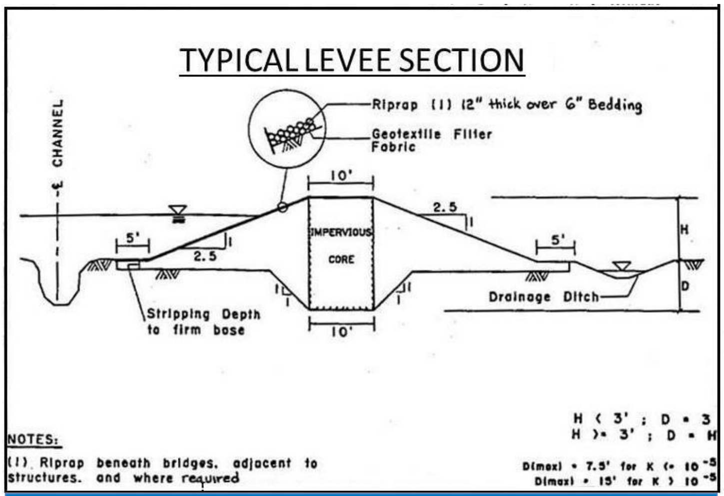


Figure VIII-9. Typical Levee Section

Parametric Unit Costs

For levee construction, first construction costs are about $1,578 per linear foot; annualized costs are about $77 per linear foot (Table VIII-9). Operation and maintenance actions for levees were also assumed to be limited to periodic inspections and clearance of debris from outlet structures. Costs for pump station maintenance would be significantly more but are site specific and were not considered in the parametric cost development.

Table VIII-9. Levee - Construction Quantities & Costs

	Quantity		Parametric Estimate	
Item	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$200,000	$200,000
Levee Construction	1	Mile	$4,744,478	$4,744,478
Drainage Outlets	13	ea	$40,000	$520,000
Subtotal				$5,464,478
Contingency	25%			$1,366,120
Total Construction				$6,830,598
E&D	12%			$819,672
S&A	10%			$683,060
Total Estimated First Construction Cost				$8,333,329
Total Estimated First Construction Cost per Foot				$1,578
Annualized First Costs				$67
O&M	$2/LF + $10,000 per drainage structure		$9	$9
Total Estimated Annual Average Cost			$80	$77

Summary: Levees and Dikes Benefits, Impacts and other Considerations

Similar to floodwalls, levees and dikes reduce risk to a specific area from high water during storm events, but are costly, can require significant require land/real estate, may impact scenic views, and may impact habitat.

VIII.5.4 Shoreline Stabilization

Description

Structures are often needed along shorelines to provide risk reduction from wave action or to stabilize and retain in situ soil or fill. Vertical structures are classified as either seawalls or bulkheads, according to their function, while protective materials laid on slopes are called revetments (USACE 1995). A bulkhead is primarily intended to retain or prevent sliding of the land, while reducing the impact of wave action is of secondary importance. Seawalls, on the other hand, are typically more massive structures whose primary purpose is interception of waves and reduction of wave-induced overtopping and flooding of the land structures behind. Note that under this definition seawalls do not include structures with the principal function of reducing risk to low-lying coastal areas. In those cases a high, impermeable, armored structure known as a sea dike is typically required to prevent coastal flooding (USACE 2002).

Figure VIII-10. Revetment at Poplar Island, MD

Revetments are onshore structures with the principal function of reducing the impacts to the shoreline from erosion and typically consist of a cladding of stone, concrete, or asphalt to armor sloping natural shoreline profiles (USACE 2002). They consist of an armor layer, filter layer(s), and toe protection. The armor layer may be a random mass of stone or concrete rubble or a well-ordered array of structural elements that interlock to form a geometric pattern. The filter assures drainage and retention of the underlying soil. Filter-type structures such as stone revetments are preferable where groundwater is part of the erosion process. Toe protection is needed to provide stability against undermining at the bottom of the structure (USACE 1995). Figure VIII-10 shows an example of a revetment at Poplar Island in Chesapeake Bay, MD (USACE 2002).

Bulkheads may be either cantilevered or anchored (like sheetpiling) or gravity structures (such as rock-filled timber cribs). Their use is limited to those areas where wave action can be resisted by such materials. In areas of intense wave action, massive concrete seawalls are generally required. These may have either vertical, concave, or stepped seaward faces (USACE 1995).

Revetments, bulkheads, and seawalls mainly reduce risk only the upland area behind them. All share the disadvantage of being potential wave reflectors that can erode a beach fronting the structure. This problem is most prevalent for vertical structures that are nearly perfect wave reflectors such as bulkheads and seawalls and is progressively less prevalent for curved, stepped, and rough inclined structures such as revetments that absorb or dissipate increasing amounts of wave energy (USACE 1995). Shoreline stabilization measures like those discussed in this section are appropriate for implementation on scarps and vegetated low banks along interior shorelines. It is assumed that existing man-made shorelines already include some form of shoreline stabilization/protection measure such as a riprap revetment, bulkhead or seawall.

Generic Design

Site-specific shoreline bank geometry, adjacent water depths, soil conditions, currents, waves, as well as other physical, environmental and economic factors will typically dictate the choice of shoreline stabilization/protection measure, i.e., vertical (bulkhead or seawall) vs. sloped (revetment). However, given the regional scale of the study it is impossible to account for these local, site-specific, conditions to determine which measure is most appropriate at each location. Therefore, for the purposes of regional framework development, a rock revetment is assumed as the standard shore stabilization/protection solution.

The principal components of a coastal revetment include:

- Protective rock armor & underlayer rock
- Toe elevation and protection
- Crest height
- Berm (if included)

The protective rock armor serves to hold the revetment in place and is often comprised of several layers of rock. Toe protection is normally an integral part of the revetment structure and is designed to prevent that structural component from undermining as a result of wave and/or current-induced scour. In some cases a revetment will be protected with concrete units rather than rock. A berm may or may not be included in the dike cross section. Where included, a berm can be used to limit wave runup and overtopping. The berm may also minimize the armoring requirements for the revetment and upper slope of the structure. Roadways or pathways are often included on or adjacent to revetments in order to provide access to hinterland areas and access for repairs to the revetments.

The generic revetment geometry used for the present work is comprised of toe protection, rock armor units (i.e. the seaward slope) and a short horizontal crest also comprised of rock. One of the more important variables of the dike design is the seaward side slope which, together with the crest height, is generally dictated by soil conditions and revetment construction methods. For the purposes of this study, it is assumed that the revetment is founded on reasonably competent soils which do not require foundation/ground improvements. Owing to the wide range of conditions within the study area, a number of other assumptions have been made to develop a generic revetment design as noted below:

- Revetments are only applicable to estuarial environments as distinct from open ocean environments
- Design waves conditions are characterized by a significant wave height, Hs, of 6 ft and a peak spectral period, Tp, of 6 seconds. These waves are considered representative of 1 percent annual chance of the design being exceeded design conditions in interior shorelines not exposed to ocean waves. In some locations the design wave will be controlled by exposure to ship wake and in others by locally generated wind-waves. Either way it is assumed that significant waves will not be larger than 6 ft.
- Local tidal conditions are used to size a revetment; calculations have been made for the tidal ranges (MLLW to MHHW) that typify NAD which range from 1-10 feet. The generic design, quantities and costs presented in this section are based on an average tidal range of 4 ft (Figure VIII-11).

- Crest elevation of the revetment is 6 feet above MHHW. This is considered a typical elevation for revetments and other structures used for shoreline stabilization in the study area. Flood risk reduction benefits associated with this elevation will depend on actual exposure to waves and related runup and overtopping, as well as storm surge elevations and could vary from 10 to 1 percent design level. A 10 percent annual chance of the design being exceeded is assumed given that revetments are typically constructed to armor and reduce impacts of erosion to a shoreline and not necessarily to reduce upland flooding.
- Bottom elevation of the revetment is 5 below MLLW. Actual elevations will vary widely across the study area, but this considered reasonable elevation for revetments along interior estuarine shorelines that are not directly adjacent to deep water areas such as navigation channels.
- Stone density is 165 lbs/ft^3
- Structure slope is 2 (Horizontal):1 (Vertical)
- Van der Meer's equations were used to size the revetment armor rock.

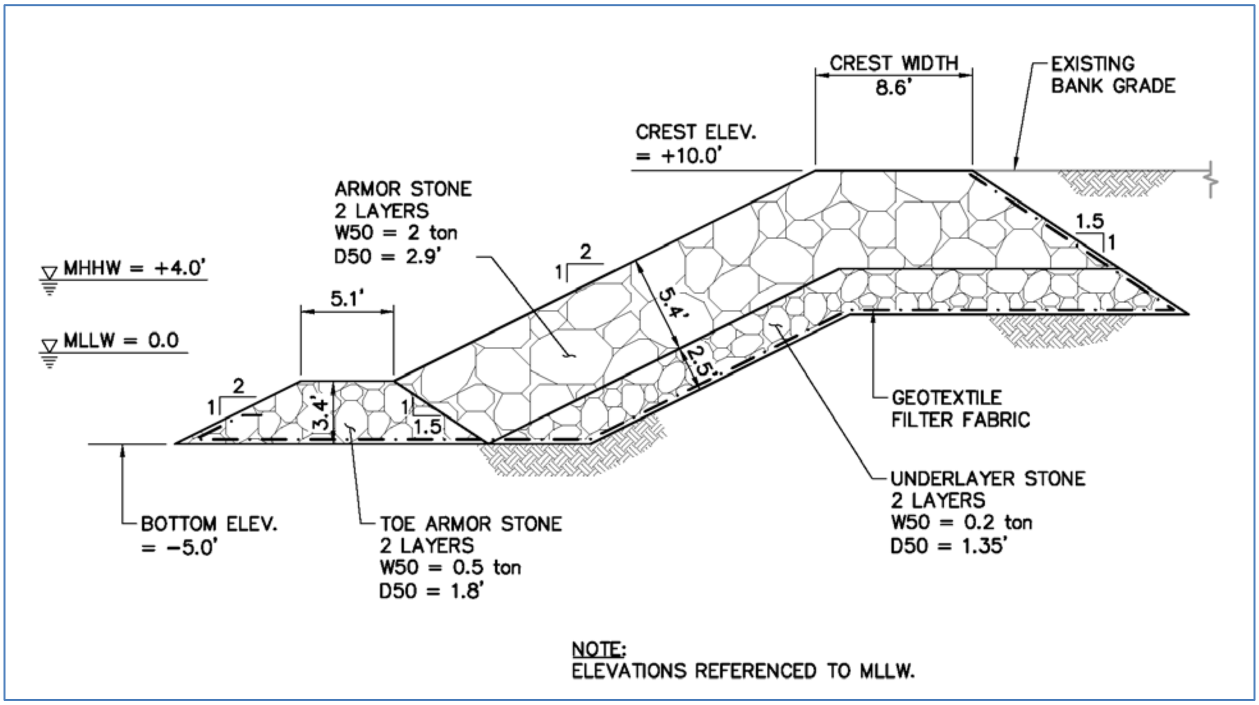


Figure VIII-11. Typical Section of a Rock Revetment

Parametric Unit Costs

A project length of 5,000 feet is used to determine total volumetric quantities required. Unit costs of $150 per ton of stone and $15 per sq.yd. of geotextile are applied in the parametric cost estimate. Cost estimates include 12% for engineering and design (E&D), 10% for construction management (S&A), and 1% for operation and maintenance (O&M). A contingency of 25% is applied to the cost estimate. Real estate costs associated with potential ocean front structure acquisitions/relocations, and easements are not included in the parametric cost estimate. Table VIII-10 provides a summary of first construction and annualized costs. Total annual costs are estimated using a 50-year project life and annual interest rate of 3.5%. The total estimated annual average cost is $263 per foot.

Table VIII-10. Revetment - Construction Quantities & Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$200,000	$200,000
Armor Stone	62,745	ton	$150	$9,411,750
Underlayer	26,335	ton	$150	$3,950,250
Toe Armor	11,085	ton	$150	$1,662,750
Geotextile	37,865	sq.yd.	$15	$567,975
Subtotal				$15,792,725
Contingency	25%			$3,948,181
Total Construction				$19,740,906
E&D	12%			$2,368,909
S&A	10%			$1,974,091
Total Estimated First Construction Cost				$24,083,906
Total Estimated First Construction Cost per Foot				$4,817
Annualized First Costs				$205
O&M	1%			$48
Total Estimated Annual Average Cost				$254

Summary: Shoreline Stabilization Benefits, Impacts and other Considerations

Erosion control methods such as stone revetments, gabions, bulkheads and rip-rap may be employed to reduce risk to beach areas, wetlands or other sensitive areas from wave energy and floodwaters.

Gabion baskets corrode quickly in salt water applications. Structures require maintenance and may require reinforcement measures if erosion occurs in front of the structure. Level of risk management and integration with other similar nearby structures should be considered during the design phase.

Figure VIII-12. Fox Point Storm Surge Barrier, Providence RI (Source: Providence Journal)

VIII.5.5 Storm Surge Barriers

Description

Storm surge barriers reduce risk to estuaries against storm surge flooding and waves. In most cases the barrier consists of a series of movable gates that stay open under normal conditions to let the flow pass but are closed when storm surges are expected to exceed a certain level. The gates are sliding or rotating steel constructions supported in most cases by concrete structures on pile foundations (USACE 2002). Storm surge barriers are often chosen as a preferred alternative to close off estuaries and reduce the required length of flood risk management measures behind the barriers. Another important characteristic is that they are often (partly) opened during normal conditions to allow for navigation and saltwater exchange with the estuarine areas landward of the barrier. Nonetheless, storm surge barriers could have negative effects on the ecological system and on navigation. Famous examples are the storm surge barriers in The Netherlands in the southwest of the country (Jonkman et al 2013). In New Orleans, several storm surge barriers have been built after Hurricane Katrina (2005) to reduce risk to the city from surges and reduce the length of the directly exposed system. Figure VIII-12 shows an example of a storm surge barrier at Fox Point, Providence, RI.

