DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
CIVIL WORKS
108 ARMY PENTAGON
WASHINGTON DC 20310-0108

NOV - 6 2013

Honorable Harold Rogers
Chairman
Committee on Appropriations
United States House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

I am pleased to provide you with the Hurricane Sandy Coastal Projects Performance Evaluation Study as required in Public Law 113-2, providing supplemental appropriations for the Corps of Engineers in response to the effects of Hurricane Sandy.

Specifically, the language in the Act states: *"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".*

Identical letters are being sent to the Chairwoman of the Senate Appropriations Committee and the Chairs of the Senate and House Appropriations Subcommittees on Energy and Water Development.

Very truly yours,

Jo-Ellen Darcy

Jo-Ellen Darcy
Assistant Secretary of the Army
(Civil Works)

Enclosure

CF: Honorable Nita Lowey
Ranking Member

Hurricane Sandy Coastal Projects Performance Evaluation Study

Disaster Relief Appropriations Act, 2013

US Army Corps
of Engineers ®

Submitted by
the Assistant Secretary of the Army for Civil Works

November 6, 2013

EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE) was directed by Chapter 4 of Public Law 113-2, Disaster Relief Appropriations Act 2013, to evaluate the performance of existing USACE projects impacted by Hurricane Sandy, with the purpose of determining their effectiveness and recommending improvements thereto. The Hurricane Sandy Coastal Projects Performance Evaluation Study's primary focus is an evaluation of 75 constructed coastal storm damage reduction projects in the North Atlantic Division. In addition, the study includes evaluations of 31 projects in the Great Lakes and Ohio River Division and nine (9) projects in the South Atlantic Division. The performance of each of these projects was reviewed to determine the effectiveness of the project with respect to both the engineering performance and the projects' ability to provide safety, economic benefits, and to recommend improvements as necessary. It is recognized that comprehensive protection is a shared responsibility among the local, state, and Federal partners. This evaluation highlights institutional and other barriers to providing comprehensive protection to affected coastal areas that have been identified to date and are subject to further investigation pursuant to the ongoing Hurricane Sandy North Atlantic Coast Comprehensive Study (NACCS), also authorized under the investigations heading of Chapter 4 of Public Law 113-2. The report also identifies benefit categories not generally considered within the National Economic Development (NED) framework typically used in project justification. These additional damage categories, evident from the impacts of Hurricane Sandy, were used to evaluate each project's economic performance and ability to provide risk reduction.

Hurricane Sandy was an extraordinary storm, particularly in the coastal areas extending from Cape May, NJ to Montauk Point, NY. Peak water levels indicate that Hurricane Sandy was at least greater than a 200 year event (1 in 200 annual exceedance probability), greatly exceeding project design levels. This resulted in damages throughout the New York City metropolitan area. Beyond the New York Bight, including New Jersey, along the north shore of Long Island, NY, Connecticut, Rhode Island, southern Massachusetts, and the Atlantic coasts of Delaware and Maryland, storm tides, although still significant, were considerably lower, typically a 20 to 30 year event. Farther away, in Massachusetts north of Cape Cod, New Hampshire, and Maine to the north and the Chesapeake Bay coastline of Maryland and Virginia to the south, Hurricane Sandy was less than a 10 year event.

Six (6) projects: Sea Bright to Manasquan, NJ; Keansburg, East Keansburg, and Laurence Harbor, NJ; Oakwood Beach, NY; Coney Island, NY; Plumb Beach, NY; and Rockaway, NY were subject to extreme storm tides and waves (> 200 year event). These projects did not eliminate, but did reduce storm damage despite the fact that storm tides and waves exceeded the design storm. Beaches served to mitigate wave-induced structural damages for most of the area. Within the project area of the existing USACE projects, wave related damages were not widespread and were usually limited to the first or second row of buildings as in Sea Bright and Manasquan in New Jersey and Rockaway in New York.

Eight (8) additional projects were subject to storm tides of between a 30 and a 200 year event. While these projects suffered significant loss of fill and will be costly to restore, they were effective in minimizing wave and erosion damages. The 61 projects in areas subject to storm tides less than a 30 year event generally performed well, though damage at several smaller projects was greater than expected.

In many locations, heavily developed areas on the bayside of many projects (and non-project areas) were subject to back-bay flooding and wide-spread inundation damage. Projects in these areas were not authorized or formulated to comprehensively manage flood risks from the back-bay. These bayside areas remain vulnerable to future flooding and sea level rise. Projects that were intended to provide comprehensive protection, including seawalls, levees and closure gates to prevent inundation, provided effective damage reduction.

The USACE recognizes that more comprehensive protection can only be realized when individuals and government agencies at non-Federal and Federal levels collectively recognize, understand, and act to manage and effectively reduce risks attributed to threats posed by flooding and coastal storms. Institutional and other impediments identified below reflect those previously encountered during implementation of USACE flood and coastal storm damaged risk reduction investigations and projects (additional discussion of barriers is included in Section 4.0):

- Delivery of more comprehensive protection to affected coastal areas requires a broader approach to the investigation and planning of flood and coastal storm damage reduction projects that includes consideration of potential flooding of back-bay reaches of barrier islands among other concerns. Provision of increased levels of flood risk reduction may increase the cost of projects, so evaluation of such projects will be based on economic benefits, as well as other factors such as reduced risk of mortality and capacity for a resilient recovery.
- The data for evaluating project performance, including measurements of water levels, nearshore waves and currents, coastal winds, and pre- and post-storm topographic and bathymetric surveys, is not available for all projects.
- The complexities associated with securing real estate easements continues to be a challenge with providing a comprehensive system of coastal storm damage risk reduction.
- Permit conditions and environmental construction windows designed to reduce or avoid impacts to endangered or threatened species limit the duration of dredging that can occur with a given year. Furthermore, environmental considerations may increase the level of effort required to identify and select borrow source sites, and may restrict site selection to Federal navigation channels even when borrow areas can be found closer to the project that would have lower borrow material transportation costs.
- Different communities value different aspects of the benefits that coasts provide, and maintaining those benefits may conflict with and challenge the Corps' flood and storm damage reduction mission. Reconciling these differences can be difficult.

This report identifies several recommendations to improve project performance, including:

- Projects should consider how to address the impacts of back-bay flooding of barrier islands to provide more comprehensive protection or identify the residual risks to ensure public and agency awareness.
- The efficacy of natural and engineered dunes in reducing risks of coastal storm damages should be evaluated. Some projects with high storm berms or those backed by significant dunes generally performed better than projects involving a berm alone,
- A broader range of project benefits should be considered to more accurately evaluate the impacts of extreme storm and flooding events. These include community resilience and recovery which would be enhanced by explicitly protecting critical infrastructure and basic services.
- The Corps should identify a limited number of strategically located projects at which to collect nearshore wave/current and coastal wind data, in coordination with other Federal, state and local agencies and partners; it should also conduct regular surveys of those projects (such as before storm season and after significant storms).
- Projects need to include an adaptive management plan or strategy for changing the design within the authorization to respond to external factors, such as changes in local weather patterns or sediment transport, shifts in development trends or public tolerance for storm risks, or changes in coastal flood risks due to climate change. In addition, coastal flood risk analysis technologies are improving at a remarkable rate. Both external factors and changing risk analysis and modeling can lead to changes in project planning, design and nourishment/ maintenance. There should be a streamlined institutional mechanism that allows changes in project dimensions during the life of the project. Design Standards should allow for flexible use of renourishment material, perhaps based on a volume-of-fill standards, which would allow for adaptive management of the beachfill design features over time to reflect changes in coastal forcing events.
- Use of regional sediment management practices could supplement coastal protection and regional planning with various Federal and non-Federal agencies and stakeholders could be conducted to identify and analyze sand resources.

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1.0 INTRODUCTION

1.1 Purpose

The Hurricane Sandy Coastal Projects Performance Evaluation Study ("Performance Evaluation Study") describes the performance of existing Corps constructed coastal storm and flood damage reduction projects[1] to document the effectiveness of projects and to recommend improvements that might offer more comprehensive risk reduction. Additionally, the study summarizes institutional and other barriers to providing comprehensive protection to coastal areas that have been identified to date and are being further investigated as part of the ongoing Hurricane Sandy North Atlantic Coast Comprehensive Study (NACCS).

1.2 Study Authorization

This Performance Evaluation Study was authorized in Chapter 4 of P.L. 113-2, Disaster Relief Appropriations Act 2013.

> *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 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:*

1.3 Study Scope

1.3.1 Study Area

The Disaster Relief Appropriations Act of 2013 (P.L. 113-2) directed the Secretary of the Army to 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 (NAD) of the USACE and an evaluation of 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. While Hurricane Sandy impacted the NY/NJ Metropolitan area with the greatest storm surges and waves, a large portion of the coastal regions of the NAD were also impacted. Additionally, coastal and interior regions

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[1] Including hurricane protection, beach erosion control, and coastal storm damage reduction projects.

of South Atlantic Division (SAD) and Great Lakes and Ohio River Division (LRD) experienced impacts from Hurricane Sandy.

1.3.2 Projects Evaluated

Due to the magnitude of the evaluation effort and the distribution of impacts from Hurricane Sandy, the Performance Evaluation Study reflects a concentration on the NAD region extending from the Maine/Canada border to the Virginia/North Carolina border and encompassing the civil works boundaries of New England, New York, Philadelphia, Baltimore and Norfolk Districts. In addition to evaluations of projects in the NAD, the study includes a less detailed performance evaluation for projects in the SAD and LRD regions. The evaluation effort examines coastal flood and storm damage reduction projects that were impacted by Hurricane Sandy's storm surge and waves, and institutional and other barriers to comprehensive protection reflect observations made to date. While delivery of comprehensive protection is recognized as a shared responsibility among local, state, and Federal partners, this report centers on projects constructed by the USACE and associated institutional and other barriers. It is important to note that many of these projects were authorized and completed over a broad range of time when different terminologies were used to name and describe projects designed and constructed to reduce risk of coastal storm damages. Throughout the report some of these projects may be referred to as coastal storm damage reduction projects, hurricane and storm damage reduction projects, shore protection projects, beach erosion control projects, or something similar. Keep in mind that all of these projects fall under the classification used today, or coastal storm damage reduction projects. The intent was to include all projects that have been constructed and /or partially constructed with the purpose of reducing risks from coastal storms. These projects may include any of the following structural components: beach fill, dunes, groins, seawalls, revetments, dikes, storm gates and barriers; or non-structural measures like home elevations. Smaller projects within the Continuing Authorities Program Sections 103, 204, and 14 have been included in this Study. Ultimately, seventy five (75) projects within NAD, nine (9) projects within SAD, and thirty one (31) projects within LRD were considered, several of which have gone through one or more renourishment cycles. The list of projects within NAD considered, from north to south by State, is provided in Table 1. The evaluation of projects in SAD and LRD was developed as supporting documentation.

1.3.3 Performance Evaluation Methodology

The performance of all the projects listed in Table 1 was initially documented in a standardized data call template that was generated for each project by each responsible NAD district. The template captured general project information (location, project description, authorization, construction history, etc.), design data, the pre-storm project condition, resources at risk, and a number of physical and economic performance metrics.

For the purposes of this study, physical performance refers to performance of the project itself as an engineered feature to limit inundation, wave attack and storm induced erosion. Data was also requested on whether the project features suffered impacts as a result of the storm, whether the project features (e.g., beach fill, dikes, revetments, gates, etc.) suffered damages as a result of the storm (e.g., erosion of beach fill or loss of rock in a revetment). Economic performance refers to the manner in and the extent to which the project achieved the intended reduction in risk of coastal storm damages to protected resources at risk (e.g., reduction in damages to protected buildings or infrastructure.)

Additionally, each template documents institutional and other barriers to providing comprehensive protection to each project area. In this study, the term "comprehensive protection" refers to protection against coastal flood risks, primarily due to storm tides and waves, over the typical life of an USACE project, 50 years. In addition, the term "barriers" generally refers to obstacles faced by USACE during project implementation. Neither the information captured in the templates nor the overall evaluation presented in this report considers other possible barriers to comprehensive protection at the State/Local/Individual level, beyond real estate acquisition.

The information that was captured in the data call templates was condensed in a consistent format in a series of individual project performance evaluation summaries and developed as supporting documentation. Finally, the most relevant information contained in the specific project performance summaries was assembled together and organized in the main body of this report as described in the following section.

1.4 Report Organization

Section 2.0 of the report provides a detailed description of Hurricane Sandy with an emphasis on coastal impacts (storm tides and waves).

Section 3.0 provides overall performance summaries for projects grouped by degree of exposure to Hurricane Sandy's storm tide and waves.

Section 4.0 summarizes barriers to comprehensive protection to coastal areas. Finally, Section 5.0 provides a summary of study findings, conclusions and recommendations.

Appendix A provides a glossary of technical terms used in the report including definitions for typical coastal flood and storm damage reduction project features such as beach fill, groins, revetments, dikes, levees, etc.

Table 1: List of Coastal Projects Considered in the NAD Study Area

Count	Project Name	Location	Year of Initial Construction	Business Line/CAP Section	Project Features
	New Hampshire (2)				
1	Hampton Beach	Hampton, NH	1955	FRM [1]	Beach Fill and Groin
2	Wallis Sands State Beach	NH	1963	FRM	Beach Fill and Groin
	Massachusetts (15)				
3	Bluffs Community Center	Swansea, MA	1994	Section 14	Rock Revetment
4	Town River Bay	Quincy, MA	1992	Section 14	Rock Revetment
5	Point Shirley	Winthrop ,MA	1995	Section 14	Rock Revetment
6	Island Ave	Quincy, MA	1983	Section 14	Rock Revetment
7	New Bedford Hurricane Barrier	New Bedford, MA	1964	FRM	Hurricane Barrier and Dikes
8	Clark Point Beach	New Bedford, MA	1980	Section 103	Beach Fill and Groins
9	Oak Bluffs Town Beach	Oak Bluffs, MA	1973	Section 103	Beach Fill and Groin
10	Plum Island	Newbury, MA	1973	Section 103/204	Beach Fill
11	Revere Beach	Revere, MA	1991	FRM	Beach Fill
12	Roughans Point	Revere, MA	1999	FRM	Revetment and Interior Drainage
13	North Scituate Beach	Scituate. MA	1967	FRM	Beach Fill
14	Quincy Shore Beach	Quincy, MA	1959	FRM	Beach Fill and Bulkheads
15	Wessagusset Beach	Weymouth, MA	1959	FRM	Beach Fill and Groins
16	Winthrop Beach	Winthrop, MA	1959	FRM	Seawall, Beach Fill and Groins
17	Salisbury Beach	Salisbury, MA	2011	Section 204	Beach Fill
	Rhode Island (4)				
18	Fox Point Hurricane Barrier	Providence, RI	1966	FRM	Hurricane Barrier and Dikes
19	Misquamicut Beach	Westerly, RI	1960	FRM	Beach Fill
20	Oakland Beach	Warwick, RI	1981	Section 103	Beach Fill, Groins, Revetment
21	Cliff Walk	Newport, RI	1972	FRM	Revetment and Retaining Walls
	Connecticut (13)				
22	Bridgeport (Port V)	Bridgeport, CT	1984	Section 14	Revetment and Retaining Wall
23	Gulf Street	Milford, CT	1988	Section 14	Rock Revetment
24	Woodmont Beach	Milford, CT	1995	Section 103	Beach Fill and Groins
25	Gulf Beach	Milford, CT	1957	FRM	Beach Fill
26	Sea Bluff Beach	West Haven, CT	1991	Section 103	Beach Fill and Groin
27	Prospect Beach	West Haven, CT	1995	Section 103	Beach Fill

Count	Project Name	Location	Year of Initial Construction	Business Line/CAP Section	Project Features
28	Sherwood Island State Beach	Westport, CT	1957	Section 103	Beach Fill and Groins
29	Southport Beach	Fairfield, CT	1958	FRM	Beach Fill and Groins
30	Middle Beach	Madison, CT	1957	FRM	Rock Revetment
31	Point Beach	Milford, CT	2004	Section 103	Non-Structural
32	New London Hurricane Barrier	New London, CT	1986	FRM	Hurricane Barrier and Dikes
33	Stamford Hurricane Barrier	Stamford, CT	1969	FRM	Hurricane Barrier and Dikes
34	Pawcatuck Hurricane Barrier	Stonington, CT	1964	FRM	Hurricane Barrier and Dikes
	New York (11)				
35	West of Shinnecock Inlet	Southampton, NY	2005	FRM	Beach Fill
36	Westhampton Interim	Southampton, NY	1997	FRM	Beach Fill and Groins
37	Fire Island to Shores Westerly	Nassau Co., NY	1975	FRM	Beach Fill
38	Rockaway	Queens, NY	1977	FRM	Beach Fill
39	Coney Island	Brooklyn, NY	1995	FRM	Beach Fill, Groin, Retaining Wall
40	Oakwood Beach	Staten Island, NY	2000	Section 103	Levee, Tide Gate
41	Shelter Island	Shelter Island, NY	1999	Section 14	Stone Revetment and Sheet Pile Wall
42	Village of Northport	Northport, NY	2004	Section 14	Stone Revetment and Sheet Pile Wall
43	Orient Harbor	East Marion, NY	2011	Section 14	Stone Revetment
44	Asharoken	Asharoken, NY	1998	Section 103	Steel Sheet Pile Wall
45	Plumb Beach	Brooklyn, NY	2012	Section 204	Beach Fill, Groins, Dike
	New Jersey (11)				
46	Keansburg, East Keansburg, Laurence Harbor	Middlesex & Monmouth Co, NJ	1966	FRM	Beach Fill, Levees, Floodwall, Storm Gate, Pump Station
47	Sea Bright to Manasquan	Monmouth Co, NJ	1995	FRM	Beach Fill
48	Barnegat Inlet to Little Egg Inlet	Long Beach Island, NJ	2007	FRM	Beach Fill
49	Brigantine Island	Brigantine, NJ	2006	FRM	Beach Fill
50	Absecon Island	Atlantic City, NJ	2004	FRM	Beach Fill, Bulkhead
51	Ocean City (Great Egg Harbor Inlet and Peck Beach)	Ocean City, NJ	1993	FRM	Beach Fill
52	Townsends Inlet to Cape May Inlet	Cape May Co, NJ	2003	FRM	Beach Fill, Stone Revetment
53	Cape May City (Cape May to Lower Township)	Cape May, NJ	1991	FRM	Beach Fill and Groins
54	Lower Cape May Meadows to Cape May Point	Cape May Point, NJ	2005	FRM	Beach Fill, Ecosystem

Count	Project Name	Location	Year of Initial Construction	Business Line/CAP Section	Project Features
					Restoration
55	Ocean Gate	Toms River, NJ	2002	Section 14	Beach Fill
56	East Point	Cumberland Co, NJ	2012	Section 14	Revetment
	Delaware (7)				
57	Roosevelt Inlet – Lewes Beach	Lewes, DE	2004	FRM	Beach Fill
58	Indian River Inlet Sand Bypassing	Sussex Co, DE	1989	FRM	Sand Bypassing
59	Bethany – South Bethany	Sussex Co, DE	2008	FRM	Beach Fill
60	Fenwick Island	Sussex Co, DE	2005	FRM	Beach Fill
61	Rehoboth Beach and Dewey	Sussex Co, DE	2005	FRM	Beach Fill
62	South Shore Indian River Inlet	Sussex Co, DE	1988	Section 103	Stone Revetment
63	North Shore Indian River Inlet	Sussex Co, DE	1988	Section 103	Stone Revetment
	Maryland (2)				
64	Atlantic Coast (Ocean City)	Ocean City, MD	1990	FRM	Beach Fill & Bulkhead
65	Assateague Island	Worcester Co, MD	2002	FRM	Beach Fill, Sand Bypassing
	Virginia (10)				
66	Chesapeake Bay Shoreline	Hampton, VA	2005	FRM	Beach Fill
67	Virginia Beach Hurricane Protection	Virginia Beach, VA	2002	FRM	Beach Fill& Bulkhead
68	Sandbridge Beach	Virginia Beach, VA	2003	FRM	Beach Fill
69	Cape Charles Shore Protection	Cape Charles, VA	1992	Section 14	Rubble Seawall
70	Saxis Island Bulkhead	Saxis, VA	1989	Section 14	Timber Bulkhead
71	Hampton Institute Shore Protection	Hampton, VA	1976	Section 103	Stone Revetment
72	Anderson Park Shore Protection	Newport News, VA	1979	Section 103	Stone Revetment
73	Tangier Island Shore Protection	Tangier Island, VA	N/A	FRM	Stone Revetment
74	Norfolk Floodwall	Norfolk, VA	1971	FRM	Steel Sheet Pile Wall
75	Jamestown Island Seawall	Jamestown, VA	1969	103	Concrete Block Wall

Notes: [1] Flood Risk Management (FRM)

2.0 DESCRIPTION OF HURRICANE SANDY

2.1 Introduction

The National Oceanic and Atmospheric Administration (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 water levels, winds, barometric pressure, and air/water temperature. The National Hurricane Center (NHC) is the division of the 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:

- Colleen Fanelli, Paul Fanelli and David Wolcott, 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

2.2 Hurricane Sandy Time Line

Hurricane Sandy initially formed as a tropical depression in the southwestern Caribbean, about 320 miles south-southwest of Kingston, Jamaica on October 22, 2012. Hurricane Sandy followed a generally northward track over the coming days, moving over eastern Jamaica as a Category 1 hurricane, eastern Cuba and the Bahamas as a Category 3 hurricane. As Hurricane Sandy moved over the Bahamas, it curved slightly to the west. Even though Hurricane Sandy remained well offshore of Florida as a Category 1 hurricane on October 26th (see Figure 1), tropical storm force winds began to affect the U.S. Atlantic coast. Hurricane Sandy[2] then began to take a more northeasterly track, following the coastline of North and South Carolina from October 27th to October 29th while remaining 250 to 300 miles offshore. Although Hurricane Sandy remained a Category 1 hurricane, the storm continued to grow in size. On October 29th, Hurricane Sandy encountered an anomalous blocking pattern over the North Atlantic preventing the storm from moving out to sea and steering it towards the mid-Atlantic coast. As Hurricane Sandy approached the mid-Atlantic coast it moved over cooler waters and into a cold air mass. The storm weakened and began transitioning into an extratropical storm. The extratropical storm made landfall near Atlantic City, NJ around 20:00 EDT on October 29th. The storm still exhibited winds equivalent to a Category 1 hurricane at landfall. Following landfall, the storm moved west-northwestward through Pennsylvania, continuing to impact areas with tropical storm force winds and heavy rainfall and snow before eventually curving northward into Canada the following day.

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[2] While Hurricane Sandy was, at times, a tropical storm, a hurricane and a post-tropical cyclone prior to making landfall along the East Coast of the U.S., the storm will be referenced as Hurricane Sandy throughout this report.

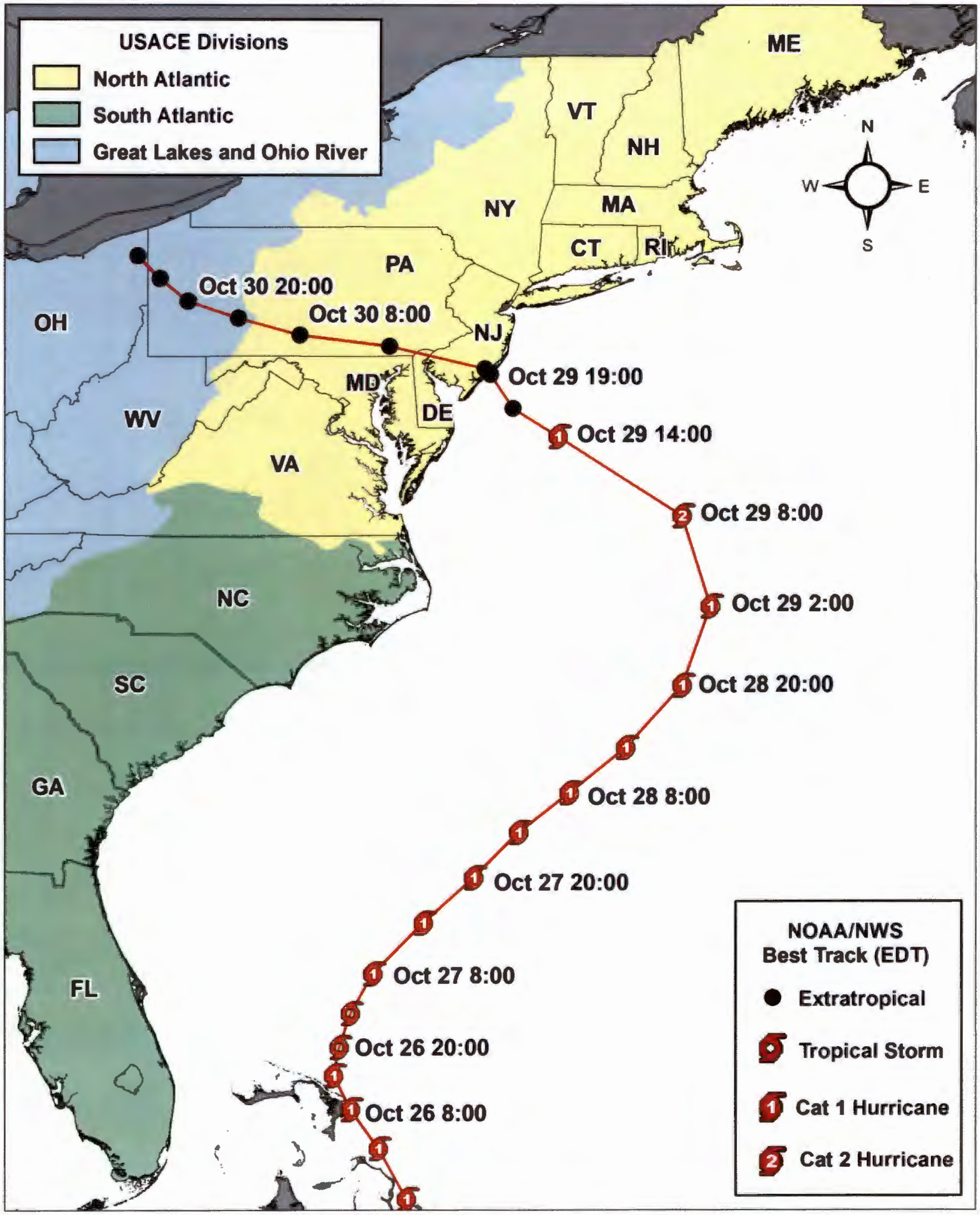

Figure 1: Best Track positions for Hurricane Sandy, 26 – 29 October 2012

2.3 Meteorological Characteristics

2.3.1 Wind Field

The National Hurricane Center (NHC) estimated that Hurricane Sandy's wind speeds peaked at 115 mph prior to landfall in Cuba, making it a Category 3 hurricane on the Saffir-Simpson Hurricane Wind Scale. As Hurricane Sandy moved over the Bahamas its maximum sustained wind speed decreased and Hurricane Sandy was downgraded to a tropical storm. Although weaker, the size of the storm greatly increased with the average radii of tropical-storm-force winds roughly doubled since its landfall in Cuba. As Hurricane Sandy moved across the Atlantic Ocean the storm strengthened, eventually reaching Category 2 status just 12 hours before landfall in New Jersey with maximum sustained winds of 98 mph. Hurricane Sandy retained its unusually large wind field as it strengthened over the Atlantic, with a radius of maximum winds estimated to be over 100 nautical miles.

Wind speed observations recorded by NOAA and the NHC indicate that sustained hurricane-force winds almost certainly occurred in New Jersey and over limited areas in New York. Several observation sites in northern New Jersey and southern Long Island reported peak wind gusts of 86-90 mph. Strong wind gusts primarily associated with the Hurricane Sandy's extratropical stage penetrated as far westward as Wisconsin and northward into Canada as well. The latter two facts exemplify the exceptionally large wind field that characterized Hurricane Sandy. Figure 2 shows Hurricane Sandy's wind field as it approached the mid-Atlantic Coast; displaying tropical storm force winds more than 100 miles beyond the center of the system.

2.3.2 Rainfall

Hurricane Sandy produced torrential rains across parts of Jamaica, eastern Cuba, and Hispaniola. 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 5-7 inches of rain[3], 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, along with storm surge, to the flooding in New York and New Jersey along the Hudson River.

2.3.3 Central Pressure

The overall minimum central pressure of Hurricane Sandy was estimated to be 940 millibars (mb), which occurred near 14:00 EDT October 29th, a few hours before its landfall in New Jersey. The minimum central pressure at landfall was estimated at 945.5 mb at 18:24 EDT October 29th, based on measurements at National Ocean Service (NOS) station ACYN4. The Atlantic City report has been noted by several agencies as the lowest sea-level pressure ever recorded north of North Carolina in the United States. The 1938 Great New England hurricane, however, is analyzed to have made landfall with a slightly lower central pressure (941 mb), although no pressure below 946 mb was recorded. Several sites across the mid-Atlantic region also recorded their all-time minimum pressures during the passage of Hurricane Sandy. Among the lowest was Atlantic City International Airport with 948.5 mb and Philadelphia, PA, with 952.2 mb.

