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NEW ENGLAND INTERSTATE WATER POLLUTION CONTROL COMMISSION

GREAT KILLS HARBOR BREAKWATER STUDY: APPROACHES FOR A SHORELINE PROTECTION SYSTEM

TASK 2 SUMMARY REPORT

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TASK 2 SUMMARY REPORT

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Executive Summary

In Task 2 of the Great Kills Harbor Breakwater study, the OCC/SCAPE team identified approaches for a shore protection system adjacent to and south of Great Kills Harbor. The approach focused on systems that integrate coastal wave protection, habitat enhancement, and shoreline erosion reduction.

The team first reviewed and cataloged publically available data, which influenced the design and selection of the two shore protection approaches. The team identified key areas in and around Great Kills which are most vulnerable to coastal storms and identified primary coastal storm influences for input into the hydrodynamic modeling. In conjunction with city and state agencies, the team identified areas where insufficient data exists.

The project team performed a field investigation along the shoreline and in the water to further identify basic site characteristics. The shoreline investigation included characterizing the assessment area, performing a GIS analysis to determine ecological structure, and conducting an assessment using the Evaluation for Planned Wetlands (EPW) worksheets. The in-water investigation consisted of sediment sampling, video recording and photographic documentation along four transects agreed upon by city and state agencies; the team obtained samples to identify the nature and diversity of the benthic community and the geological character of the substrate.

Multiple shoreline protection approaches were evaluated based on several categories. An explanation of the approaches, evaluation criteria and summary of the evaluation, including the overall score, was presented to project stakeholders in matrix format for each approach.

On August 5, 2014, the OCC/SCAPE team met with project stakeholders to review the then-current project status, review project goals, specific boundaries, constraints and assumptions, discuss potential shoreline protection strategies and solicit input on the development of modeling scenarios.

Based on the matrix analysis and stakeholder meetings, two modeling scenarios were agreed upon:

Model Option 1 includes a harbor-wide breakwater which spans the length of Crescent Beach from Retford Ave. to Robinson Ave. (1450 ft) and aims to blocks direct wave propagation from offshore into the harbor ('L' shape). Wave diffraction through openings on a harbor-wide breakwater will likely be significant, therefore the structure is recommended without gaps. The distance from the shoreline is recommended at approximately ¼ mile to reduce the potential for wave regeneration in the lee of the breakwater. An additional breakwater on the ocean-side of Crooke's Point was also included to protect Nichols Marina. This breakwater is 1400 ft in length, located in front of the National Park Service (NPS) facilities on Crooke's Point, and is located 1/10 mile from the shoreline.

Model Option 2 includes a segmented breakwater along the length of Crescent Beach from Retford Ave. to Winman Ave. Empirical results of wave diffraction through breakwater lengths of approximately 250 ft suggested an average 85 ft gap between segments would be effective at attenuating waves while allowing some wave energy to pass through the breakwater line. This scenario would be located closer to shore (approximately 1/10 mile) to encourage sedimentation and reduce the potential for superposition of the diffracted waves in the lee of the breakwaters. Along Crooke's Point, a 600 ft constructed dune was proposed to connect the topographical high points and protect Nichols Marina.

The orientation of the Great Kills Harbor entrance suggests it is vulnerable from waves propagating from the south, typically occurring during nor'easters. The damage caused by Sandy was devastating, however damage from nor'easters has the potential to occur at a higher frequency. Therefore, the project team recommended modeling four storm cases in Task 3: (1) Nor'easter-type, (2) Nor'easter-type with 31" sea level rise, (3) Sandy-like storm, and (4) Sandy-like storm with 31" sea level rise.

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1 Project Management

1.1 Document Control

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Table 1-1: Revision History

Revision	Date	Prepared By	Checked By	Approved By
1.0	11/21/2014	BRCO	TPMA	AZSL
2.0	12/19/2014	TPMA	TPMA	AZSL

1.2 Project Organization and Distribution List

The detailed project organization and distribution list can be found in the Quality Assurance Project Plan, or QAPP, prepared as Task 1 of this project.