Storm surge barriers range in scale from small/local gates reducing risk to a small coastal inlet to very large barrier “systems” reducing risk to a large estuary or bay and consist of a series of coastal dikes, gates, and in some cases navigation locks. Both are usually combined with other flood risk reduction measures such as levees and floodwalls. Designs that allow for navigation are important in port areas. The applicability of storm surge barriers cannot be determined based on shoreline type; it depends on other factors such as coastal geography, development density, physical and environmental conditions, etc.

Parametric Unit Costs

Potential sites for storm surge barriers include the following:

- Embayments characterized by relatively high development (such are needed to provide benefits to offset the relatively high costs of the barriers)
- Embayments with reasonably narrow entrances and therefore lower relative costs
- Some preference was also given to existing harbors featuring navigation channels

A list of candidate sites based on these considerations is provided in Table VIII-11. For the purposes of this discussion, engineering, economic, environmental, etc. constraints are not considered even though it is fully acknowledged that in most cases, some or all of these concerns would make actual implementation impossible. The goal is to provide enough information to be able to make a relative comparison to other coastal flood risk management strategies including local structural, natural and nature-based, and non-structural measures.

Storm surge barriers have not been built extensively throughout the world for a variety of reasons:

- Barriers are expensive and best applied to densely populated and low areas where damage costs from flooding are sufficient high to justify the barrier costs
- Barriers can have problematic impacts on the environment particularly when the barriers significantly change the tidal hydraulics of a natural estuarial basin.
- Barriers can complicate and/or compromise shipping

A construction cost estimate based on the actual design of a storm surge barrier for each location considered is well beyond the scope of this study. This would require knowing the general characteristics and dimensions of each component, including dikes, closure structures, gates, gate monoliths, etc. which would require a significant amount of additional study and design work.

Therefore, for this study an approach has been chosen which considers the actual construction costs of several storm surge barriers in various countries around the world. De Ridder (1996) developed a methodology for analyzing the capital costs of storm surge barriers. This approach involved three correlating construction costs to the combination of three variables: barrier width, barrier total height, and head (water differential) acting on the barrier. This methodology has also been used by other authors for similar conceptual level studies: Dircke et al (2012), Van Ledden et al (2012), and Jonkman et al (2013). Construction costs and relevant variables were collected for a number of storm surge barriers (Van Ledden et al 2012). These costs have been escalated to a price level of 2013 using the Civil Works Construction Cost System Index and are listed in Table VIII-11 plots the data in Figure VIII-13 and shows that there is very strong correlation between volume (height x head x width) and cost. For the purposes of this study, the average value of $32,200 per cubic meter or $912 per cubic foot (see Table VIII-11) was used to estimate cost of storm surge barriers within the study area.

Table VIII-11. Dimensions and costs for storm surge barriers around the world

Name, Country	Type	Year	Width (m)	Height (m)	Head (m)	Vol (m3)	FY13 costs (x $Million)	FY13 costs (x $1,000/ m3)
Ems Barrier, Germany	Sector gate	1980	360	8.5	3.8	11,628	566	49
Thames Barrier, UK	Sector	1980	530	17	7.2	64,872	2,229	31
Eastern Scheldt Barrier, NL	Lifting gates	1986	2400	14	5	168,000	6,185	33
Maeslant Barrier, NL	Floating gate	1991	360	22	5	39,600	1,009	23
Hartel Barrier, NL	Lifting gates	1991	170	9.3	5.5	8,696	220	23
Ramspol, NL	Bellow barrier	1996	240	8.2	4.4	8,659	203	21
Seabrook barrier, USA	Sector gates	2010	130	8	4	4,160	176	38
IHNC barrier, USA	Sector gates	2010	250	12	6	18,000	797	40
Average								32.2

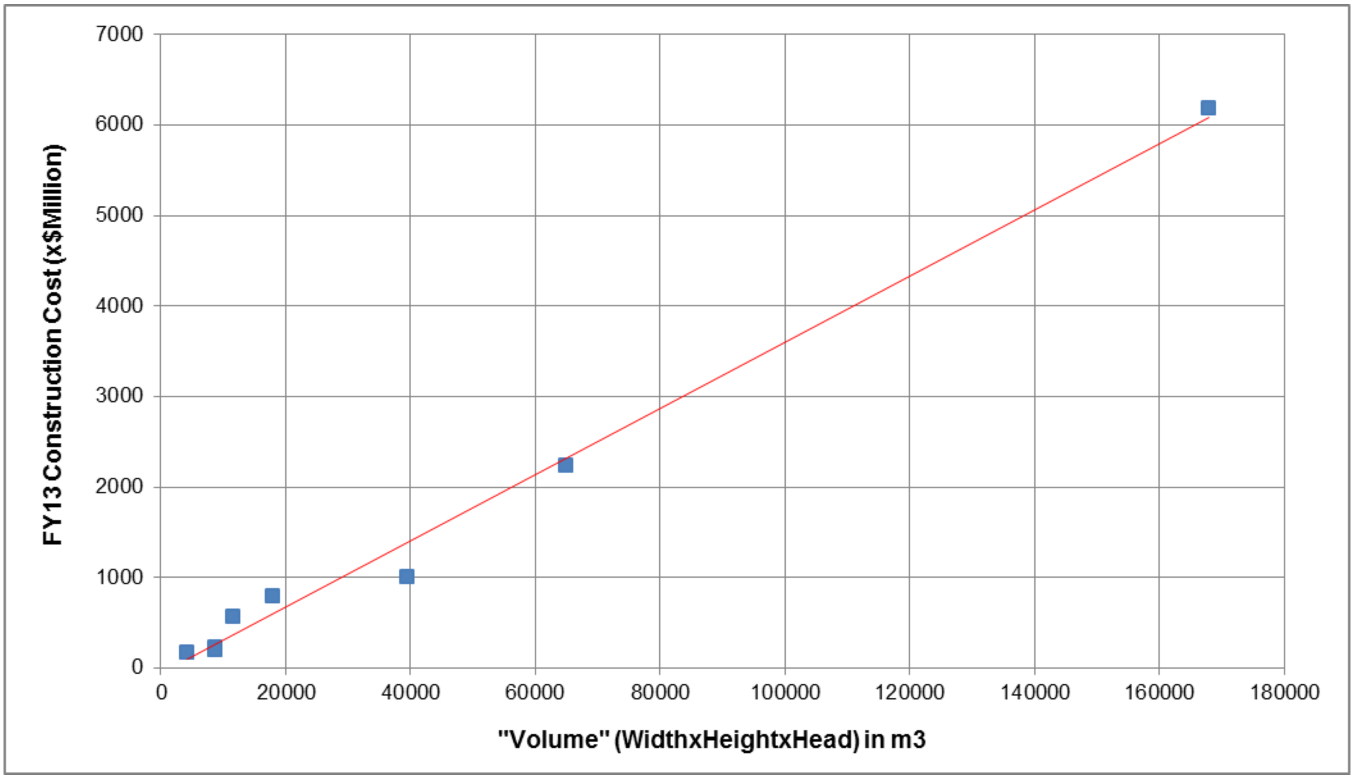


Figure VIII-13. Correlation between storm surge barrier “volume” and cost

In addition to the construction costs based on this empirical correlation, parametric cost estimates include 12% for engineering and design (E&D) and 10% for construction management (S&A). A contingency of 25% is applied to the cost estimate. Real estate costs associated with structure acquisitions/relocations, and easements vary considerable by project and are not included in the parametric cost estimate. Operation and maintenance costs of a large storm surge barrier will be substantial. From maintenance numbers of three large barriers in the world (Thames Barrier, Maeslant barrier, Eastern Scheldt barrier), it has been estimated that the annual maintenance costs are approximately 0.5% of the first construction costs (van Ledden et al, 2012). Table VIII-12 provides a summary of the first construction and annual costs on a unit basis (cubic foot). Total annual costs are estimated using a 50-year project life and annual interest rate of 3.5%.

Table VIII-13 presents storm surge barrier costs for each of the inlet and/or harbor opening considered in this study. The estimates were made on the basis of the cost per volume method described above. The table presents the design water level conditions, barrier dimensions, and corresponding cost estimates. A constant design water level of 11.5 ft above local MHHW, corresponding to approximately the 0.2 percent flood in the New York Bight, was used throughout the study area to determine the design hydraulic head. This value is based on the most recent FEMA modeling as part of their effort to update Flood Insurance rate Maps in for 14 coastal New Jersey counties and New York City. This value can be updated in the future as NACCS storm surge modeling results become available. In the meantime, the only local adjustment made is on the basis of the local tidal range. A 3 feet allowance to account for future sea level change was also included.

Table VIII-12. Storm Surge Barrier - Unit Construction Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Barrier Volume	1	cu.ft.	$912	$912
Subtotal				$912
Contingency	25%			$228
Total Construction				$1,140
E&D	12%			$137
S&A	10%			$114
Total Estimated First Construction Cost per cu.ft.				$1,391
Annualized First Costs				$59
O&M	0.5%			$7
Total Estimated Annual Average Cost per cu.ft.				$66

The resulting costs are a reasonable basis for planning and on the whole demonstrate that while storm surge barriers can be quite effective in managing coastal flood risk. Nevertheless, storm surge barriers are quite expensive especially for large structures (e.g. Sandy Hook-Breezy Point Barrier). Smaller structures such as Stamford CT, Fox Point, RI, and New Bedford, MA have performed well and have proven to be cost-effective. One of the additional challenges is that a storm surge barrier may be adequately designed but it will not perform satisfactorily unless it ties into surrounding areas of sufficient elevation to prevent flooding waters from simply flowing around the barriers.

Summary: Storm Surge Barrier System Benefits, Impacts and other Considerations

Large regional storm surge barrier systems provide for reliable, long-term engineered flood risk management for a large area. Barriers systems typically are deployed when unusually high tides are expected, but allow water traffic to pass through during normal conditions.

Potential impacts of large storm barrier systems include environmental disruptions and impacts to fish migration and also to shipping and water traffic which would need to be channeled through gates, sluices or passageways. Some installations have adversely affected historical properties.

Large regional storm surge barrier systems are very expensive and require long-term construction efforts coordinated in multiple locations. Systems may require strengthening or upgrade projects on existing dikes, floodwalls, etc. A key consideration in these projects is determining what level of risk management is desired.

Table VIII-13. Storm Surge Barriers – Parametric Cost Estimates

Barrier Location		Local NAVD-MLLW (ft)	MHHW -MLLW (ft)	Length (ft)	Chart Depth (ft, MLLW)	Barrier Height (ft)	Hydraulic Head (ft)	Volume (x1000 cu.ft)	First Cost ($MILL)	Total Average Annual Cost ($MILL)
Boston Harbor	MA	5.4	10.1	2,000	40.0	64.6	24.6	3,183	2,903	211
Beverly	MA	5.1	9.7	900	15.0	39.2	24.2	854	779	57
Pt. Judith Harbor	RI	1.9	3.4	300	12.0	29.9	17.9	161	147	11
Bridgeport	CT	3.8	7.3	3,000	35.0	56.8	21.8	3,712	3,385	246
Milford	CT	3.6	6.9	180	7.0	28.4	21.4	109	100	7
Verrazano Narrows	NY	2.7	5.2	4,190	varies	varies	19.7	5,822	5,810	199
Arthur Kill	NY	2.9	5.6	2,700	35.0	55.1	20.1	2,992	2,729	26
Newtown Creek	NY	2.7	4.8	400	23.0	42.3	19.3	327	298	162
Rockaway Inlet	NY	2.8	5.3	2,800	23.2	43.0	19.8	4,769	4,349	
East Rockaway Inlet	NY	2.7	5.0	1,400	20.0	39.5	19.5	1,081	986	407
Jones Inlet	NY	2.6	4.8	2,250	23.0	42.3	19.3	1,842	1,680	198
Fire Island Inlet	NY	2.4	4.5	2,700	25.0	44.0	19.0	2,256	2,058	22
Moriches Inlet	NY	2.1	3.8	900	24.0	42.3	18.3	697	635	316
Shinnecock	NY	2.1	3.7	900	23.0	41.2	18.2	674	615	72
Cedar Beach	NY	3.6	7.0	600	25.0	46.5	21.5	599	546	122
Port Jefferson	NY	3.7	7.1	1,150	25.0	46.6	21.6	1,157	1,055	149
Huntington Bay	NY	4.0	7.7	2,700	25.0	47.2	22.2	2,823	2,575	46
Oyster Bay	NY	4.1	7.8	2,400	25.0	47.3	22.3	2,535	2,312	45
Sandy Hook-Breezy Point	NY/ NJ	2.8	5.2	28,500	varies	varies	19.7	39,124	35,681	2,592
Cheesequake	NJ	2.9	5.6	270	11.0	31.1	20.1	168	154	11
Shrewsbury River	NJ	2.8	5.2	1,650	16.0	35.7	19.7	1,164	1,062	77
Shark River	NJ	2.6	4.9	100	10.0	29.4	19.4	56	52	4
Manasquan Inlet	NJ	2.5	4.6	420	10.0	29.1	19.1	234	214	16
Indian River Inlet	DE	2.4	4.2	800	70.0	88.7	18.7	1,327	1,210	88
Christiana River	DE	2.8	6.0	1,250	38.0	58.5	20.5	1,501	1,369	99
Darby Creek	PA	2.9	6.1	420	2.0	22.6	20.6	196	179	13
Schuylkill	PA	2.9	6.3	720	28.0	48.8	20.8	732	668	49
Baltimore Patapsco	MD	0.8	1.6	2,250	50.0	66.1	16.1	1,776	1,620	151
Baltimore Bear Creek	MD	0.8	1.6	3,600	15.0	31.1	16.1	1,810	1,651	120

Solomons Island	MD	0.9	1.5	750	20.0	36.0	16.0	433	394	29
Ocean City	MD	2.3	3.8	2,000	28.0	46.3	18.3	1,694	1,545	112
Chincoteague Inlet	MD	2.2	4.1	6,500	15.0	33.6	18.6	4,051	3,695	268
Rudee Inlet	VA	2.5	3.7	100	15.0	33.2	18.2	60	55	4
Lynnhaven Inlet	VA	1.8	3.1	1,000	15.0	32.6	17.6	571	521	38
Little Creek	VA	1.7	2.8	950	22.0	39.3	17.3	647	591	43
Elizabeth River	VA	1.7	2.9	2,640	32.6	49.9	17.4	2,288	2,087	152

VIII.6. Structural/NNBF Measures

As listed in Table VIII-3, the Structural/NNBF Measures include Beach Restoration (beach fill, dune creation) – Barrier Island Preservation, Beach Restoration with Breakwaters, Beach Restoration with Groins, Drainage Improvements, and Living Shorelines.