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

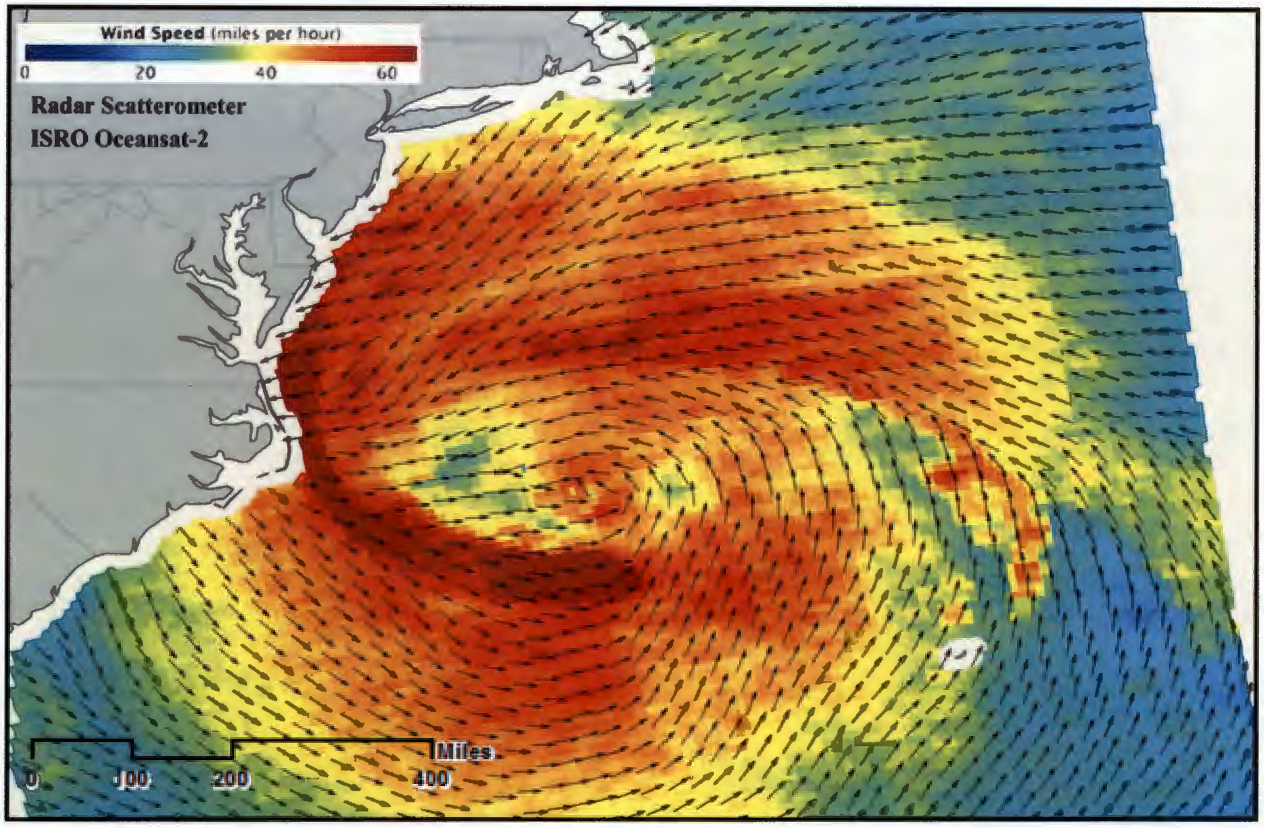

Figure 2: Hurricane Sandy Wind Field on October 28 (source: NASA[4])

2.4 Storm Tide

2.4.1 NOAA Observations

Hurricane Sandy caused water levels to rise along the entire east coast of the United States from Florida northward to Maine. The highest storm surges and greatest inundation on land occurred in the states of New Jersey, New York, and Connecticut, especially in the New York City metropolitan area.

Several terms are used to describe water levels due to a storm. Storm surge is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tide. Since storm surge represents the deviation from normal water levels, it is not referenced to a vertical datum, and is expressed in terms of height above normal tide levels. Storm tide is defined as the water level due to the combination of storm surge and the astronomical tide, and is expressed in terms of elevation referenced to a vertical datum, e.g. the North American Vertical Datum of 1988 (NAVD88) or a local tidal datum such as Mean Higher High Water (MHHW). Inundation is the total water depth that occurs on normally dry ground as a result of the storm

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[4] http://earthobservatory.nasa.gov/IOTD/view.php?id=79626

tide, and is expressed in terms of height above ground level. At the shoreline, normally dry land is roughly defined as areas higher than the normal high tide line, or MHHW.

Table 2 provides maximum storm tide elevations recorded during Hurricane Sandy at NOAA stations in the study area. Storm tide elevations are presented in Table 2 relative to both NAVD88 and MHHW. Referencing the storm tide elevations to MHHW provides a sense of the inundation or depth of water above normal high tide along the shoreline. Figure 3 and Figure 4 present the maximum NOAA storm tide observations in Table 2 spatially in relation to Hurricane Sandy's track. It is evident from Figure 4 that maximum storm tides relative to MHHW were greatest in the New York City metropolitan area and generally less severe with distance from New York City.

Table 2 puts storm tides in perspective by comparing the observations during Hurricane Sandy with the 100-year event (the storm tide that has a 1% annual chance of exceedance in any given year.) For a select set of NOAA stations that have historical records greater than 70 years, these values have been determined by NOAA[5] and are presented in Table 2. It is noted that the statistical analysis of extreme water levels performed by NOAA does not account for Hurricane Sandy which would modify the 100-year event storm tide estimates. From the table it is evident that storm tides in SC, VA, DC, MD, MA, and ME were elevated, but well below the 100-year event. Storm tides in DE, PA, CT and RI were significantly elevated, but still below the 100-year event. Whereas some stations in NY and NJ near the New York City metropolitan area exceeded the 100-year event storm tide. This is further exemplified by the estimates presented in the last column of Table 2, which display the estimated event corresponding to Hurricane Sandy's storm tide. For example, the observation of +6.3 ft NAVD88 at Atlantic City is an estimated 30-year event storm tide, while the observed +11.3 ft NAVD88 at The Battery, NY is estimated to be in excess of a 200 year event according to the NOAA statistical analysis.

A statistical analysis recently performed by the U.S. Army Engineer Research and Development Center (ERDC), including data from Hurricane Sandy, suggests that the storm tide observed at The Battery, NY corresponded to a 700 year event, approximately (the analysis did not include the potential impacts of climate change). At Sandy Hook, NJ, the maximum observed storm tide was approximately +10.4 ft NAVD88. According to ERDC's analysis this elevation corresponded to approximately a 940-year event. However, the tide gage at Sandy Hook was destroyed during the storm, and an adjacent USGS high water mark suggests that the peak storm tide at Sandy Hook was approximately +11.6 ft NAVD88, corresponding to an even greater event at this station.

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

Table 2: Storm Tide Elevations Recorded at NOAA Tide Stations

NOAA Station	Storm Tide (ft, MHHW)	Storm Tide (ft, NAVD88)	100-year Event Storm Tide (ft, NAVD88)	Event associated to Hurricane Sandy Storm Tide (years)
Charleston, SC	1.6	4.2	7.1	1
Sewells Point, VA	4.1	5.2	7.1	13
Kiptopeke, VA	3.9	4.9	n/a	n/a
Washington, DC	2.9	4.7	12.4	4
Baltimore, MD	3.0	3.8	6.7	8
Ocean City, MD	3.5	4.4	n/a	n/a
Lewes, DE	4.0	6.1	6.9	30
Delaware City, DE	3.8	6.8	n/a	n/a
Philadelphia, PA	4.1	7.5	7.9	50
Cape May, NJ	3.6	5.9	n/a	n/a
Atlantic City, NJ	4.3	6.3	7.1	30
Sandy Hook, NJ	8.0[1]	11.6[1]	8.4	>> 200
Bergen Point, NY	9.1	11.6	n/a	n/a
The Battery, NY	9.0	11.3	7.3	>> 200
Kings Point, NY	6.5	10.2	12.9	25
Montauk, NY	4.3	5.5	6.9	25
Bridgeport, CT	5.8	9.3	n/a	n/a
New Haven, CT	5.5	8.7	n/a	n/a
New London, CT	4.9	6.2	7.6	30
Providence, RI	4.5	6.9	11.5	10
Newport, RI	4.3	6.1	8.1	22
Woods Hole, MA	3.6	4.4	7.3	10
Boston, MA	2.6	7.4	9.6	1
Portland, ME	2.0	6.6	8.8	1
Eastport, ME	1.4	10.7	14.3	<1

Notes: [1] Sandy Hook gage failed before the peak of the storm. Storm tide shown is based on and an adjacent USGS high water mark.

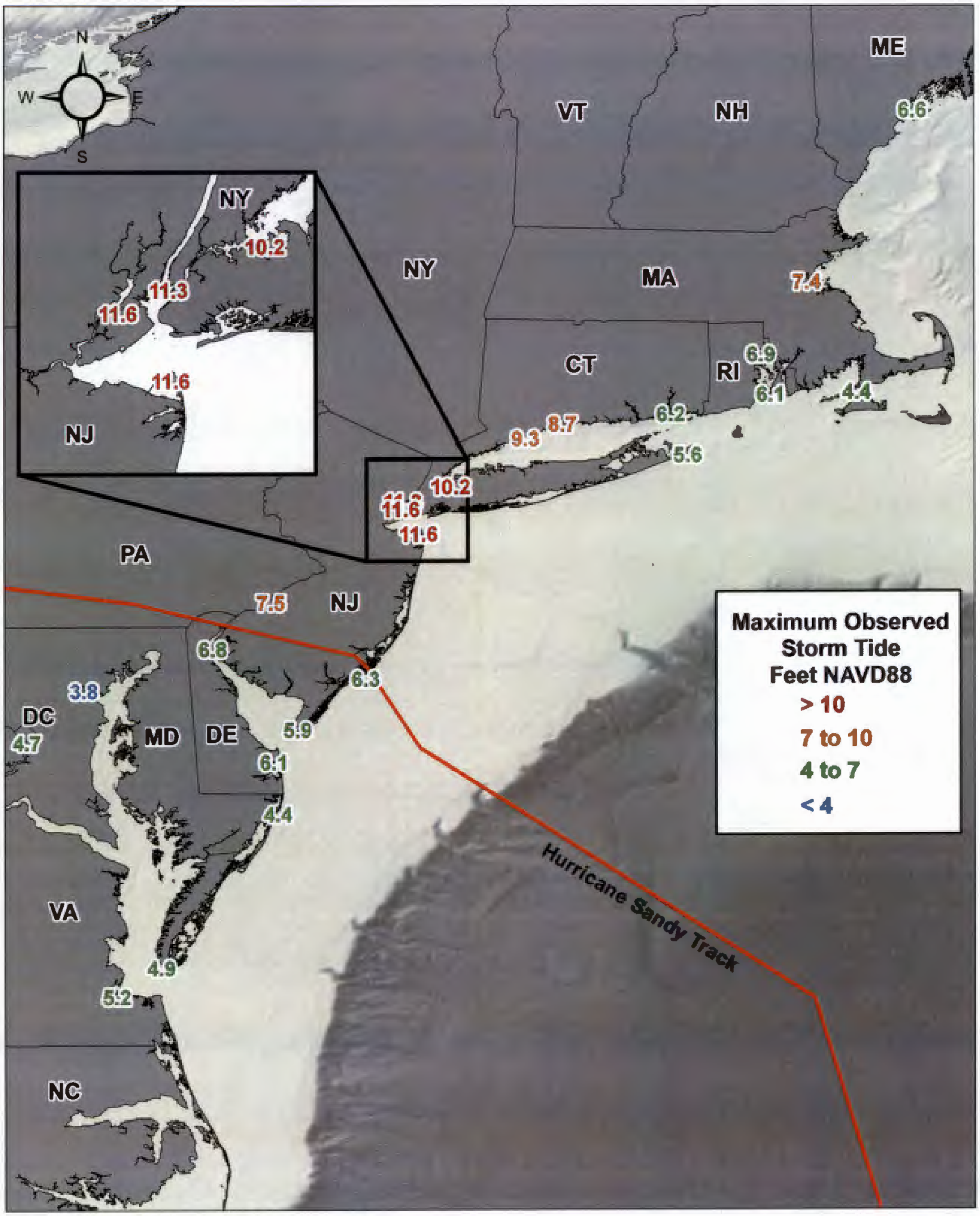

Figure 3: Storm Tide Elevations (NAVD88) Recorded at NOAA Gages

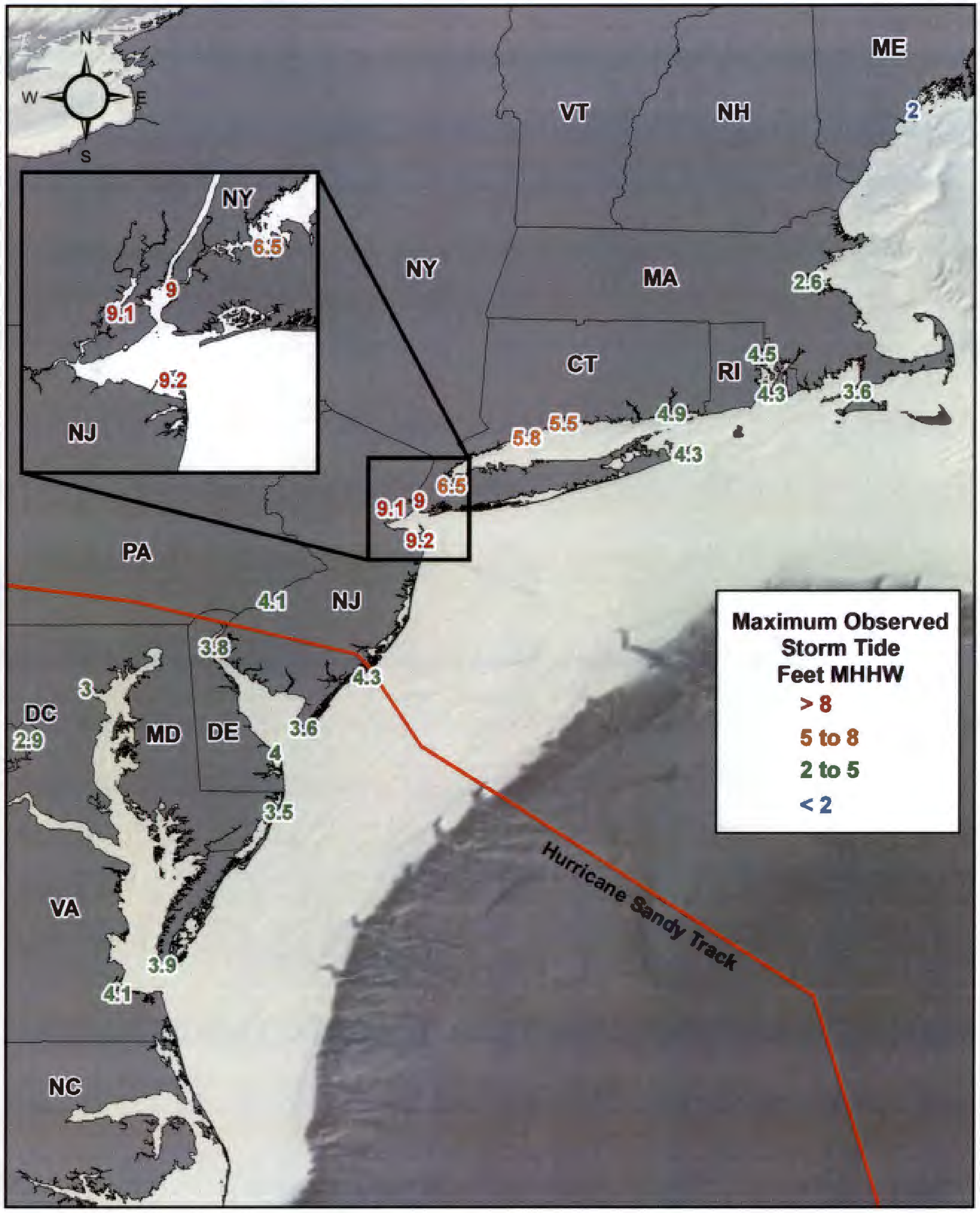

Figure 4: Storm Tide Elevations (MHHW) Recorded at NOAA Gages

2.4.2 Comparison of Hurricane Sandy and Storms of Record

The maximum storm tides measured at Sandy Hook, NJ and The Battery, NY exceed the previous Storm of Record at these stations (Hurricane Donna in September 1960) by 4.3 ft and 4.1 feet respectively. Table 3 compares the maximum observed storm tides during Hurricane Sandy to the Storm of Record at NOAA stations in the study area with at least 70 years of historical data. Outside of Sandy Hook and The Battery, Hurricane Sandy is below the Storm of Record. However, at Atlantic City, NJ Hurricane Sandy came within 0.1 feet of exceeding the Storm of Record. It is noted that storm tide elevations for the historical Storm of Record have not been adjusted to account for historical sea level rise.

Table 3: Hurricane Sandy vs. Previous Storm of Record at NOAA Stations

Station	Hurricane Sandy Storm Tide (ft, NAVD88)	Storm of Record Storm Tide (ft, NAVD88)	Storm of Record (Date)
Sewells Point, VA	5.2	6.4	23-Aug-1933
Baltimore, MD	3.8	7.4	19-Sep-2003
Atlantic City, NJ	6.3	6.4	11-Dec-1992
Sandy Hook, NJ	11.6	7.3[1]	12-Sep-1960
The Battery, NY	11.3	7.2[1]	12-Sep-1960
Kings Point, NY	10.2	12.7	21-Sep-1938
Montauk, NY	5.5	6.9	31-Aug-1954
New London, CT	6.2	8.7	21-Sep-1938
Providence, RI	6.9	15.0	21-Sep-1938
Newport, RI	6.1	11.3	21-Sep-1938
Woods Hole, MA	4.4	9.4	21-Sep-1938
Boston, MA	7.4	9.6	7-Feb-1978

Notes: [1] New Storm of Record for this station is Hurricane Sandy

2.4.3 Storm Surge

As Hurricane Sandy made a turn towards the mid-Atlantic coast and continued to grow in size, significant storm surges were observed from North Carolina to New England, especially across New Jersey, New York and Connecticut. Storm surge is produced by water being pushed toward the coastline by the winds. A small component of the storm surge is caused by the low pressure associated with the center of a storm. The orientation and size of Hurricane Sandy's wind field prior to landfall (Figure 2) caused strong winds to blow across the continental shelf towards New Jersey, New York, and Connecticut. A combination of the extent of the radius of maximum winds and the orientation of the NY/NJ coastlines (e.g. the New York Bight) caused extreme storm surges to be observed at NOAA stations in these states.

The combination of the storm surge and the full-moon high-tide on October 29 exacerbated storm flooding, particularly in areas where the astronomical high tide and storm surge were in phase. In New York Harbor, the astronomical high tide occurred nearly simultaneously with the peak storm surge (Table 4) resulting in record storm tides. At Kings Point, NY the maximum storm surge occurred nearly simultaneously with the astronomical low tide resulting in lower storm tides. The maximum storm surge in the study area was 12.65 feet at Kings Point, NY. This indicates that if Hurricane Sandy had made landfall several hours earlier or later, the storm tides in Long Island Sound (e.g. Kings Point) would have been significantly higher than in New York Harbor. Table 4 compares the maximum storm surge to the storm surge at the time of the maximum storm tide.

Table 4: Storm Surge Heights Recorded at NOAA Tide Stations

NOAA Station	Max Storm Surge (ft)	Time of Max Storm Surge (UTC)	Storm Surge at Max Storm Tide (ft)	Time of Max Storm Tide (UTC)	Time Difference (Hours)
Charleston, SC	2.39	10/28/2012 3:48	1.2	10/28/2012 12:06	-8.3
Sewells Point, VA	4.57	10/29/2012 7:24	3.8	10/29/2012 13:18	-5.9
Kiptopeke, VA	3.76	10/29/2012 7:42	3.8	10/29/2012 13:18	-5.6
Washington, DC	4.03	10/30/2012 21:42	3.2	10/31/2012 0:06	-2.4
Baltimore, MD	3.69	10/30/2012 14:18	3.5	10/30/2012 10:36	3.7
Ocean City, MD	4.33	10/29/2012 16:48	3.7	10/29/2012 13:42	3.1
Lewes, DE	5.34	10/29/2012 17:30	3.9	10/29/2012 13:00	4.5
Delaware City, DE	5.99	10/30/2012 6:54	5.4	10/30/2012 5:54	1.0
Philadelphia, PA	5.83	10/30/2012 9:18	5.4	10/30/2012 8:06	1.2
Cape May, NJ	5.16	10/29/2012 18:00	3.5	10/29/2012 13:42	4.3
Atlantic City, NJ	5.82	10/29/2012 20:42	4.8	10/30/2012 0:24	-3.7
Sandy Hook, NJ	n/a [1]	n/a [1]	n/a [1]	n/a [1]	n/a [1]
Bergen Point, NY	9.56	10/30/2012 1:48	9.4	10/30/2012 1:24	0.4
The Battery, NY	9.4	10/30/2012 1:24	9.4	10/30/2012 1:24	0.0
Kings Point, NY	12.65	10/29/2012 23:00	8.5	10/30/2012 2:06	-3.1
Montauk, NY	5.89	10/29/2012 22:12	5.2	10/30/2012 0:12	-2.0
Bridgeport, CT	9.83	10/30/2012 0:18	7.8	10/30/2012 2:06	-1.8
New Haven, CT	9.14	10/30/2012 0:06	8.1	10/30/2012 1:36	-1.5
New London, CT	6.5	10/29/2012 22:54	5.9	10/30/2012 1:36	-2.7
Providence, RI	6.2	10/29/2012 22:12	5.4	10/29/2012 23:30	-1.3
Newport, RI	5.34	10/29/2012 22:18	5.1	10/29/2012 23:00	-0.7
Woods Hole, MA	5.07	10/29/2012 22:06	5.0	10/29/2012 22:18	-0.2
Boston, MA	4.57	10/29/2012 21:00	2.6	10/29/2012 15:48	5.2
Portland, ME	3.27	10/29/2012 22:06	1.9	10/29/2012 15:18	6.8

Notes: [1] Sandy Hook gage failed before the peak of the storm

2.5 High Water Marks

Prior to Hurricane Sandy, the U.S. Geological Survey (USGS)[6] deployed an extensive network of water-level and barometric pressure sensors at 224 locations along the Atlantic Coast to characterize the height, extent, and timing of storm tides in more detail than could be accomplished by existing USGS or NOAA tide stations. In addition, over 653 post-flood high-water marks (HWM) were surveyed by the USGS relative to NAVD88, with particular emphasis in New Jersey and New York where the impacts of the storm were the most pronounced. These efforts were undertaken as part of coordinated Federal emergency response as outlined by the Stafford Act under a directed mission assignment by the Federal Emergency Management Agency (FEMA).

High water marks may consist of debris lines, stains from flood waters, or some other identifiable mark representative of the maximum water elevation at that location. In areas exposed to wave action, high water marks may be representative of the wave crest elevations or limit of wave runup. Therefore, the high water marks may be higher than the storm tide (still water level) in areas with significant wave action.

A summary of the USGS peak storm tides derived from HWM and water level gages is presented in Figure 5. The USGS peak storm tide data reinforces the conclusions drawn from the NOAA gages which indicate that storm tide elevations were greatest in the New York City metropolitan area and generally less severe with the distance removed from New York City. Figure 5 indicates that there were numerous USGS HWM and peak storm tide elevations above +12 ft NAVD88 in Raritan Bay and along the south shore of Staten Island. There is considerable scatter in the USGS peak storm tide data due to the aforementioned effect that wave action might have on the elevations. For example, at Nantucket, MA it is evident that the peak storm tides are several feet greater on the south side of the island which was exposed to large waves.

Along the ocean shoreline, waves can also contribute to storm tide elevation through a process known as wave setup. Wave setup is the super-elevation of the still water at the shoreline due to wave breaking. A wave gauge deployed by the USGS on the Atlantic Shoreline at Sea Bright, NJ suggests that the maximum still water level elevation along the ocean was approximately +16.5 ft NAVD88, with individual wave crests reaching at least +19.5 ft NAVD88. If this measurement is accurate, it would indicate that wave setup along this portion of New Jersey could have contributed approximately 5 ft to the storm tide elevations.

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[6] 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.

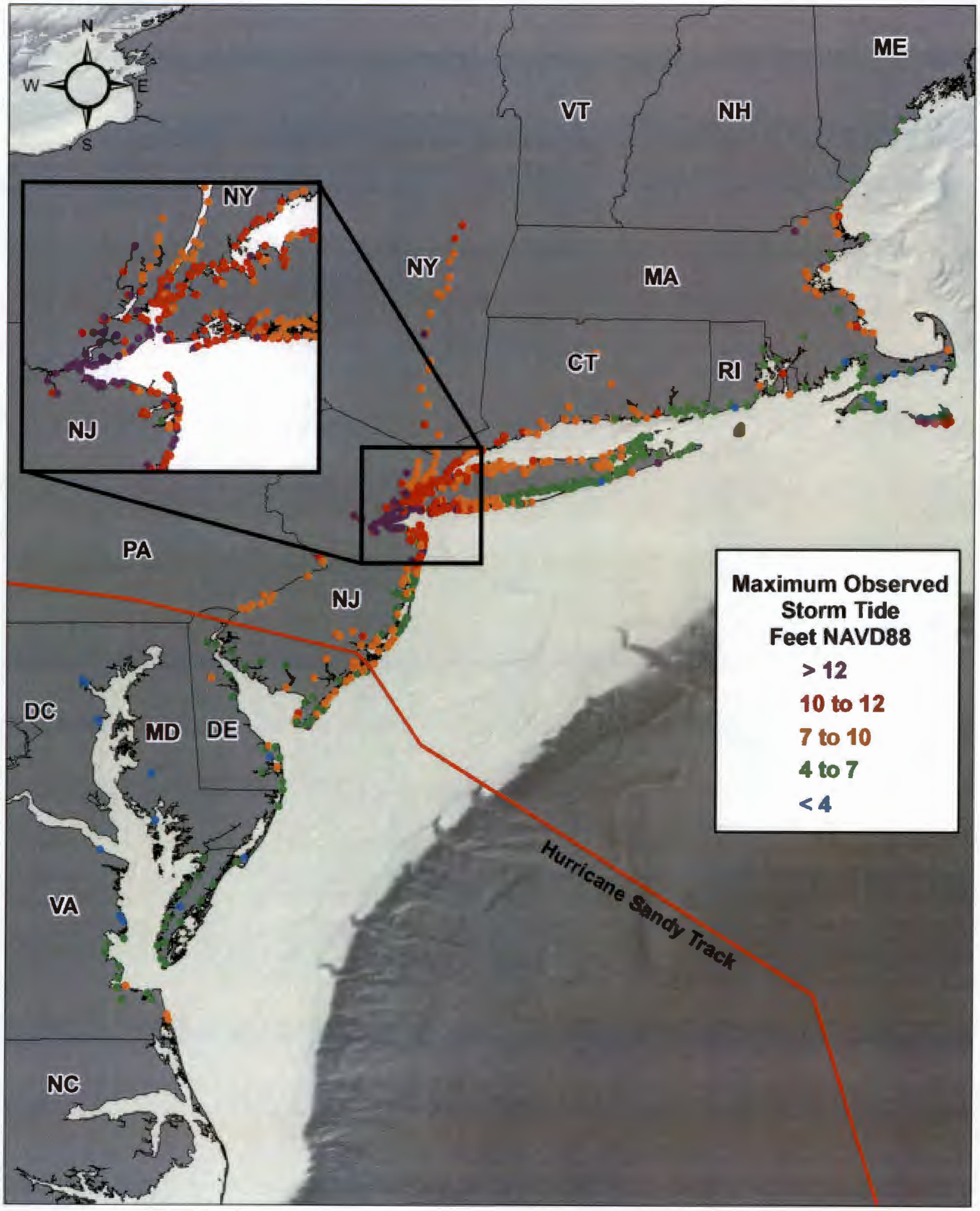

Figure 5: USGS Peak Storm Tides from High Water Marks and Gages

2.6 Waves

As previously discussed Hurricane Sandy caused water levels to rise along the entire east coast of the United States from Florida northward to Maine. The highest storm surges and greatest inundation on land occurred in the states of New Jersey and New York. In many of these locations, especially along the coast of central and northern New Jersey, Staten Island, and the south shore of Long Island, the surge was accompanied by powerful waves.

Hurricane Sandy's unusually large diameter resulted in long fetch lengths (the distance over which the wind was building the wave field) and subsequently generated extreme wave heights along the East Coast of the United States. An extensive record of these waves was acquired by the Coastal Data Information Program (CDIP[7]) and National Data Buoy Center (NDBC). CDIP is an extensive network for monitoring waves along the coastlines of the United States that is funded by the USACE and the California Department of Boating and Waterways, for certain sites, cost-shared with the U.S. Navy and the U.S. Integrated Ocean Observing System (IOOS). In addition, NDBC, which is part of NOAA, designs, develops, operates, and maintains a network of about 90 buoys and 60 Coastal Marine Automated Network stations.

A summary of the wave conditions measured by CDIP and NDBC buoys during the passage of Hurricane Sandy are listed in Table 5. These 25 buoys extend from Florida to Maine and include nearshore and offshore buoys. The significant wave height[8] at each of the 25 buoy locations is shown graphically alongside Hurricane Sandy's track in Figure 6. The largest wave recorded was 39.6 ft at the West of Bermuda buoy. Wave heights from Florida to Maine were in excess of 25 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 just over 30 ft. The 32.5 ft significant wave height measured at Long Island, NY was the largest recorded wave height since that buoy began operation in 1975. It exceeded the previous record of 30 ft set during a nor'easter on December 11, 1992.

It is noted that waves over 30 ft were measured in depths ranging from 130 to over 17,000 ft at locations relatively far away from the coastline. Waves at the shoreline (i.e., the waves that impacted the projects evaluated in this report) were significantly smaller as a result of various energy losses associated with nearshore wave propagation, including bottom friction and wave breaking. Nonetheless, it is likely that many exposed coastal areas were exposed to record or near record wave impacts, although sufficient data is not available to state definitely.