The project team is led by OCC|COWI and SCAPE/Landscape Architecture PLLC (SCAPE) and consists of, ARCADIS US (ARCADIS), Biohabitats, Inc. (Biohabitats), Parsons Brinckerhoff (PB), and SeArc Consulting.

In addition to the project team, this document will be distributed to key project stakeholders, including: the New England Interstate Water Pollution Control

Commission (NEIWPCC) and the New York State Department of Environmental Control (NYS DEC).

1.3 Problem Definition and Background

Historically the South Shore of Staten Island was comprised of a much more subtle edge and coastline, with extensive subtidal flats and shoals. The early 1900s saw a sharp decrease in water quality with the development of industry, shellfish overharvesting, and habitat degradation as a result of increased urbanization along the shoreline. Shipping lanes were carved through the flats as the harbor was further developed resulting in the current, urbanized edge condition of the Staten Island South Shore. This hardened shoreline has been further armored in the wake of coastal storms such as Hurricane Sandy, with private homeowners adding seawalls in a piecemeal fashion in front of their properties, disrupting coastal processes, cutting off cultural access to the water and leading to the call for a rethinking of our relationship to coastal protection.

This feasibility study will provide guidance on the use of offshore breakwaters as an adaptation strategy to respond to wave action and coastal land loss (*Hudson River Estuary Action Agenda Goal 6, Target 1*). The coastal protection offered by a breakwater may also present a unique opportunity to restore or enhance aquatic habitat functions and values for a range of biota - including shellfish, crustaceans, and juvenile finfish. In addition, an offshore breakwater can serve as an avenue towards environmentally friendly shoreline management by decreasing shoreline erosion (*Hudson River Estuary Action Agenda Goal 2, Target 2*). Initiative # 13 of *A Stronger, More Resilient New York* specifically calls for the study of an offshore breakwater system in this location. The project's objective seeks to determine the technical feasibility and marine habitat benefits offered by an offshore breakwater system outside of and adjacent to Great Kills Harbor. The results of the study will serve to inform New York City's Office of Recovery and Resiliency (ORR), New York City Department of City Planning, New York State's Department of Environmental Conservation (DEC) and the Hudson River Estuary Program (HREP), and other agencies and community groups for use in community planning, shoreline adaptation, and resiliency.

1.4 Purpose

The purpose of Task 2: Identify and Evaluate Approaches for a Shoreline Protection System, is to identify the data necessary to characterize the area in and around Great Kills harbor, identify key areas intended to benefit from storm risk reduction, identify and evaluate various shore protection approaches, and recommend two approaches for modeling and development in future tasks.

1.5 Scope of Work

Within Task 2, the OCC/SCAPE team identified approaches for a shore protection system adjacent to and south of Great Kills Harbor. The approach focused on systems that integrate coastal wave protection, habitat enhancement, and shoreline erosion reduction.

In the first step of this task, the team gathered and reviewed publically available reports and in order to inform the design and selection of the shore protection approaches. The team identified key areas, such as maritime business, infrastructure, and low-lying properties, in and around Great Kills which are the most vulnerable to coastal storms. The primary coastal storm influences were identified for input into the hydrodynamic modeling which included storm driven waves. Existing site information published by reliable sources was collected and catalogued for reference. In addition, the team, in conjunction with city and state agencies, identified areas where insufficient data exists.

A field investigation along the shoreline and in the water was performed to identify basic site characteristics. The shoreline investigation included characterizing the assessment area, performing a GIS analysis to determine ecological structure, and conducting an assessment using the Evaluation of Planned Wetlands (EPW) worksheets (see section 5.1). The in-water investigation consisted of sediment sampling, video recording and photographic documentation. A professional dive team accompanied by a marine biologist completed the offshore field investigation. The team obtained samples to identify the nature and diversity of the benthic community and the geological character of the substrate.

Multiple approaches were reviewed and evaluated based on several criteria categories. An explanation of the approaches and evaluation criteria and the summary of the evaluation, along with the overall score, is presented in matrix format for each approach in section 6. A project stakeholder meeting was held to discuss the evaluation and solicit feedback on the preferred study alternatives. Using this approach along with stakeholder input, two variations of an emergent breakwater have been recommended for development.