VIII.6.1 Beach Restoration

Description

Beach restoration, also commonly referred to as beach nourishment or beachfill, typically includes the placement of sand fill to either replace eroded sand or increase the size (width and/or height) of an existing beach, including both the beach berm and dunes (Figure VIII-14) (USACE 2002). Material similar to the natural sand is artificially placed on the eroded part of the beach. Beach restoration might reduce risk not only the beach where it is placed and infrastructure landward of the beach, but also downdrift stretches by providing an updrift point source of sand (USACE 2002). Beach restoration can also be used to construct and/or restore barrier islands. Most coastal engineering practitioners consider beach restoration as a technically sound shore risk management engineering alterative when properly designed and placed in the appropriate location (NRC 1995).

The direction and rate of movement of the newly deposited sand along the shoreline should be considered to avoid shoaling and filling of any adjacent navigable waterways. As indicated by the numerous federal, state, and local beach restoration projects located throughout the study area, beach restoration is a very effective and thus commonly used method of storm damage reduction in the Northeast.

Figure VIII-14. Beach Restoration project under construction in June 2013 at Brant Beach, NJ

A well designed beach restoration project reduces risk to the structures and populations behind it by providing a buffer against the increased wave energy and storm surge generated during a coastal storm event. Beach restoration can also be used in combination with other structural shoreline risk management measures such as seawalls, breakwaters, and groins (see discussion below), but can also function well as a standalone measure. For this reason, beach restoration can be used in locations where the use of hard structures is not acceptable. Although very effective in reducing storm damage to the areas they are designed to reduce risk to, beach restoration projects are typically applicable only where there is an existing, gently sloping, sandy shoreline having a natural source of sand to help sustain the beach.

Beach restoration alone is a viable solution for the reduction of storm damages at locations where shore erosion is not severe. Beach restoration could be limited in its effectiveness in areas where renourishment/rehabilitation is required frequently (e.g. adjacent to inlets or erosional hot spots). At these highly erosive locations, it is often advisable to combine beachfill with other methods for reducing erosion (e.g., groins, breakwaters or seawalls). The longevity of a beach restoration project is also related to the length of the filled shoreline. Consequently, beach restoration projects are ideally applied to long segments and are less suitable for local, isolated storm risk management.

Generic Design

Typically beachfill design templates or cross-sections, dune height/width and berm width, are designed to provide a certain level of risk management. Beachfill designs must also consider the quantity of sand and frequency of renourishments that are required to maintain the design berm and dune over the life of the project. There are many other site specific design criteria that are not discussed in detail here but must be considered for during detailed beach restoration design: identification of onshore or offshore sources of compatible sediment, beachfill tapers, dune crest alignment, etc.

Beachfill design templates are defined by the berm elevation, berm width, foreshore slope, dune elevation, dune width, dune slope. Berm elevations are typically designed to correspond with existing beach conditions. USACE Engineering Manual 1110-2-3301 suggests, *"if possible, constructed berm elevations should be designed to be the same or slightly less than the natural berm crest elevations".* Natural berm elevations are controlled by normal tide and wave conditions are typically about 6 feet above Mean Higher High Water (MHHW). A berm elevation of +8 feet NAVD was selected for the generic design based typical MHHW elevations along ocean shorelines within the study area. If fill materials are compatible with the native sediment than the seaward beach slopes will mirror native beach conditions offshore to the closure depth. A representative closure depth at the -25 feet NAVD contour has been identified based on typical ocean wave heights in the study area.

The berm width and dune elevation/width are designed to provide risk management during a 1 percent storm. The berm width and volume must be sufficient to reduce wave energy during storm events and the dune must be high and wide enough to prevent significant wave overtopping and erosion during storm events. Previous planning and design studies for ocean shorelines in the study area evaluated the level of risk management provided by different dune and berm combinations. The results indicate that a dune crest elevation approximately 8 feet above the 1 percent flood, a dune crest width of 25 feet, and dune slope of 1V:5H provides approximately a 1 percent flood level of risk management when combined with a berm width of 120 feet. Therefore, the proposed dune crest elevation for the generic design profile is +18 feet NAVD (8 feet above a representative 1 percent flood +10 feet NAVD).

In addition, it is assumed that the existing beach berm width is about 50% of the required design beach berm (i.e., 60 ft of additional berm required) and that the existing dune is small or non-existing (i.e., 100% of the 18 ft dune will be required). This leads to approximately 100 cubic yards of beachfill per foot shoreline required, a number typical of many beach restoration projects in the study area.

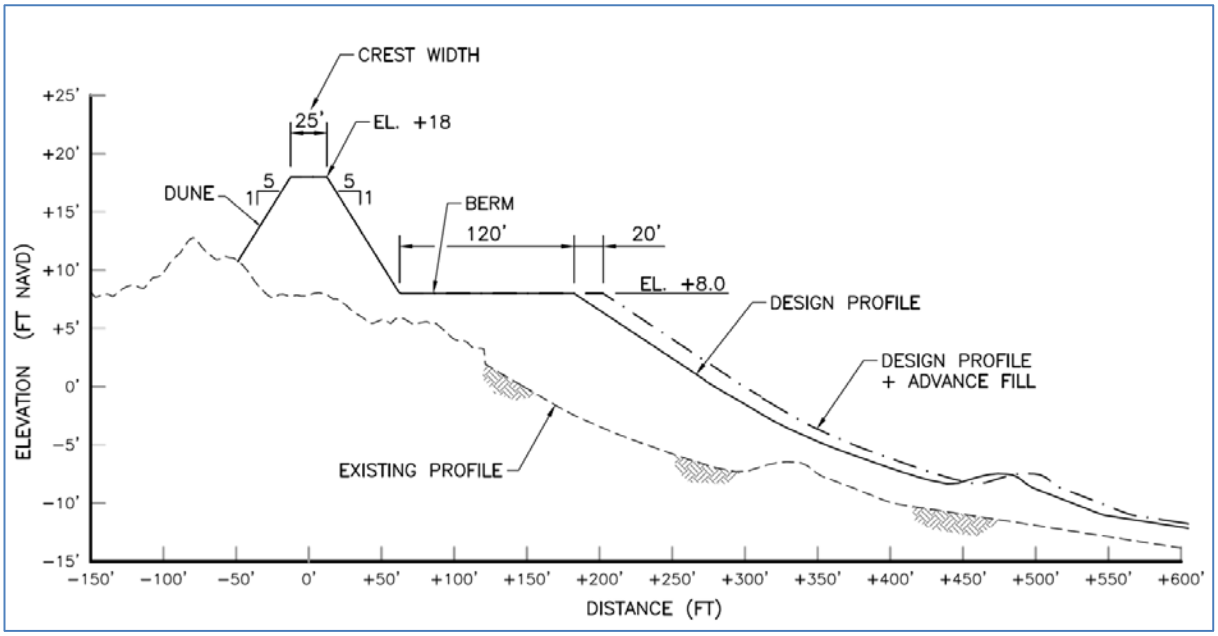


Figure VIII-15. Typical Section of Beach Restoration

Beachfill alone does not alter pre-existing shoreline erosion rates. Generally it is assumed that the background shoreline erosion will continue at the same rate as before the project. Typically, background erosion is caused by a deficit in sediment budget. Beachfill projects typically experience additional erosion from “spreading out” or diffusion of sand resulting from the shoreline anomaly or “bump” created by the beachfill. Diffusion losses are function of the longshore length of the beachfill, cross-shore width of the beachfill, and wave climate (diffusivity). The rate of diffusion is particularly sensitive to the longshore length of the beachfill project. Shorter projects will generally experience a much higher rate of diffusion than longer projects. A typical shoreline erosion rate of 5 feet/year, encompassing background erosion and beachfill diffusion, was applied in the generic beachfill design estimates. In addition, a RSLC of 3 feet over a hundred years, equating to approximately 1.5 ft/yr of shoreline erosion, was added for a total erosion rate of 6.5 feet/year.

Parametric Unit Costs

Beach restoration is normally constructed using either hopper or pipeline hydraulic dredges. Fill material is typically obtained from offshore borrow areas located in the vicinity of the project area. Initial beachfill quantities are usually determined by comparing survey profiles to the design template. Initial beachfill quantities are site specific and will vary considerably depending on the existing beach width and dune heights. In order to develop parametric costs it is estimated that initial construction of each beach fill will require placement of 50% of the design berm width, 100% of the dune fill, and 100% of the required advance fill.

Advance beachfill is required to maintain the design section before the first scheduled renourishment. Advance fill requirements are based on the expected shoreline erosion between the initial fill and first renourishment and are equivalent to renourishment volumes. The interval between renourishment events is dependent on the expected shoreline erosion rate; a shorter renourishment interval is generally required for higher erosion rates. A renourishment interval of four years is applied in this study and is typical of existing projects in the area. All fill quantity estimates include dredging tolerance (15%) and overfill (10%) allowances. Table VIII-14 shows the estimated first fill and renourishment fill quantities.

Unit beachfill costs may vary considerably based on the type of dredge used and distance to sediment source (e.g. borrow area). A value of $12.0 per cubic yard is applied in the parametric costs based recent bids and detailed cost estimates for beachfill projects performed with hopper dredges and a sediment source within approximately 10 miles of the placement site. In addition, recent bids indicate that each mobilization/demobilization costs approximately $3 million. A small project length (3,000 feet) will require 1 mob/demob whereas a larger project length (15,000 feet) may still only require 1 mob/demob. Therefore, the relative cost of the mobilization will be much higher for a small beachfill project resulting in a greater parametric cost. A typical project length of 10,000 feet (~ 2 miles) is used to determine the parametric beachfill costs.

An additional cost associate with beachfill projects are berm fill maintenance costs. Berm maintenance ($15 per foot) is typically required to address shoreline undulations and erosional hotspots. Regular fill maintenance, such as tiling, is included under the regular operation & maintenance.

Cost estimates include 12% for engineering and design (E&D), 10% for construction management (S&A), and 1% for operation and maintenance (O&M). A contingency of 25% is applied to the cost estimate. Real estate costs associated with structure acquisitions/relocations, and easements vary considerable by project and are not included in the parametric cost estimate. Table VIII-14 and Table VIII-15 provide a summary of the first construction and renourishment quantities and costs.

Total annual costs are estimated using a 50-year project life and annual interest rate of 3.5%. Table VIII-16 presents the annualized costs for first costs, renourishment costs, fill maintenance, and O&M. The total annual cost is approximately $488 per foot.

Table VIII-14. Beach Restoration - First Construction Quantities & Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$3,000,000	$3,000,000
Design Beach Fill Volume	1,279,056	cu.yd.	$12	$15,348,672
Advance Fill Volume	401,989	cu.yd.	$12	$4,823,868
Subtotal				$23,172,540
Contingency	25%			$5,793,135
Total Construction				$28,965,675
E&D	12%			$3,475,881
S&A	10%			$2,896,568
Total Estimated First Construction Cost				$35,338,124
Total Estimated First Construction Cost per Foot				$3,534

Table VIII-15. Beach Restoration - Renourishment Quantities & Costs				
Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$3,000,000	$3,000,000
Renourishment Fill Volume	401,989	cu.yd.	$12	$4,823,868
Subtotal				$7,823,868
Contingency	25%			$1,955,967
Total Construction				$9,779,835
E&D	12%			$1,173,580
S&A	10%			$977,984
Total Estimated Renourishment Cost				$11,931,399
Total Estimated Renourishment Cost per Foot				$1,193

Table VIII-16. Beach Restoration - Annualized Costs per Foot		
Annualized First Costs		$151
Annualized Renourishment Costs		$279
Fill Maintenance		$23
O&M	1%	$35
Total Estimated Annual Average Cost		$488

Summary: Beach Restoration Benefits, Impacts and other Considerations

Beach fill or beach replenishment increases beach width which provides a buffer zone against storm erosion to reduce risk to property and vulnerable population. Increased beach area also provides more recreational space or “towel area” as an added benefit. Beach fill avoids the construction of expensive, hard, permanent structures such as seawalls, revetments and groins and can also provide for the replacement of lost habitat. Beach fill reduces storm damage and may often help to increase tourism.