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[7] Richard J. Seymour, Corey B. Olfe, and Juliana 0. Thomas, *CDIP wave observations in Superstorm Sandy*, Shore & Beach • Vol. 80, No.4 • Fall 2012..

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

Table 5: Maximum Recorded Wave Heights during Hurricane Sandy

Station Name	Station	Source	Depth (ft)	UTC (day, hr)	H_s (ft)	T_p (s)	MWD (deg, TN)
Fort Pierce, FL	41114	CDIP	55	26-23	18.1	12.5	73
East of Cape Canaveral, FL	41009	NDBC	130	26-23	26.5	13.8	66
Fernandina Beach, FL	41112	CDIP	50	26-22	11.4	14.3	126
St. Augustine, FL	41012	NDBC	125	27-03	21.2	13.8	107
Southeast of Savannah, GA	41008	NDBC	65	27-12	9.6	12.9	n/a
South Hatteras, SC	41002	NDBC	14,000	28-22	29.6	12.1	344
Frying Pan Shoals, NC	41013	NDBC	80	27-11	20.4	12.9	148
Masonboro Inlet, NC	41110	CDIP	50	28-00	11.2	13.3	113
Onslow Bay Outer, NC	41036	NDBC	80	27-20	18.7	13.8	103
New River Inlet, NC	41109	CDIP	40	27-11	8.8	13.3	144
Oregon Inlet, NC	44095	CDIP	60	28-22	25.9	14.3	82
Duck, NC	44100	CDIP	85	28-20	24.9	13.3	94
West of Bermuda	41048	NDBC	17,000	29-01	39.6	14.8	256
Cape Henry, VA	44099	CDIP	60	29-06	15.9	14.3	89
Cape Charles, VA	44096	CDIP	40	29-06	15.0	14.3	97
Delaware Bay, DE	44009	NDBC	100	29-10	24.2	13.8	n/a
Long Island, NY	44025	NDBC	130	29-23	31.7	14.8	83
NY Harbor Entrance, NY	44065	NDBC	160	30-00	32.3	13.8	121
Block Island, RI	44097	CDIP	160	29-22	31.1	14.3	164
Nantucket, MA	44008	NDBC	215	29-20	36.0	13.8	133
Nantucket Sound, MA	44020	NDBC	30	29-18	10.1	5.6	76
Boston, MA	44013	NDBC	210	30-01	22.7	11.4	98
Jeffreys Ledge, NH	44098	CDIP	250	30-00	25.0	11.0	11
Gulf of Maine, ME	44005	NDBC	675	30-04	28.4	11.4	n/a
Portland, ME	44007	NDBC	80	30-03	23.3	10.8	n/a

UTC hr: Universal Time of day and hour in October 2012 of the maximum H_s
H_s: Largest recorded significant wave height
T_p: Peak period corresponding to the measured H_s,
MWD: for NDBC Mean Wave Direction corresponding to the measured H_s
At CDIP stations the Dominant Wave Direction is reported instead of the MWD

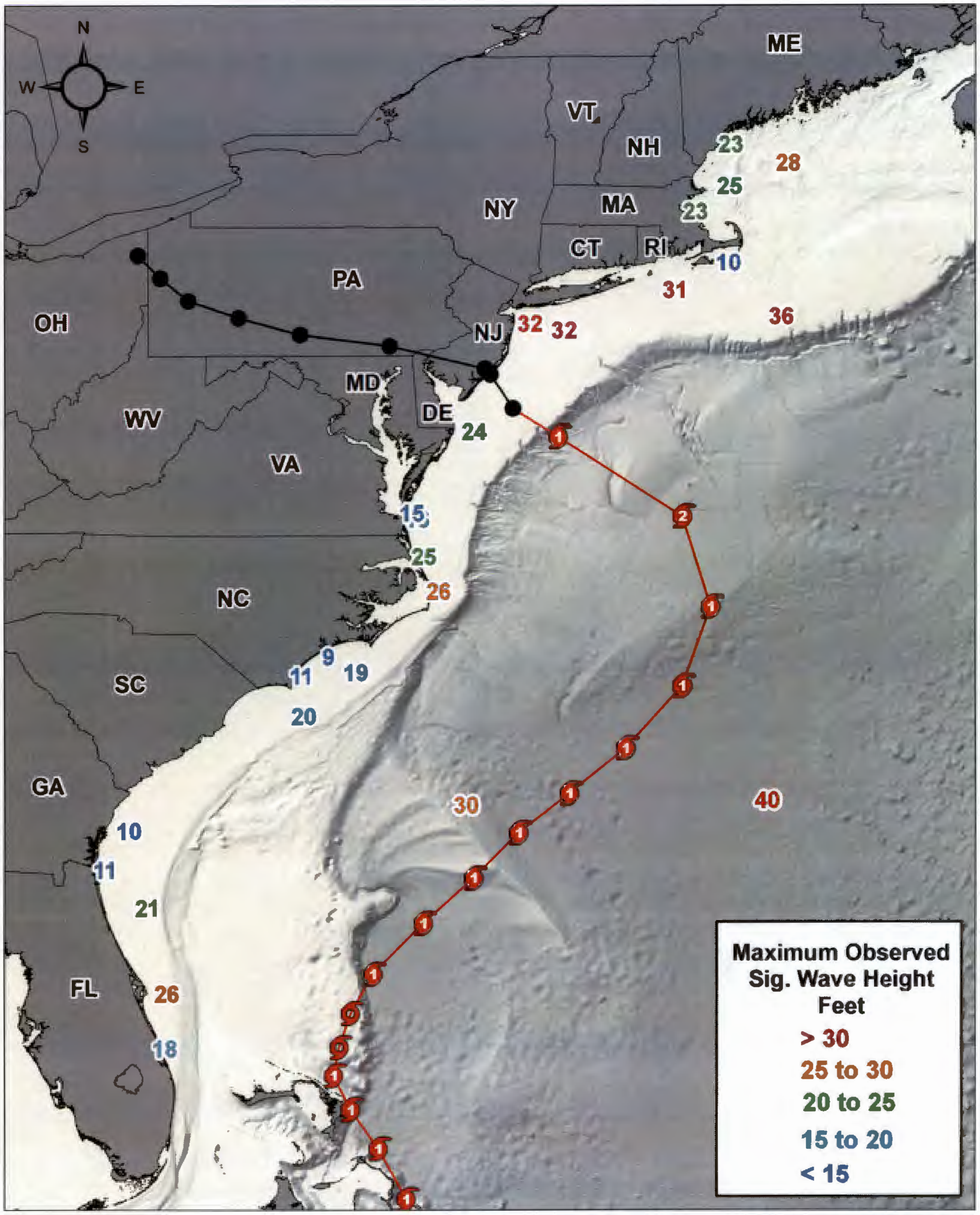

Figure 6: Observed CDIP and NDBC Wave Heights during Hurricane Sandy

3.0 OVERALL PERFORMANCE SUMMARY

Coastal areas impacted by Hurricane Sandy extend throughout the USACE North Atlantic Division (NAD) from the North Carolina/Virginia border to Maine. While winds and storm surge and storm duration are important storm characteristics, storm tide[9] and to a slightly lesser degree, waves, serve as the best measure of storm impacts in coastal areas. Therefore, this report section is organized according to project exposure to storm tides and waves as follows:

- **Extreme:** Storm tide greater than +9 ft MHHW and greater than 30 ft offshore significant wave heights. Greater than a 200 year event. Generally includes projects from Mantoloking, NJ to East Rockaway Inlet, NY including those in Raritan Bay, NJ.
- **Major:** Storm tide between +6 and +9 ft MHHW and greater than 30 ft offshore significant wave heights. Between a 30 and a 200 year event.
- Generally includes projects from Townsend Inlet, NJ to Mantoloking, NJ and East Rockaway Inlet, NY to Easthampton, NY.
- **Moderate:** Storm tide between +4 and +6 ft MHHW and 20 to 30 ft offshore significant wave heights. Between a 10 and a 30 year event. Generally includes projects from Assateague Island, MD to Townsend Inlet, NJ including projects in Delaware Bay. Also includes projects in Long Island Sound and from Easthampton NY to Chatham, MA.
- **Minor:** Storm tide less than +4 ft MHHW and less than 20 ft offshore significant wave heights. Less than a 10 year event. Generally includes projects north of Chatham, MA and south of Assateague Island, MD.

The four classifications were developed for this study. Note that the storm tide thresholds used in the classification above are referenced to the local MHHW datum to better represent the severity of the storm tide at each specific location and account for the fact that certain areas (e.g., western Long Island Sound, Massachusetts north of Cape Cod, New Hampshire, and Maine) have a larger astronomical tide range than others.

The resulting project groupings are summarized in Table 6 and Figure 7 to Figure 12. Note that the groupings do not necessarily follow exactly the storm tide and wave limits defined above. In some cases, projects fall under one category for storm tide and another for waves. In these cases, engineering judgment was used to classify the project. For example, projects in Virginia were exposed to similar surge tide levels as projects in Maryland; however waves impacting the Maryland projects were significantly larger.

Ultimately, the proposed groupings are just a way of organizing the evaluation study so that the performance of projects exposed to similar storm tides and waves is presented together. The classification is not meant to presuppose, overstate, or understate the level of physical impacts and damages suffered by any project. Finally, the classification does not affect in any way the conclusions of the performance evaluation. That evaluation depends on each project's physical and economic performance relative to its design level.

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[9] The actual level of sea water resulting from the astronomic tide combined with the storm surge.

Table 6: Project Groupings According to Hurricane Sandy Exposure

Count	Project Name	Project Features	Exposure to Hurricane Sandy
	New Hampshire (2)		
1	Hampton Beach, Hampton	Beach Fill and Groin	Minor
2	Wallis Sands State Beach	Beach Fill and Groin	Minor
	Massachusetts (15)		
3	Bluffs Comm. Center, Swansea	Rock Revetment	Moderate
4	Town River Bay, Quincy	Rock Revetment	Minor
5	Point Shirley, Winthrop	Rock Revetment	Minor
6	Island Ave, Quincy	Rock Revetment	Minor
7	New Bedford Hurricane Barrier	Hurricane Barrier and Dikes	Moderate
8	Clark Point Beach, New Bedford	Beach Fill and Groins	Moderate
9	Oak Bluffs Town Beach, Martha's Vineyard	Beach Fill and Groin	Moderate
10	Plum Island, Newbury	Beach Fill	Minor
11	Revere Beach	Beach Fill	Minor
12	Roughans Point, Revere	Revetment and Interior	Minor
13	North Scituate Beach, Scituate	Beach Fill	Minor
14	Quincy Shore Beach, Quincy	Beach Fill and Bulkheads	Minor
15	Wessagusset Beach, Weymouth	Beach Fill and Groins	Minor
16	Winthrop Beach	Seawall, Beach Fill and	Minor
17	Salisbury Beach	Beach Fill	Minor
	Rhode Island (4)		
18	Fox Point Hurricane Barrier, Providence	Hurricane Barrier and Dikes	Moderate
19	Misquamicut Beach, Westerly	Beach Fill	Moderate
20	Oakland Beach, Warwick	Beach Fill, Groins, Revetment	Moderate
21	Cliff Walk, Newport	Revetment and Retaining	Moderate
	Connecticut (13)		
22	Bridgeport	Revetment and Retaining	Moderate
23	Gulf Street, Milford	Rock Revetment	Moderate
24	Woodmont Beach, Milford	Beach Fill and Groins	Moderate
25	Gulf Beach, Milford	Beach Fill	Moderate
26	Sea Bluff Beach, West Haven	Beach Fill and Groin	Moderate
27	Prospect Beach, West Haven	Beach Fill	Moderate
28	Sherwood Island State Beach, Westport	Beach Fill and Groins	Moderate
29	Southport Beach, Fairfield	Beach Fill and Groins	Moderate
30	Middle Beach, Madison	Rock Revetment	Moderate
31	Point Beach, Milford	Non-Structural	Moderate
32	New London Hurricane Barrier	Hurricane Barrier and Dikes	Moderate
33	Stamford Hurricane Barrier	Hurricane Barrier and Dikes	Moderate
34	Pawcatuck Hurricane Barrier	Hurricane Barrier and Dikes	Moderate
	New York (11)		
35	West of Shinnecock Inlet	Beach Fill	Major

36	Westhampton	Beach Fill and Groins	Major
Count	**Project Name**	**Project Features**	**Exposure to Hurricane Sandy**
37	Fire Island to Shores Westerly (Gilgo)	Beach Fill	Major
38	Rockaway	Beach Fill	Extreme
39	Coney Island	Beach Fill, Groin, Retaining	Extreme
40	Oakwood Beach (Section 103)	Levee, Tide Gate	Extreme
41	Shelter Island (Section 14)	Stone Revetment and Sheet	Moderate
42	Village of Northport (Section 14)	Sheet Pile Wall, Revetment	Moderate
43	Orient Harbor (Section 14)	Stone Revetment	Moderate
44	Asharoken (Section 103)	Steel Sheet Pile Wall	Moderate
45	Plumb Beach (Section 204)	Beach Fill, Groins, Dike	Extreme
	New Jersey (11)		
46	Keansburg, East Keansburg, Laurence Harbor	Beach Fill, Levees,	Extreme
47	Sea Bright to Manasquan	Beach Fill	Extreme
48	Barnegat Inlet to Little Egg Inlet	Beach Fill	Major
49	Brigantine Island	Beach Fill	Major
50	Absecon Island	Beach Fill, Bulkhead	Major
51	Ocean City (Great Egg Harbor Inlet and Peck	Beach Fill	Major
52	Townsends Inlet to Cape May Inlet	Beach Fill, Stone Revetment	Moderate
53	Cape May City (Cape May to Lower	Beach Fill and Groins	Moderate
54	Lower Cape May Meadows to Cape May Point	Beach Fill, Ecosystem	Moderate
55	Ocean Gate (Section 14)	Beach Fill	Major
56	East Point (Section 14)	Revetment	Moderate
	Delaware (7)		
57	Roosevelt Inlet – Lewes Beach	Beach Fill	Moderate
58	Indian River Inlet Sand Bypassing	Sand Bypassing	Moderate
59	Bethany – South Bethany	Beach Fill	Moderate
60	Fenwick Island	Beach Fill	Moderate
61	Rehoboth Beach and Dewey	Beach Fill	Moderate
62	South Shore Indian River Inlet (Section 103)	Stone Revetment	Moderate
63	North Shore Indian River Inlet (Section 103)	Stone Revetment	Moderate
	Maryland (2)		
64	Atlantic Coast (Ocean City)	Beach Fill & Bulkhead	Moderate
65	Assateague Island	Beach Fill, Sand Bypassing	Moderate
	Virginia (10)		
66	Chesapeake Bay Shoreline, Hampton	Beach Fill	Minor
67	Virginia Beach Hurricane Protection	Beach Fill& Bulkhead	Minor
68	Sandbridge Beach	Beach Fill	Minor
69	Cape Charles Shore Protection (Section 14)	Rubble Seawall	Minor
70	Saxis Island Bulkhead (Section 14)	Timber Bulkhead	Minor
71	Hampton Institute Shore Protection (Section	Stone Revetment	Minor
72	Anderson Park Shore Protection (Section 103)	Stone Revetment	Minor
73	Tangier Island Shore Protection (GI)	Stone Revetment	Minor
74	Norfolk Floodwall, Norfolk (GI)	Steel Sheet Pile Wall	Minor

75	Jamestown Island Seawall, Jamestown Island	Concrete Block Wall	Minor

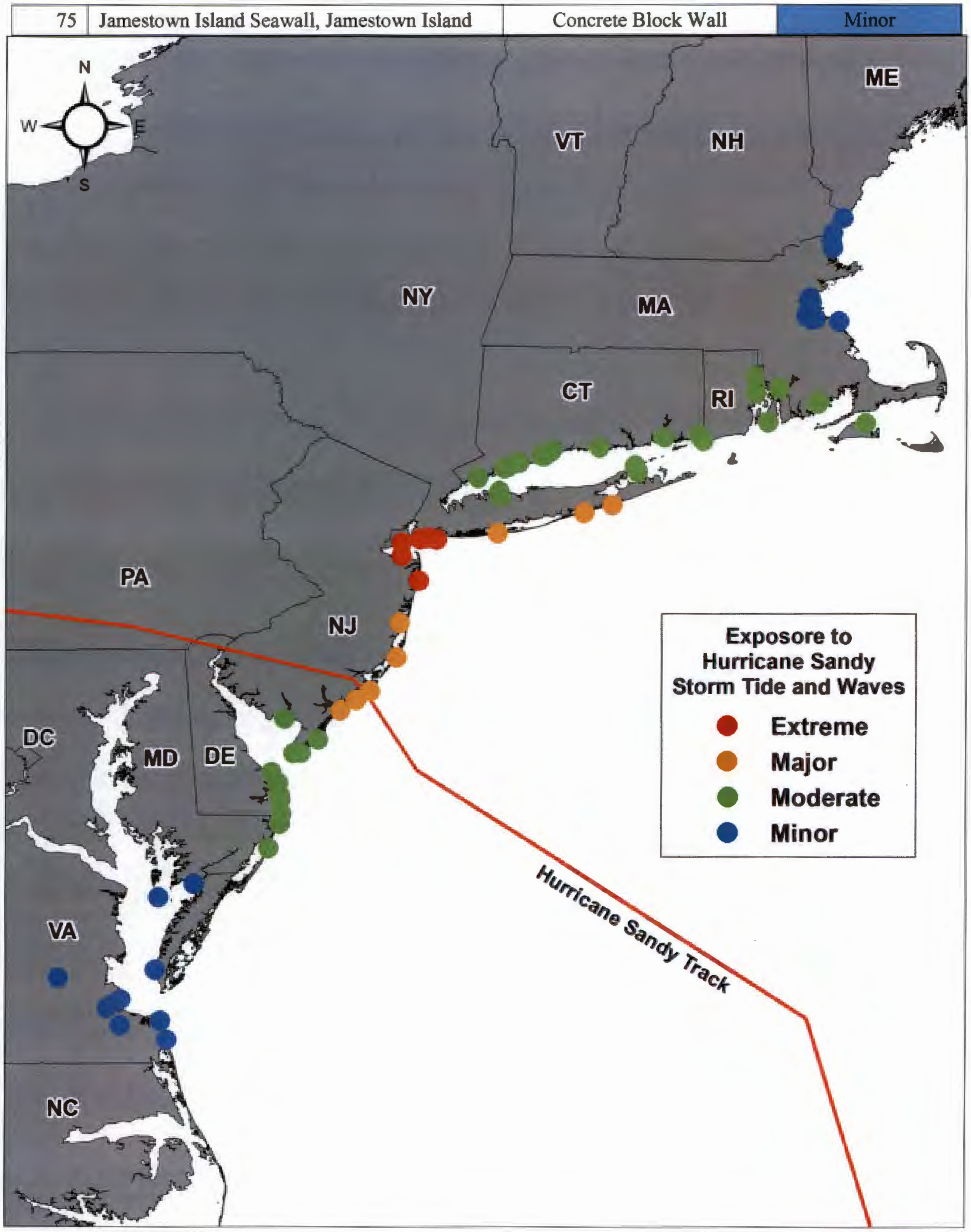


Figure 7: Exposure to Hurricane Sandy Storm Tide and Waves

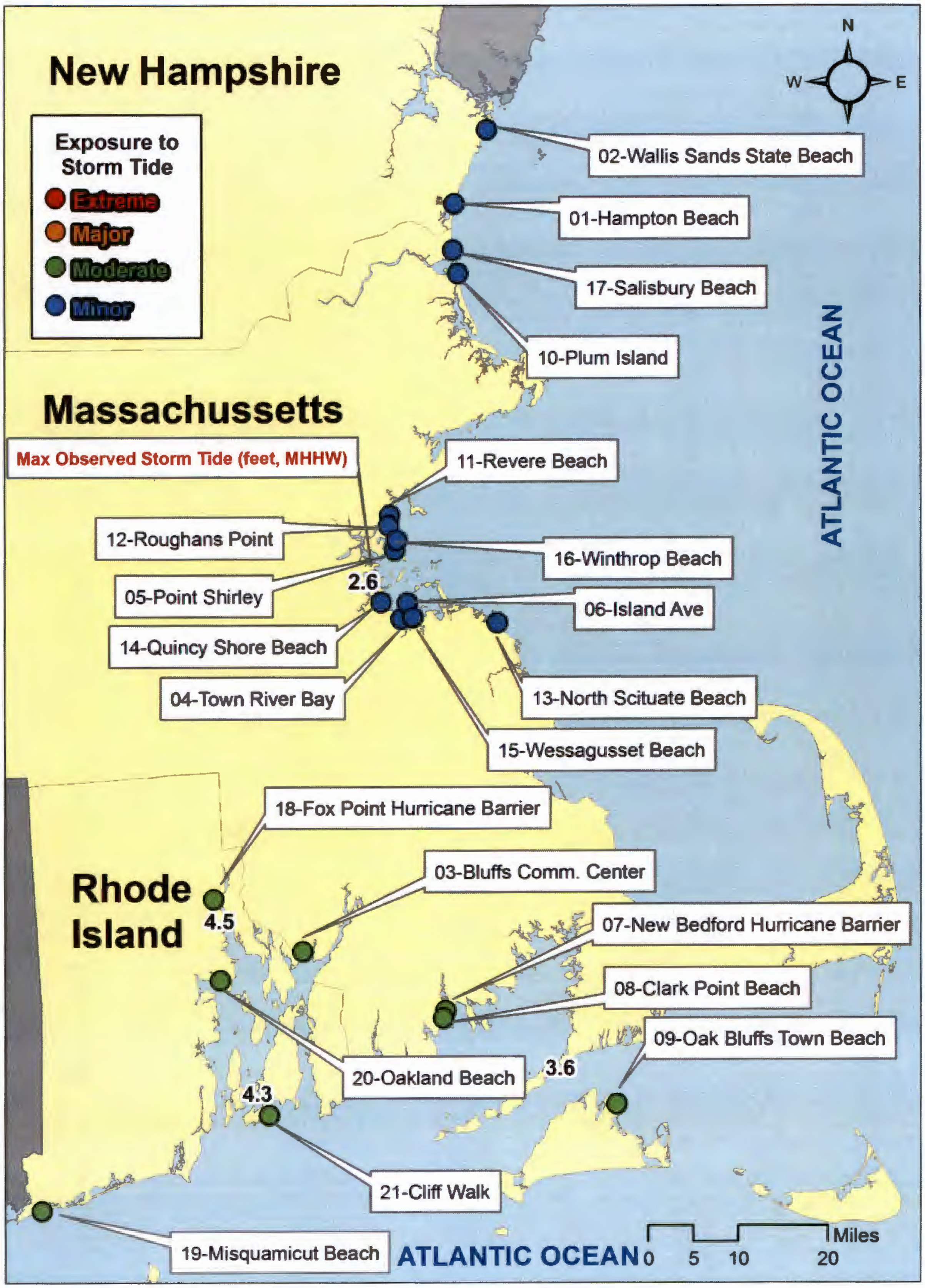


Figure 8: NH, MA and RI Project Groupings According to Hurricane Sandy Exposure

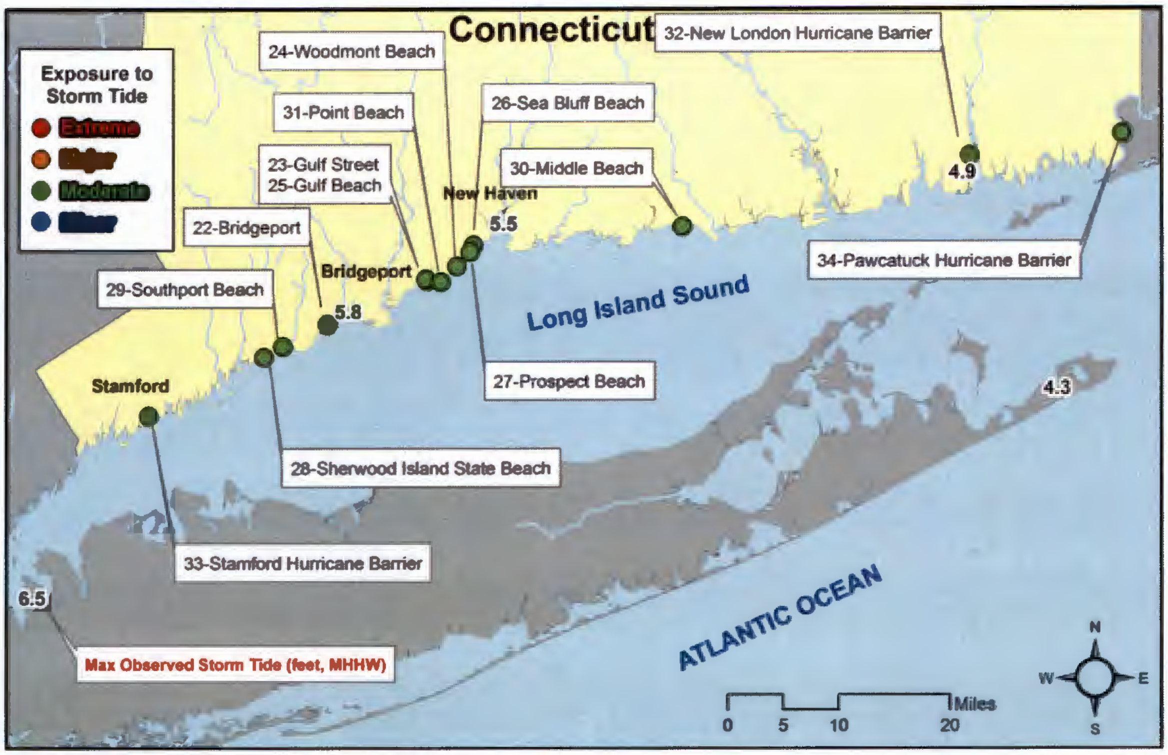


Figure 9: CT Project Groupings According to Hurricane Sandy Exposure

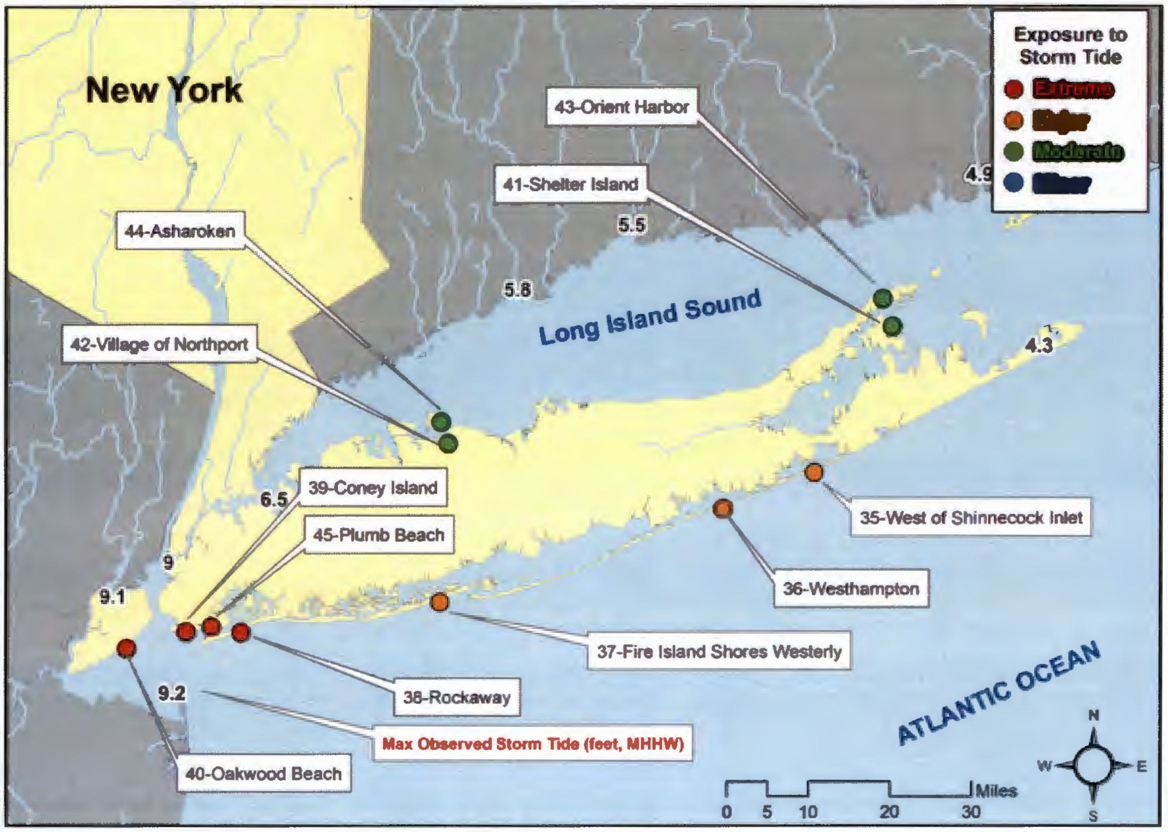


Figure 10: NY Project Groupings According to Hurricane Sandy Exposure

Figure 11: NJ Project Groupings According to Hurricane Sandy Exposure

Figure 12: DE, MD and VA Project Groupings According to Hurricane Sandy Exposure

Coastal flood and storm damage reduction projects within the NAD have been designed for a range of design events but most exceed 30 years. As can be seen from Table 2, storm surge events equaling or exceeding 30 years were recorded at Lewes, DE, Atlantic City, NJ and New London, CT. Storms corresponding to greater than 200 year event were recorded at Sandy Hook, NJ and the Battery, NY. These two locations document the epicenter of extreme storm tide during Hurricane Sandy. The storm tide elevations that occurred during Hurricane Sandy at these two locations significantly exceeded elevations recorded during the previous storm of record.