2 Existing Site Information

Existing site information published by reliable sources has been collected and cataloged for reference. The project team searched publically available databases and websites, including: National Oceanic and Atmospheric Administration's (NOAA) Tides and Currents, NOAA Navigation Charts, U.S. Army Corps of Engineers – New York District controlling depth reports and hydrographic surveys, and the New York State GIS Clearinghouse (please see Section 8 for a full list of reference sources).

2.1 Resiliency

A number of previously published resiliency reports were leveraged for this study, including NY Rising Community Reconstruction Program's *Community Resilience Techniques*, PlaNYC's *A Stronger, More Resilient New York*, and the U.S. Climate Change Science Program's *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. Synthesis and Assessment Program 4.1*. The information sourced in these documents come from scientific reporting on the topic and are distilled to the region and presented objectively for use in city planning. The use of these references would be appropriate for use in this study.

2.2 Meteorological and Oceanic Characterization

Meteorological and ocean data used to characterize the area in and around the Great Kills Breakwater Study was gathered from a wide variety of resources as described in the following sections.

2.2.1 Wind

There are two weather stations that have wind data over an adequately long time within 10 miles of the project site: Newark International Airport (US Air Force 725020) and Sandy Hook, New Jersey (NOAA 8531680). The Sandy Hook station is approximately 2 miles closer to the project site and is likely to contain wind records with less overland wind dissipation due to the proximity to the coastline on a peninsula, and relatively flat ground surface. The station is operated by the National Oceanic and Atmospheric Administration (NOAA) and is considered a reputable source. Data collected from this station includes 6-minute observed wind speeds, gusts, and directions.

2.2.2 Current Stations:

No relevant current stations were located in the vicinity of the project. The nearest active current stations reported by the NOAA Tides and Currents website are the Gowanus Flats Lbb 30, n04010 and 32, n05010. They are located approximately 10 miles north northeast of Great Kills Harbor around the northeast side of Staten Island and are not expected to be representative of the currents anticipated at Great Kills due to geography and relationships between water bodies within New York Harbor.

2.2.3 Bathymetry:

The bathymetric data for the Great Kills Harbor area was obtained from the Digital Elevation Model (DEM) developed by the Federal Emergency Management Agency (FEMA) as part of the ongoing flood insurance study (FEMA 2014). Additional bathymetric information was obtained from NOAA navigation charts 12327 New York Harbor and 12331 Raritan Bay and Southern Part of Arthur Kill. Additional detailed bathymetry for the federal navigation channel was obtained from the most recent U.S. Army Corps of Engineers (USACE), Controlling Depth Report and survey for Great Kills Harbor, NY, dated 3/12/2013.

Comparison of the FEMA DEM and the NOAA navigation charts showed that the bathymetry outside Great Kills Harbor is similar for both datasets, with the exception of dredged channels, which were not well defined in the FEMA DEM. Similar to the dredged channels, bathymetry data inside the harbor are distinctly different for the FEMA DEM and the NOAA navigation charts. The information obtained from FEMA, NOAA, and the USACE is reliable and has/is currently being used in other ongoing studies throughout the region and used for vessel navigation. The best reliable data source was used for each area. Additional discussion on the bathymetry is available in Section 3.1 of the Hydrodynamic Modeling report (separately issued).

2.2.4 NOAA Tidal Benchmarks:

The NOAA Tidal benchmark chosen for the Great Kills Breakwater Study is Sandy Hook, NJ, Station 8531680. The benchmark is located approximately 8.5 miles (13.7 km) southeast of the mouth of Great Kills Harbor. Water levels at Sandy Hook are shown in *Figure 2-1* and summarized in *Table 2-1*.