Beach fill impacts include damage to habitat in borrow areas and also to the habitat areas that is being filled. Beach fill can cause short term water quality impacts due to turbidity and may disrupt the natural beach system due to variations in the introduced sand grain size mix. Beach fill may also create steeper beaches with ledges and scarp.

Beach fill considerations include the both initial cost, and the long term need for continued renourishment and maintenance.

VIII.6.2 Beach Restoration with Groins

Description

Most coastlines experience waves and currents that transport sand parallel to shore; this is generally referred to as longshore sediment transport. On some coastlines there is more sand leaving the area via longshore sediment transport than there is sand arriving thus causing a net deficit of sand and attendant erosion. Groins are structures that extend perpendicularly from the shoreline. They are usually built to stabilize a stretch of natural or artificially nourished beach against erosion that is due primarily to a net longshore loss of beach material. The effect of a single groin is accretion of beach material on the updrift side and erosion on the downdrift side; both effects extend some distance from the structure. Consequently, a groin system (series of groins) results in a saw-tooth-shaped shoreline within the groin field and a differential in beach level on either side of the groins (USACE 2002). In most cases, groins are sheet-pile or rubble-mound constructions. An example of a groin field at Westhampton, on the Atlantic coast of Long Island, NY, is shown in Figure VIII-16 (USACE 2002).

Figure VIII-16. Groin Field at Westhampton, NY

Groins are occasionally constructed non-perpendicular to the shoreline, can be curved, have fishtails, or have a shore-parallel T-head at their seaward end. Also, shore-parallel spurs are provided to shelter a stretch of beach or to reduce the possibility of offshore sand transport by rip currents (USACE 2002). Groins can be long or short and high or low. Long and/or high groins will trap more sediment than comparatively shorter and/or lower ones. Some cross-groin transport is beneficial for obtaining a well-distributed retaining effect along the coast. For the same reason permeable groins, which allow sediment to be transported through the structure and may reduce rip currents, may be advantageous. Proper spacing of groins allows for sand to accumulate along the entire length of the area between the groins. The relatively high initial construction costs with groins may be offset by a reduction in the quantity and frequency of future renourishments over the project life.

Generic Design

The beach restoration and groin design assumes that the beachfill cross-section is unchanged and that the groin compartments would be filled initially to promote sand bypassing. The optimal groin field layout (groin geometry, length and spacing) is typically determined by balancing the initial cost of the groins with the cost reductions in renourishments (i.e. groin retention efficiency). Groin retention efficiency is the reduction of beachfill losses with groins and typically increases with groin length (G) and shorter groin spacing (L). The Shore Protection Manual (USACE 1984) recommends groin spacing to length ratios (L/G) between 2 and 3, where the groin length is measured from the seaward berm crest. Based on previous alternative screening studies performed for ocean shorelines within the study area, a groin spacing of 1,150 feet and groin length of 412 feet was selected for the generic design (L/G = 2.8) providing a retention efficiency of 55%. Figure VIII-17 shows the groin field layout.

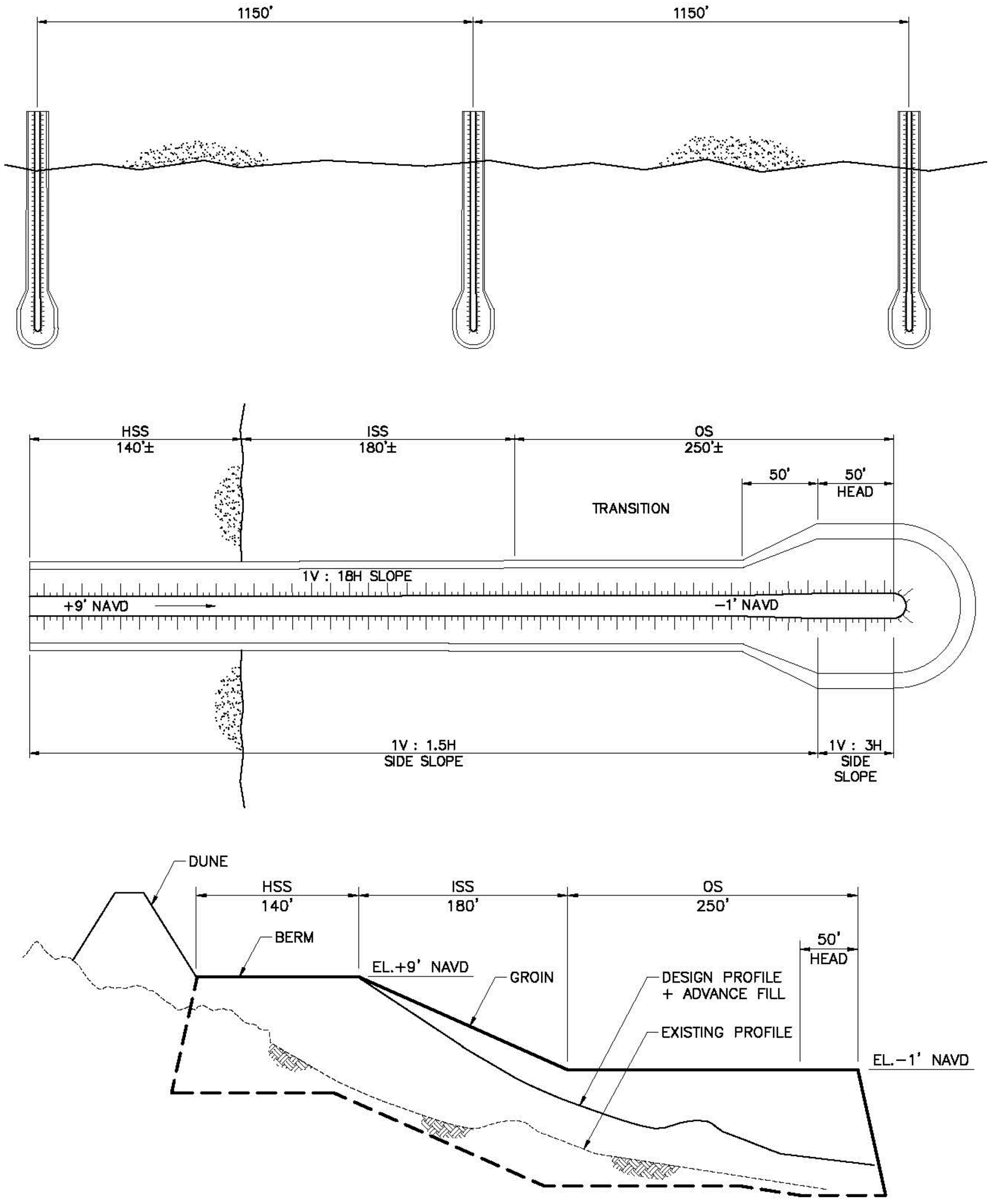


Figure VIII-17. Typical Groin Layout

Groin design is summarized as: (1) a horizontal shore section (HSS) extending from a crest elevation of +8 feet NAVD to a bottom elevation of -2 feet NAVD; (2) an intermediate sloping section (ISS) extending from a crest elevation of +8 to -1 feet NAVD at a slope of 1V:18H; and (3) an outer sloping section (OS) extending from a crest elevation of -1 feet NAVD to a bottom elevation of -13 feet NAVD. Figure VIII-17 depicts the three groin sections and the length of each section. The SPM groin length is defined as the ISS and OS sections (412 feet).

Armor stone sizes increase along the groin with water depth and were determined based on assumed 1 percent storm wave conditions which will be limited by depth at the toe of the structure and therefore a function of the storm tide. The groin trunk consists of side slopes of 1V:1.5H, one layer of armor stone with sizes from 8 to 10 ton, underlayer with 2 layers of stone, core and blanket layer comprised of 9 to 180 pound stone, and geotextile filter. At the groin head a minimum of two armor stone layers (16.4 ton) are placed. Typical sections at the HSS, OS, and Head section are shown in Figure VIII-18.

Parametric Unit Costs

The design beach fill volumes and costs for first construction are the same as the beach restoration only alternative. However, due to the increased sediment retention (55%) a longer renourishment interval, 8 years, is applied. Volumetric losses from RSLC (1.5 feet/year) remain the same as the beach restoration only alternative, only the volumetric losses associated with background erosion and diffusion (5 feet/year) are reduced. A project length of 10,000 feet (~2 miles) is used to determine the number groins and total volumetric quantities required. A more expensive mobilization/demobilization is required for the additional equipment required for the groin construction. A 1 foot tolerance is applied to the armor stone quantity estimates. Unit costs of $150 per ton of stone, $15 per sq.yd. of geotextile, and $13 per cu.yd of excavation are applied in the parametric cost estimate. Berm fill maintenance, typically required in beach restoration only alternatives to address shoreline undulations and erosional hotspots, is not included since the groin field is expected to stabilize the shoreline.

Cost estimates include 12% for engineering and design (E&D), 10% for construction management (S&A), and 1% for operation and maintenance (O&M). A contingency of 25% is applied to the cost estimate. Real estate costs associated with potential ocean front structure acquisitions/relocations, and easements are not included in the parametric cost estimate Table VIII-17 and Table VIII-18 provide a summary of the first construction and renourishment quantities and costs.

Total annual costs are estimated using a 50-year project life and annual interest rate of 3.5%. Table VIII-19 presents the annualized costs for first costs, renourishment costs, fill maintenance, and O&M. The total annual cost is $532 per foot.

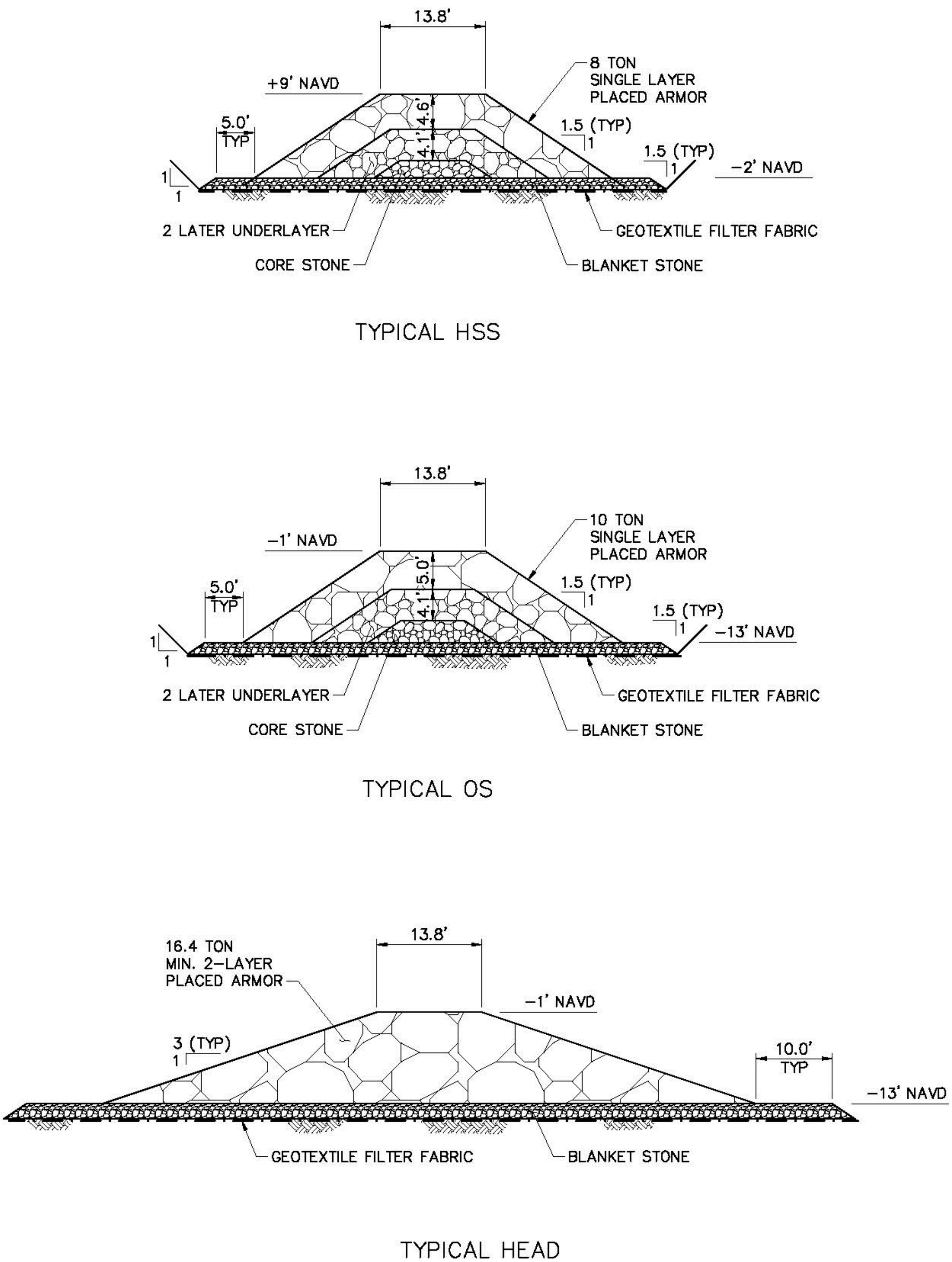


Figure VIII-18. Typical Groin Section

Table VIII-17. Beach Restoration with Groins - First Construction Quantities & Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$4,000,000	$4,000,000
Design Beach Fill Volume	1,279,056	cu.yd.	$12	$15,348,672
Advance Fill Volume	463,833	cu.yd.	$12	$5,565,996
Armor Stone	79,676	ton	$150	$11,951,400
Underlayer / Core Stone	31,092	ton	$150	$4,663,800
Blanket Stone	36,875	ton	$150	$5,531,250
Geotextile	38,219	sq.yd.	$15	$573,285
Excavation	75,621	cu.yd.	$13	$983,073
Subtotal				$48,617,476
Contingency	25%			$12,154,369.00
Total Construction				$60,771,845
E&D	12%			$7,292,621
S&A	10%			$6,077,185
Total Estimated First Construction Cost				$74,141,651
Total Estimated First Construction Cost per Foot				$7,414

Table VIII-18. Beach Restoration with Groins - Renourishment Quantities & Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$3,000,000	$3,000,000
Renourishment Fill Volume	463,833	cu.yd.	$12	$5,565,996
Subtotal				$8,565,996
Contingency	25%			$2,141,499
Total Construction				$10,707,495
E&D	12%			$1,284,899
S&A	10%			$1,070,750
Total Estimated Renourishment Cost				$13,063,144
Total Estimated Renourishment Cost per Foot				$1,306

Table VIII-19. Beach Restoration with Groins - Annualized Costs per Foot

Annualized First Costs		$316
Annualized Renourishment Costs		$142
Fill Maintenance		$0
O&M	1%	$74
Total Estimated Annual Average Cost		$532

Summary: Beach Restoration with Groins Benefits, Impacts and other Considerations

By trapping a portion of the littoral drift sand groins help to sustain a beach by preventing further erosion. The beach in turn helps to reduce risk to the shoreward coastal property and population.