The performance evaluation considered three key factors:

- The type, extent and magnitude of storm damages experienced and benefits provided by the project
    - This is the measure of whether a project met its intended purpose. Comparisons of Hurricane Sandy's impact to immediately adjacent communities and the neighboring areas are a gage of a project's effectiveness.
- The pre-storm condition of the projects and whether advanced or delayed nourishment or deferred maintenance affected the reliability of the project
    - This could inform recommendations on maintenance and re-nourishment practices.
- How the physical features of the projects performed relative to design expectations and other nearby projects
    - This evaluation could affect recommendations regarding design standards or best practices.

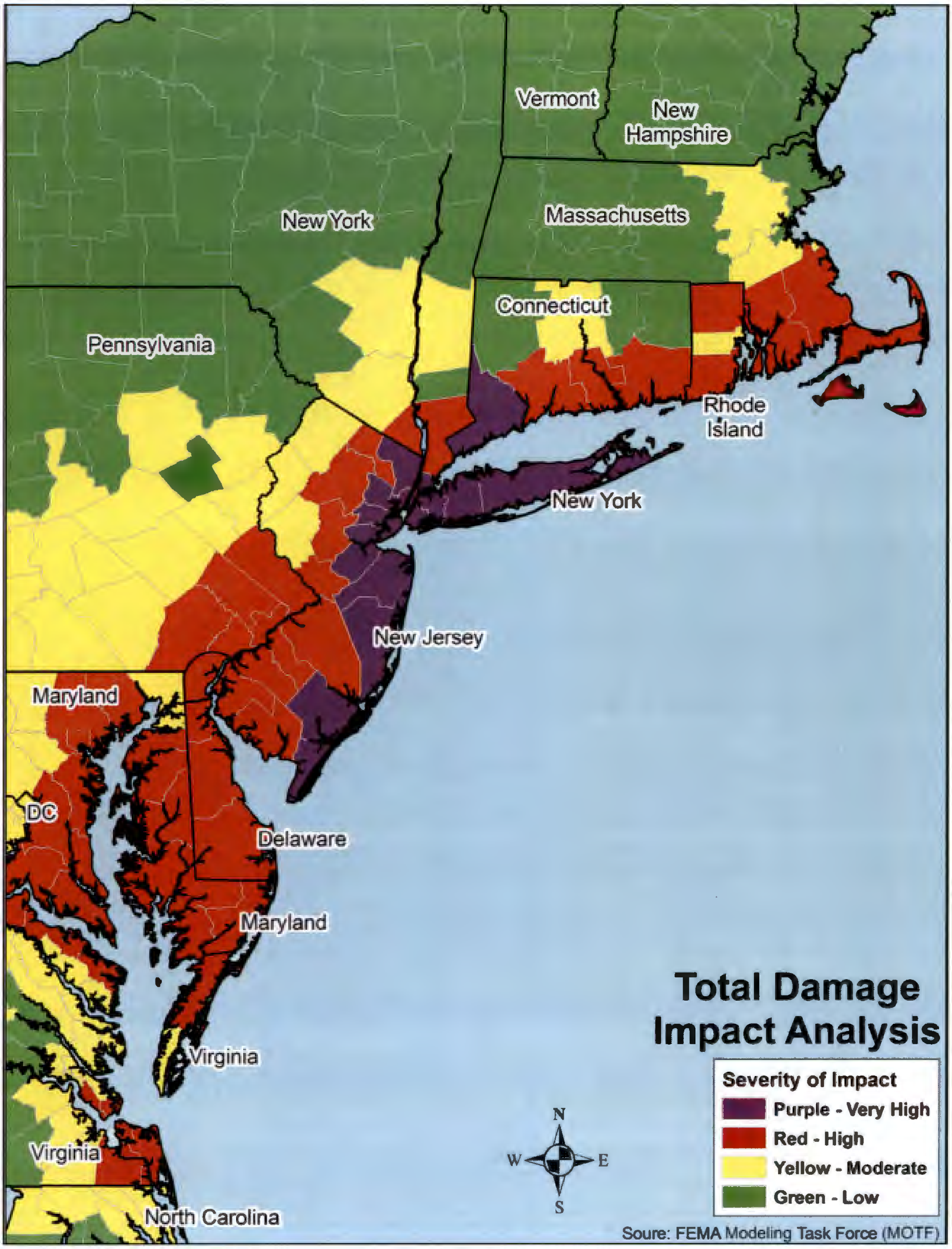
Hurricane Sandy had widespread economic impacts related to storm tides, intense rainfall and high winds. Figure 13 provides an overview of the damage from all sources as developed by the FEMA Modeling Task Force. The economic performance evaluation of the coastal projects was focused on storm tide and waves. The evaluation considered the extent of damage at each project site relative to what conditions would have been without the project. As part of the performance evaluation, the types of benefits expected for each project were reviewed. A small number of projects are hurricane/ storm surge barriers consisting of seawalls/ levees and closure gates designed to prevent inundation of entire communities. The majority of projects provides some combination of erosion control, storm damage risk reduction and enhanced recreational beaches. This analysis also indicates that while a significant number of the projects were intended to primarily provide recreation opportunities, these tended to be relatively small projects located in areas not severely impacted by Hurricane Sandy. For some projects, such as the levees and surge barrier in Keansburg and East Keansburg, NJ, the evaluation identified the protection of infrastructure and transportation routes as benefits that were not included in the economic justification of the project.

Pre-storm conditions were generally determined on the basis of available pre-storm surveys, aerial photographs, and recent condition assessment. A component of the evaluation was to identify for every project the status of renourishment activities at the time of Hurricane Sandy.

The physical performance of the projects considered the extent of inundation and wave damages to coastal flood and storm damage reduction project features (mostly berm and dune erosion) relative to design performance expectations. The latter was determined by comparison of project design levels and the return interval associated with Hurricane Sandy peak storm tides at each specific project site. Whenever sufficient information was available, beach fill performance was characterized in terms of berm width, berm height, dune width, dune height, and total fill volume losses.

In general, projects that were subjected to their individual design event, or a lesser event, performed well. Only projects exposed to conditions worse than the design event (e.g., most projects in the Extreme and Major exposure areas as well as a few smaller Section 14 and recreational projects in other areas) suffered significant damages. Nonetheless, these projects still performed to their design standards.

Overall performance summaries for projects in NAD were grouped by degree of exposure to Hurricane Sandy`s storm tide and waves and are provided in Sections 3.1 through 3.4. A summary of environmental performance for projects in NAD is described in Section 3.5. Sections 3.6 and 3.7 include brief summary performance evaluations for SAD and LRD projects, respectively.



Soure: FEMA Modeling Task Force (MOTF)

Figure 13: FEMA Modeling Task Force (MOFT) Total Damage Impact Analysis

3.1 Extreme Exposure to Storm Tide and Waves

The area of Extreme Exposure (> +9 ft MHHW and > 30 ft offshore significant wave heights) is mapped in Figure 7 and extends approximately from Mantoloking, NJ in the south to Kings Point, NY in the north and East Rockaway Inlet, NY to the northeast. This area includes six projects: (1) Rockaway, NY, (2) Coney Island, NY, (3) Plumb Beach, NY (4) Oakwood Beach, NY, (5) Keansburg, East Keansburg, and Laurence Harbor, NJ and (6) Sea Bright to Manasquan Inlet, NJ. The location of these projects is shown in Figure 10 and Figure 11.

Statistical analysis performed by ERDC shows that the Hurricane Sandy at the Battery is about a 700 year event (the analysis did not include the potential impacts of climate change). Similarly, the Sandy Hook gage analysis suggests a 940 year event at that location. These events are significantly larger than the design event for USACE projects within the Extreme Exposure area, which ranges from 15 to 200 years. Only the Keansburg project was designed to withstand a 100-year storm.

It is important, therefore, to recognize that the projects were subject to substantially greater wave and water level conditions than for which they were designed, and to understand the condition of the project at the time of Hurricane Sandy. Accordingly, significant or extreme damage could be expected at the relevant project locations. Expected damages would include beach erosion, wave-induced structural damage, and flooding. Later portions of this report document project performance. It is mentioned here, however, that many projects provided significant storm damage reduction despite the fact that these projects were subjected to a storm that greatly exceeded the design storm. Despite the severity of the storm, beaches served to mitigate wave-induced structural damages in most cases and there were no significant structural failures of any projects.

Flooding is an important issue in coastal flood and storm damage reduction projects. With its unprecedented intensity, Hurricane Sandy produced significant flooding in the Extreme storm tide areas. It is important to recognize that there are multiple pathways for storm surge flooding. The most obvious is the flooding that occurs on/from the ocean side of a project. If the project is located on an island or peninsula, however, the project can also flood from the back side of the island or peninsula. Of the projects in the Extreme Storm Tide area, Coney Island, Rockaway, and Sea Bright to Manasquan Inlet were subject to back-bay/peninsula flooding. It is important to note that none of these projects were designed to reduce back-bay/peninsula flooding.

These projects differ in scale and/or type. With the exception of Oakwood Beach, the projects involved placement of beach nourishment, erosion control structures (mostly groins), and flood protection structures such as levees. The group of projects includes a combination of beach erosion projects, storm damage protection projects, and recreational projects. The design parameters for all six projects are summarized in Table 7.

Table 7: Design Parameters for Extreme Exposure Projects

Id	Project Name	Berm Elev. (ft, NAVD88)	Berm Width (ft)	Dune Elev. (ft, NAVD88)	Dune Width (ft)	Structure Elev. (ft, NAVD88)	Design Event (years)	Nourish-ment Cycle (years)
38	Rockaway	8.9	100	No Dune	No Dune	N/A	30	2
39	Coney Island	11.9	100	No Dune	No Dune	N/A	>70 [1]	20
40	Oakwood Beach[2]	N/A	N/A	N/A	N/A	9.0	15	N/A
45	Plumb Beach	8.0	50	11.0	25	N/A	N/A	4
46	Keansburg, East Keansburg, and Laurence Harbor	5.3-14.8	25-100	No Dune	No Dune	14.8	200	N/A
47	Sea Bright to Manasquan	7.3	100	9.3 [3]	80	15.0-20.0	35-40	6

Notes:

[1] Project design (public beach reach only) was estimated to provide greater than a 1,000-year level of protection against storm-induced erosion, 200-250 year level of protection against wave attack for most structures, and 70-100 year level of protection against wave attack for localized structures on the beach (comfort stations, vehicle access, lifeguard stations).

[2] Oakwood Beach is a Hurricane Shore Protection Project (HSPP) consisting of an earthen levee. The project does not include a Beach Fill feature.

[3] At Sea Bright to Manasquan there is no "dune" feature but there is a 2-ft berm cap and a relatively high seawall along a significant portion of the project.

The Sea Bright to Manasquan project is significantly larger than any others in the extreme storm tide category. Additionally, the Sea Bright to Manasquan project experienced the highest storm tide levels of any project impacted by Hurricane Sandy. The above projects are described in the following report sections in terms of pre-storm conditions, physical performance and economic performance.

3.1.1 Pre-storm Project Conditions

This section addresses pre-storm conditions for Extreme exposure project group. As previously stated, the group includes six projects: (1) Rockaway, NY; (2) Coney Island, NY; (3) Plumb Beach, NY; (4) Oakwood Beach, NY; (5) Keansburg, East Keansburg and Laurence Harbor, NJ; and (6) Sea Bright to Manasquan, NJ. A separate description based on the best information available for each project is provided in the following paragraphs.

Rockaway, NY

The project was initially constructed in 1977 and was authorized for renourishment through 1988. A post authorization change authorized construction of a groin which was completed in 1982. The project was re-nourished in 1996, 2000, and 2004 under the Section 934 authority of Water Resource Development Act (WRDA) 1986, which allow continued renourishment of projects when it is shown to be cost effective under current guidelines and conditions. As previously noted, this is a beach erosion control project; it is not a flood damage reduction project. The project has not been renourished since 2004 because the project's authority (Section 934 of WRDA 1986) authorized renourishments in 1996, 2000 and 2004. Maintenance material from East Rockaway Inlet is periodically placed on the beach. The most recent placement occurred in 2010. There is no surveyed information regarding the pre-storm beach dimensions, however they were below the project design dimensions.

Coney Island, NY

Pre-project conditions were taken from survey profiles collected in spring 2011. The berm width at the design elevation of +11.9 ft NAVD88 met or exceeded the design width of 100 ft at 10 out of 14 profiles. The three (3) profiles that did not meet the design width at the design elevation but it still had significant width (120-170 ft) at one foot below the design elevation of +10.9 ft NAVD88. One (1) profile had a berm width of 11 ft at the design elevation (+11.9 ft NAVD88) and 73 ft width one foot below the design elevation, at +10.9 ft NAVD88.

Plumb Beach, NY

Prior to Hurricane Sandy, the project was under construction under the Section 204 CAP authority. In areas that were completed, the beach was at design dimensions. In areas that were not completed, the beach was not at its authorized design. At the time of the storm, 95% of the beach fill template was constructed.

Oakwood Beach, NY

Periodic levee inspections have been performed at the site. Although minor scour on the levees had been noted there were no documented major deficiencies in the structure. Prior to the storm, the tide gate was functioning and there was no documentation of recent maintenance.

Keansburg, East Keansburg, Laurence Harbor, NJ

Prior to Hurricane Sandy the berm width portion of the project varied from approximately 0 to 50 feet (design width varied from 25 to 100 ft) and the berm elevation varied from approximately +12 to +15 feet NAVD88 (comparable to, or higher than the original berm). The site had never been nourished because renourishments were not included in the original project authorization.

Sea Bright to Manasquan, NJ

The first renourishment to the Sea Bright to Monmouth Beach segment occurred in 2002. No renourishment has taken place in Section II of the project (Asbury Park to Manasquan) since initial construction in 1999, except a small portion of Spring Lake in 2002. Monmouth Beach had berm heights of +9.2 NAVD88 owing to renourishment in 2012. Most other project locations had berm heights lower than the design. Berm widths varied throughout the project with the widest at Asbury Park and the north end of Sea Bright. Locally built small dunes in Sea Bright, Monmouth Beach, Bradley Beach, Spring Lake, Sea Girt and Manasquan provide higher elevations than the project design berm. No full-scale detailed profile monitoring had been done since 2003.

It is worth noting that the project also included rehabilitation of a pre-existing seawall in Sea Bright and Monmouth Beach. The seawall was generally in good condition prior to Hurricane Sandy with the exception of a few specific locations in Sea Bright.

3.1.2 Physical Performance

This section addresses the physical performance of the Extreme exposure project group. As previously stated, the group includes six USACE projects: (1) Rockaway, NY; (2) Coney Island, NY; (3) Plumb Beach, NY; (4) Oakwood Beach, NY; (5) Keansburg, East Keansburg and Laurence Harbor, NJ; and (6) Sea Bright to Manasquan, NJ. Pre-storm project conditions and physical performance metrics are summarized in Table 8 below. The performance of each project is described separately in the following paragraphs.

Table 8: Pre-Storm Condition and Physical Performance for Extreme Exposure Projects

Id	Project Name	Pre-Storm Condition	Storm Tide		Storm Event[1] (years)	Depth over berm (ft)	Project Over-topped?	Significant Beach and/or Dune Erosion?
			Elevation (ft, NAVD88)	Gage Location				
38	Rockaway	Mostly below design level	11.6	Sandy Hook	940	2.7	Yes[2]	Yes Volume N/A
39	Coney Island	Mostly at design level	11.6	Sandy Hook	940	-0.3	Yes[2]	Yes 0.3 MCY[3]
40	Oakwood Beach	Mostly at design level	13.2	Great Kills Harbor	>500	N/A	Yes	N/A
45	Plumb Beach	Fair, project recently completed	10.7	Rockaway Inlet	>500	2.7	Yes	No
46	Keansburg, East Keansburg, and Laurence Harbor	Fair, mostly at design level	13.8	Keansburg	>500	0-8	Yes	Yes 0.3 MCY[3]
47	Sea Bright to Manasquan	Mostly below design level	16.5[3]	Sea Bright	>500	9.2	Yes[2]	Yes 4.5 MCY[3]

Notes: [1] Based on a statistical analysis recently performed by ERDC, including data from Hurricane Sandy, with data from the Battery, NY and Sandy Hook, NJ NOAA stations

[2] Project does not include a dune so overtopping refers to berm only

[3] MCY (million cubic yards)

Rockaway, NY

There is no detailed information to document the physical performance of this project except to note that the beach was heavily eroded with associated damage to the shoreline structures including the boardwalk. The two photos in Figure 14 and Figure 15 show Rockaway before and after the storm in the vicinity of Beach 94th Street and Shore Front Parkway; this area was one of the more heavily damaged along the Rockaway project. The beach eroded significantly during the storm and waves destroyed the boardwalk. Note that in areas of the project farther east where the pre-storm beach appeared to be wider, possibly as a result of the stabilizing effect of the existing groins, the boardwalk appeared to suffer less damage or at least it was not completely destroyed.

Coney Island, NY

Storm impacts to the project area consist of a 0-2 foot lowering/flattening of the beach berm along the length of the project. Available pre and post-storm aerial photography suggest relatively small berm width losses. Total volume of sand loss is estimated at 270,000 cubic yards (CY) with 11,000 CY of the total lost along the Sea Gate shoreline. The terminal groin was not damaged during the storm. Loss of supporting stone on the seaward end of the 32nd Street outfall may have caused damage to the end of the outfall pipe.

Plumb Beach, NY

Damages to the project were minimal. Some sand overwashed onto the Belt Parkway. A portion of the geotube used to temporarily hold the sand fill in place deflated somewhat and was partially buried by sand.

Oakwood Beach, NY

The levee was overtopped and afforded no flood damage reduction, yet the levee itself experienced minor damage. Approximately 80 feet of the levee will have to be repaired. Overtopping caused scour on the landward side of the levee and damaged the tide gate. The electrical components for the tide gate will need to be replaced. The low elevation of the levee/gate led to flooding behind the system.

Keansburg, East Keansburg, and Laurence Harbor, NJ

The berm narrowed 0-5 feet and the berm height lowered 0-5 feet during the storm. One groin experienced minor damage.

Figure 14: Rockaway before Hurricane Sandy

Figure 15: Rockaway after Hurricane Sandy

Sea Bright to Manasquan, NJ

The primary impact to the project was loss of beach fill. Storm impacts to the beach cross-section consisted of lowering/flattening of the berm above water, plus reduction of berm width.

Berm lowering/flattening occurred over the entire project length (Sea Bright to Manasquan Inlet) with an estimated average drop in beach elevation of 5-10 feet. Berm widths decreased generally, however berm widths did increase in some locations. Locations which had locally built dunes prior to the storm lost all or near all of the existing dunes, plus any established dune vegetation. The total volume lost is estimated to be 4.5 MCY. Significant overwash of sand into landside streets occurred.

Hurricane Sandy greatly exceeded the project design in terms of water level, especially in Monmouth Beach and in areas between Asbury Park and Manasquan. The project provided considerable storm damage reduction benefits compared to a without project condition. These benefits included those associated with wave damage and beach erosion. The project provided a sand buffer between the ocean and the seawall in Sea Bright, Monmouth Beach and Long Branch, and prevented any damage to shoreline-parallel main roads along the length of the project area. However, certain areas of Sea Bright where there are holes in the seawall and at the south end of Manasquan where the beach berm was far narrower than the design experienced significant damages from both waves and storm tide. These areas were far more vulnerable due to their pre-storm condition.

It is important to note that without the beach fill the seawall would have likely been undermined and damaged by storm waves. Additionally, documented damages in areas with and without a seawall along the project area suggest that the seawall was necessary to provide adequate protection to the area (see photos in Figure 16 to Figure 19). This finding supports the design approach to the project.

3.1.3 Economic Performance

The projects exposed to extreme storm tides and waves provided significant economic benefits even though the design level of every project was exceeded. With the exception of Coney Island, which has a berm elevation of +11.9 ft NAVD88, the beach berms were significantly overtopped (i.e., maximum water levels exceeded the berm elevation) allowing storm surge and waves to impact landward structures including dunes, seawalls, boardwalks and exposed buildings. Structures on the beach, such as boardwalks, access ramps, and cabanas were generally destroyed or severely damaged by surge and waves. As a general observation, the buildings set back some distance from the shoreline were not subject to significant wave or erosion damages, but many of these buildings were subject to inundation. The projects provided a reduction in storm damage, protected some critical infrastructure and reduced the post storm recovery efforts. Each project is discussed separately in the following paragraphs.

Figure 16: Pre-storm beach condition at northern Sea Bright (area w/ seawall)

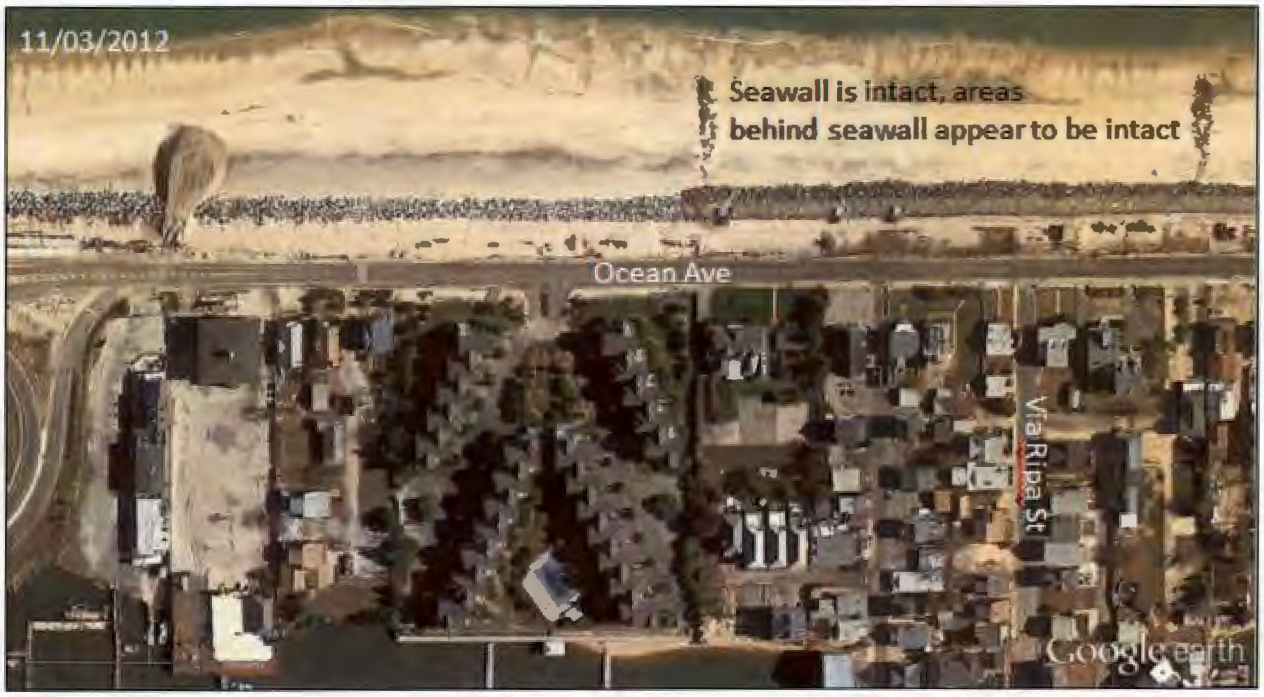


Figure 17: Post-storm beach condition at northern Sea Bright (area w/ seawall)

Figure 18: Pre-storm beach condition at Sea Bright (area w/o seawall)

Figure 19: Post-storm beach condition at Sea Bright (area w/o seawall)

Rockaway, NY

The beach berm at Rockaway was overtopped by waves and storm surge and about 100 buildings were reported destroyed. One thousand (1,000) buildings were significantly damaged and a number of residents were drowned by floodwaters. At Rockaway a large proportion of the damage was due to flooding from both ocean storm tide, which was not impeded by any dune, seawall or other barrier, and from Jamaica Bay. Floodwaters from Jamaica Bay caused severe damage to critical infrastructure including the subway system. The damage to the subway system (A line) disrupted commutes for about 35,000 daily riders.

Coney Island, NY

The high elevation of the beach berm at Coney Island project helped to reduce the impact of the storm, particularly damaging waves, on development landward of the beach. Many areas of the Island suffered significant flooding from Sheepshead Bay and Coney Island Creek. Flooding in areas behind the project resulted in damage to critical infrastructure and damage to the subway system. Buildings in the Sea Gate area, just outside of the constructed project limits, suffered major damage from waves in addition to flooding.

Plumb Beach, NY

The Plumb Beach Coastal Flood Risk Management Project prevented undermining of the Belt Parkway. The Parkway was temporarily closed due to overwash and sand deposition, but the project helped to significantly reduce the duration of disruption. Preventing an extended closure of this key access road contributed to recovery efforts.

Oakwood Beach, NY

The Oakwood Beach Coastal Flood Risk Management Project was a relatively small project constructed under the Section 103 Continuing Authority Program that essentially extended the low level of protection provided by existing revetments around to the Oakwood Beach Waste Water Treatment Plant (WWTP) and the nearby residential communities. With the exception of the WWTP, these areas are extremely low lying (about elevation +4 to +5 ft NAVD88) and subject to repetitive flooding. Generally, once a structure is overtopped, the storm surge tends to flood the area/community behind the engineered feature (i.e. levee, beach berm/dune) at a faster rate. The fact that the surge phased very close with high tide added to this phenomenon of rapid water level rise.

Keansburg, East Keansburg, and Laurence Harbor, NJ

The project at Keansburg protected the majority of shorefront and nearshore structures and prevented widespread inundation, which would have affected a population of over 100,000 people. Flood elevations behind the line of protection were about +5.1 ft NAVD88, compared to elevations of +11.7 ft NAVD88 along the levee on Pews Creek. The damage was limited to local areas where the dune was breached and the first row of buildings was exposed to storm tide and waves. The majority of the protected properties suffered little, if any, damage and the community was spared the widespread devastation that occurred in the adjacent communities of Union Beach and Port Monmouth. Among the critical infrastructure that was protected were three nursing homes and a water desalination plant.

Sea Bright to Manasquan, NJ

The beach berm at the Sea Bright to Manasquan, NJ Project was reportedly overtopped, but the presence of the seawall in the northern reach (Sea Bright to Long Branch) and the high upland elevations limited the extent of direct wave impact on most of the buildings and protected much of the water, sewer, gas, and transportation infrastructure. Coastal spits and barrier islands provide a reduction in risk from coastal damage mechanisms specifically waves and inundation on mainland communities.

Many of the shorefront communities lost large portions of their boardwalks, experienced damage or destruction of fishing piers, and incurred damage to bathing pavilions. These public facilities are essential to economic survival as summer tourist destinations. One of the most severely affected areas was in Manasquan, where a large portion of the boardwalk (nearer the inlet) was destroyed and the landward buildings were extensively damaged. Where waves shifted shorefront homes off their foundations, natural gas lines were damaged and the lines were contaminated with sand and salt water. Because of the extremely low elevations landward of the beachfill, sand deposition reached depths approaching 10 ft at some locations in Manasquan.

Many areas also suffered devastating flooding with recorded stages in the tidal rivers as high as +13 ft NAVD88. In the downtown portion of Sea Bright alone there are over 150 structures (125 residential and 25 non-residential) with elevations of +5 ft NAVD88 or below that were subject to flood depths of 8 ft or more from the Shrewsbury River. Low lying areas along the Shark River and Manasquan River were also subject to extensive flooding through the inlets.

In an attempt to identify the patterns of damage relative to the rivers and inlets over this 21 mile project length, data from the FEMA Modeling Task Force (MOTF)-Hurricane Sandy Impact Analysis was compiled for the various individual communities in the project area. This data categorizes damage as: Affected (typically less than $5,000 in damage), Minor (typically $5,000 to $17,000 damage), Major (more than $17,000 damage which frequently led to demolition or complete reconstruction) and Destroyed (where the house was no longer standing for inspection). Table 9 provides a summary of this data for the 14 towns in the Sea Bright to Manasquan project area. The damage reports indicate that the communities affected by flooding from the Shrewsbury and Navesink Rivers (Sea Bright, Monmouth Beach, and Long Branch), the Shark River (Avon by the Sea and Belmar) and the Manasquan River (Manasquan) all have a large number of buildings that were destroyed or suffered major damage. Only two buildings in protected communities not subject to the effects of tidal rivers or inlets (Asbury Park, Ocean Grove, Bradley Beach, Spring Lake and Sea Girt) were considered destroyed or subject to major damage.

Table 9: Summary of Building Damages from Sea Bright to Manasquan, NJ

Community	Destroyed	Major	Minor	Affected	Total
Sea Bright	19	108	225	305	657
Monmouth Beach	4	222	362	369	957
Long Branch	4	229	321	256	810
Deal	5	7	2	62	76
Allenhurst				13	13
Loch Arbor			18	37	55
Asbury Park			6	22	28
Ocean Grove			8	66	74
Bradley Beach	1		2	89	91
Avon by the Sea		22	80	130	232
Belmar		14	341	496	851
Spring Lake			19	165	184
Sea Girt		1	3	75	79
Manasquan	2	265	371	258	896
Source: FEMA Modeling Task Force: Hurricane Sandy Impact Assessment (V27)					

3.2 Major Exposure to Storm Tide and Waves

The area of Major Exposure Storm Tide (+6 to +9 ft MHHW and > 30 ft offshore significant wave heights) is mapped in Figure 7 and extends approximately from Townsend Inlet, NJ to Mantoloking, NJ and from East Rockaway Inlet, NY to Easthampton, NY. This area includes eight (8) projects from north to south: West of Shinnecock Inlet, NY, Westhampton Interim, NY, Fire Island to Shores Westerly (Gilgo), NY, Ocean Gate, NJ, Barnegat Inlet to Little Egg Inlet, NJ, Brigantine Island, NJ, Absecon Island, NJ, Great Egg Harbor and Peck Beach (Ocean City), NJ. The location of these projects is also shown in Figure 10 and Figure 11.