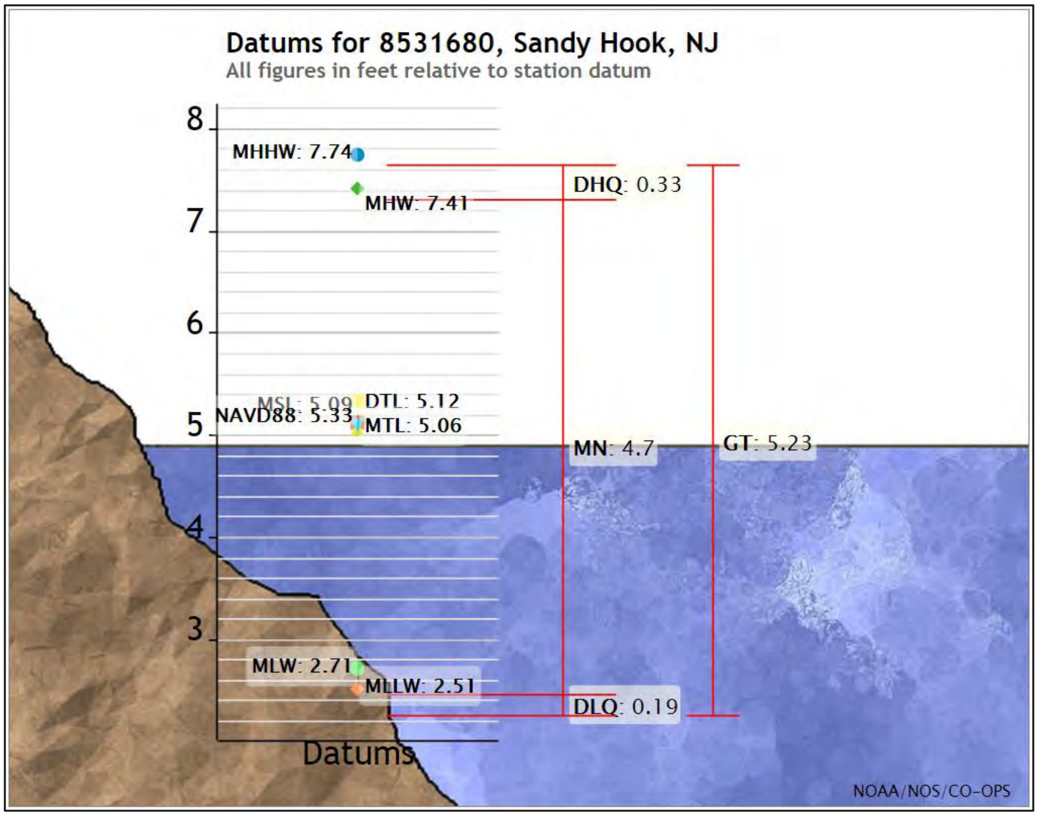

Figure 2-1: NOAA Tidal Benchmark 8531680, Sandy Hook, NJ

Table 2-1: Tidal Data for Sandy Hook, New Jersey (NOAA 8531680)

Datum	Values (ft, Station Data)	Values (ft, NAVD88)
Mean High-High Water (MHHW)	7.74	2.41
Mean High Water (MHW)	7.41	2.08
NAVD88	5.33	0.00
Mean Sea Level (MSL)	5.09	-0.24
Mean Tide Level (MTL)	5.06	-0.27
Mean Low Water (MLW)	2.71	-2.62
Mean Low-Low Water (MLLW)	2.51	-2.82

2.2.5 Water Levels, Storm Surge and Design Wave Characteristics

Water levels, including storm surges and design wave heights will be discussed in more detail in the Task 3: Hydrodynamic Modeling Report.

2.3 Key Areas

A number of "Key Areas" were identified by the project team. These areas, in and around Great Kills Harbor and Crescent Beach are most vulnerable to coastal storms; they include: maritime businesses, infrastructure, low-lying properties, properties vulnerable to coastal storms and limited access sites. The areas identified the project team primarily consisted of:

- Marinas
- On shore development (mostly residential, 1-3 stories, detached with one area of attached town homes)
- “High value” ecosystems including wetlands, beach/dune environments and maritime habitat
- Publicly accessible waterfronts and recreational parks properties
- Shoreline edge infrastructure (existing and planned revetments, bulkheads, and absorptive edges)

Key areas are conveyed in a series of maps created by the project team. These maps were included in the presentation materials discussed during the stakeholder meetings, further discussed in section 4. The maps are found amongst other meeting handouts appended to this report in Appendix D.