Groins typically create deposition and erosion problems by upsetting the natural equilibrium between the sources of beach sediment and the littoral drift pattern. Groin fields tend to shift the zone of erosion out of the immediate area to the down drift neighbor.

Figure VIII-19. Breakwater Field at Ocean View

VIII.6.3 Beach Restoration with Breakwaters

Description

In general, breakwaters are structures designed to reduce risk to shorelines, beaches, or harbor areas from the impacts of wave action thereby reducing shoreline erosion and storm damage. When used as harbor risk management structures they are typically attached to the shore and enclose the harbor basin to reduce the impacts from waves. Shoreline risk reduction breakwaters are usually built some distance from the shore (detached breakwaters), in relatively shallow water, and roughly parallel to it so as to maximize amount of risk reduction they provide and to optimize their efficiency at reducing erosion. Figure VIII-19 shows an example of a field of detached breakwaters (USACE 2002). Beach restoration may be combined with offshore breakwaters along severely eroding shorelines to increase the longevity of a project by increasing the sediment retention. The relatively high initial construction costs with breakwaters may be offset by a reduction in the quantity and frequency of future renourishments over the project life.

Breakwaters are usually built as rubble-mound structures (USACE 2002) though they can be constructed from a variety of materials such as geotextile and concrete. The dissipation of wave energy allows sand to be deposited behind the breakwater. This accretion further reduces risk the shoreline and may also widen the beach. In some cases the beach “salient” formed by the accretion effect connects to the breakwater thus forming a “tombolo”; whether or not the detached breakwaters become attached to shore is a function of placement distance offshore and length of the structure. The gaps between the breakwaters are in most cases on the same order of magnitude as the length of one individual structure. Breakwaters, usually in combination with beach restoration, are appropriate for implementation on beaches as a stabilization measure.

Generic Design

In contrast to the beach restoration and groin design, the design beachfill cross-section changes with the inclusion of offshore breakwaters. A 33% reduction in the design berm width is justified by an equivalent reduction in the incident wave energy along the shoreline. The dune dimensions are not altered since the breakwaters would have little impact on the storm tide.

The objective of the breakwater layout is to stabilize the shoreline with the formation of salients and avoid excessive erosion in the gaps between breakwaters. If the spacing between breakwaters is too small or if the breakwaters are too close to the shoreline, tombolos may form behind the breakwaters. Tombolos block the longshore sediment transport and essentially function as groins. Criteria established for breakwater design was applied to determine the appropriate breakwater length, spacing, distance from shoreline, and depth (Chasten et al, 1993, and Rosati 1990) for a typical ocean shoreline. The generic breakwater layout consists of breakwater segments of 300 feet, 400 foot gaps between segments, and breakwaters located 500 feet seaward of the design shoreline. Figure VIII-20 shows the breakwater layout. For the purpose of plan comparison, an increased sediment retention efficiency of 65% (relative to beachfill alone) is estimated.

The breakwater cross-section is similar to the design of the groin trunk and consists of 2 layers of 18 ton armor stone, an underlayer with 2 layers of 1.8 ton stone, and a core and blanket layer comprised of 9 to 180 pound stone. A typical section for the breakwater is shown in Figure VIII-20. The armor stone sizes were determined based on typical 1 percent storm wave conditions in the study area.

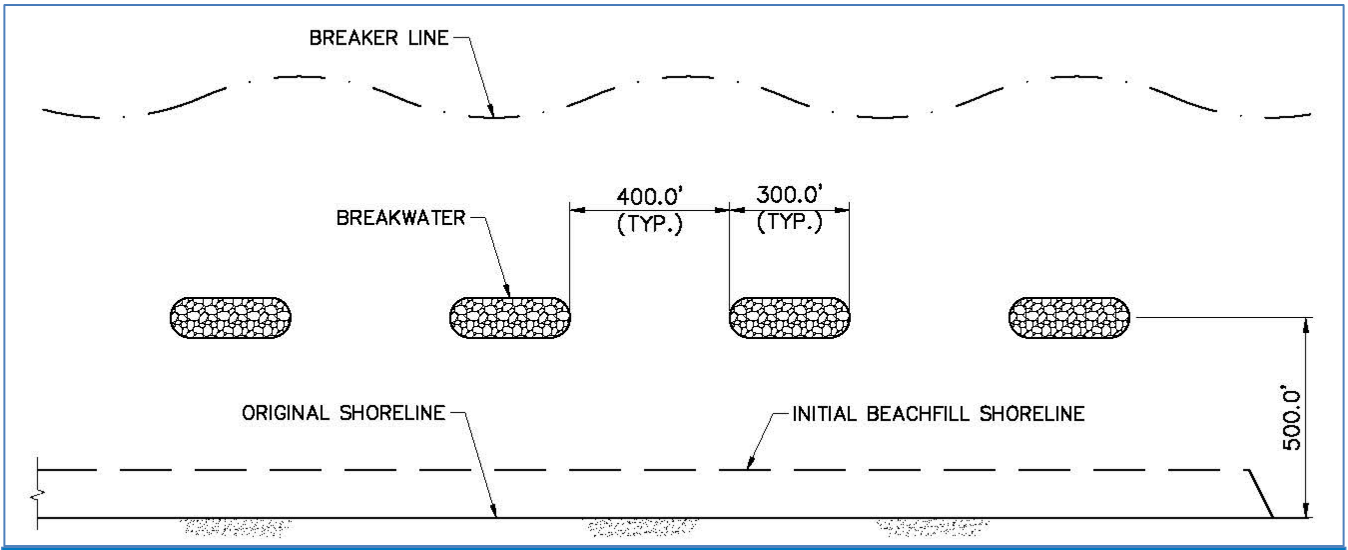


Figure VIII-20. Typical Offshore Breakwater Layout

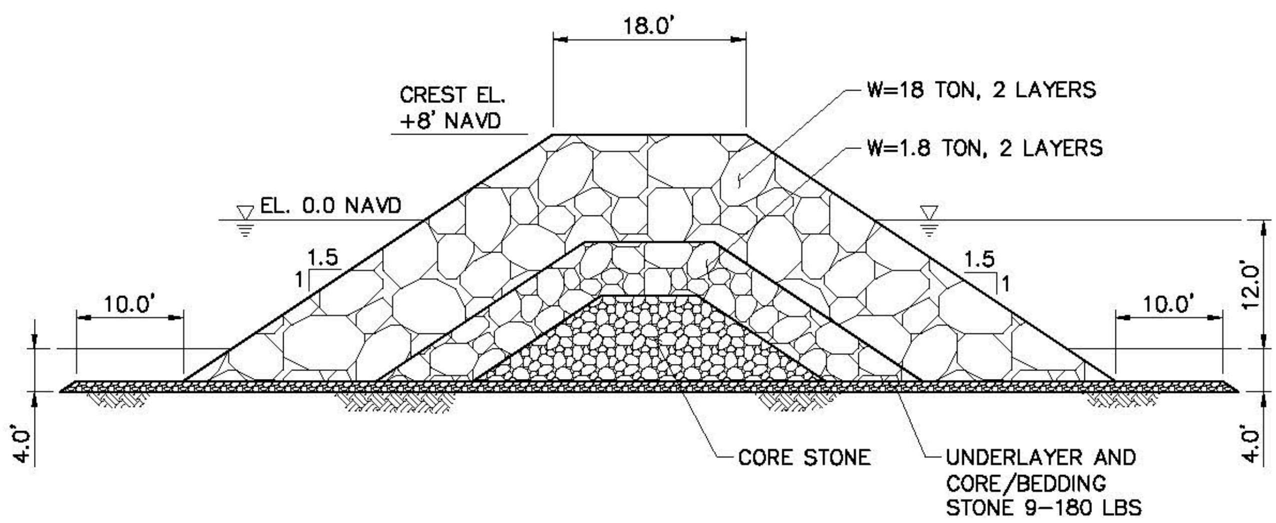


Figure VIII-21. Typical Breakwater Section

Parametric Unit Costs

The design beach fill volumes for first construction decrease significantly since the design berm is reduced to 80 feet. In addition, advance fill volumes and renourishment quantities are lower due to the increased sediment retention (65%). An 8 year renourishment interval is applied (same as beach restoration with groins). Volumetric losses from sea level change remain the same as the beach restoration only alternative, only the volumetric losses associated with background erosion and diffusion (5 feet/year) are reduced. A project length of 10,000 feet (~2 miles) is used to determine the number breakwaters and total volumetric quantities required. A more expensive mobilization/demobilization is required for the additional equipment required for the breakwater construction. A 1 foot tolerance is applied to the armor stone quantity estimates. Unit costs of $150 per ton of stone are applied in the parametric cost estimate. Berm maintenance, typically required in beach restoration only alternatives to address shoreline undulations and erosional hotspots, is not included since the offshore breakwaters are expected to stabilize the shoreline.

Cost estimates include 12% for engineering and design (E&D), 10% for construction management (S&A), and 1% for operation and maintenance (O&M). A contingency of 25% is applied to cost estimate. Real estate costs associated with potential ocean front structure acquisitions/relocations, and easements are not included in the parametric cost estimate. Table VIII-20 and Table VIII-21 provide a summary of the first construction and renourishment quantities and costs.

Total annual costs are estimated using a 50-year project life and annual interest rate of 3.5%. Table VIII-22 presents the annualized costs for first costs, renourishment costs, fill maintenance, and O&M. The total annual cost is $613 per foot.

Table VIII-20. Beach Restoration with Breakwaters - First Construction Quantities & Costs				
Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$4,000,000	$4,000,000
Design Beach Fill Volume	660,611	cu.yd.	$12	$7,927,332
Advance Fill Volume	401,989	cu.yd.	$12	$4,823,868
Armor Stone	223,328	ton	$150	$33,499,200
Underlayer	58,165	ton	$150	$8,724,750
Core/Bedding Stone	8,025	ton	$150	$1,203,750
Subtotal				$60,178,900
Contingency	25%			$15,044,725
Total Construction				$75,223,625
E&D	12%			$9,026,835
S&A	10%			$7,522,363
Total Estimated First Construction Cost				$91,772,823
Total Estimated First Construction Cost per Foot				$9,177

Table VIII-21. Beach Restoration with Breakwaters - Renourishment Quantities & Costs				
Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$3,000,000	$3,000,000
Renourishment Fill Volume	401,989	cu.yd.	$12	$4,823,868
Subtotal				$7,823,868
Contingency	25%			$1,955,967
Total Construction				$9,779,835
E&D	12%			$1,173,580
S&A	10%			$977,984
Total Estimated Renourishment Cost				$11,931,399
Total Estimated Renourishment Cost per Foot				$1,193

Table VIII-22. Beach Restoration with Breakwaters - Annualized Costs per Foot		
Annualized First Costs		$391
Annualized Renourishment Costs		$130
Fill Maintenance		$0
O&M	1%	$92
Total Estimated Annual Average Cost		$613

Summary: Beach Restoration with Breakwaters Benefits, Impacts and other Considerations

Breakwaters reduce risk to a portion of the shoreline area from wave erosion, which in turn reduces risk to property and vulnerable populations.

Breakwaters typically create deposition and erosion problems by upsetting the natural equilibrium between the sources of beach sediment and the littoral drift pattern. Shorelines near breakwaters must change their configuration in an attempt to reach a new equilibrium. Breakwaters do not provide direct tide surge risk management.