These eight projects are located in an area that was exposed to major storm tides ranging from +6 to +9 feet MHHW, approximately, corresponding to an event in the 30 to 200 year range based on comparison of measured storm tides to project design stage vs. frequency curves and available NOAA-NOS extreme storm tide statistical analyses. For the projects located in New York, Hurricane Sandy storm tides exceeded the design events, which are 44 years or less. For projects located in NJ a design level was not defined. Nonetheless, Hurricane Sandy storm tides generally exceeded design beach berm elevations.

Accordingly, significant damage could be expected at the project locations including beach erosion, wave-induced structural damage, and flooding. It is mentioned here, however, that all projects addressed in this section provided important levels of storm damage protection despite the fact that these projects were subjected to storm impacts that exceeded their design levels.

It is important to note all of the projects addressed in this section are located on barrier islands except for one, Ocean Gate, NJ, which is on the mainland bay shoreline in Barnegat Bay. The barrier island projects were also subject to flooding from the unprotected back side of the island. None of these projects were designed to reduce back-bay flooding. The design parameters for all eight projects are summarized in Table 10.

Table 10: Design Parameters for Major Exposure Projects

Id	Project Name	Berm Elev. (ft, NAVD88)	Berm Width (ft)	Dune Elev. (ft, NAVD88)	Dune Width (ft)	Structure Elev. (ft, NAVD88)	Design Event (years)	Nourish-ment Cycle (years)
35	West of Shinnecock Inlet	8.6	90	14.1	25	N/A	44	2
36	Westhampton Interim	8.5	90	14.0	25	N/A	44	3
37	Fire Island to Shores Westerly (Gilgo)	7.8	100	No dune	No dune	N/A	N/A	2
48	Barnegat Inlet to Little Egg Inlet	8.0	125	22.0	30	N/A	N/A	7
49	Brigantine Island	6.0	100	10.0	25	N/A	N/A	6
50	Absecon Island	7.2	100-200	12.7-14.7	25	N/A	N/A	3
51	Ocean City (Great Egg Harbor Inlet and Peck Beach)	6.7	100	No dune	No dune	N/A	N/A	3
55	Ocean Gate	2.5	100	No dune	No dune	N/A	N/A	No Renourishment

3.2.1 Pre-storm Project Condition

West of Shinnecock Inlet (WOSI), NY

The most recent sediment placement from the Shinnecock Inlet deposition basin was in 2010. The project area had been affected by Hurricane Irene (August of 2011) and was the subject of a repair under USACE's Flood Control and Coastal Emergency (FCCE) program, which had yet to be accomplished before Hurricane Sandy impacted the area. The design dune was lowered in several locations and the berm was also lowered and eroded. Immediately following Irene, the Town of Southampton funded the deployment of heavy machinery to place additional sand on the dune. This was initiated to rebuild the dune in critical locations to prevent further lowering of the dune elevation and breaching from future storms so that damage to the road and the fishing cooperative would be minimized. Available aerial photography suggests that the beach was relatively wide before the passage of Hurricane Sandy.

Westhampton Interim, NY

The Westhampton Interim Project has been renourished as planned. The next renourishment cycle was scheduled for Fall 2013. Therefore, the berm width was less than the design width. However, dune height was greater than design with elevations varying from +14 ft NAVD88 to +20 ft NAVD88.

Fire Island to Shores Westerly (Gilgo), NY

The last dredging and fill project occurred in 2007. Available pre-storm aerial photography (March 2012) suggests that the seaward edge of the beach berm was approximately 200 to 300 ft from the southern edge of Ocean Parkway, or slightly narrower than the design width of 320 ft from the southern edge of Ocean Parkway. A narrower section was also evident from West Gilgo to Tobay Beach at the western end of the project area.

Barnegat Inlet to Little Egg Inlet (Long Beach Island), NJ

The Harvey Cedars and Surf City portions of the project were due for their first renourishment project since initial construction in 2006-2007. As a result, the Surf City portion of the project area was at approximately three-fourths of its authorized design dimensions. The Harvey Cedars reach had approximately half of the project at or below authorized design dimensions. The Brant Beach reach (completed in June 2012) was at full authorized design dimensions prior to Hurricane Sandy.

Brigantine Island, NJ

The project was below the design template along its northern half prior to Hurricane Sandy. FCCE fill was placed between September and December 2011 to replace sand lost in the November 2009 Nor`easter (Ida). However, the contract to place the first post-construction periodic nourishment had been awarded, but was not scheduled for construction until December 2012.

Absecon Island, NJ

The pre-storm conditions were close to the full authorized design dimensions due to renourishment activities having been completed in summer 2012.

Ocean City (Great Egg Harbor Inlet and Peck Beach), NJ

About one-half of the Ocean City project length (northeast end) was below the authorized design dimensions. The rest of the project met or exceeded the authorized design.

Ocean Gate, NJ

The relative condition of the project prior to Hurricane Sandy is unknown.

3.2.2 Physical Performance

Pre-storm project conditions and physical performance metrics for the Major Storm Tide group of projects are summarized in Table 11. The performance of each project is described separately in the following paragraphs.

West of Shinnecock Inlet (WOSI), NY

The beach berm eroded approximately 50 to 100 ft to a width of approximately 50 ft from toe of the dune. Approximately 100,000 CY were lost from the berm. Dune erosion resulted in a loss of 3-5 ft of dune height and 25-30 ft of dune width. The eroded seaward dune face was nearly vertical as is common during severe erosion events. Some 50 to 80% of the dune volume (approximately 30,000 CY) was lost during the storm. While there were no breaches of the dune, a significant portion of the eastern project area was overtopped with sediment overwashing into leeward roads and buildings. As for the beach berm, it was lowered 1-3 feet by the storm and eroded 50 to 100 feet. The volumetric loss of the berm has been estimated at 100,000 CY.

Westhampton Interim, NY

Storm impacts to the beach cross-section consist of lowering and flattening of the berm above the mean tide line, reduction of berm width, and damage to the dune cross-section. Although no ocean water level data were available at this location, measured ocean storm tide elevations to the west (Ocean Beach, Fire Island) and east (Easthampton) suggest that the beach berm was inundated with at least 0.5 ft of still water plus waves at the peak of the storm. Lowering and flattening of the berm occurred over the entire project length (Groin 7 through to the park facility at Cupsogue) with an estimated average drop in beach elevation of 5-8 feet. Berm widths decreased along the entire project shoreline. The primary dune, initially constructed in 1996 and located most landward, suffered at least 50% to almost 80% volume loss for 4,100 feet, out of the 10,000 ft of the dune from Groin 15 to the western limit of the project within Cupsogue Park. Secondary lower dunes, more oceanward, were destroyed along 9,300 feet of the project length. Within the groin field from groin 7 through groin 15, the beaches lowered and receded, and there were considerable impacts to the most-oceanward dunes. There was evidence of wave runup over the primary landward dune and overwash of ocean water in some project locations. Overwash of sand over the existing dune occurred at Pike Beach in the area of the vehicle cross-over, which had been consistently at a lower dune elevation than the surrounding dunes. Total beach and dune volume lost due to Hurricane Sandy has been estimated to be 450,000 cubic yards (CY). It is noted that the barrier island breached during the storm at a location approximately 1 mile west of the western terminus of the project and 1,500 ft from Moriches Inlet (Cupsogue Beach County Park). This area previously breached during a storm in 1980, although the breaching mechanism may have been different during Hurricane Sandy.

Fire Island to Shores Westerly (Gilgo), NY

Hurricane Sandy inundated much of the island area from Fire Island Inlet to Jones Inlet. However, most of the flooding appears to have been related to extreme bay side water levels and not significant barrier island overtopping and overwash as there is no evidence of large overwash fans extending north of Ocean Parkway. Although no specific quantitative data are available, nearby ocean storm tide elevations (Ocean Beach, Fire Island) suggest that the beach berm was inundated with at least 2 ft of still water plus waves at the peak of the storm.

Table 11: Pre-Storm Condition and Physical Performance for Major Exposure Projects

Id	Project Name	Pre-Storm Condition	Storm Tide		Storm Event (years)	Depth over berm (ft)	Project Overtopped?	Significant Beach and/or Dune Erosion?
			Elev. (ft, NAVD88)	Gage Location				
35	West of Shinnecock Inlet	Deficient as a result of Irene impacts and lack of renourishment	8.0	Easthampton	50 [3]	Just below	No	Yes 0.1 MCY[2]
36	Westhampton Interim	Fair. Berm width less than design due to proximity to end of renourishment cycle	9.0	Ocean Beach & Easthampton	50 [3]	0.5 ft	No	Yes 0.45 MCY
37	Fire Island to Shores Westerly (Gilgo)	Deficient as a result of lack of recent renourishment	10.0	Long Beach & Ocean Beach	50 [3]	2.2 ft	Yes [1]	Yes Volume N/A
48	Barnegat Inlet to Little Egg Inlet	Narrow berm widths in portions of the project to end of renourishment cycle	~8.0	Estimated based on HWMs	~50 [4]	0.0	No	Yes (mostly at end of fill segments) 2.0 MCY
49	Brigantine Island	Deficient Northern Half due to proximity to end of renourishment cycle	~8.0	Estimated based on HWMs	~50 [4]	2.0	No	Yes 0.1 MCY
50	Absecon Island	Mostly at design level. Renourishment in 2012	6.3	Atlantic City	30 [4]	-0.9	No	Yes 1.1 MCY
51	Ocean City	Northern half below design level. End of renourishment cycle	6.3	Atlantic City	30 [4]	-0.4	Yes [1]	Yes 0.8 MCY
55	Ocean Gate	Mostly below design level	6.5	HWMs	N/A	4.0	Yes [1]	No

Notes:
[1] Project does not included a dune so overtopping refers to berm only
[2] MCY (million cubic yards)
[3] Based on design stage-frequency curves and available storm tide measurements
[4] Based on NOAA stage-frequency curves at Atlantic City and measured water levels or HWMs

Barnegat Inlet to Little Egg Inlet (Long Beach Island), NJ

The dune and berm were overtopped at the ends of the three fill segments, adjacent to unconstructed portions of the project. Constructed dunes were not overtopped outside those areas. Significant overwash of the existing beaches and dunes occurred in unconstructed areas in-between and outside of Harvey Cedars, Surf City, and Brant Beach. The lack of project construction in adjacent unconstructed segments lead to flooding, overwash, and damage in portions of the constructed segments. The primary causes of damage within the constructed segments of the project were due to flooding, waves, and erosion. Again, this damage only occurred at the ends of the constructed segments and the adjacent unconstructed segments. The damages at the ends of the constructed segments were relatively minor compared to damage in adjacent segments where no project features were constructed. Approximately 2.0 million CY of sand were eroded and lost from the project due to Hurricane Sandy.

Brigantine Island, NJ

Storm impacts to the beach cross-section consist of lowering and flattening of the berm above the mean tide line, reduction of berm width, and damage to the dune cross-section along the entire project shoreline. The dune, initially constructed in 2006, suffered from erosion. There was evidence of overwash of ocean water in some project locations. Overwash occurred for less than 12 hours and resulted in sand covering the roadway. Total beach and dune volume lost due to Hurricane Sandy was been estimated at 127,000 CY.

Absecon Island, NJ

Hurricane Sandy reduced the width and elevation of the beach berm along the entire project shoreline. The front of the dunes also suffered some erosion; however, they were not overtopped. Approximately 1.1 million CY of sand is needed to restore the project to the pre-storm condition. The lone structure of the authorized project has not yet been constructed, so it received no damage.

Ocean City (Great Egg Harbor Inlet and Peck Beach), NJ

The authorized project does not include a dune – it is a "berm only" configuration. In some locations, the absence of a dune and the length of time since the previous renourishment combined to permit overtopping of the beach. Approximately 800,000 CY of sand is needed to restore the project to the pre-storm condition.

Ocean Gate, NJ

Impacts to the beach fill features were not surveyed.

3.2.3 Economic Performance

The projects provided economic benefits, and protection from major storm tides or reduction in damages incurred. The projects suffered erosion and in some cases overtopping. However, in most cases they provided significant protection from tidal surge and waves to landward structures and infrastructure. Sand berms and some or all of the dunes were sacrificed as a result. At project sites along the barrier islands, such as Barnegat Inlet to Little Egg Inlet (Long

Beach Island) the projects clearly provided a reduction in shorefront storm damage but many landward structures suffered inundation from the back-bay.

Relative to the without project conditions, it is likely that the West of Shinnecock Interim Project and the Westhampton Interim Project prevented barrier island breaches which would have destroyed numerous homes, cut off access along Dune Road and contributed to increased flooding in Shinnecock Bay and Moriches Bay. In addition, inlet breaches that are not immediately closed sometimes widen and capture the tidal prism from nearby inlets, which can cause shoaling in the nearby inlets.

West of Shinnecock Inlet (WOSI), NY

The WOSI project performed as designed by: (1) minimizing storm damage to structures and their contents, (2) preventing infrastructure loss/disruption, (3) minimizing damage to critical facilities, and (4) averting the emergency response costs and loss of access to the fishing fleet associated with a breach in the barrier island. There were temporary road disruptions stemming from sand overwash and bay flooding of Dune Road, however, the project was not designed to protect against a storm of Hurricane Sandy's intensity. The road disruption in the western non-overwashed area lasted until the bay flooding receded, approximately 36 hours. It took more time to clear the eastern road and property areas where significant volumes of overwashed sand were deposited. Overall, the project prevented significant impact to the fish processing facilities and prevented a breach in the barrier, both of which would have severely impacted the fishing fleet or incurred significant expense to close a breach.

Westhampton Interim, NY

From an economic/benefit perspective, the project performed as designed: the project berm and dune acted as barriers to high water and waves, prevented barrier island breaching, and eliminated wave damage and undermining of properties behind the dunes. In addition, the project prevented losses of and disruptions to infrastructure, minimized risk of coastal storm damages to critical facilities, and averted emergency response costs. There were road disruptions stemming from bay flooding on the mainland element of the project area; however, the project was not designed to protect against this effect. The road disruptions lasted until the bay flooding receded, approximately 36 hours. The population at risk in this area is approximately 50,000 people, the vast majority of whom live on the mainland behind the barrier island. From an environmental perspective there were significant losses to the existing habitat resulting from the storm. The loss of beach berm will impact piping plover nesting areas.

Historically, the Tiana Beach area, just to the west of the groin field, has been the site of numerous breaches and washovers. The last breach at this location occurred in 1992 and remained open for over 10 months. Without Westhampton Interim Project in place it is likely that one or more breaches would have occurred during Hurricane Sandy.

Fire Island to Shores Westerly to Jones Inlet (Gilgo), NY

Infrastructure/utility losses/disruptions and damage to critical facilities were not part of the project justification.

Structures in the area were flooded from back-bay storm tides; however there was no widespread undermining of buildings. Two sections of Ocean Parkway were undermined. One 1,000-ft length near the Gilgo Beach and a second section farther east had loss of the entire shoulder and the entire southern travel lane to the road centerline.

Overall, the project berm and dune acted as barriers to high water and waves and prevented barrier island breaching. Breaching of the island would have likely resulted in higher back-bay water surface elevations during the storm, which, in turn, would have resulted in increased inundation damages to the mainland.

Barnegat Inlet to Little Egg Inlet (Long Beach Island), NJ

As documented by USACE and FEMA staff, the areas protected by the three constructed segments of the project – Harvey Cedars, Surf City and Brant Beach – appeared to be less damaged than adjacent, unprotected areas of Long Beach Island. The damage reports indicate that most of the communities were affected by flooding from Barnegat Bay; however, those communities without coastal flood and storm damage reduction projects also suffered severe erosion and wave damage and had more structures considered destroyed or subject to major damage.

Brigantine Island, NJ

Although suffering the loss of the beach berm and impacts to the dune, the project performed as designed, significantly reducing damages that would have been incurred without the project. The area, however, was subject to significant flooding from the bay and over 2,200 structures were reported damaged (FEMA Modeling Task Force). While damage on Brigantine Island was extremely widespread, only three structures were reported destroyed and 22 structures were reported to have suffered major damage.

Absecon Island, NJ

The project performed as designed. Areas in which the project had been constructed - Atlantic City and Ventnor - incurred little to no damage along the oceanfront. Areas in which the project had not yet been constructed, Margate and Longport, incurred significant damage along the oceanfront. In total 8,000 buildings were reported to have suffered damage within the four project area communities, primarily from bay side flooding.

Ocean City (Great Egg Harbor Inlet and Peck Beach), NJ

The project performed as designed; however, due to the lack of a dune in the design, there was some overwash in portions of the project. Regardless, there was significantly less damage in protected areas of the project compared to adjacent unprotected properties of Ocean City where over 6,000 buildings were reported damaged. .

Ocean Gate, NJ

The Ocean Gate project was designed as a one-time erosion control measure to protect the adjacent roadway from continued, daily/season erosion and was not designed to withstand a major storm event. The adjacent roadway was flooded but undamaged. Over 700 structures were damaged.

3.3 Moderate Exposure to Storm Tide and Waves

The area of Moderate Exposure (+4 to +6 ft MHHW and 20 to 30 ft offshore significant wave heights) is mapped in Figure 7 and extends from Swansea, MA in the north, to Assateague Island, MD in the south including numerous projects on the Rhode Island and Connecticut coasts to the west. This area includes thirty eight (38) projects in seven states, namely, MA, RI, CT, NY, NJ, DE and MD.

These thirty eight projects are located in an area that was exposed to moderate storm tides ranging from +4 to +6 feet MHHW, approximately, corresponding to an event in the 10 to 30 year range based on comparison of measured water levels to project design stage vs. frequency curves and available NOAA-NOS extreme water level statistical analyses.

This section of the report summarizes project performance by state. The type construction features included in each of the projects in this group is summarized Table 6.

3.3.1 Pre-storm Project Condition

Massachusetts

There are four projects in Massachusetts: (1) Bluff Commercial Center, Swansea; (2) New Bedford Hurricane Barrier, New Bedford; (3) Clark Point Beach, New Bedford; and (4) Oak Bluffs Town Beach, Martha's Vineyard. All of the MA projects were in good condition prior to Hurricane Sandy.

Rhode Island

There are four projects in Rhode Island, namely: (1) Fox Point Hurricane Barrier, Providence; (2) Misquamicut Beach, Westerly; (3) Oakland Beach, Warwick; and (4) Cliff Walk, Newport. These projects were in reasonably good condition prior to the storm.

Connecticut

Connecticut features 13 projects: (1) Port V Facility, Bridgeport; (2) Gulf Street, Milford; (3) Woodmont Beach, Milford; (4) Gulf Beach, Milford; (5) Sea Bluff Beach, West Haven; (6) Prospect Beach, West Haven; (7) Sherwood Island State Beach, Westport; (8) Southport Beach, Fairfield; (9) Middle Beach, Madison; (10) Point Beach, Milford; (11) New London Hurricane Barrier, (12) Stamford Hurricane Barrier, and (13) Pawcatuck Hurricane Barrier.

These projects were in good condition before the storm except for Sherwood and Southport (unknown) and Middle Beach which was in poor condition.

New York

Four projects are located in NY: (1) Shelter Island, (2) Village of Northport, (3) Orient Harbor, and (4) Asharoken. The projects were in good condition before the storm.

New Jersey

There are four projects in New Jersey: (1) Townsends Inlet to Cape May, (2) Cape May City, (3) Lower Cape May Meadows to Cape May Point, (4) East Point. Each of the projects was in good condition prior to the storm.

Delaware

Delaware has seven moderate storm tide projects: (1) Roosevelt Inlet-Lewes Beach, (2) Indian River Inlet Sand Bypassing, (3) Bethany-South Bethany, (4) Fenwick Island, and (5) Fenwick Island Rehoboth Beach, (6) South Shore Indian Inlet Interior Shoreline, and (7) North Shore Indian Inlet Interior Shoreline.

The Indian River Inlet Sand Bypassing project was in need of sand as the beach north of the inlet was in an eroded state prior to the arrival of Hurricane Sandy. The rest of the projects in Delaware were in good condition pre-storm.

Maryland

There are two projects in Maryland: (1) Ocean City and (2) Assateague Island. Ocean City was in good pre-storm condition. The pre-storm condition of Assateague Island is not known.

3.3.2 Physical Performance

Massachusetts

The Bluff Commercial Center, Swansea project was subjected to a 24-year storm tide (+4.44 ft NAVD88), performed well, and was not damaged.

The New Bedford Hurricane Barrier experienced a +6 ft NAVD88 storm tide. The Harbor gate and roadway crossings were closed per protocol. There was no damage to the project or the areas protected by the hurricane barrier.

Clark Point Beach New Bedford was also subject to a +4.44 ft NAVD88 storm tide. The structures were not damaged and prevented flooding.

Oak Bluffs Town Beach Coastal Flood Risk Management Project at Martha's Vineyard experienced beach erosion. There were no damages to the groin structure.

Rhode Island

Storm tides at Fox Point Hurricane Barrier were far below design levels. The project performed well. The beach at Misquamicut Beach was overtopped and dunes severely eroded all along its length. Storm impacts to the Oakland Beach, Warwick beach cross-section and/or the coastal structures (groins) have not been documented. The Cliff Walk, Newport project was exposed to a +6.1 ft NAVD88 storm tide estimated to correspond to the 10-year design event. The project was heavily damaged from wave impacts and overtopping. This included failed concrete and masonry toe walls, collapsed walkways, and eroded banks.

Connecticut

Most of the Connecticut projects were subject to a 30-year event, approximately. The Bridgeport project stone retaining wall performed well (no loss of armor rock or significant scour). The Gulf Street Milford project was not damaged by Hurricane Sandy and protected the street behind it. The Woodmont beach and groin project eroded but a portion of the berm remained at pre-storm elevation.

An estimated total of 9,200 CY was lost from the beach profile at the Gulf Beach Coastal Flood Risk Management Project, the beach berm was overtopped and the parking area and Gulf Street were flooded. The Sea Bluff New Haven project accreted sand during the storm. Prospect Beach in New Haven lost height and width and the beach at Sherwood State Park in Westport lowered. The beach lowered and the groin was slightly damaged at Southport. The rock revetment at Middle Beach in Madison suffered slight damage but performed reasonably.

The Point Beach Coastal Flood Risk Management Project elevated 36 existing homes a foot above FEMA's Base Flood Elevation (100-year flood) in the affected neighborhood. The available information indicates that project homes experienced minimal damage compared to neighboring homes.

The New London Hurricane Barrier was designed for a 100-year still water elevation of +9.5 ft NAVD88. The peak storm tide during Hurricane sandy at the New London NOAA-NOS tide gage was +6.2 ft NAVD88, corresponding approximately to a 30-year event based on NOAA extreme water level statistics. The hurricane barrier was not overtopped and inundation of lands and damage to buildings, roadways, and utility infrastructure did not occur.

The Stamford Hurricane Barrier was designed for a still water elevation of +13.7 ft NAVD88. The tide gage in Stamford Harbor at the navigation gate recorded a peak storm tide of +10.0 ft NAVD88 during Hurricane Sandy. Therefore, Hurricane Sandy did not exceed the design event; the hurricane barrier was not overtopped.

The Pawcatuck Hurricane Barrier project in Stonington consists of 1,915 feet of earth-fill dike, 940 feet of concrete wall (both with a top elevation of +16.1 ft NAVD88), two vehicular gates, and a pumping station. No significant impacts were reported as a result of Hurricane Sandy.

New York

The Shelter Island beach and seawall was subjected to a 30-year storm tide and performed well. The Northport seawall also performed very well. The Orient Harbor bulkhead/revetment performed well. The Asharoken project was subject to a 25-year storm tide and was overtopped. The road embankment behind the wall was scoured.

New Jersey

There are four projects in New Jersey: (1) Townsends Inlet to Cape May, (2) Cape May Inlet to Lower Township, (3) Lower Cape May Meadows to Cape May Point, (4) East Point. The area was subject to a 50-year storm tide at Cape May and a 30-year storm tide at Atlantic City.

The Townsend to Cape May Inlet Project is a beach fill (4.3 miles long) and a seawall (2.2 miles). A 500-foot long section of the northernmost (inner) end of the Hereford Inlet (North Wildwood) seawall was damaged due to current scour at the toe, leading to damage to the side-slope of the structure. Approximately 520,000 CY of sand was eroded from the beachfill project on the oceanfront of Avalon and Stone Harbor.

The Cape May to Lower Township project extends from the southwest jetty of Cape May Inlet to 3rd Avenue in Cape May City. As the project does not include a dune feature, Hurricane Sandy caused overtopping of the berm resulting in 400,000 CY of sand loss.

The Lower Cape May Meadows to Cape May Point Project is an ecosystem restoration, flood and coastal storm damage reduction project. The project features a 1.9 mile beach berm and dune fill. Hurricane Sandy caused major to moderate beach and dune erosion.

The East Point Project is a 350-foot long and 4-foot high gabion revetment, including stone-filled marine mattresses covered with geotextile material to protect the beach profile. The structure was part of a Continuing Authority Project CAP project. Therefore, there was no "design storm." Minor flooding of the road was reported during the storm. There was no reported damage to the structure from Hurricane Sandy.

Delaware

Delaware projects were subject to a 30-year event, approximately, based on comparison of measured water levels to project design stage vs. frequency curves and available NOAA-NOS extreme water level statistical analyses.

The Roosevelt Inlet-Lewes project is a beachfill project that experienced storm impacts to the beach cross-section consisting of erosion of approximately 10,000 CY and primarily consisted of reduction of berm width. Minimal lowering of the berm (maximum six inches) above the mean tide line was observed. The erosion occurred over the entire project length with an estimated berm width reduction varying from 10 to 50 feet.

The Indian River Inlet sand bypassing prevented damage to the roadway, but its pre-storm degraded state led to the beach and remaining dunes being overtopped. Overwashed sand blocked Delaware Highway 1.

The Bethany Beach/South Bethany project is a 2.8 mile beach fill. The project was at its design level and it performed well and remained fully intact during the storm.

The Fenwick Island project preformed as expected. The primary damage was from waves and erosion. Flooding mostly occurred from the bay side. The main roadway was protected from wave erosion by the dunes but was flooded from the bayside. Flooding lasted approximately one day.

The Rehoboth-Dewey Beach Coastal Flood Risk Management Project berm was eroded but the dune was not impacted and protected the back beach area from wave attack. The local roads were flooded mostly from the bay water source but the flood waters receded within one day. There was no structural damage to buildings or utilities from flooding or wave impacts; therefore, the project helped avoid or minimize damages to structures from the storm.

The Indian River Interior shoreline projects feature stone revetments extending from the inlet 1,580 feet on both the North and South interior shorelines. It is a shoreline erosion project that was not expressly designed as storm protection. Still, they survived Hurricane Sandy intact and prevented shoreline retreat and breach of the roadway. There was no damage to the structure.

Maryland

The Ocean City Coastal Flood Risk Management Project prevented island breaching and wave property damages. The dune and steel sheet pile bulkhead was overtopped by wave runup. In general, the overall width of the dunes did not change significantly. In some cases the overwash from the wave action pushed material from the top of the dune to the landside toe. In other cases, sand was removed from the seaward face of the dune and re-deposited lower on the profile. Breaches in the dune system formed at Old Wharf Road, the Sea Watch Condominium (near 11500 Coastal Highway), and between 118th – 119th Streets.

Storm impacts to the Assateague Island beach fill project were not significant. Most emergency costs consisted of debris removal. This storm caused some damages, however, it was not a severe event locally and the City quickly returned to normal.

3.3.3 Economic Performance

In most cases, the projects affected by moderate storm tide were designed for a more significant storm event than experienced during Hurricane Sandy or were designed primarily as recreation beaches. The storm tide at these projects was significant and likely would have caused extensive damage in the absence of a project. This includes storm surge barriers that effectively protected the cities of New Bedford, MA, Providence, RI, New London, CT, Stamford, CT and Stonington, CT.

The major beach fill projects in the moderate storm surge areas typically suffered erosion to the beach berms, but the dunes usually remained intact and prevented any significant damage from overtopping and wave action. This in turn protected critical infrastructure, landward structures, and in the case of the Cape May Meadows project, protected landward wetlands. Beachfill projects whose primary benefits were recreational typically suffered some degree of erosion. Those that did suffer more significant overwash damage, such as Misquamicut Beach in Rhode Island, are expected to be repaired and operational by the summer.

Most infrastructure protection projects consisting of beach fill features, such as the Indian River Inlet Sand Bypass Project, performed well. For instance, at Indian River the beach was eroded and experienced some dune loss due to overwash, but Delaware Highway 1 was undamaged and only closed for sand removal.

3.4 Minor Exposure to Storm Tide and Waves

The area of Minor Exposure (generally less than +4 ft MHHW and less than 20 ft offshore significant wave heights) is mapped in Figure 7 and extends north and south of Chatham, MA and Assateague Island, MD, respectively, to the NAD boundaries. The area includes a total of 23 projects, 13 on the Massachusetts and New Hampshire coasts to the north and an additional 10 on the Virginia coast to the south.