2.4 Geospatial Information Systems Data

2.4.1 Project Study Area

The project study area is composed of three zones of analysis relative to the topic of study: Risk Reduction, Ecological Data Collection, and Modeling. These zones can be seen in the map provided in Appendix D.

Risk Reduction Study Area

The risk reduction study area boundary identifies the zone where the effectiveness and impact of breakwaters and other wave attenuation structures will be studied. The boundary was developed in coordination with the NY Department of City Planning and the Office of Recovery and Resiliency, and extends from Fairlawn Ave to the North, wrapping the edge of Great Kills Harbor to the East (including the National Park Service Nichols Marina), Crescent Beach Park to the South, and Hylan Boulevard to the west.

Ecological Data Collection Study Area:

The ecological data collection study area identifies zones where field observations of ecological conditions will be collected as part of Task 2. The shoreline analysis study boundary wraps the shoreline from the southern edge of Crescent Beach, encircling the inner shore of Great Kills harbor, wrapping Crooke's Point and terminating where the Harbor spit intersects the mainland on the seaward facing side of Great Kills park. Shoreline analysis extends approximate 100' offshore along the study area. Additional benthic data is collected via diver along four transects of variable length, perpendicular to the shoreline: one adjacent to the neighborhood of Crescent Beach (transect 1), one extending through the interior of Great Kills Harbor (transect 2), one along the harbor side edge of Crooke's Point (transect 3), and one along the seaward side of Crooke's point (transect 4). The field investigation is further described in section 5 of this report.

Modeling Study Area:

The modeling study area encompasses a larger area and is designed to capture any impacts of the studied scenarios outside of the risk reduction study area. The modeling study area boundary extends approximately ½ mile offshore, from the Great Kills wastewater treatment plant at the north to Arbutus Lake at the south. All wave impacts of the proposed scenario are anticipated to be captured within this zone.

2.4.2 Site Analysis Maps

Land Use and Property Ownership

The risk reduction study area includes a variety of land uses along and near the shoreline including residential, open space and recreation, commercial, and transportation infrastructure. The Great Kills and Crescent Beach neighborhoods are composed of predominantly 1-2 family buildings, with a small number of larger multifamily walkup buildings adjacent to the shoreline. The predominant home construction typology is freestanding or semi-attached wood frame houses. Commercial uses concentrate along Hylan Boulevard, and with the exception of the inner Great Kills Harbor area, do not intersect the shoreline. Six marina facilities (five private and one public) are located within Great Kills Harbor and provide boat storage, slips, and repair services as well as tourism and restaurant services. Significant park resources lay within and adjacent to the study area, including Great Kills Park, part of the Staten Island unit of Gateway National Recreation Area, and numerous city owned and operated parks. Within the risk reduction study boundary, parcel boundaries of federal, city, and privately owned lands extend from the shoreline into the water, in some cases up to a quarter mile offshore. Property ownership may influence the location of offshore strategies and is a factor in evaluating the capacity to implement the proposals. Over half of the shoreline within the risk reduction study area is controlled by city, state, or federal entities.

Hydrologic Resources

Bathymetric conditions vary within the study area. South of Great Kills Harbor, adjacent to Crescent Beach, the predominant water depth is within the range of 0-6'. Further information on the sediment type can be seen in the ecological data that was collected during Task 2 (see section 5). Within the harbor, water depths range from 0-18' in depth, and contain areas noted by the clammers as being "historically abundant" as hard clam harvesting zones, including a shallow water zone in the middle of the harbor and the southeastern edge adjacent to Nichols Marina. A federal navigation channel runs through the harbor and is periodically dredged, most recently in 2003 and 2014. The channel is marked by navigational buoys.

Shoreline change and Current Conditions

The south shore of Staten Island is shaped by the geology of the terminal moraine, gradually sloping from higher upland areas to sea level along the length of the shore. Much of the study area has been dramatically modified through human intervention, in particular the gradual landfilling of historic tidal wetland areas within present day Great Kills Park, and the hardening and extension of the area now known as Crooke's Point into a spit of land perpendicular to the shore. Incremental filling and hardening of the shoreline has occurred along multiple parcels within and south of Great Kills Harbor. Current shoreline conditions include coarse grain beach, fine-medium grain beach, brackish salt water marshes, riprap, boat launches, seawalls, groins, piers, and localized breakwaters.