VIII.6.4 Drainage Improvements

Measures in this category include pump stations, culverts/drains/inlets, and water storage/retention features. A drainage system can perform two functions: it carries water away via conveyance systems and, during times of high water, may store water until it can be carried away in storage facilities. Conveyance systems utilize measures such as pump stations, culverts, drains, and inlets to remove water from a site quickly and send it to larger streams. Storage facilities or features are used to store excess water until the storm or flood event has ended. Drainage improvement measures are appropriate for implementation on all shoreline types. The most significant application of drainage improvements in coastal flood storm management is as part of any plan that uses structures, such as seawalls, gates or levees, to create a line of risk management against tidal inundation. Drainage outlets, flood storage, or pumps are needed to control flooding from rainfall runoff from behind the line of risk reduction or from waves overtopping the structures.

Summary: Drainage Improvements Benefits, Impacts and other Considerations

Drainage improvements enable more rapid and efficient evacuation of rain and floodwaters from a specific area to a receiving body of water, reducing the risk of flood water buildup.

Considerations include cost and maintenance requirements and also potential impacts to utilities during construction.

VIII.6.5 Living Shoreline

Description

Living shorelines represent a shoreline management option that combines various erosion control methods and/or structures while restoring or preserving natural shoreline vegetation communities and enhancing resiliency. Typically, creation of a living shoreline involves the placement of sand, planting marsh flora; and, if necessary, construction of a rock structure on the shoreline or in the near shore (VIMS 2013b). An example of a living shoreline application is shown in Figure VIII-22. However, living shorelines can use a variety of stabilization and habitat restoration techniques that span several habitat zones and use a variety of materials. Specifically, living shorelines can be used on upland buffer/backface zones, coastal wetlands and beach strand zones, and the subtidal water zone. Living shoreline materials may include sand fill, clean dredge material, tree and grass roots, marsh grasses, mangroves, natural fiber logs, rock, concrete, filter fabric, seagrasses, etc. (Maryland DNR, 2007).

The benefits of living shorelines include stabilization of the shoreline, reduction of impacts to surrounding riparian and intertidal environment, reduction of impacts to cultural resources particualrly prehistoric resources along the coast improvement of water quality via filtration of upland run-off, and creation of habitat for aquatic and terrestrial species (Chesapeake Bay Foundation, 2007). Living shorelines are generally applicable to relatively low current and wave energy environments in estuaries, rivers, and creeks. Areas exposed to larger waves do not benefit significantly from a living shoreline application since the marsh vegetation and underlying soils would likely be eroded. Some instances of living shoreline applications in the Delaware Bay and Chesapeake Bay have indicated success in coastal storm risk management.

Figure VIII-22. Living Shoreline

Living shorelines are essentially tidal wetlands constructed along a shoreline to reduce coastal erosion, maintain dynamic shoreline processes, and provide habitat for organisms such as fish, crabs and turtles. They are natural landscape features that function primarily under normal tidal range conditions and provide a varied mix of habitat such as: shallow water, intertidal, beach, marsh and dune. They provide some benefits as a wave reducing component by functioning as shallow water under high water and storm conditions. A typical living shoreline is relatively narrow, and they have been promoted in embayments and other lower energy areas to replace revetments, bulkhead and other hard structures to serve as shoreline risk management. An essential component of a living shoreline is constructing a rock structure (breakwater/sill) offshore and parallel to the shoreline to serve as risk management from wave energy that would impact the wetland area and cause erosion of the substrate and damage or removal of the tidal plants. Also, the rock structure serves to hold the sand that is located shoreward in place, maintaining the substrate for the plants.

Two other items of importance to incorporate into a living shoreline are: 1) ensure there is adequate sunlight for the plants, and 2) take measures to prevent waterfowl (primarily Canada geese) from eating the plants. Since living shorelines are located close to the land, and possibly in areas with high banks, trees may overhang the area and significantly reduce exposure of the plants to sunlight. Tidal wetland plants generally thrive in areas where there are no trees, and the presence of them could affect the growth of the tidal plants. Non-migratory Canada geese are common along the east coast, and a flock of them can very quickly destroy newly planted vegetation, often pulling a new plant out by the roots. Goose-exclusion fencing is mandatory to prevent this predation and allow the marsh to grow and develop into a mature system. The fencing should be installed to prevent geese from flying or walking into the marsh. Once the grasses have had time to develop a strong root system, the fencing is no longer required and the waterfowl can eat the grasses without destroying the marsh.

Design

Typically, the living shoreline rock structure is designed for average, regular wave conditions, i.e., the crest elevation is at or slightly above mean high water (MHW) or mean higher high water (MHHW). The rock size is also designed to withstand average wave condition, which generally allows for the use of common riprap sizes and gradations. It is assumed that under storm flood conditions, the living shoreline would be under water and the larger waves would pass over the top and impact on the shore at a higher elevation. Thus, using a large rock size (with concomitant higher costs) is not required. Side slopes of the outer side of the breakwater range from 1.5H:1V to 3H:1V. Due to the small height of the breakwater, the difference in rock quantity for the slopes is not significant.

A living shoreline is constructed in fairly shallow water, usually less than 5 ft below mean lower low water (MLLW). The actual water depth is site-specific, but the shallower the water the lower the material quantities and subsequent construction costs for a given length of shoreline.

Another important feature of the living shoreline is openings in the rock structure to allow fish, crabs, turtles and other organisms to move from the deeper, open water into the wetland area for feeding and shelter. These openings can be either low-crested regions (crest elevation at about MLLW) about 5 to 10 ft wide, or the breakwater can be segmented. If segmented, smaller breakwaters can be constructed either inside or outside the alignment at the openings to minimize wave energy through them.

The sand that is placed behind the breakwater should be relatively coarse to minimize loss of material from the waves and currents that can enter through the breakwater. It is common to specify sand material with a maximum fines content of 10 percent. The slope of the sand should be fairly flat, with a maximum slope of 10H:1V.

Living shorelines should be designed to have both low and high marsh vegetation, and a 50/50 design ratio is preferred and typical. Site specific conditions as well as local preference could change this ratio, as well as environmental conditions following construction. It is practical and acceptable to allow the ratio to vary over time and not be strict about maintaining a certain ratio. Low marsh vegetation is typically Spartina alterniflora and high marsh vegetation is typically Spartina patens.

Figure VIII-23 shows a schematic of a representative typical cross-section of a living shoreline that includes the rock breakwater/sill, sand fill behind the breakwater and vegetative marsh grass plantings. For the purposes of the generic design and parametric costs estimates it is assummed that the living shoreline is located in -2 ft MLLW and has a fill width of about 50 ft. The crest elevation of the sill would be set at +4 ft (approximately MHHW). The outside side slope of the breakwater is 1.5H:1V and it is constructed of riprap with a median weight of 200 pounds. The assumed fetch distance is on the order of one to two miles and the average design waves are about one to two feet. This assumed generic or typical design and dimensions could easily be adapted to other specific site conditions such water depth and and tidal range once the potential application areas are identified. Water depth as well as tidal range (the difference between MHHW and MLLW) could be determined from avaiable coastal charts. On the other hand, design waves are more difficult to determine as they would require at least a desktop study of local wind statistics, fetch lenghts, and analytical wave calcualtions. For more detailed design a numerical wave model may be required.

Note that the design of living shoreline is not very sensitive to the extreme flood elevations (e.g., FEMA BFE) because, as explained above, it is assumed that under storm flood conditions, the living shoreline would be under water and the larger waves would pass over the top and impact on the shore at a higher elevation. Therefore, extreme water levels were not considered as an input design parameter. However, sea level change would have an impact over time on the performance of the living shoreline as the new mash is exposed to higher and higher elevations. Depending on the SLR scenario it is possible that the living shoreline would lose its marsh. Alternatively, the marsh could be "renourished" with additional fill material and even new plantings. The rock sill could also be raised with new riprap as required.

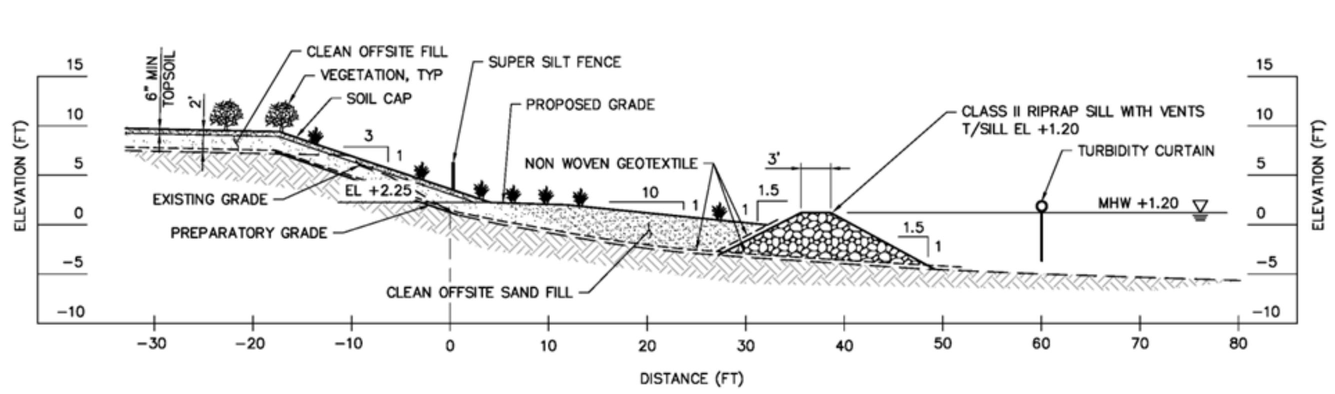


Figure VIII-23. Typical Section of Living Shoreline

Parametric Unit Cost Estimate

A parametric cost estimate based on the generic living shoreline design presented above is summarized in Table VIII-23. The costs are developed for a representative shoreline length of 5,000 feet and reduced to provide a cost per linear foot of living shoreline. The costs are based on representative unit costs for similar projects in study area. However, it is acknowledged that there will be significant variability in these unit costs depending location, material availability, local transportation costs, etc. After specific locations are selected for the application of a living shoreline, the unit costs, as well as the design, will be adjusted accordingly. First construction costs are about $1,415 per linear foot of living shoreline; annualized costs are about $67 per linear foot.

Table VIII-23. Living Shoreline - Construction Quantities & Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$500,000	$500,000
Armor Stone	20,000	ton	$150	$3,000,000
Geotextile	16,667	sq.yd.	$15	$250,000
Sand Fill	27,778	cu.yd.	$20	$555,556
Grass Plantings	166,667	each	$2	$333,333
Subtotal				$4,638,889
Contingency	25%			$1,159,722
Total Construction				$5,798,611
E&D	12%			$695,833
S&A	10%			$579,861

Table VIII-23. Living Shoreline - Construction Quantities & Costs				
Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Total Estimated First Construction Cost				$7,074,306
Total Estimated First Construction Cost per Foot				$1,415
Annualized First Costs				$60
O&M	0.5%			$7
Total Estimated Annual Average Cost				$67

Summary: Living Shoreline Benefits, Impacts and other Considerations

A Living Shoreline is generally considered to be a shoreline with bank stabilization using plants, sand and limited rock or other materials. The term is often expanded to include living breakwaters such as oyster reefs and systems of manmade wave attenuation devices (WADs) which are designed to promote habitat growth within and on the devices.

Living shoreline measures are aesthetically pleasing, preserve/create habitat, may retain runoff and pollutants, and can be less expensive than hard structure shoreline erosion risk management. Vegetation must be segregated to reduce impacts from human traffic by providing designated walkways and access paths.

The living shoreline approach is generally works best in low-erosional settings. More research is needed with regard to the effectiveness of living breakwaters in preventing beach erosion.

VIII.7. Natural and Nature-Based Features

As discussed in the previous section NNBF can be used in combination with structural and non-structural interventions to provide an integrated approach to reducing coastal risks while increasing human and ecosystem resilience across the North Atlantic Coast. Natural features are created and evolve over time through the action of physical, biological, geologic, and chemical processes operating in nature. Nature-based features are those that may mimic characteristics of natural features, but are created by human design, engineering, and construction to provide specific services such as coastal risk reduction. Nature-based features are acted upon by the same physical, biological, geologic, and chemical processes operating in nature, and as a result, generally must be maintained to reliably provide the expected level of service. Natural and nature-based features can enhance the resilience of coastal areas challenged by RSLC (Borsje et al. 2011) and coastal storms (e.g., Gedan et al. 2011, Lopez 2009).

As listed in Table VIII-3, the NNBF measures include overwash fans, reefs, submerged aquatic vegetation (SAV and wetlands).

VIII.7.1 Overwash Fans

Description

Overwash is the landward transport of beach sediments across a dune area. Large coastal storms and their associated high winds, waves, and tides can result in overwash of the beach and dune system. During storm conditions, elevated storm tides and high waves may erode beaches and dunes, and the eroded sand can be carried landward by surging water. The sand and water may wash over or break through the dunes, and spill out onto the landward side of the barrier island. This deposit is usually fan-shaped and therefore is known as an overwash fan (or washover) fan (Delaware Sea Grant, 2009). An example of an overwash fan is shown in Figure VIII-24.

Figure VIII-24. Overwash at the Pea Island National Wildlife Refuge, Kinnakeet, NC (Credit: USGS Coastal & Marine Geology)

Consequences of natural overwash processes may include loss of, or damage to, property; or loss of access to property, roads and infrastructure as a result of flooding and sediment intrusion. In addition, if existing dunes are lowered by overwash barrier island may be more susceptible to breaching and therefore lose some of their flood risk management capacity (Donnelly et al. 2004). On the other hand, overwash fans are component of the sediment budget of barrier islands (Pierce 1969) and are also believed to be a relevant process in the rollover or retreat mechanism of some coastal barriers in response to RSLC (Dillon 1970, Kraft et al. 1973) by increasing the island width and providing a new foundation for back bay wetland growth. However, new inlet and flood tidal delta formation are believed to be a larger contributor to barrier island migration (Leatherman 1976) along the Atlantic coast.