These 23 projects are located in an area that was exposed to minor storm tides of +4.1 ft MHHW or less corresponding to an event in the 10 to 30 year range based on comparison of measured storm tides to project design stage vs. frequency curves and available NOAA-NOS extreme storm tide statistical analyses. Offshore significant wave heights in this area ranged from 16 ft (northern VA coast) to 25 ft (northern MA and ME coastline).

The performance of the projects in this region is summarized in the sections below. The type construction features included in each of the projects in this group is summarized Table 6.

3.4.1 Pre-storm Project Condition

Most of the projects in this group were in good condition prior to Hurricane Sandy and several exceeded the design template (e.g., Chesapeake Bay Shoreline, VA). For a few of the older projects in Maine and Massachusetts pre-storm project conditions were unknown (Hampton Beach, ME and Island Avenue, MA)

3.4.2 Physical Performance

For the 10 projects located in Virginia, Hurricane Sandy was a 10-year event, approximately, and therefore these projects were exposed to comparatively minor storm tides and waves. Although the event exceeded the design level of some projects (e.g., Sandbridge Beach) impacts to beach fill features were minor to moderate with no significant losses in berm or dune height and width. One project, Cape Charles Shore Protection, did suffer a significant amount of beach fill loss due to overwash during Hurricane Sandy. There was some damage to the revetment structure. Some armor stone was lost and should be repaired in order to restore the project to design. Other than that, the only other significant damage reported was some of the material behind the Saxis Island bulkhead being lost during the storm, but the integrity of the bulkhead structure itself was not affected.

For the 13 projects in northern Massachusetts and Maine, Hurricane Sandy was generally less than a 5-year event. Projects were exposed to relatively minor storm tides and moderate offshore waves. In general, damages to projects` elements, including berm and/or dune erosion, were negligible or non-existent.

3.4.3 Economic performance

Areas affected by minor storm tides and waves experienced limited wave overtopping of features and damages were typically limited to nuisance flooding, minor erosion and temporary road closures. Areas impacted were a significant distance from the storm center, such as Virginia and Massachusetts, or northern New England. No measurable damage was reported to any infrastructure and all recreational projects (i.e., beaches) remained fully operational, although in need of debris removal.

3.5 Environmental Performance

With few exceptions, past projects of the North Atlantic Division projects have not been formulated with consideration of environmental benefits and thus this metric has not generally been considered in reviewing the project performance. Moving forward, there is an expectation that environmental considerations will be a larger part of project consideration. Two projects in Virginia; Virginia Beach Erosion Control and Hurricane Protection Project; and the Sandbridge Coastal Flood Risk Management Project, reported that environmental benefits had been used in the formulation process, but in each case they reflected less than 10% of the benefits and were associated with preventing loss of sand and associated loss of habitat. The Lower Cape May Meadows Project in Cape May Point New Jersey was the only project authorized, at least in part, as an ecosystem restoration project. The project included planting 18 acres of dune vegetation; restoration of an adjacent wetland consisting of eliminating 95 acres of Phragmites Australis and planting 105 acres of emergent wetland vegetation; restoring the sites original hydrology and improving freshwater flow; and creation of three "piping plover" ponds and five frog ponds resulting in a gain of 388 Habitat Units (HU). An assessment of impacts by the American Littoral Society following Hurricane Sandy revealed the project performed as intended as indicted by the following quote from their December 17, 2012 report:

"The Meadows fared very well during the storm and achieved its goal of flood protection. 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 extra water well."

While the remaining projects were not specifically formulated to address environmental issues, their very presence resulted in environmental changes to the pre-project conditions and in many cases Hurricane Sandy has had a significant altering effect on those changes, often adversely impacting threatened and endangered species of flora and fauna. The most common impact appears to be to bird nesting habitat. It was reported for several project sites that the movement and subsequent loss of sand has the potential to create significant impacts to piping plover nests and foraging areas. Additionally the impact to seabeach amaranth, an endangered plant, from movement and sand loss could prove extremely detrimental. The plover and seabeach amaranth do not yet have quantified or calculated losses, however their zone of inhabitation resides at the forefront of surge and wave action within the project locations. Hurricane Sandy had a direct influence on their local habitat, either by reducing the overall area available due to the loss of sand or due to increased flooding due to the lowering of the beach berm. Additionally in the case of the plover, in some instances the shifting of the berm landward has placed the nesting sites in closer proximity to human activity which may result in impacting the value of the nesting site. However not all changes are detrimental. In the National Fish and Wildlife publication, "Responding to Major Storm Impacts, Ecological Impacts of Hurricane Sandy on the Chesapeake and Delmarva Coastal Bays" they point out that at Assateague Island the morphological change including the beach over wash resulting from Hurricane Sandy created more suitable habitat for the threatened birds (piping plovers), endangered plant species (seabeach amaranth) and a rare insect (tiger beetle).

While wetlands generally faired satisfactory, at Asharoken Beach, New York, for example sand from the beach was carried by the waves and deposited on the wetlands, and trees were downed. Extensive wrack mats smothered habitat. Even in areas where the wetlands and marshes fared well, there is some concern because the invertebrates and small mammals that inhabit these areas did not due to the prolonged inundation of many of these areas. This presents a potential food shortage for predators such as the northern harriers and may impact the food supply for the long-legged wading birds as well.

The following two issues, though not directly attributable to a project site, were widely reported in various source documents and warrant attention here as they reflect an issue that should be considered when formulating future projects. As reported by the National Littoral Society, in several of the wildlife refuges, including Jamaica Bay in New York over wash and breaching has resulted in freshwater ponds being transformed into saltwater bodies of water rendering them unable to support species that depend on them for freshwater. Additionally Loss of sand along the Delaware Bay Coast line has resulted in a loss of nearly 70% of the suitable breeding habitat for horseshoe crabs. Sand loss has exposed peat base in many areas or has left insufficient sand cover for the horseshoe crabs to successfully lay eggs.

The loss of sand resulting in the loss of nesting habitat; the over wash of projects leading to debris and sand deposition in wetlands, and hydrologic changes to freshwater sources should all be considered when evaluating future projects. A more comprehensive project may help to avoid or mitigate these impacts to the environment; however, it must be recognized that even a comprehensive project may not fare well with a storm of this magnitude, and natural processes will occur.

3.6 Army Corps of Engineers, South Atlantic Division (SAD)

Hurricane Sandy had devastating consequences on Federal hurricane and storm damage reduction projects causing extensive beach and dune erosion along several hundred miles of the Southeast U.S. coastline. Due to the slow forward speed of the storm, high-energy waves and elevated water levels (storm surge and wave setup) persisted for more than a week, which is longer than typical for tropical storms and hurricanes. The combination of high waves and water levels over a long duration creates the potential for extensive beach erosion. The erosion potential of the storm, based on the Central Florida wave and water level gages, is a Category 5 hurricane using the Storm Erosion Index (SEI). Based on this index, the erosion potential of Hurricane Sandy was higher than either of the severe storms of 2004 (Hurricanes Frances and Jeanne) and it represents a 30-year erosion event. Maximum storm surge/residuals from Florida to South Carolina ranged from 0.9 to 3.6 ft during the passage of Hurricane Sandy. The storm passed within 160 nautical miles of the southeast Florida coastline with buoys offshore of Cape Canaveral recording wave heights as high as 30.5 feet. Hurricane Sandy then began to take a more northeasterly track, following the coastline of North and South Carolina from October 27th to October 29th while remaining 250 to 300 miles offshore. Water levels at Cape Canaveral, FL were one foot more than predicted tides for more than 48 hours and peak water levels were approximately two feet more than predicted for a 24 hour period. As Hurricane Sandy passed offshore of South Carolina, the maximum storm tide measured was +5.6 feet NAVD88 at Clarendon Plantation, SC and 4.2 feet NAVD88 within Charleston Harbor.

Conditions along the Southeast U.S. coast varied from project to project, however, all were in adequate condition to provide the authorized storm damage protection prior to the storm. The long duration of the storm caused significant erosion of project berms, increasing the vulnerability of project areas to future storms. However, due to the existence of the protective berms, most areas had minimal erosion into the dune or upland structures. The exceptions are in Broward County, FL, Segment II where the shorefront road (and evacuation route) was undermined and partially collapsed. Traffic rerouting was required and an emergency repair of the roadway was conducted. The road remains vulnerable to future storms until the beach rehabilitation is realized. In Folly Beach, SC eight homes were damaged during the storm, with undermining of the structures causing temporary displacement of the residents. For the projects evaluated in this South Atlantic region, the benefits provided by restoring to the pre-storm condition were greater than the costs. The benefits for national economic development include storm damage reduction benefits. .

As Hurricane Sandy passed by the Southeast U.S. coastline, elevated water levels and strong waves were experienced over several days. The duration of the storm in its slow passage caused significant erosion in parts of Florida and South Carolina. Projects performed as intended, absorbing the storm energy and buffering shorefront structures. In most locations, damage to shorefront structures was minimal and damage was limited to the beach berm and dune system. However, the amount of erosion exceeded that designed for in the project and project areas remain vulnerable to future storms.

3.7 Army Corps of Engineers, Great Lakes & Ohio River Division (LRD)

After battering the east coast of the United States, Hurricane Sandy moved inland and brought high winds and rain far into the nation's interior. The winds were generally from the north over the Great Lakes, with a wind speed of 68 mph felt as far west as Michigan City, IN on the southern Lake Michigan shore. With the wind from the north and aligned with the longest fetch, waves within the southern portion of Lake Michigan built to over 20 feet. The intensity of the winds over Lake Erie, while not aligned with the longest fetch, created extraordinarily rare large waves from the north of over 17 feet offshore of Cleveland, Ohio. The southern shore of Lake Ontario also had wave heights of up to about 15 feet near Irondequoit Bay, NY.

Storm impacts within the Great Lakes and Ohio River Division (LRD) were primarily focused along the southern shores of Lakes Michigan, Erie and Ontario consisting of additional channel shoaling and navigation structure damage at Federal harbors in addition to several inland locations. Thirty one (31) projects are identified in LRD as requiring repair due to damages sustained from the storm, with 28 of those projects being navigation (NAV) projects Additionally, there are two (2) inland Flood Risk Management (FRM) projects, and one (1) Environmental (ENR) project. The five (5) districts affected were: Buffalo (LRB), Chicago (LRC), Detroit (LRE), Huntington (LRH) and Pittsburgh (LRP).

The maintenance needs of the harbor structures and navigation channels throughout the Great Lakes coupled with the age of the structures (most are over a century old), made the structures more vulnerable to storm damage. Navigation channels that were not maintained to their full width or depth were more vulnerable to additional shoaling from the storm. These factors contributed to the impacts experienced from the severe waves generated by Hurricane Sandy.

4.0 BARRIERS TO COMPREHENSIVE PROTECTION

Comprehensive protection can only be realized when all agencies, municipalities and individuals recognize the risks and collectively make efforts to reduce the risks. The concept is displayed in Figure 20. For the purpose of this report, comprehensive protection will be limited to the risk reduction measures afforded by USACE recommendations and projects. This report is intended to identify institutional barriers to providing a comprehensive Federal (USACE) project. It should be noted that each institutional barrier may not be a noteable impediment by itself, but that the relationship among the barriers can create a combined effect causing more significant impediments overall. The totality of the influence of the institutional barriers is reliant on all of the barriers that exist.

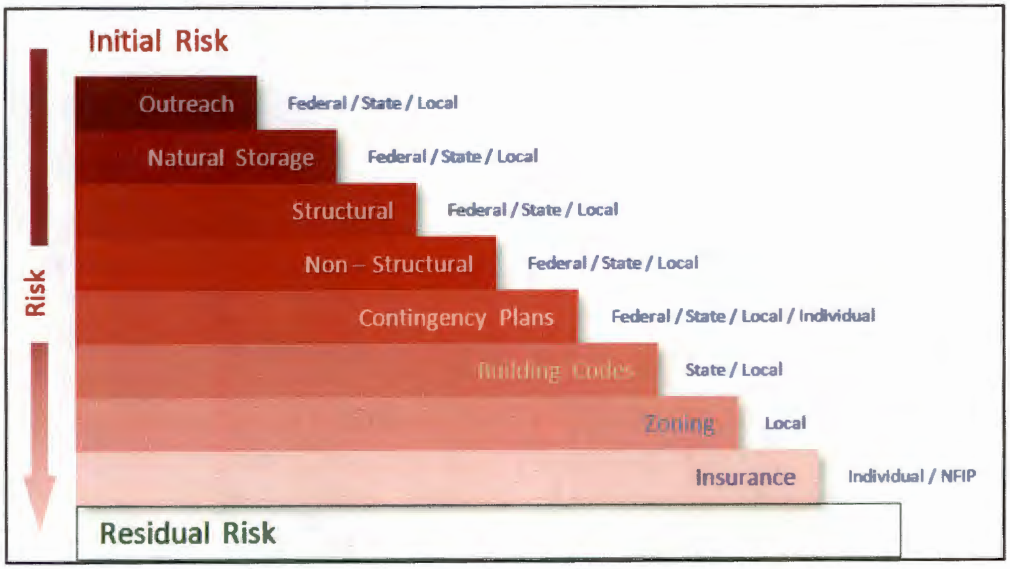


Figure 20: Collective Effort to Accomplish Comprehensive Protection

Managing flood risk is a shared responsibility for the local, state, and Federal governments because of the independent but interrelated authorities and responsibilities associated with delivery of more comprehensive risk reduction. Comprehensive protection is best realized when all public and private interests collaboratively develop and coordinate implementation of solutions that include structural and non-structural elements. However, some degree of residual risk will always remain. Hurricane Sandy and the post-storm reviews have revealed impediments to delivery of more comprehensive protection to coastal communities. Impediments revealed to date include those that are described for purposes of this report as being of a technical, financial, environmental, and procedural nature. It should be recognized that no plan, project, or strategy can provide complete protection and that there will always be residual risks that should be expected and can be managed. Likewise, policies at all levels of government that allow for risk-based decisions, and the resulting choices that are made by individuals and governments at all levels affect the degree to which more comprehensive risk reduction may be assisted by Federal civil works projects.

4.1 Back-bay Flooding

The USGS recorded record water levels, record measured high water marks (HWM), and even record waves at a few locations from the North Carolina and Virginia border to Boston, Massachusetts. These data facilitated efforts to understand flooding impacts witnessed throughout the NAD. Importantly, the HWM shows the prevalence of flood levels in back-bays (e.g. leeward side of barrier islands, within larger estuaries, etc.). Focusing on areas that experienced Extreme exposure (e.g. classification of Extreme exposure - storm tide greater than +9 ft Mean Higher High Water, greater than 30 ft offshore significant wave heights, and greater than a 200-year storm event), it is clear from interpretation of data gathered for the forthcoming Performance Evaluation Study that the Rockaway, Coney Island and Sea Bright to Manasquan projects were each flooded from the adjacent back-bays. While floodwater levels were lower in the back-bays than on the ocean shoreline, they still caused widespread flooding and attendant inundation damages to structures. None of these USACE projects had features that would reduce the magnitude and extent of back-bay flooding. The project authorizations did not include addressing back-bay flooding through the implementation of coastal flood risk management measures. Examples of such authorizations are as follows:

- Rockaway – The Flood Control Act of 1965 (River and Harbor Act of 1965); P.L. 89-298, as amended by Section 72 of the Water Resources Development Act (WRDA) of 1974; P.L. 93-251, as amended by Section 1002 of the WRDA of 1986; P.L. 99-662 (100 Stat. 4082).
- Coney Island – Section 501(a) of the WRDA of 1986; P.L. 99-662 (100 Stat. 4135), as amended by Section 1076 of the Surface Transportation Act of 1991.
- Sea Bright to Manasquan – The River and Harbor Act of 1958, as modified by Section 854 of the WRDA of 1986; P.L. 99-662, and further modified by Section 4 of the WRDA of 1988; P.L. 100-676 and Section 102 (r) of the WRDA of 1992.

Moving forward, desires to reduce damages associated with back-bay flooding might be given greater consideration and priority during the framing of study and project authorities, and the formulation of Federal civil works projects to contribute to more comprehensive risk reduction in coastal areas. Additionally, more effective communication of residual risks, that may still be present following implementation of an ocean-side project that lacks back-bay features, may improve collective understandings of what might be required to deliver more comprehensive risk reduction. Such communication can facilitate more informed decision making.

4.2 Lack of Dunes

Natural dunes are features of many ocean beaches, particularly on barrier islands, and can reduce the potential for breaching, overtopping and overwashing of land-backed beaches and barrier islands. Dunes can significantly contribute to the volumes of sediment available for redistribution along the shoreline during a storm, reducing the potential for undermining and exposure of land-based infrastructure, and impeding the landward reach of storm tides. Dunes have not been included in a number of beach nourishment projects (Federal or otherwise) for several reasons (1) provision of desired levels of damage reduction may be possible without a dune; (2) some projects may not need a dune because of high upland elevations; and (3) some plans that include dunes are opposed by stakeholders due to the aesthetic effects of dunes related to ocean views. At many locations, development has encroached on areas that were once occupied by dunes. The dynamic processes that once shaped the coastal dunes and their influence on beaches have been altered. By way of example, houses were constructed on the natural dune in Manasquan, NJ during the late 1800s and early 1900s, and since the 1960s similar development has occurred in Florida, where beachfront high rise buildings were built directly on or adjacent to the existing dunes in an effort to build as close to the oceanfront as possible. Looking to the future, greater consideration of the multiple roles served by dunes, and the full suite of associated benefits that they provide should be required as part of delivering more comprehensive risk reduction along coastlines. Additionally, more effective communication of residual risks that may still be present following implementation of an ocean-side project that lacks dunes may improve collective understandings of what might be required to deliver more comprehensive risk reduction landward of beach-fill projects. Such communication can facilitate more informed decision making.

4.3 Limited Availability of Data

Sufficient pre and post-storm data are required to monitor the conditions of projects, and the types and magnitudes of forces acting on the projects, improve project performance. Any objective metric to be utilized in evaluating the performance of a storm damage reduction project performance during a specific event requires (at a minimum): water level measurements (e.g. storm tide); nearshore wave measurements (i.e., in addition to offshore buoy data); coastal wind measurements; and pre- and post- storm topographic and bathymetric surveys of the project. In many instances, these data are not available (or are not all available for the same project location). As a result, post-event assessments of performance and subsequent attempts to understand and improve upon (what might have been) observed levels of performance are frequently limited to the availability of data. In the forthcoming NACCS, an acute awareness of USACE's reliance on other sources of data (from Federal and state agencies, along with local municipalities) has been demonstrated. Based on experiences from Hurricane Sandy and a review of USACE project performance, it is believed that more uniform availability and accessibility of monitoring data could contribute to more effective management and adaptation of coastal projects, contributing to more comprehensive risk reduction along coastlines.

4.4 The Roles of Real Estate Easements

The high cost of real estate easements required for project elements, and challenges in securing real estate easements required to implement features of coastal projects that might contribute to improved effectiveness, continues to impede delivery of more comprehensive coastal storm damage risk reduction. While ongoing USACE efforts to evaluate the performance of flood and coastal storm damage reduction projects have focused on the performance of constructed USACE projects, the complications associated with securing real estate easements required to implement a coastal flood and storm damage reduction project might be best demonstrated by looking at New Jersey south of the Manasquan Inlet, as documented in New Jersey Shore Protection, Manasquan Inlet to Barnegat Inlet, NJ Feasibility Study, dated June 2002, where the Manasquan Inlet to Barnegat Inlet project has never been constructed due to difficulty securing required real estate easements. The challenges are also visible on the Barnegat Inlet to Little Egg Harbor Inlet (Long Beach Island) Project, as documented in the New Jersey Shore Protection, Barnegat Inlet to Little Egg Inlet, NJ Feasibility Study, dated September 1999, which has been constructed not as a single continuous project, but rather as a number of smaller disconnected projects (as evidenced by the map shown in Figure 21) due to challenges associated with securing real estate easements. The result is an intermittent rather than continuous system of projects along the coastline.

As documented in the Long Beach Island Project, the capacity to acquire easements required to construct the planned project has been limited due to opposition to: project features that limit views of the ocean and are perceived to reduce the value of properties; required provisions of public access to Federal civil works projects involving points of access that cross over private property; and liability issues associated with public use of privately owned lands. The New Jersey State appeals court recently upheld a $375,000 award for one property owner's loss of ocean view that resulted from construction of a dune in Harvey Cedars, NJ. The resulting implications for real estate expenses and associated project costs could present challenges for delivery of more comprehensive risk reduction in coastal areas by making economic justification of some projects (that are part of a more comprehensive risk-reduction strategy) more difficult, and/or limiting the capacity for non-Federal sponsors to support project construction.

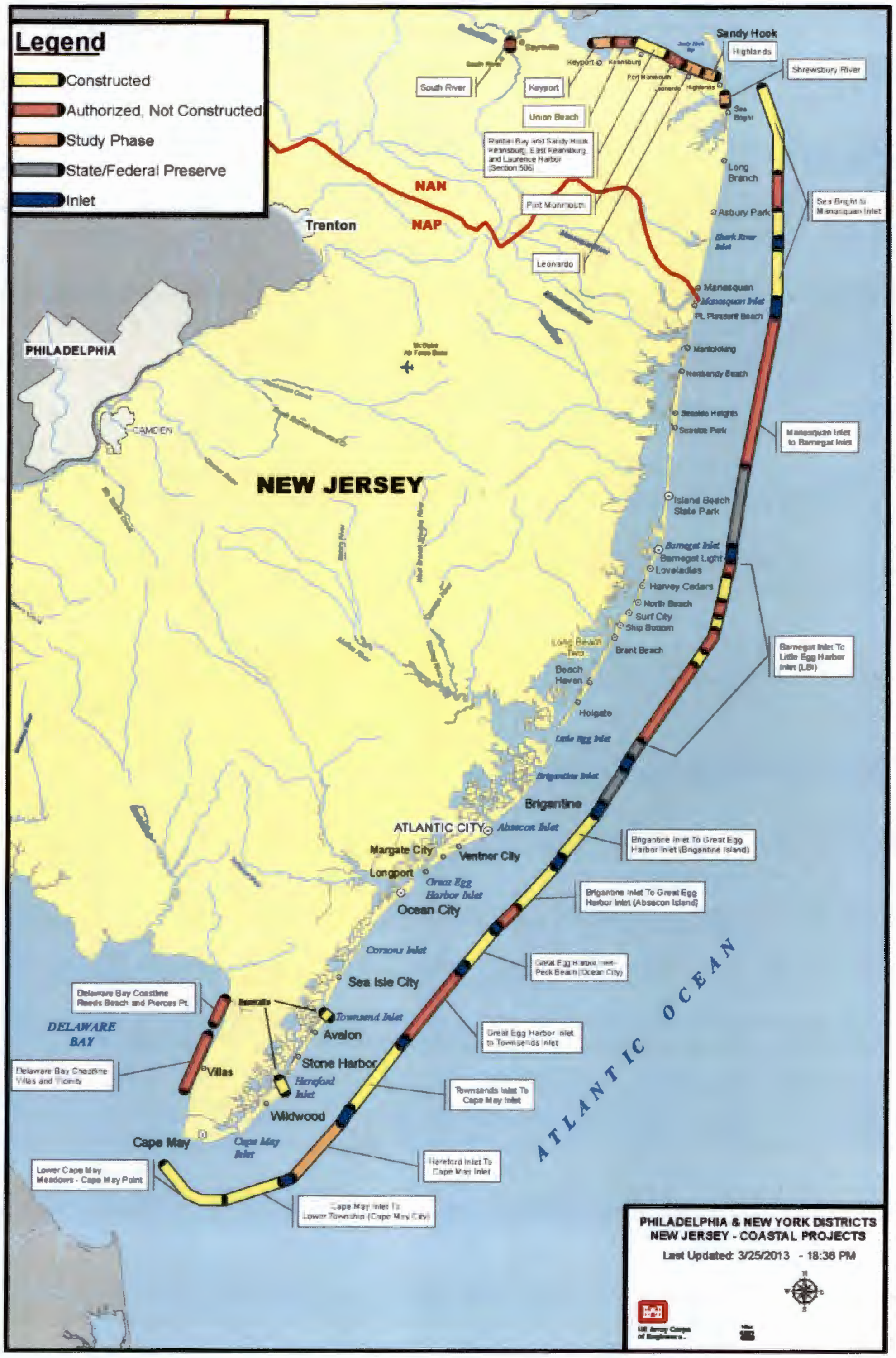


Figure 21: Status of Coastal Flood and Storm Damage Reduction Projects before Hurricane Sandy

4.5 Maintaining the Profile of a Nourished Shoreline

The benefits associated with a nourished coastline depend upon the maintenance of the condition and volume of the beach profile. Disruption of planned maintenance and renourishment activities, and accelerated degradation of project conditions caused by random coastal storms can affect the project's capacity to deliver expected benefits. Factors that can affect maintenance of nourished coastlines include: magnitude and frequency of coastal storms and associated forces on projects; priorities of project sponsors and partners; environmental conditions that affect the scheduling of sediment dredging and placement activities; availability and accessibility of suitable sediment; and availability and capacity of the domestic contractor dredging fleet to name a few.

According to estimated 5-year future Federal cost data compiled in the Coastal Systems Portfolio Initiative (CSPI) Technical Review Document, dated Spring 2011, Federal funding associated with projects in states like New York and New Jersey accounts for at least 50 percent of the annual appropriations for the Nation's coastal flood risk management projects in some years and exceeds the historic annual appropriations amount of 100 to 150 million dollars in other years. The majority of USACE beach nourishment projects constructed after the WRDA of 1986 include periodic renourishment as a continuing construction project feature. The renourishment volumes are selected based on the time between scheduled renourishment events. In order to complete beach renourishment as scheduled, both the Federal and non-Federal funding must be available at the appropriate time.

4.6 Permitting Constraints and Environmental Construction Windows

The Corps planning and permitting processes, the National Environmental Policy Act (NEPA), and the Coastal Zone Management Programs (CZMP) provide the Corps with tools to balance competing land and water zone uses and values. Balancing functions in the coastal zone is an important dimension to the planning and environmental compliance processes for risk management projects as the factors that attract growing numbers of people to shoreline environments, and the resulting pressures on these fragile systems, are often at odds with the perpetuation of the very ecosystem services which make them so attractive. However, over time there has been both increasing pressure on coastal biota and a concomitant elaboration of the regulatory landscape which protects them. This has resulted in a situation in which it is progressively more challenging to achieve the balance envisioned by CZMPs, NEPA, and other planning and permitting requirements when planning and constructing coastal projects intended to manage coastal risks. Hence, the coastal projects that would result in more space in which to resolve competing coastal uses and values and provide Federal and restore healthy coastal ecosystems are increasingly difficult and more expensive to construct.

During the planning process the Corps consults with resource managers who are charged with protecting species and natural resources. This consultation process can result in protective measures incorporated into project plans in order to reduce or avoid impacts to endangered or threatened species. These measures often include permit conditions on construction techniques or time-of-year "no construction windows". In the aggregate, the permit conditions and environmental construction windows limit the duration of dredging that can occur with a given year. This presents a planning and operational challenge as the Corps balances the competing resource demands in partnership with expert resource agencies to ensure environmentally sensitive and sustainable dredging / dune building projects. Examples of these project planning and operational challenges include elongated construction schedules, repetitive impacts due to remobilizations, delaying the initiation of borrow area recovery, and adding significant project costs due to the remobilization of construction dredges and other construction equipment, and increased competition for that equipment in the limited period during which construction is allowed. Additionally, these planning considerations often require dredging activities occur in the winter months, increasing the risk to personal safety for the dredge crew members. Rising industry costs also reflect these increased risks and liabilities.

Permit conditions and environmental construction windows can limit the duration of dredging that can occur within a given year. As an example, construction schedules compiled for the Long Beach, NY coastal flood and storm damage reduction project (currently under study) propose a 52-month implementation schedule that includes a 7-month period during each year when work cannot occur due to the presence of nesting birds. The construction schedule would otherwise be completed within 24 months. The limited duration can increase construction costs by increasing demand for dredges during operating windows, affecting the overall accessibility of commercial dredges and effectively decreasing competition. Furthermore, environmental considerations can increase the level of effort and associated costs required to identify and access new sources of borrow material, and at times restrict site selection to Federal navigation channels.. In addition, new and expanded fishery/wildlife designations and/or jurisdictions of resource management and regulatory agencies can further limit dredging borrow site opportunities.

It is recognized that the National Environmental Policy Act (NEPA) requires and allows for stakeholder engagement, input, and insight into the Federal decision process however the process is sometimes blamed for project delays. Opportunities to prepare and deliver programmatic Environmental Impact Statements (EIS) and regional sediment management plans are a way to expedite the projects while still satisfying the purpose and intent of NEPA.

4.7 Future Coastal and Storm Damage Reduction Projects

Utilizing the full suite of potential damage and project benefits will allow the decision makers to have a better understanding of the benefits of comprehensive coastal risk management projects, allow implementation of projects that address impacts of larger storms and will better define the true residual risk associated with projects. This full suite of potential damage and project benefits will be examined further during the NACCS to determine challenges or impediments that could be encountered in their use.

4.8 Cost Sharing Requirements and Local Sponsors' Willingness to Pay

Delivery of more comprehensive coastal flood risk management project is likely to come with added cost. The capacity of non-Federal sponsors to support projects that deliver greater risk reduction with a higher degree of predictability/reliability may be insufficient to cover cost-share requirements for construction and/or long-term operation and maintenance of Federal civil works projects. The willingness of non-Federal parties to fund, and sustain funding of their contributions to strategies and systems (including Federal civil works projects subject to cost-share requirements) for providing more comprehensive risk reduction may prove to be a notable challenge.