Sediment Type and Transport

General sediment movement along Crooke's Point and Crescent Beach was deduced from existing erosion protection structures adjacent to the study area identified on aerial photographs. Groins located to the north of the site show sand accretion on the northeast sides indicating the primary longshore sediment transport is from the northeast to the southwest. Groins located to the south of the site also show sand accretion on the northeast sides indicating the longshore sediment transport continues in the same direction beyond the mouth of the harbor. A review of the historic aerial photographs available show sediment accumulation on Crooke's Point with erosion along Crescent Beach, suggesting an eddy-type effect of sediment falling out of the water column at the Point, then being suspended again at Crescent Beach and heading southwest.

The sediment outside the harbor is characterized as fine to medium sand with an average layer thickness of 27 ft (Bokuniewicz, H.J., and Fray, 1979). This characterization was later confirmed with underwater observations (see Section 5.2) for areas outside the harbor. Fine grained sediment was commonly observed within the harbor.

FEMA Flood Maps

The south shore of Staten Island was heavily impacted by Hurricane Sandy and is documented in *A Stronger, More Resilient New York (City of New York, 2013)*. Wave action and erosion are significant threats along the South Shore, and impact the study area adversely. FEMA flood zone boundaries show numerous shoreline properties and structures within the V and coastal A zones, with a majority experiencing wave heights of 1'-3' and some exceeding 3'. FEMA V and Coastal A zones are concentrated along the shoreline, while the 100 year and 500 year FEMA floodplains extend further inland into more densely populated residential areas, limited by Hylan Boulevard at the west. During Hurricane Sandy the shoreline along Crescent Beach lost on average 14 ft of beach due to erosion, with Crooke's Point accumulating approximately 70 ft of sand on its southerly end. A breach occurred along Crooke's Point at the location of a Parks Department building and parking lot, about halfway down the length of the peninsula. Approximately 895 boat slips were destroyed in total between the 5 marinas, and an additional 96 were significantly damaged. A more detailed description of potential risks and wave damage analysis is included in the Task 3 and Task 4 reports.

Ongoing initiatives

A number of ongoing initiatives are advancing within and adjacent to the study area, including maintenance dredging of the federal navigation channel by USACE, emergency dune constructions at Crescent Beach by NYC Department of Parks and Recreation, and radium testing in Great Kills Park. Projects in planning include the Crooke's Point comprehensive restoration plan, multiple initiatives identified in the NY Rising Staten Island Community Reconstruction plan, including seawall construction and shoreline armoring, and the Phase II USACE study which includes the analysis of a Crescent Beach dune, levee, and seawall installation.

Other Reports

A number of other publically available reports were also consulted during execution of this task, including:

› US Army Corps of Engineers FY 2014 Maintenance Dredging project documents

› Northwest Regional Planning Commission's Shoreline Stabilization Handbook for Lake Champlain and Other Inland Lakes

› New York City, Department of Planning's report: Coastal Climate Resilience, Urban Waterfront Adaptive Strategies

› New York City, Economic Development Corporation's Waterfront Facilities Maintenance Management System

› 1979 NY Sea Grant report on Sand and Gravel Resources in Lower New York Harbor

› NYS DEC's Coastal Erosion Hazard Area Maps of the southern side of Staten Island, 1988

- Ms. Stephanie Rosenberg's Master's Thesis: "Hydrogeology of Staten Island, New York"

- NY Sea Grant's 1979 MESA New York Bight Atlas Monograph

- NYS DEC's "Flood Plain Management. Beach Erosion and Hurricane Damage Reduction, South Shore Long Island." report from February 25, 1976.

- NYS DEC's "Shoreline Stabilization Techniques"

- Stevens Institute's "Engineering Approaches for Limiting Erosion along Sheltered Shorelines: A Review of Existing Methods" by Andrew J. Rella and Jon K. Miller.