Prevention of overwash and breaching may eliminate sand transport to the lagoon system and possibly preclude the ability of barrier islands to adapt to rising sea levels (Smith et al. 2008). Overtime, the lack of cross-barrier sediment transport may lead to a relatively narrow barrier island fronting relatively deep back bay water depths and therefore, more susceptible to catastrophic breaching and back bay flooding.

Allowing for natural overwash processes in developed barriers or barrier and back bay systems that are already very susceptible to breaching and flooding is risky and rarely feasible. A potential, albeit not yet commonly implemented, alternative is to construct overwash fans that mimic the beneficial effects of natural overwash without the damages typically associated with overwash. Engineered overwash fans would increase overall barrier island stability and back bay flood risk management capacity by increasing its width/volume and providing a substrate suitable for wetland growth. Sandy sediment could be mined from borrow sources "outside" the barrier island sediment budget system such as offshore borrow sites similar to those use for beach restoration projects. Other sources may include beneficial reuse of dredged sediments from adjacent back bay and inlet channels.

The level of risk reduction associated with engineered overwash features could vary significantly depending on the size of the overwash and specific site conditions. For example, a large overwash fan behind an existing low, narrow, barrier island could significantly reduce the likelihood of a breach and therefore the risk of back bay flooding during extreme events (up to a 1 percent flood). However, generally back bay flooding is mostly a function of the storm tide penetrating through existing inlets, particularly for the more frequent, smaller, coastal flood events. Combined with reasonable limitations in the size and elevation, this means that in most cases overwash fans will have relatively low risk reduction capacity (around a 10 percent flood). Nonetheless, over the long term engineered overwash fans may be essential to the overall resiliency of barrier islands, particularly those with high levels of development and limited opportunity for natural barrier island rollover and migration processes.

Generic Design and Parametric Cost Estimate

For the purposes of this study it was assumed that the engineered overwash fan would be approximately 2,000 feet long and 200 feet wide. It was further assumed that the average thickness of the overwash fan is 9 feet (from an existing bottom depth of 5 ft below MLLW to 4 ft above MLLW). Parametric costs assuming are summarized in Table VIII-24. Given the relatively small volume it was assumed that the fan would be built with a small to medium size hydraulic dredge and using a back bay source of sand. Alternatively overwash fan(s) could be constructed as part of larger beach restoration projects with offshore sand sources. This would approach would help offset the very costly mob/demob associated with oceangoing dredges.

Table VIII-24. Overwash Fan - Construction Quantities & Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$500,000	$500,000
Overwash Fill Volume	133,333	cu.yd.	$20	$2,666,667
Subtotal				$3,166,667
Contingency	25%			$791,667
Total Construction				$3,958,333
E&D	12%			$475,000
S&A	10%			$395,833
Total Estimated First Construction Cost				$4,829,167
Total Estimated First Construction Cost per Foot				$2,415
Annualized First Costs				$103
O&M	0%			$0
Total Estimated Annual Average Cost				$103

Summary: Overwash Fans Restoration Benefits, Impacts and other Considerations

Overwash fans occur when storm tides surge over or through low points in a dune system. The overwash water introduces sand on the landward side of the dune which is often configured in a fan shape. Natural processes usually introduce vegetation on the overwash fan creating new dune growth. This process of landward movement of beach sand is considered vital to the barrier beach system (island transgression). But Overwash fan deposits can often occur on private real estate and manmade features.

Overwash fan formation is part of natural barrier island survival. Overwash fan formation should not be considered a means of prevention or mitigation of storm surge damage. Overwash fan formation is often considered an unwanted consequence of dune washovers by storm surge waters.

VIII.7.2 Reefs

Description

Artificial reefs are established for various reasons; they may be used to restore degraded or damaged natural reefs, to provide three dimensional habitat structure above the bottom, to provide fishing and scuba diving opportunities, to deter illegal netting, and other purposes. Artificial reefs also enhance the resilience of coastal areas by reducing the degradation and shoreline erosion that would occur during a storm event.

Oyster reef restoration in particular provides spatially-complex substrate and benthic structure that is important for many estuarine organisms. A well-developed reef will typically consist of intricately layered formations of live oysters on the exterior and layers of old oyster shell forming the base and reef interior. Deep crevices created by the oyster shell provide refuge for numerous species of small aquatic organisms (USACE 2009).

Overall, embayments in the North Atlantic have been subject to erosion and subsequent deposition from the heavy sediment loads. Principal sediment sources are upland runoff that enters the bays from the watershed's river systems and shoreline erosion. As a result, productive natural reefs, especially oyster reefs, have been degraded or covered with silt, and have reduced productivity or function. Former natural reefs that are covered with sediment provide bottom habitat for certain benthic marine organisms, but do not support thriving reef communities or distinguishable aggregation sites, such as for schooling prior to annual migrations, and typically would not provide conditions associated with finfish foraging. The development of artificial reefs in the bays would provide a means to reestablish and enhance reef communities, while at the same time providing shoreline erosion risk management. This erosion risk management thus serves two beneficial purposes: reducing risk to fastland as well as structures, and preventing sediment from covering the reef. The structural material provides suitable surfaces for attachment of small filter feeders such as barnacles and marine vegetation, whereas voids and passages in the reef structures provide cover from predators for crabs and juvenile and small fish. Sedimentation effects are reduced, as the vertical height of artificial reef structures provides longevity relative to existing reefs that are relatively level, near the bottom and more susceptible to the effects of sedimentation.

Reef sites may be developed using natural materials such as oyster shells, clam shells, or rock. Additionally, reef material may be obtained from discarded construction debris such as clean, rebar-free concrete, slag, metals (steel, aluminum), rubber or plastic. Also, man-made structures specifically designed for reef creation can be used, such as Reef Balls™ which are made of concrete, or other similar designs. The use of the latest generation of designed reef structures with specific biologically oriented features provides a significant improvement over debris materials and earlier designed structures. One benefit to Reef Balls™ is that their design and performance are supported by readily available engineering, scientific and monitoring data and there is a proven track record in providing value habitat and fishing opportunities in the mid-Atlantic region (e.g., New York, Virginia, New Jersey, and Massachusetts reefs) for benthic organisms, crustaceans, and multiple fish species. They are not specifically designed, however, for shore risk management and may need to be incorporated with other reef structures and materials to achieve this goal.

Generic Design

Reef design and restoration technology has advanced to a state of practice in which reef products that are specifically designed and proven to achieve biological objectives have demonstrated a significant potential to provide three dimensional structures for colonization by benthic marine organisms, cover for crabs and juvenile and small fish, and foraging sites for larger fish. Modification of the reef design to also consider shoreline erosion risk management can readily be accomplished using the technology components available for reef construction.

The water depth in which the reef would be located is an important cost factor for achieving the goal of shoreline risk management. Deeper water would require more material to create a reef with a top elevation high enough to break large waves that would occur during the storm events with high water elevations. For this application, it is proposed that the top elevation of the reef be established at -1 ft MLLW that will maintain the structure underwater for most of the time while placing it as high as possible to reduce wave energy during storms. Note that generally wave reduction is not the controlling design factor in oyster reef projects. Instead these are typically driven and ecological restoration goals. Therefore, in most cases restored reefs are relatively low relief (1 to 2 feet above the existing bottom elevation). A higher relief reef will be more effective at reducing waves but it will also be significantly more costly for the same restoration area.

For generic design and costs estimating purposes it is assumed that the reef is located in -5 ft MLLW and has a width relative to the shoreline of about 100 ft. The reef is constructed using riprap as a base material up to elevation -2 ft MLLW, then placing a one-foot layer of oyster shell on top to bring the final elevation up to -1 ft MLLW (i.e., 4 feet above the bottom). The riprap would have a median weight of 50 pounds and would be obtained from a local quarry. Oyster shell would likely have to be hauled by rail from a quarry in Florida (near Tallahassee) that currently is the only location to obtain the material. Both the riprap and the oyster material would be transferred to a shallow-draft barge for placement in the water.

Parametric Unit Cost Estimate

Table VIII-25 presents construction cost estimates for the schematic reef design. The costs are developed for a shoreline length of 5,000 feet and reduced to provide a cost per linear foot linear foot of reef. First construction costs are about $4,752 per linear foot of reef; annualized costs are about $203 per linear foot.

Table VIII-25. Oyster Reef - Construction Quantities & Costs				
Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$250,000	$250,000
Base Stone	83,333	ton	$150	$12,500,000
Oyster Reef Material	18,519	cu.yd	$200	$2,314,815
Seeding of Top Layer	11.5	acre	$45000	$516,529
Subtotal				$15,581,344
Contingency	25%			$3,895,336
Total Construction				$19,476,680
E&D	12%			$2,337,202
S&A	10%			$1,947,668
Total Estimated First Construction Cost				$23,761,549
Total Estimated First Construction Cost per Foot				$4,752
Annualized First Costs				$203
O&M	0.0%			$0
Total Estimated Annual Average Cost				$203

Summary: Reef Benefits, Impacts and other Considerations

Reef breakwaters can provide shoreline risk management by reducing wave energy and creating sand deposition areas which grow the nearby shoreline. Reef breakwaters can be installed with minimal environmental impact and can provide area for habitat growth. A variety of manufactured structures such as reef balls and wave attenuation devices (WADs) can be used. These structures are designed to encourage marine habitat growth.

Calm waters in lee of the reefs encourages accumulation of sediment in the vicinity of the reef as an intended consequence, however, this condition often creates areas of erosion down shore. Reef breakwaters can become obstacles to boat traffic in lower tide conditions, depending on specific construction applications.

Living reef breakwaters are a relatively new technology and new specific applications would require some site-specific research into their effectiveness in preventing beach erosion.

VIII.7.3 SAV Restoration

Description

Submerged aquatic vegetation (SAV) are grasses that grow to the surface of shallow water, but do not emerge from the water surface. SAV performs many important ecosystem functions, including wave attenuation and sediment stabilization, water quality improvement, primary production, food web support for secondary consumers, and provision of critical nursery and refuge habitat for fisheries species, as well as for the attachment of epiphytic organisms (USACE 2008).

SAV grows only in shallow water to allow sufficient light to reach them. SAV generally grows taller than five or six feet but have to be submerged almost all the time to avoid drying out. Special air cells allow SAV to float upright in the water column (NOAA Chesapeake Bay Office n.d.)

Generic Design

For this study, it is assumed that the top elevation of the SAV substrate will be established at -1 ft MLLW that will maintain the vegetation underwater for most of the time while placing it as high as possible to reduce wave energy during storms.

To construct the SAV bed, sand would be placed in a layer on the bottom with a small hydraulic dredge to build it up, the individual plants would be installed using snorkel. The depth of the final elevation would be shallow enough to permit snorkel versus SCUBA. This would require scheduling placement around low tide. Alternatively, SCUBA could be used if it is desired to plant SAV at any phase of the tide.

It is assumed that the SAV bed is constructed over and existing bottom at -5 ft MLLW and has a fill width of about 300 ft with a generally flat slope.

Parametric Cost Estimate

Table VIII-26 presents construction cost estimates for the schematic SAV bed design. The costs are developed for a shoreline length of 5,000 feet and reduced to provide a cost per linear foot linear foot of reef. First construction costs are about $2,423 per linear foot of SAV bed; annualized costs are about $103 per linear foot.

Table VIII-26. SAV Restoration - Construction Quantities & Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$500,000	$500,000
Sand Fill	222,222	cu.yd.	$20	$4,444,444
SAV Plantings	750,000	each	$4	$3,000,000
Subtotal Construction				$7,944,444
Contingency	25%			$1,986,111
Total Construction				$9,930,556
E&D	12%			$1,191,667
S&A	10%			$993,056
Total Estimated First Construction Cost				$12,115,278
Total Estimated First Construction Cost per Foot				$2,423
Annualized First Costs				$103
O&M	0.0%			$0
Total Estimated Annual Average Cost				$103

Summary: SAV Restoration Benefits, Impacts and other Considerations

Submerged aquatic vegetation (SAV) helps to buffer shorelines by stabilizing sediments with plant roots. SAV also provides habitat, food and shelter for an array of marine life, improves water quality and clarity and traps suspended particles.

Since SAV's are fragile, SAV restoration zones must be safeguarded from significant human activities.

Local water quality is a critical factor in SAV restoration success. Suitability for SAV restoration must be assessed at particular target sites.

VIII.7.4 Wetlands

Description

Coastal wetlands may contribute to coastal risk flood risk management wave attenuation and sediment stabilization. The dense vegetation and shallow waters within wetlands can slow the advance of storm surge somewhat and slightly reduce the surge landward of the wetland or slow its arrival time (Wamsley et al. 2010). Wetlands can also dissipate wave energy; potentially reducing the amount of destructive wave energy, though evidence suggests that slow-moving storms and those with long periods of high winds that produce marsh flooding can reduce this benefit (Resio and Westerlink 2008). The magnitude of these effects depends on the specific characteristics of the wetlands, including the type of vegetation, its rigidity and structure, as well as the extent of the wetlands and their position relative to the storm track.

Figure VIII-25. Elders East Wetland Restoration, Jamaica Bay, NY, Under Construction (Galvin Brothers, Inc.)