4.9 Lack of Implementable and Enforceable Flood Plain Management Plans

It is important at all levels of government to have effective communication about the risks of living in flood-prone areas among public and private interests. These communications help to plan for and manage land use and future development in vulnerable areas, and the absence of incentive and disincentive-based policies such as the elimination of Federal flood insurance, for developing flood plain management plans can be an impediment to provision of more comprehensive and sustainable coastal flood risk management.

4.10 Opposition from Recreational Shoreline Users

Surfing and fishing groups have expressed concerns about beach nourishment projects stating they change the wave surfability and reduce nearshore fishing "holes". Similarly, opposition to project features that affect access to water, aesthetics, and views can also present challenges for flood risk reduction projects that might include elements such as floodwalls, bulkheads and seawalls. There can be considerable trade off considerations in water resources planning.

5.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The Findings and Recommendations presented in this section are intended to summarize the benefits and performance of the USACE projects impacted by Hurricane Sandy and to identify opportunities for improving future project performance.

5.1 Findings

5.1.1 Records for Storm Tides and Waves

Hurricane Sandy was an extraordinary storm, especially in the New York / New Jersey Bight coastal areas extending from Cape May, NJ to Montauk Point, NY. The storm produced record water levels at both the Sandy Hook, NJ tide gage (an estimated peak of +11.6 ft NAVD88, +10.4 NAVD88 before failing) and the New York Battery tide gage +11.3 ft NAVD88. The peak water level at the Battery was 4.1 feet above the previous storm of record set by Hurricane Donna in 1960. The measured water levels for the New York and Sandy Hook tide gages represent 700 and 940 year events, respectively. No project in the Extreme exposure area was designed for anything greater than a 200 year event. Most were designed for a 40 year event or less. Accordingly, significant storm damage should have been anticipated for the USACE projects in the Northern New Jersey and New York City area.

5.1.2 Projects Performed Better than Expected

There are six (6) projects in the Extreme exposure area which extends from Manasquan Inlet, New Jersey (Southern limit) up along the New Jersey Coastline, across the Raritan Bay and east along the south facing shoreline of New York to East Rockaway Island, NY (Eastern Limit). The six (6) projects impacted by the Extreme storm tides and waves include Sea Bright to Manasquan, NJ; Keansburg, East Keansburg, and Laurence Harbor NJ; Oakwood Beach, NY; Coney Island, NY; Plumb Beach, NY; and Rockaway, NY.

It is important to recognize that the above projects were subject to unprecedented waves and water levels substantially greater than design conditions. Accordingly, significant or extreme damage could be expected at the relevant project locations. Expected damages would include beach erosion, wave-induced structural damage, and flooding. With the exception of Oakwood Beach (which was designed for a 15-year event), each of these projects provided significant levels of storm damage reduction despite the fact that they were subjected to a storm that greatly exceeded the design storm. In fact, the beaches served to mitigate wave-induced structural damages for most of the area. Of the six (6) projects, only Sea Bright to Manasquan and Rockaway had any significant wave impact damages and these damages were not widespread. Rather, the wave impact damages were usually limited to the first or second row of buildings landward of the shoreline.

5.1.3 Widespread Back-bay Flooding

Despite the relative success described in the preceding paragraph, heavily developed areas on the bayside of many project and non-project locations including the Sea Bright to Manasquan, Coney Island, Rockaway, Westhampton, Gilgo, and Barnegat Inlet to Little Egg Inlet (Long Beach Island) projects were subject to significant back-bay flooding. None of these projects were planned or designed as part of a comprehensive system to provide flood risk management within the bays. This is a significant issue insofar as there was widespread inundation in many of the bays and that the lower elevations of development within the bays make these structures highly vulnerable to significant storm events and future sea level rise.

5.1.4 Protective Dunes and High Storm Berms

The only project in the Extreme Storm Surge area that included a protective dune was the Keansburg, East Keansburg, and Laurence Harbor, NJ project, which incorporated the dune into a flood risk management system including levees, floodwalls and closure gates. When compared to nearby Union Beach that had no project but was exposed to similar storm surge and wave action the value of the dunes were evident. Union Beach suffered extreme losses with many structures being destroyed or suffering significant damage. Hurricane Sandy caused the dune in parts of Keansburg and East Keansburg to fail, but it held damages to a minimum.

Coney Island is an example of a project with a high elevation storm berm (+11.6 ft NAVD88) that provided an exemplary level of protection and project performance. The berm cap (storm berm) at Sea Bright to Manasquan (+9.3 NAVD88), combined with the additional protection afforded by the existing rock seawall, also had a positive effect on project performance.

5.1.5 Increased Damages at the Project Ends

For some projects, damages only occurred or were worse at the ends of the constructed beach fill segments, immediately adjacent to no-project or unconstructed segment areas. Nonetheless, the damage at the ends of constructed beach fill segments was relatively minor compared to damage in adjacent segments with no project features constructed.

5.1.6 Characterization of Hurricane Sandy Damages

Wide-spread damages were expected given Hurricane Sandy's intensity (> 500 year event in some areas) and the projects in the Extreme exposure group certainly suffered damages. Damages were highest and occurred over a wide area within the Sea Bright to Manasquan (21 miles) and the Rockaway (6 miles) projects. There were three types of coastal flood damages to the 27 miles of coast for these two projects: (1) beach erosion and overwash, (2) wave attack damage to near-shore structures including buildings, boardwalks and other infrastructure, and (3) inundation damage from ocean and back-bay flooding. As has been emphasized, specific project features for protection against back-bay flooding was not provided in any of the subject USACE projects.

Sea Bright to Manasquan and Rockaway were subject to beach erosion, flooding from the ocean, and wave damages. Both projects were subject to significant beach erosion. This allowed ocean waves and flood waters to reach upland buildings and other structures. Additionally, overwashing waves carried significant volumes of beach and dune sand landward from the ocean. In many cases the distances of sand transport were as much as 1,000 feet. Structural damages were generally limited to: (1) destruction of boardwalks and (2) damage to the first and sometimes second row of buildings. In many cases, sea-side buildings were not damaged structurally. Inundation flood damages, however, were widespread and appear to have resulted from both ocean and back-bay flooding mechanisms. Again, back-bay flooding was not addressed by either of the projects.

The projects performed well given the extreme storm conditions. The level and expanse of oceanfront damages is judged to be significantly less than would be expected under the without project condition for the storm tide and wave conditions that characterized Hurricane Sandy. One only needs to look at the extensive devastation in non-project areas such Union Beach, Mantoloking, and Ortley Beach versus nearby project areas in Keansburg, East Keansburg, and Laurence Harbor as well as Sea Bright to Manasquan, respectively, to appreciate how well these projects performed. In this sense the projects were highly successful in reducing magnitude storm damages although significant residual damages were incurred and the project features require post-storm restoration. The principle concern moving forward after Hurricane Sandy appears to be how the issue of back-bay flooding should be addressed.

5.1.7 Institutional Issues

Coastal storm damage reduction projects typically do not provide a specific level of protection. As a result, many coastal storm damage reduction projects, particularly those that derive protection from beach nourishment, intrinsically include a significantly high risk to project design exceedance during the lifetime of the project. The reason for this is because the greatest return on investment has typically been accomplished by eliminating or greatly reducing risk of coastal storm damages resulting from higher frequency storm events (e.g. less than a 40 year event), and accepting moderately reduced risk of coastal storm damages from lower frequency major storm events (low frequency events). In addition, projects are rarely re-evaluated for changes in risk over their service life. For example the dune and levees in Keansburg, East Keansburg, and Laurence Harbor were designed for a 200 year event in the mid 1960's and the dune construction was completed in 1969. Since that time the area has experienced about 0.5 feet of sea level rise and the current effective Flood Insurance Rate Maps (2009) consider the project as not providing effective protection for a 100 year event. The reference to fixed dimensions in the project authorization limits opportunities to improve project performance by updating the design dimensions in response to changed conditions.

5.2 Recommendations

Several recommendations to improve project performance have been identified in response to the findings in this report. In parallel, a Design Standards and Criteria Team was formed to examine existing USACE coastal engineering design standards and criteria as part of the NACCS.

Headquarters USACE directed the establishment of a team under the NACCS to examine current science and coastal engineering design standards. The team was formed with sixteen (16) technical specialists from the following entities: coastal engineering design experts and national/regional technical specialists from CENAE, CENAP, CENAN, CESAJ, and CENWP; specialists in Risk, Beach Fill, Structures, Hydrodynamics, Coastal Numerical Modeling from the Engineering Research and Development Center – Coastal and Hydraulics Laboratory and Environmental Laboratory; Sea Level Rise & Climate Change Specialists from the Institute for Water Resources; Structural Engineering & Geotechnical Engineering Technical Leadership from HQUSACE; and CENAD Technical Leadership. Design Standards and Criteria Team provided input to these recommendations.

For presentation purposes the recommendations are grouped into (1) future project planning, (2) design/construction, and (3) renourishment/maintenance phases of the project life. While the recommendations have been grouped into these phases, several of these recommendations could be applied at any point in the project life.

5.2.1 Future Project Planning

- The majority of past study authorizations did not encompass the back-bay shorelines, and focused on erosion control and storm damage reduction along ocean shorelines. Those studies focused on three damage mechanisms (storm induced erosion, wave attack, and inundation), but priority was given to the first two because it is more cost effective to reduce risks against those mechanisms. Flooding of the barrier island bayside and nearby mainland development is a major source of storm damage. These impacts should be quantified and every project should identify opportunities to mitigate such risks through a systems approach. This will help to ensure that the plan selection is not incompatible with comprehensive solutions that address back-bay flooding.

- Experience and observations from Hurricane Sandy suggest that consideration of a broader range of project benefits should be considered to more accurately evaluate the impacts of such an extreme event and consideration of how climate change increases risk. Consideration of long term recovery costs, secondary impacts due to damage to critical facilities, the potential for injury and loss of life, and environmental damage could alter the selected scale of a project to reduce the residual risk.
- Hurricane Sandy has provided dramatic examples of the economic, social and environmental impacts of damage to key infrastructure and the benefits of protecting critical facilities. Community resilience and recovery can be enhanced by explicitly protecting critical transportation, water supply, wastewater treatment, power, and communication infrastructure, and important community buildings such as hospitals, schools, and emergency response facilities against major storms. This may require supplemental protection features to ensure a lower level of risk for these critical facilities.
- Those involved in the planning of coastal storm and flood risk management projects might consider using a more comprehensive approach that recognizes impacts and benefits of risk reduction to critical infrastructure and that accounts for all consequences and impacts of disruption. Lack of access to storm impacted areas for response and recovery is not normally considered in benefit to cost analysis. Understanding relationships between primary and secondary impacts is crucial to understand functions of infrastructure and impacts of disruption.
- Beach nourishment projects should explicitly evaluate a dune feature. Because the dune is typically a low cost addition to the beach fill, any decision not to include a dune should be discussed as part of the plan selection documents. To mitigate resistance by local residents and to facilitate acquiring the necessary easements, greater flexibility needs to be considered in the permitted language to limit public access to specific areas, to provide assurance that board walks and future crossovers will not later be added and to provide relief against future liability associated with public use of privately held lands.
- Interstate collaboration (e.g. state compacts) can be integral to facilitating successful comprehensive protection through coastal flood risk management projects.
- Use of regional sediment management practices can supplement coastal protection and should be institutionalized within Federal and navigation maintenance operations. Regional planning with various Federal and non-Federal agencies and stakeholders should be conducted to identify and analyze additional sand resources.

5.2.2 *Design and Construction*

- The surges experienced during Hurricane Sandy exceeded the levels considered during the design of several projects. The understanding of residual risks would be enhanced with better analysis and understanding of extreme events and projected impacts of climate change.
- Incorporation of a higher elevation storm berm in the design template can improve the physical performance of the project and reduce or eliminate wave induced damages to

upland structures. Inclusion of a storm berm feature near the toe of the dune should be considered on projects that involve a wide berm cross-section.

- Dunes can provide protection for a relatively small volume of sand both on the ocean and bay shorelines. Conventionally, dunes should be constructed along with a protective beach. At the time of construction, dunes should be actively vegetated to reduce loss from wind-blown sand transport and increase their resistance to erosion. In principle the dune provides protection for storm events and the beach provides both shore erosion protection and protection to the dune. There are many communities that resist dunes because they block views and complicate the access to the ocean. Nonetheless, such combinations can be an essential feature of any project intended to reduce risk of coastal storm damages.
- Hard structures such as rock seawalls in combination with beach fill should be considered in highly urban areas when protection by means of beach fill alone may not be practical or economical particularly at lower design event return frequencies. The structure can be "buried" under a sand dune so that it would only be exposed during extreme events when the extra protection is required.
- Beach fill projects should consider longer tapers or additional protection at the end of the constructed beach fill segments, at least during initial project construction and the first one or two nourishments, to prevent increased risk of coastal storm damages in those areas. The transition between protected and non-protected areas needs to be designed and detailed more rigorously. This also would apply to transitions between different types of protection
- A methodology should be developed to be more consistent across all USACE Districts and Divisions to address if and how the concept of "design level of protection" or project design exceedance is utilized and presented.
- If possible, coastal flood risk management projects built by the USACE would have permanently installed and maintained near-shore wave/current gages and a local weather station (at least an anemometer and a barometer). Such data could be collected at a limited number of strategically located projects. These projects would also be surveyed on a regular basis, particularly just before the onset of storm season and immediately after significant storm events.
- The USACE must strengthen its Coastal Risk-Based Design Framework. The USACE should conduct a long-term reassessment of risk-based shoreline protection project methods. Design standards should explicitly articulate the risk of project instability or failure as well as the risk of unacceptable consequences; these standards should also be performance-based. Risk should be communicated to partners and stakeholders more effectively.

5.2.3 Improvements to Project Nourishment and Maintenance

- The Corps recognizes that the nourishment and maintenance of beaches is generally already part of current study efforts, but this report recommends some possible improvements to renourishment efforts. Note that the Comprehensive Study currently being developed will evaluate maintenance alternatives and identify options that are both sustainable in the long-term and cost effective.

- O&M of navigation channels can provide sand for beaches, but the timing of operations (e.g., environmental windows, beach activity) or the sediment size may not permit placement on the beach. Possible recommended options include (a) local and Federal stakeholders having standing paperwork and liens up-to-date for beach placement; (b) establish permitted nearshore placement locations to allow placement which will take advantage of natural processes to winnow out fines and transport sands onshore; and (c) in view of damages that occurred from the bayside, establish permitted placement locations on the bay.
- Need mechanism to prioritize projects. The Coastal Structures Asset Management Program is starting to look at beaches and other flood risk reduction projects which could allow for improved practices.
- Over the life-cycle of a project there may be changed conditions that warrant changes in the project design. These could include accelerated sea level rise, shifts in development trends, public tolerance for storm risks, changes in coastal storm patterns, or changes in coastal flood risks due to climate change. Currently the approach to implementing relatively minor changes in design dimensions is unclear. It is recommended that guidance clarify the level of agency approval required for potential changes in project dimensions (e.g. adding storm berms and/or dunes) during renourishment activities. Design Standards could allow for flexible use of renourishment material, perhaps based on a volume-of-fill standards, which would allow for adaptive management of the beachfill design features over time to reflect changes in coastal forcing events.
- Flood Control and Coastal Emergencies (FCCE) funding to pre-storm template does not recognize the life cycle of coastal projects. There is a need to adjust FCCE regulations (ER 500-1-1) to recognize that the design minimum should exist, e.g., allow rebuilding to the design minimum. FCCE guidance might be adjusted to recognize the roles of locally contributed project features (e.g., dune built by locals) in reducing risk.

Appendix A - Glossary

Adapted and expanded from **U.S. Army Corps of Engineers, 2002.** Coastal Engineering Manual. Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

A

ACCRETION
May be either natural or artificial. Natural accretion is the buildup of land, solely by the action of the forces of nature, on a beach by deposition of water- or airborne material. Artificial accretion is a similar buildup of land by reason of an act of man, such as the accretion formed by a GROIN, BREAKWATER, or beach fill deposited by mechanical means.

ALONGSHORE
Parallel to and near the shoreline; LONGSHORE.

ARTIFICIAL NOURISHMENT
The process of replenishing a beach with material (usually sand) obtained from another location.

ASTRONOMICAL TIDE
The tidal levels and character which would result from gravitational effects, e.g. of the Earth, Sun and Moon, without any atmospheric influences.

BACK BARRIER
Pertaining to the lagoon-marsh-tidal creek complex in the lee of a coastal barrier island, barrier spit, or baymouth barrier.

BARRIER BEACH
A bar essentially parallel to the shore, the crest of which is above normal high water level. Also called offshore barrier and BARRIER ISLAND.

BARRIER ISLAND
A detached portion of a barrier beach between two inlets. It commonly has DUNES, vegetated areas, and swampy areas extending from the beach into the lagoon.

BAY
A recess in the shore or an inlet of a sea between two capes or headlands, not as large as a gulf but larger than a cove. See also BIGHT, EMBAYMENT.

BEACH
The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually

the effective limit of storm waves). The seaward limit of a beach--unless otherwise specified--is the mean low water line. A beach includes foreshore and backshore. (See Figure D-1).

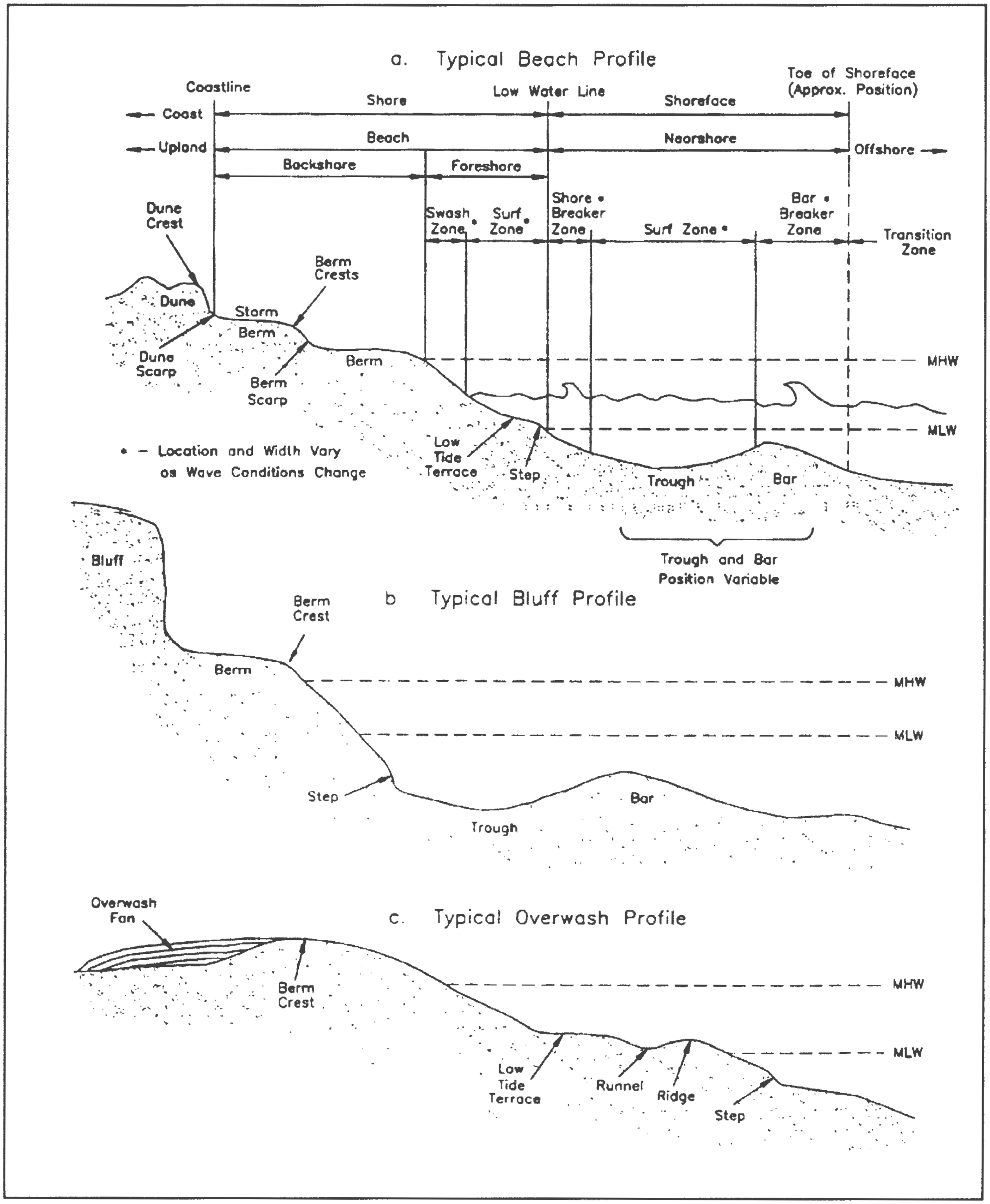


Figure D-1: Definition of terms and features describing the coastal zone

BEACH BERM
A nearly horizontal part of the beach or backshore formed by the deposit of material by wave action. Some beaches have no berms, others have one or several. (See Figure D-1)

BEACH CREST
The point representing the limit of normal HIGH TIDE wave run-up (see BERM CREST)

BEACH EROSION
The carrying away of beach materials by wave action, tidal currents, littoral currents, or wind.

BEACH FACE
The section of the beach normally exposed to the action of the wave uprush. The FORESHORE of a BEACH. (Not synonymous with SHOREFACE.)

BEACH FILL
Material placed on a beach to renourish eroding shores, usually pumped by dredge but sometimes delivered by trucks.

BEACH NOURISHMENT
See BEACH FILL.

BEACH PROFILE
A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or sea wall, extend over the backshore, across the foreshore, and seaward underwater into the NEARSHORE zone.

BEACH WIDTH
The horizontal dimension of the beach measured normal to the shoreline and landward of the higher-high tide line (on oceanic coasts) or from the still water level (on lake coasts)

BERM
(1) On a beach: a nearly horizontal plateau on the beach face or backshore, formed by the deposition of beach material by wave action or by means of a mechanical plant as part of a beach renourishment scheme. Some natural beaches have no berm, others have several. (2) On a structure: a nearly horizontal area, often built to support or key-in an armor layer.

BERM, BEACH
See BEACH BERM.

BERM CREST
The seaward limit of a BERM. Also called BERM EDGE. (See Figure D-1)

BIGHT
A bend in a coastline forming an open BAY. A BAY formed by such a bend.

BREACHING
(1) Formation of a channel through a barrier spit or island by storm waves, tidal action, or river flow. Usually occurs after a greater than normal flow, such as during a hurricane. (2) Failure of a dike allowing flooding.

BREAKING
Reduction in wave energy and height in the surf zone due to limited water depth

BREAKWATER
A man-made structure protecting a shore area, harbor, anchorage, or basin from waves. A harbor work.

BULKHEAD
A structure or partition to retain or prevent sliding of the land. A secondary purpose is to protect the UPLAND against damage from wave action.

BYPASSING, SAND
Hydraulic or mechanical movement of sand from the accreting updrift side to the eroding downdrift side of an inlet or harbor entrance. The hydraulic movement may include natural movement as well as movement caused by man.

C

CHANNEL
(1) A natural or artificial waterway of perceptible extent which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. (2) The part of a body of water deep enough to be used for navigation through an area otherwise too shallow for navigation. (3) A large strait, as the English Channel. (4) The deepest part of a stream, bay, or strait through which the main volume or current of water flows.

CLIMATE
The characteristic weather of a region, particularly regarding temperature and precipitation, averaged over some significant internal of time (years).

COAST
(1) A strip of land of indefinite width (may be several kilometers) that extends from the SHORELINE inland to the first major change in terrain features. (See Figure D-1.) (2) The part of a country regarded as near the coast.

COASTAL AREA
The land and sea area bordering the SHORELINE. (See Figure D-1.)

COASTAL CURRENTS

(1) Those currents which flow roughly parallel to the shore and constitute a relatively uniform drift in the deeper water adjacent to the surf zone. These currents may be tidal currents, transient, wind-driven currents, or currents associated with the distribution of mass in local waters. (2) For navigational purposes, the term is used to designate a current in coastwise shipping lanes where the tidal current is frequently rotary.

COASTAL DEFENSE
General term used to encompass both coast protection against erosion and sea defense against flooding.

COASTAL FORCING
The natural processes which drive coastal hydro- and morphodynamics (e.g.winds, waves, tides, etc).

COASTAL PLAIN
The plain composed of horizontal or gently sloping strata of clastic materials, generally representing a strip of sea bottom that has emerged from the sea in recent geologic time. May extend inland many km.

COASTAL PROCESSES
Collective term covering the action of natural forces on the SHORELINE, and near shore seabed

COASTAL ZONE
The transition zone where the land meets water, the region that is directly influenced by marine and lacustrine hydrodynamic processes. Extends offshore to the continental shelf break and onshore to the first major change in topography above the reach of major storm waves. On barrier coasts, includes the bays and LAGOONS between the BARRIER and the mainland.

COASTAL ZONE MANAGEMENT
The integrated and general development of the coastal zone. Coastal Zone Management is not restricted to coastal defense works, but includes also a development in economical, ecological and social terms. Coastline Management is a part of Coastal Zone Management.

COASTLINE
(1) Technically, the line that forms the boundary between the coast and the shore. (2) Commonly, the line that forms the boundary between the land and the water, esp. the water of a sea or ocean. The SHORELINE. A more general term than COAST LINE.

CREST
Highest point on a beach face, BREAKWATER, or SEAWALL.

CREST OF BERM
The seaward limit of a berm. Also called BERM EDGE. (See Figure D-1.)

CYCLONE

A system of winds that rotates about a center of low atmospheric pressure. Rotation is clockwise in the Southern Hemisphere and anti-clockwise in the Northern Hemisphere. In the Indian Ocean, the term refers to the powerful storms called HURRICANES in the Atlantic.

D

DATUM
Any permanent line, plane or surface used as a reference datum to which elevations are referred.

DATUM, PLANE
The horizontal plane to which soundings, ground elevations, or water surface elevations are referred. Also REFERENCE PLANE. The plane is called a TIDAL DATUM when defined by a certain phase of the tide.

DEEP WATER
Water so deep that surface waves are little affected by the ocean bottom. Generally, water deeper than one-half the surface wavelength is considered deep water. Compare SHALLOW WATER.

DEEP WATER WAVES
A wave in water the depth of which is greater than one-half the WAVE LENGTH.

DEPTH
The vertical distance from a specified datum to the sea floor.

DESIGN HURRICANE
See HYPOTHETICAL HURRICANE.

DESIGN STORM
A hypothetical extreme storm whose waves coastal protection structures will often be designed to withstand. The severity of the storm (i.e. return period) is chosen in view of the acceptable level of risk of damage or failure. A DESIGN STORM consists of a DESIGN WAVE condition, a design water level and a duration.

DESIGN WAVE
In the design of HARBORS, harbor works, etc., the type or types of waves selected as having the characteristics against which protection is desired.

DESIGN WAVE CONDITION
Usually an extreme wave condition with a specified return period used in the design of coastal works.

DIKE
Earth structure along sea or river in order to protect low lands from flooding by high water (see for an example see Figure D-2); dikes along rivers are sometimes called LEVEES. Sometimes written as DYKE.

Figure D-2: Dike constructed as part of the New Bedford Hurricane Barrier, MA

DREDGING
The practice of excavating or displacing the bottom or shoreline of a water body. Dredging can be accomplished with mechanical or hydraulic machines. Most is done to maintain channel depths or berths for navigational purposes; other dredging is for shellfish harvesting, for cleanup of polluted sediments, and for placement of sand on beaches.

DUNES
(1) Ridges or mounds of loose, wind-blown material, usually sand. (2) Bed forms smaller than bars but larger than ripples that are out of phase with any water-surface gravity waves associated with them.

E

ECOSYSTEM
The living organisms and the nonliving environment interacting in a given area, encompassing the relationships between biological, geochemical, and geophysical systems.

ELEVATION
The vertical distance from mean sea level or other established datum plane to a point on the earth's surface; height above sea level. Although sea floor elevation below msl should be marked as a negative value, many charts show positive numerals for water depth.

EMBANKMENT
Fill material, usually earth or rock, placed with sloping sides and with a length greater than its height. Usually an embankment is wider than a dike.

EROSION

The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.

ESCARPMENT
A more or less continuous line of cliffs or steep slopes facing in one general direction which are caused by erosion or faulting. Also SCARP. (See Figure D-1.)

ESTUARY
(1) The part of a river that is affected by tides. (2) The region near a river mouth in which the fresh water of the river mixes with the salt water of the sea and which received both fluvial and littoral sediment influx.

EUSTATIC SEA LEVEL CHANGE
Change in the relative volume of the world`s ocean basins and the total amount of ocean water.

F

FEEDER BEACH
An artificially widened beach serving to nourish downdrift beaches by natural littoral currents or forces.

FETCH
The area in which SEAS are generated by a wind having a fairly constant direction and speed. Sometimes used synonymously with FETCH LENGTH.

FETCH LENGTH
The horizontal distance (in the direction of the wind) over which a wind generates seas or creates a WIND SETUP.

FETCH-LIMITED
Situation in which wave energy (or wave height) is limited by the size of the wave generation area (fetch).

FLOODGATE
Adjustable gates used to control water flow in flood barriers, reservoir, river, stream, or levee systems. They may be designed to set spillway crest heights in dams, to adjust flow rates in sluices and canals, or they may be designed to stop water flow entirely as part of a levee or storm surge system (See NAVIGATION GATE).

FLOOD INTERVAL
The interval between the transit of the moon over the meridian of a place and the time of the following flood.

FLOOD MARK

Proof of any kind on the shoreline, or on structures like bridge abutments, used to determine the highest level attained by the water surface during the flood (note: the height of the flood mark usually includes the wave run-up).

FLOOD WALL, SPLASH WALL
Wall, retired from the seaward edge of the seawall crest, to prevent water from flowing onto the land behind.

FORWARD SPEED (hurricane)
Rate of movement (propagation) of the hurricane eye in meters per second, knots, or miles per hour.

FREEBOARD
At a given time, the vertical distance between the water level and the top of the structure. On a ship, the distance from the waterline to main deck or gunwale.

G

GAUGE (GAGE)
Instrument for measuring the water level relative to a datum or for measuring other parameters.

GROIN
Narrow, roughly shore-normal structure built to reduce longshore currents, and/or to trap and retain littoral material. Most groins are of timber or rock and extend from a SEAWALL, or the backshore, well onto the foreshore and rarely even further offshore (See Figure D-3 for an example).

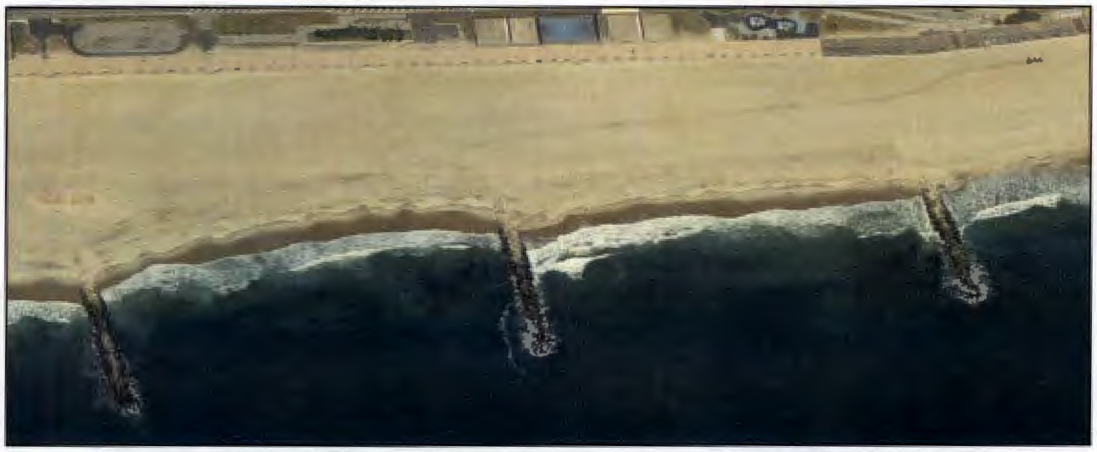
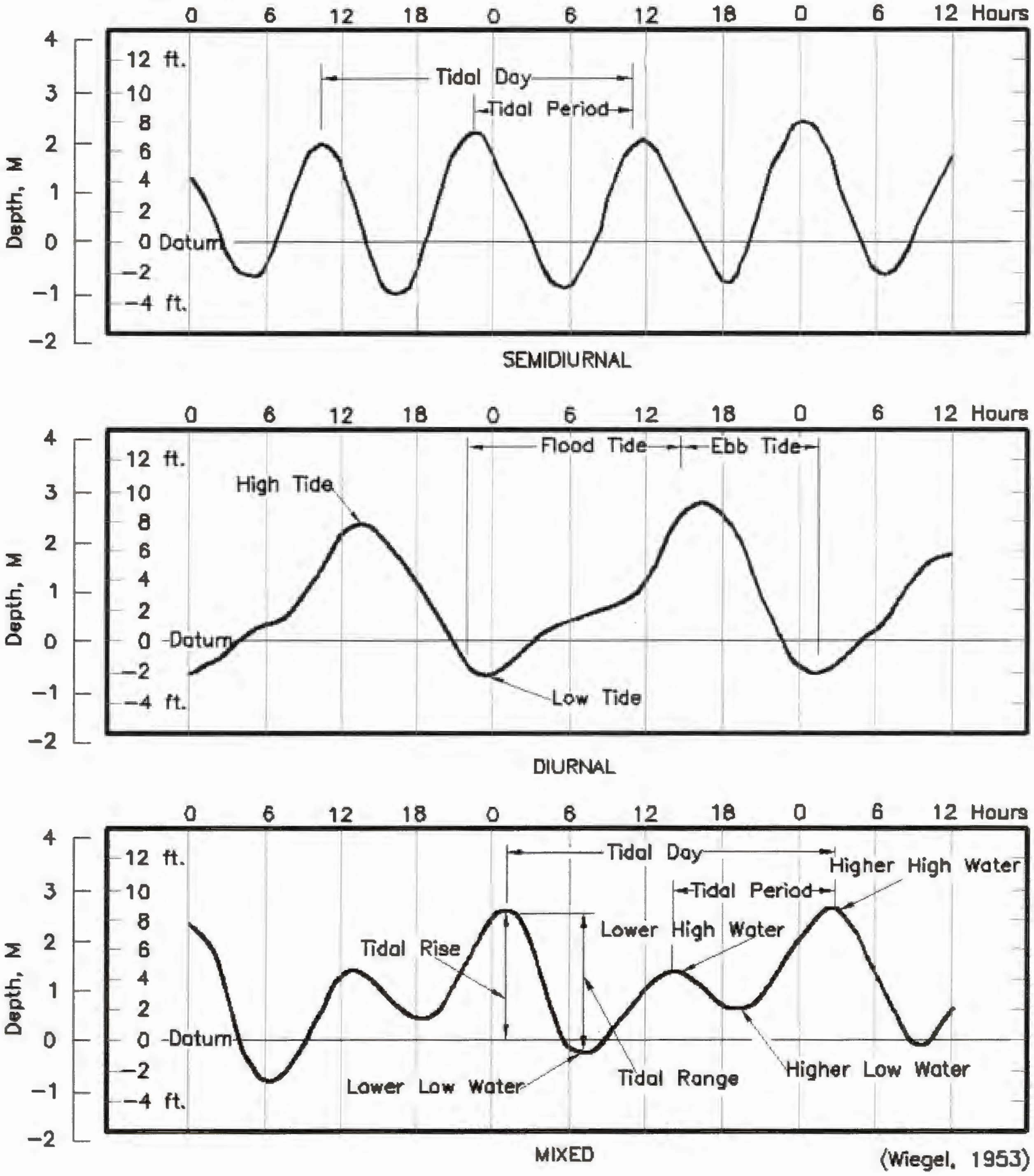


Figure D-3: Groins at Rockaway Beach, New York

H

HIGH TIDE, HIGH WATER (HW)
The maximum elevation reached by each rising tide. See TIDE. (See Figure D-4)



SEMIDIURNAL

DIURNAL

MIXED

(Wiegel, 1953)

Figure D-4: Types of Astronomical Tides

HIGH WATER (HW)

Maximum height reached by a rising tide. The height may be solely due to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meteorological conditions. Nontechnically, also called the HIGH TIDE.

HIGH WATER MARK
A reference mark on a structure or natural object, indicating the maximum stage of tide or flood (see Figure D-9.)

HURRICANE
An intense tropical cyclone in which winds tend to spiral inward toward a core of low pressure, with maximum surface wind velocities that equal or exceed 33.5 m/sec (75 mph or 65 knots) for several minutes or longer at some points. TROPICAL STORM is the term applied if maximum winds are less than 33.5 m/sec but greater than a whole gale (63 mph or 55 knots). Term is used in the Atlantic, Gulf of Mexico, and eastern Pacific.

HURRICANE PATH or TRACK
Line of movement (propagation) of the eye through an area.

STANDARD PROJECT HURRICANE (SPH)
A hypothetical hurricane intended to represent the most severe combination of hurricane parameters that is reasonably characteristic of a specified region, excluding extremely rare combinations. It is further assumed that the SPH would approach a given project site from such direction, and at such rate of movement, to produce the highest HURRICANE SURGE HYDROGRAPH, considering pertinent hydraulic characteristics of the area. Based on this concept, and on extensive meteorological studies and probability analyses, a tabulation of "Standard Project Hurricane Index Characteristics" mutually agreed upon by representatives of the U. S. Weather Service and the Corps of Engineers, is available.

DESIGN HURRICANE
A representation of a hurricane with specified characteristics that would produce HURRICANE SURGE HYDROGRAPHS and coincident wave effects at various key locations along a proposed project alignment. It governs the project design after economics and other factors have been duly considered. The design hurricane may be more or less severe than the SPH, depending on economics, risk, and local considerations.

I

INLET
(1) A short, narrow waterway connecting a bay, lagoon, or similar body of water with a large parent body of water. (2) An arm of the sea (or other body of water) that is long compared to its width and may extend a considerable distance inland. See also TIDAL INLET.

JETTY
(1) (United States usage) On open seacoasts, a structure extending into a body of water, which is designed to prevent shoaling of a channel by littoral materials and to direct and confine the stream or tidal flow.

Jetties are built at the mouths of rivers or tidal inlets to help deepen and stabilize a channel. (2) (British usage) WHARF or PIER. See TRAINING WALL.

K

KNOT
The unit of speed used in navigation equal to 1 nautical mile (6,076.115 ft or 1,852 m) per hour.

L

LEVEE
(1) A ridge or EMBANKMENT of sand and silt, built up by a stream on its flood plain along both banks of its channel. (2) A large DIKE or artificial EMBANKMENT, often having an access road along the top, which is designed as part of a system to protect land from floods.

LITTORAL
Of or pertaining to a shore, especially of the sea. Often used as a general term for the coastal zone influenced by wave action, or, more specifically, the shore zone between the high and low water marks.

LITTORAL DRIFT, LITTORAL TRANSPORT
The movement of beach material in the littoral zone by waves and currents. Includes movement parallel (long shore drift) and sometimes also perpendicular (cross-shore transport) to the shore.

LITTORAL TRANSPORT RATE
Rate of transport of sedimentary material parallel or perpendicular to the shore in the littoral zone. Usually expressed in cubic meters (cubic yards) per year. Commonly synonymous with LONGSHORE TRANSPORT RATE.

LONGSHORE
Parallel to and near the shoreline; ALONGSHORE.

LOW TIDE (LOW WATER, LW)
The minimum elevation reached by each falling tide. See TIDE. (See Figure D-4.)

LOW WATER (LW)
The minimum height reached by each falling tide. Nontechnically, also called LOW TIDE.

LOWER LOW WATER DATUM
An approximation to the plane of MEAN LOWER LOW WATER that has been adopted as a standard reference plane for a limited area and is retained for an indefinite period regardless of the fact that it may differ slightly from a better determination of MEAN LOWER LOW WATER from a subsequent series of observations.

M

MARSH

(1) A tract of soft, wet land, usually vegetated by reeds, grasses and occasionally small shrubs. (2) Soft, wet area periodically or continuously flooded to a shallow depth, usually characterized by a particular subclass of grasses, cattails and other low plants.

MEAN HIGH WATER (MHW)

The average height of the high waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All high water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high water heights are included in the average where the type of tide is diurnal. So determined, mean high water in the latter case is the same as mean higher high water.

MEAN HIGHER HIGH WATER (MHHW)

The average height of the higher high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

MEAN LOW WATER (MLW)

The average height of the low waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All low water heights are included in the average where the type of tide is either semidiurnal or mixed. Only lower low water heights are included in the average where the type of tide is diurnal. So determined, mean low water in the latter case is the same as mean lower low water.

MEAN LOWER LOW WATER (MLLW)

The average height of the lower low waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. Frequently abbreviated to LOWER LOW WATER.

MEAN RANGE OF TIDE

The difference in height between MEAN HIGH WATER and MEAN LOW WATER.

MEAN SEA LEVEL

The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. Not necessarily equal to MEAN TIDE LEVEL. It is also the average water level that would exist in the absence of tides.

N

NATIONAL TIDAL DATUM EPOCH (NTDE)

A period of 19 years adopted by the National Ocean Service as the period over which observations of tides are to be taken and reduced to average values for tidal datums.

NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD29)
The Sea Level Datum of 1929 was the vertical control datum established for vertical control surveying in the United States of America by the General Adjustment of 1929. The datum was used to measure elevation (altitude) above, and depression (depth) below, mean sea level (MSL). Since the Sea Level Datum of 1929 was a hybrid model, it was not a pure model of mean sea level, the geoid, or any other equipotential surface. Therefore, it was renamed the National Geodetic Vertical Datum of 1929 (NGVD29) in 1973. NGVD29 was superseded by the North American Vertical Datum of 1988 (NAVD 88.

NAVIGATION GATE
A FLOODGATE that remains open during normal conditions to permit continued water exchange and navigation. During storm events the gate is closed to provide flood protection (see Figure D-5). Normally part of a larger flood protection system including dikes, levees, gates, etc. See Figure D-6 for an example.

Figure D-5: Navigation Gates at the Fox Point Hurricane Barrier, Providence, RI

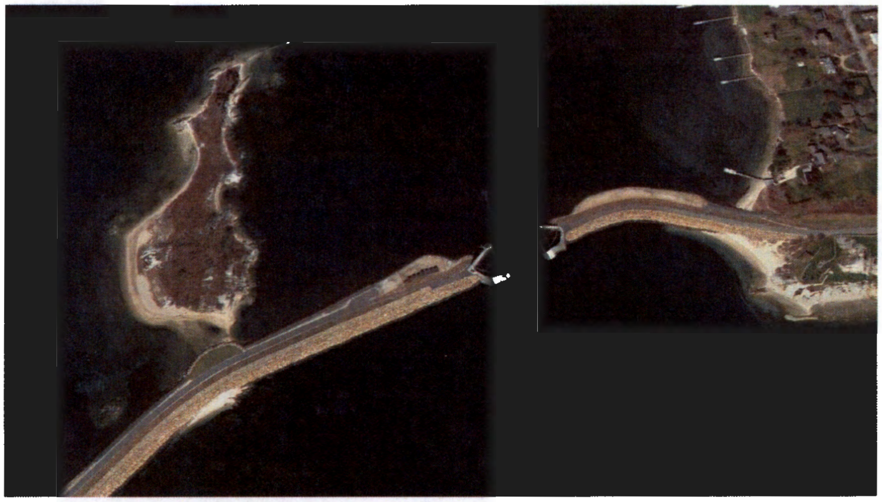


Figure D-6: Dike and Navigation Gate at the new Bedford Hurricane Barrier, MA

NEARSHORE
(1) In beach terminology an indefinite zone extending seaward from the SHORELINE well beyond the BREAKER ZONE. (2) The zone which extends from the swash zone to the position marking the start of the offshore zone, typically at water depths of the order of 20 m.

NEARSHORE BERM
Artificial berm built in shallow water using dredged material. Often, the berm is intended to renourish the adjacent and downdrift shore over time under the influence of waves and currents.

NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)
The vertical control datum of orthometric height established for vertical control surveying in the United States of America based upon the General Adjustment of the North American Datum of 1988.

NOURISHMENT
The process of replenishing a beach. It may occur naturally by longshore transport, or be brought about artificially by the deposition of dredged materials or of materials trucked in from upland sites.

O

OFFSHORE
(1) In beach terminology, the comparatively flat zone of variable width, extending from the SHOREFACE to the edge of the CONTINENTAL SHELF. It is continually submerged. (2) The direction seaward from the shore. (3) The zone beyond the nearshore zone where sediment motion induced by waves alone effectively ceases and where the influence of the sea bed on wave action is small in comparison with the effect of wind. (4) The breaker zone directly seaward of the low tide line. (See Figure D-1.)

OVERTOPPING

Passing of water over the top of a structure as a result of wave runup or surge action.

OVERWASH
(1) The part of the UPRUSH that runs over the crest of a BERM or structure and does not flow directly back to the ocean or lake. (2) The effect of waves overtopping a COASTAL DEFENSE, often carrying sediment landwards which is then lost to the beach system.

P

PROFILE, BEACH
The intersection of the ground surface with a vertical plane; typically perpendicular to the local shoreline, and may extend from the behind the DUNE line or the top of a bluff to well seaward of the breaker zone. (See Figure D-1.)

R

RADIUS OF MAXIMUM WINDS
Distance from the eye of a hurricane, where surface and wind velocities are zero, to the place where surface windspeeds are maximum.

RANGE OF TIDE
The difference in height between consecutive high and low waters. The MEAN RANGE is the difference between MEAN HIGH WATER and MEAN LOW WATER. The GREAT DIURNAL RANGE or DIURNAL RANGE is the difference in height between MEAN HIGHER HIGH WATER (MHHW) and MEAN LOWER LOW WATER (MLLW). Where the type of tide is diurnal, the mean range is the same as the diurnal range.

RESIDUAL (WATER LEVEL)
The components of water level not attributable to astronomical effects.

RETURN PERIOD
Average period of time between occurrences of a given event.

RETAINING WALL
A structure designed and constructed to resist the lateral pressure of soil when there is a desired change in ground elevation that exceeds the angle of repose of the soil (see Figure D-7).

Figure D-7: Rock Revetment and retaining wall at Cliff Walk, Newport, RI

REVETMENT

A facing of stone, concrete, etc., to protect an EMBANKMENT, or shore structure, against erosion by wave action or currents (see Figure D-7)

RUBBLE

(1) Loose angular waterworn stones along a beach. (2) Rough, irregular fragments of broken rock.

RUBBLE-MOUND STRUCTURE

A mound of random-shaped and random-placed stones protected with a cover layer of selected stones or specially shaped concrete armor units. (Armor units in a primary cover layer may be placed in an orderly manner or dumped at random.)

RUNUP, RUNDOWN

The upper and lower levels reached by a wave on a beach or coastal structure, relative to still-water level.

S

SALT MARSH

A marsh periodically flooded by salt water (also tidal marsh; sea marsh).

SAND

Sediment particles, often largely composed of quartz, with a diameter of between 0.062 mm and 2 mm, generally classified as fine, medium, coarse or very coarse. Beach sand may sometimes be composed of organic sediments such as calcareous reef debris or shell fragments.

SCARP, BEACH
An almost vertical slope along the beach caused by erosion by wave action. It may vary in height from a few cm to a meter or so, depending on wave action and the nature and composition of the beach. (See Figure D-1.) See also ESCARPMENT.

SEA
(1) A large body of salt water, second in rank to an ocean, more or less landlocked and generally part of, or connected with, an ocean or a larger sea. Examples: Mediterranean Sea; South China Sea. (2) Waves caused by wind at the place and time of observation. (3) State of the ocean or lake surface, in regard to waves.

SEA LEVEL RISE
The long-term trend in MEAN SEA LEVEL.

SEAWALL
(1) A structure, often concrete or stone, built along a portion of a coast to prevent erosion and other damage by wave action. Often it retains earth against its shoreward face. (2) A structure separating land and water areas to alleviate the risk of flooding by the sea. Generally shore-parallel, although some reclamation SEAWALLS may include lengths that are normal or oblique to the (original) shoreline. A SEAWALL is typically more massive and capable of resisting greater wave forces than a BULKHEAD.

SEDIMENT
(1) Loose, fragments of rocks, minerals or organic material which are transported from their source for varying distances and deposited by air, wind, ice and water. Other sediments are precipitated from the overlying water or form chemically, in place. Sediment includes all the unconsolidated materials on the sea floor. (2) The fine grained material deposited by water or wind.

SEDIMENT TRANSPORT
The main agencies by which sedimentary materials are moved are: gravity (gravity transport); running water (rivers and streams); ice (glaciers); wind; the sea (currents and LONGSHORE DRIFT). Running water and wind are the most widespread transporting agents. In both cases, three mechanisms operate, although the particle size of the transported material involved is very different, owing to the differences in density and viscosity of air and water. The three processes are: rolling or traction, in which the particle moves along the bed but is too heavy to be lifted from it; SALTATION; and suspension, in which particles remain permanently above the bed, sustained there by the turbulent flow of the air or water.

SETUP, WAVE
Superelevation of the water surface over normal surge elevation due to onshore mass transport of the water by wave action alone.

SETUP, WIND
See WIND SETUP.

SHALLOW WATER

(1) Commonly, water of such a depth that surface waves are noticeably affected by bottom topography. It is customary to consider water of depths less than one-half the surface wavelength as shallow water. See TRANSITIONAL ZONE and DEEP WATER. (2) More strictly, in hydrodynamics with regard to progressive gravity waves, water in which the depth is less than 1/25 the wavelength.

SHEET PILE

One of a group of piles made of timber, steel, or prestressed concrete set close together to resist lateral pressure, as from earth or water (see Figure D-8.)

Figure D-8: Sheet Pile Bulkhead under Construction

SHORE

The narrow strip of land in immediate contact with the sea, including the zone between high and low water lines. A shore of unconsolidated material is usually called a BEACH. (See Figure D-1.) Also used in a general sense to mean the coastal area (e.g., to live at the shore).

SHORELINE

The intersection of a specified plane of water with the shore or beach (e.g., the high water shoreline would be the intersection of the plane of mean high water with the shore or beach). The line delineating the shoreline on National Ocean Service nautical charts and surveys approximates the mean high water line (United States).

SIGNIFICANT WAVE

A statistical term relating to the one-third highest waves of a given wave group and defined by the average of their heights and periods. The composition of the higher waves depends upon the extent to which the lower waves are considered. Experience indicates that a careful observer who attempts to establish the character of the higher waves will record values which approximately fit the definition of the significant wave.

SIGNIFICANT WAVE HEIGHT
The average height of the one-third highest waves of a given wave group. Note that the composition of the highest waves depends upon the extent to which the lower waves are considered. In wave record analysis, the average height of the highest one-third of a selected number of waves, this number being determined by dividing the time of record by the significant period.

STANDARD PROJECT HURRICANE
See HYPOTHETICAL HURRICANE.

STILL-WATER LEVEL (SWL)
The surface of the water if all wave and wind action were to cease. In deep water this level approximates the midpoint of the wave height. In shallow water it is nearer to the trough than the crest. Also called the UNDISTURBED WATER LEVEL.

STONE
Quarried or artificially-broken rock for use in construction, either as aggregate or cut into shaped blocks as dimension stone.

STORM SURGE
A rise above normal water level on the open coast due to the action of wind stress on the water surface (see Figure D-9.) Storm surge resulting from a hurricane also includes that rise in level due to atmospheric pressure reduction as well as that due to wind stress. See WIND SETUP.

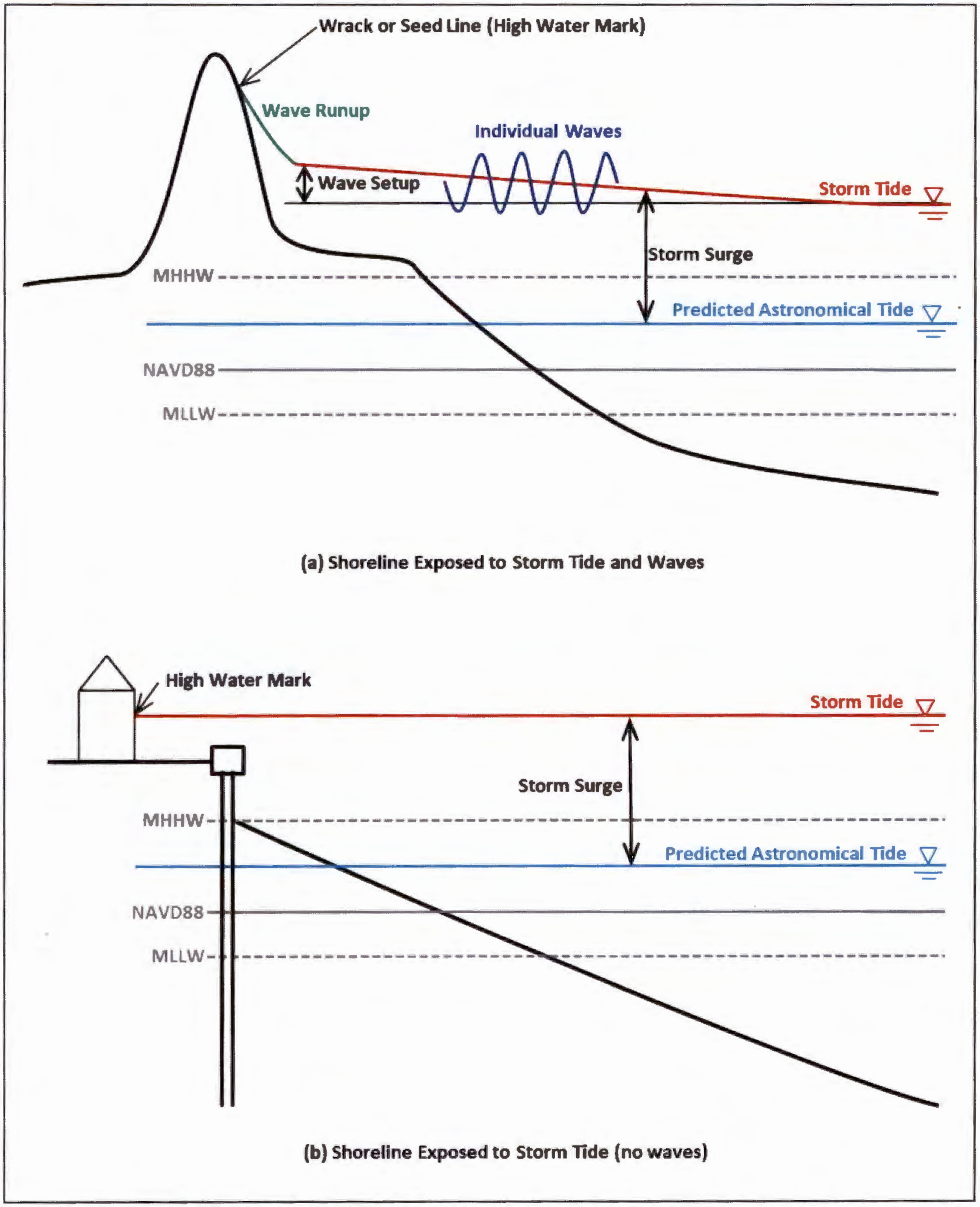


Figure D-9: Storm Surge, Storm Tide and High Water Mark Definitions

STORM TIDE

The water level due to the combination of storm surge and the astronomical tide expressed in terms of elevation referenced to a vertical datum, e.g. the North American Vertical Datum of 1988 (NAVD88) or a local tidal datum such as Mean Higher High Water (MHHW). See Figure D-9.

SURVEY, HYDROGRAPHIC
A survey that has as its principal purpose the determination of geometric and dynamic characteristics of bodies of water.

SURVEY, TOPOGRAPHIC
A survey which has, for its major purpose, the determination of the configuration (relief) of the surface of the land and the location of natural and artificial objects thereon.

SYZYGY
The two points in the Moon's orbit when the Moon is in conjunction or opposition to the Sun relative to the Earth; time of new or full Moon in the cycle of phases.

T

T-GROIN
A GROIN built in the shape of a letter "T" with the trunk section connected to land.

TERMINAL GROIN
A GROIN, often at the end of a littoral cell or at the UPDRIFT side of an inlet, intended to prevent sediment passage into the channel beyond.

TIDAL INLET
(1) A natural inlet maintained by tidal flow. (2) Loosely, any inlet in which the tide ebbs and flows. Also TIDAL OUTLET.

TIDAL RANGE
The difference in height between consecutive high and low (or HIGHER HIGH and LOWER LOW) waters. (See Figure D-4.)

TIDE
The periodic rising and falling of the water that results from gravitational attraction of the Moon and Sun and other astronomical bodies acting upon the rotating Earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as TIDAL CURRENT, reserving the name TIDE for the vertical movement.

TIDE GAGE
An instrument that automatically registers the rise and fall of the tide. In some instruments, the registration is accomplished by printing the heights at regular intervals, in others by a continuous graph in which the height of the tide is represented by the ordinates of the curve and the corresponding time by the abscissae.

TIDE GATE
An opening through which water may flow freely when the tide moves in one direction, but which closes automatically and prevents the water from flowing in the other direction (see Figure D-10 for an example.)

Figure D-10: Tide Gate at the Bolsa Chica Wetlands Restoration Project, CA

TIDE STATION
A place at which tide observations are being taken. It is called a primary tide station when continuous observations are to be taken over a number of years to obtain basic tidal data for the locality. A secondary tide station is one operated over a short period of time to obtain data for a specific purpose.

TIDE, STORM
See STORM SURGE.

TIDE, WIND
See WIND TIDE.

TROPICAL CYCLONE
See HURRICANE

TROPICAL STORM
A tropical cyclone with maximum winds less than 34 m/sec (75 mile per hour). Compare with HURRICANE or TYPHOON (winds greater than 34 m/sec).

W

WASHOVER
Sediment deposited inland of a beach by overwash processes.

WATER DEPTH
Distance between the seabed and the still water level.

WATER LEVEL
Elevation of still water level relative to some datum.

WATERLINE
A juncture of land and sea. This line migrates, changing with the tide or other fluctuation in the water level. Where waves are present on the beach, this line is also known as the limit of backrush (approximately, the intersection of the land with the still-water level.)

WAVE
A ridge, deformation, or undulation of the surface of a liquid.

WAVE HEIGHT
The vertical distance between a crest and the preceding trough. See also SIGNIFICANT WAVE HEIGHT.

WAVE SETUP
See SETUP, WAVE.

WETLANDS
Lands whose saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities that live in the soil and on its surface (e.g. Mangrove forests).

WIND SETUP
On reservoirs and smaller bodies of water (1) the vertical rise in the still-water level on the leeward side of a body of water caused by wind stresses on the surface of the water; (2) the difference in still-water levels on the windward and the leeward sides of a body of water caused by wind stresses on the surface of the water. STORM SURGE (usually reserved for use on the ocean and large bodies of water).

WRACK LINE
The line of vegetation and debris left on the beach by the action of the tides and waves.