Functionally restored wetlands act in the same manner as natural wetlands, though design features may be included to enhance risk reduction or account for adaptive capacity considering future conditions (e.g., by allowing for migration due to changing sea levels). An example of an engineered wetland under construction at the Gateway National Recreational Area in Jamaica Bay, NY is shown in Figure VIII-25.

Generic Design

For this study, the tidal wetlands that would be constructed along a shoreline do not have a protective rock breakwater/sill along the outer edge. As the goal is to reduce coastal erosion from flooding while maintaining dynamic shoreline processes and providing habitat for organisms such as fish, crabs and turtles, it would be necessary for wetland designs to be wider than that for a living shoreline. The top elevation of the wetland will be placed at MHHW (assumed about + 4 ft above MLLW) to protect the plants from being washed away during a tidal cycle and from regular, frequently occurring waves.

Further, the material to be used in the beach region will be relatively coarse sand material with a minimal amount of fines (less than 10 percent passing a #100 sieve). The sand material in the wetland area behind the beach could contain a higher quantity of fines; however sand material is preferred in the wetland to allow plant roots to develop more effectively.

Tidal wetlands are natural landscape features that function primarily under normal tidal range conditions and provide a varied mix of habitat such as: shallow water, intertidal, beach, marsh and dune. They provide some benefits as a wave reducing component by functioning as shallow water under high water and storm conditions. A typical wetland for this study would be fairly wide to incorporate the beach and provide an effective region for wave breaking and wave energy reduction even if significant erosion of portions of the wetland would occur during a storm event.

The wetland would be constructed in fairly shallow water, usually less than 5 ft below mean lower low water (MLLW). The actual water depth would site-specific, and for shallower water material quantities and subsequent construction costs for a given length of shoreline would be lower. For purposes of this generic design, it is assumed that the water depth that the wetland would be constructed is -5 ft below MLLW.

The sand that is placed to construct the wetland should be relatively coarse to minimize loss of material from the waves and currents that can enter through the breakwater. It is common to specify sand material with a maximum fines content of 10 percent. The slope of the wetland surface should be fairly flat. It also would be necessary to install tidal channels into the wetland to allow more effective water exchange and allow for fish and other aquatic organisms to enter and utilize the wetland plants and refuge.

Wetlands should be designed to have both low and high marsh vegetation, and a 50/50 design ratio is preferred and typical. Site specific conditions as well as local preference could change this ratio, as well as environmental conditions following construction. It is practical and acceptable to allow the ratio to vary over time and not be strict about maintaining a certain ratio. Low marsh vegetation is typically *Spartina alterniflora* and high marsh vegetation is typically *Spartina* patens.

Another item of importance to incorporate into a wetland is to take measures to prevent waterfowl (primarily Canada geese) from eating the plants. Non-migratory Canada geese are common along the east coast, and a flock of them can very quickly destroy newly planted vegetation, often pulling a new plant out by the roots. Goose-exclusion fencing is mandatory to prevent this predation and allow the marsh to grow and develop into a mature system. The fencing should be installed to prevent geese from flying or walking into the marsh. Once the grasses have had time to develop a strong root system, the fencing is no longer required and the waterfowl can eat the grasses without destroying the marsh.

For quantity a cost estimating purposes it was assumed that a typical wetland restoration would consist of a 300 feet wide platform constructed to +4 ft MLLW (approximately MHHW). The outside side slope of the wetland is assumed to be 15H:1V. The existing bottom slope is also assumed to be approximately 15H:1V. The design also includes vegetative marsh grass plantings 1.5 ft on center. It is assumed that the wind fetch distance is relatively short (on the order of one to two miles) and the average waves are about one to two feet so that additional wave risk management measures along the exposed wetland perimeter are not required.

Parametric Unit Cost Estimate

Table VIII-27 presents construction cost estimates for the generic wetland design. The costs are developed for a shoreline length of 5,000 feet and reduced to provide a cost per linear foot linear foot of wetland. A small hydraulic dredge would be used to pump the sand into the wetland area. Post-placement shaping of the wetland to create tidal channels would be performed using low-ground pressure construction equipment. First construction costs are about $2,593 per linear foot of wetland; annualized costs are about $123 per linear foot.

Table VIII-27. Wetlands - Construction Quantities & Costs

Item	Quantity		Parametric Estimate	
	Number	Unit	Unit Cost	Total Cost
Mob/demob	1	LS	$500,000	$500,000
Sand Fill	333,333	cu.yd.	$20	$6,666,667
Grass Plantings	666,667	each	$2	$1,333,333
Subtotal				$8,500,000
Contingency	25%			$2,125,000
Total Construction				$10,625,000
E&D	12%			$1,275,000
S&A	10%			$1,062,500
Total Estimated First Construction Cost				$12,962,500
Total Estimated First Construction Cost per Foot				$2,593
Annualized First Costs				$111
O&M	0.5%			$13
Total Estimated Annual Average Cost				$123

Summary: Wetlands Benefits, Impacts and other Considerations

Wetlands trap and hold floodwaters and absorb wave energy which would otherwise degrade a shoreline. Wetlands recharge groundwater, remove pollution and provide diverse habitat as well as recreational activities.

Due to land acquisition costs, Restoration/preservation of existing wetlands is likely to be more successful than creation of new wetlands. Wetland restoration design considerations include site selection criteria, hydrology, water source and quality, substrate and plant material selection and handling, buffer zone placement and long term management.

IX. NACCS Coastal Storm Risk Management Framework Applications

IX.1. NACCS Tier 1 Assessment

The evaluation of measures is a relative comparison of the general assumption of a change in risk by applying a particular management measure based on shoreline type. The NACCS Tier 1 assessment utilizes national datasets for the North Atlantic coast scale. At this scale and corresponding level of detail in the datasets, the Tier 1 analyses include the broad evaluation of exposure and then risk defined as a function of exposure and probability of flooding, which corresponds to an assumed flood return periods associated with flood inundation mapping. The Tier 1 assessment incorporates the following datasets: shoreline types, shoreline lengths, inundation mapping, NACCS composite exposure results, structural measures applicable to shorelines types, and parametric unit costs. Additional information related to the theory of the Tier 1 assessment is included in the Economics and Social Analyses Appendix, with the results of the Tier 1 assessment presented in the State and District of Columbia Analyses Appendix. It is important to note that this level of analysis should be considered a preliminary approximation, which requires much more detail before any decisions can be made for implementation. By completing a tiered analysis, the assumptions and data requirements become more refined at a smaller scale (Tier 2 and Tier 3).

As part of the NACCS Framework Tier 1 evaluation, an initial screening of potentially applicable measures for each risk area identified as part of the exposure and risk assessment was performed considering shoreline types and the estimated reduction in risk for a given cost. For each risk area, using the management measures identified by applicable shoreline type, and identifying the shoreline types and computing the corresponding shoreline lengths within the risk areas, a general evaluation and comparison of the measures that might be applicable in those areas was completed. Additionally, with the qualitative assessment of risk reduction potential identified for the management measures, as well as using the parametric unit costs, an evaluation of the measures as part of an initial screening of measures was also completed. For those areas of the coast that were not specifically identified as a risk area as part of the Tier 1 exposure and risk assessment, local communities and stakeholders could use the information presented in the Framework to develop similar comparisons. Additional discussion of the evaluation of the change in risk reduction potential related to corresponding costs is presented in the Economics and Social Analyses Appendix.

The primary limitation to the NACCS Tier 1 evaluation and comparison of structural (including NNBF) and non-structural solutions to address flood risk was the scale at which the analyses were completed. Because the study area scale was vast, covering 10 states and the District of Columbia, the Tier 1 evaluation required the use of consistent national datasets that were available across the entire study area, which decreased the level of detail and granularity. For example, in some areas of rather homogenous shorelines, such as beaches or urban areas, only a few measures are likely to be applicable in those areas based on the NACCS measures application to shoreline type. The lowest parametric unit cost of those measures that may be applicable for the corresponding shoreline type and that provided the same level of qualitative risk reduction potential results in the same measures identified in those risk areas. Scale and corresponding level of detail necessary to inform decision-makers as to the appropriate adaptation strategy and management measures to employ requires further analysis as part of the aforementioned Tier 2 and Tier 3 assessments to be completed at a smaller scale with refined objectives, constraints, and datasets. Furthermore, the subsequent analyses should also adequately consider the range of future, long-term scenarios associate with climate change adaptation planning in order to adequately address and account for risk-based planning analyses of potential future risk when attempting to address existing risk.

IX.2. NACCS Tier 2 Example Areas: Relative Costs for Various Risk Management Strategies

As part of the NACCS Tier 2 example area assessment, one risk area for each state and the District of Columbia was further divided into subareas to generally identify those areas appropriate for the various flood risk management adaptation strategies - avoid, accommodate, and preserve - along with applicable structural (including NNBF) and non-structural management measures. The purpose of this iterative evaluation is to reevaluate the Tier 1 assessment at a smaller scale while considering existing coastal storm risk management projects and planned projects.

The NACCS Tier 1 composite exposure and risk assessments were used for the Tier 2 assessments because the analysis was intended to be consistent applications across each of the ten Tier 2 examples completed as part of the NACCS. As a result, the change in risk for the example areas could not be further refined to the subareas of the risk area. However, the assumptions for various costs were updated as opposed to parametric unit costs based on shoreline type, which was the basis for the Tier 1 evaluation and comparison of management measures. For specific Tier 2 applications of the Framework by coastal communities, the exposure, risk, and potentially vulnerability assessments would be updated or completed in addition to refining the adaptation strategies and corresponding management measures. In addition, more refined costs would be developed as well in order to better address the comparability of the adaptation strategies and corresponding management measures necessary to lead to a plan for implementation.

IX.3. Tier 3 Assessments

A Tier 3 assessment to address coastal flood risk would likely consist of a feasibility-level analysis, which includes considering combinations of measures for comparison of alternative plans at a much finer level of detail and incorporating a benefit-cost analysis. Additional characteristics or metrics beyond change in risk and cost should be explicitly considered at this level of analysis and the best available data should be incorporated. At this level of evaluation consideration should be given to other metrics associated with exposure, risk, and vulnerability, including refined metrics associated with exposure to incorporate site-specific datasets of finer detail and resolution, sensitivity and adaptive capacity, as well as various metrics associated with evaluation of management measures objectives like risk reduction (life safety), damage reduction, feasibility, and impacts. The various technical products developed as part of the NACCS could aid in the completion of these analyses, available on the NACCS webpage http://www.nad.usace.army.mil/CompStudy.aspx.

X. Real Estate

The NACCS Framework provides additional information for any Federal, state, tribal, local, or non-governmental entity to consider structural, non-structural, and NNBF management measures for further study and/or implementation. The NACCS does not identify a "recommended plan" nor justify projects. It is not a decision document, but a framework from which more detailed evaluations can be pursued.

To consider as part of Tier 2 and Tier 3 analyses, a real estate plan or analysis for any type of study or project should include a minimum of the following:

- Description of Lands, Easements, Rights-of-Way, and Roadway Requirements for Project: A description of the LER required for each project purpose (e.g., flood control, mitigation, recreation, etc.) and feature (e.g., dunes, levees, borrow areas, staging areas, access, etc.) should be explained, including LER required for construction and operation and maintenance of the project. If construction will be accomplished in phases, which is often the case for large shoreline stabilization projects, the analysis should provide an outline and breakdown the LER required for each phase.
- Estate Language: Estate types and language should be provided including the acreage required for each estate, number of tracts, number of ownerships, and the gross estimated value for each estate. For shoreline stabilization projects this most often will be a perpetual Beach Storm Damage Reduction Easement. Temporary Work Area Easements are also often necessary for construction staging and access. Due to the many similar, but distinct, local, state, and Federal projects that may be initiated over time, inter-agency and partner coordination is recommended. In order that appropriate easements are acquired from the onset that will be acceptable for potential overlapping projects, it would be beneficial if all parties utilized the Federal standard storm damage reduction easement, to reduce the need to have to acquire additional easement rights over the same properties for future projects.
- Current Ownership: A list of parcels and owners shall be included. Such lists are usually derived from county tax records and the estate acreage for the particular portion necessary for each project parcel is added. This is considered preliminary ownership data only. A full title search of ownership for each parcel should be conducted later prior to acquisition.
- Real Estate Mapping: Real Estate mapping should be included, showing the tracts, acreages and estates required for the project in relation to the design. Also, utilities or facilities to be relocated should be shown.
- Relocations: Provide the number of any persons (owners and tenants), businesses and farms to be relocated, including estimated cost of relocation benefits, availability of replacement housing, and any anticipated need for last resort housing, and the reasons therefore. Generally such relocations are performed under the guidance of Federal Public Law 91-646.
- Utility and Facility Relocations: Describe the owners and type of any utility/facility relocation with a description of the impact to each.
- LER Acquisition Schedule: A detailed schedule of all the real estate acquisition activities shall be provided with a minimum of the anticipated dates for surveys, title work, appraisals, appraisal reviews, negotiations, closings, condemnations, and possession.
- Baseline Cost Estimate for Real Estate: A cost estimate for real estate and any anticipated relocations shall be attached as an exhibit. The estimated cost shall include both administrative costs as well as estimated costs for the LER.

A real estate plan or analysis should be included as part of climate change adaptation planning actions to fully incorporate potential long-term impacts from sea level change inundation. In addition, adaptive management actions should also include real estate considerations to address future conditions and potential future real estate acquisitions.

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