- U.S. EPA's "Final Environmental Impact Statement for Phase III and Future Phases of the Oakwood Beach Water Pollution Control Project" August, 1986.

- Marine Sciences Research Center's "The Volume of Sand and Gravel Resources in the Lower Bay of New York Harbor." December, 1979.

Full citations for these reports are provided in Section 8, below.

2.5 Data Gaps

In addition to the sources located and reviewed during this task, the team, in conjunction with city and state agencies, has identified areas where insufficient data exists. The data gaps may need to be addressed before the selected approaches can be developed beyond the scope of this project.

No relevant current stations were located during this task. It may be necessary to obtain accurate current data to inform the design of the selected approaches in the next phase of this project.

Information on shoreline change, historic erosion patterns, and current rates of sediment deposition and movement is extremely limited.

Little data exists on damages associated with waves separate from those of surge. These damage estimates are difficult to quantify and will be based on best available information.

Limited geotechnical information for the study area was discovered in the data research. Additional geotechnical information will be required to advance any designs.

3 Shoreline Protection System Strategies and Scenarios

The project team used the information identified in the QAPP and above to identify and complete preliminary evaluations of a number of Shoreline Protection System Approaches.

3.1 Goals

The primary goal of the Great Kills Harbor breakwater study is to evaluate approaches with the greatest potential to reduce shoreline erosion and reduce wave action in and around Great Kills Harbor. Secondary goals of the study are to evaluate the potential for reducing shoreline inundation and preserving existing and/or restoring historic aquatic habitat function.

The results of the study will serve to inform New York City's Office of Recovery and Resiliency (ORR), New York City's Department of City Planning (NYCDCP), New York State's Department of Environmental Conservation (DEC) and The Hudson River Estuary Program (HREP), and other agencies and community groups for use in community planning, shoreline adaptation, and resiliency. The project team has been coordinating with USACE, such that the results of the Great Kills Harbor Breakwater Study will also inform the ongoing efforts in Staten Island and the East Coast.

3.2 Protection Strategies

Shoreline protection approaches evaluated for this study generally fall within two categories: Primary In-Water Strategies and Complimentary Shoreline Strategies. Those strategies are detailed below and were the basis for the evaluation matrix (see section 6).

3.2.1 Primary In-Water Strategies

Primary in-water alternatives are located either offshore, or nearshore.

No Action Alternative

The no action alternative is considered the baseline for this study. It is the option that other alternatives are compared against in order to determine the relative costs and benefits of that particular alternative.

Submerged Vegetation

Submerged Aquatic Vegetation (SAV) involves preparing the sea floor and planting/installation of SAV along the seafloor. SAV reduces wave energy by increasing the resistance to wave propagation at the seafloor. SAV also reduces erosion as the vegetation reduces the mobility of the substrate in which it is planted.

Submerged Breakwater

A submerged breakwater is an offshore feature in which structural fill is placed in open water to create a bathymetric relief feature. Fill is typically comprised of stone and/or concrete. Breakwaters may be dumped material or more complex engineered structures consisting of core and armor layers of distinct materials. The crest elevation of the submerged breakwater is below the MLLW water level, i.e. it remains below the surface of the water in all tide cycles.

Semi-Emergent Breakwater

Similar to a submerged breakwater, a semi-emergent breakwater is an offshore feature created by placing structural fill. A semi-emergent breakwater is designed such that the crest elevation is exposed at low tide and submerged at high tide.

Emergent Breakwater

An emergent breakwater, similar to submerged and semi-emergent alternatives is created by placing structural fill offshore to create a dry "land". The crest of the emergent breakwater is located above MHHW, and may be designed to account for sea level rise, storm surge and wave action.

Floating Breakwater

Floating breakwaters are large floating structures, typically steel or concrete that are moored to the seafloor either using an anchor system or by piles. Floating breakwaters rise and fall with the tide, acting at the optimal level to block wave energy. Floating breakwaters are typically tuned to act optimally over a range of frequencies; they tend to be more effective at filtering steep, short period waves and are less effective at blocking large, long period waves.

Wave Screen

Waves screens are fixed structures that allow a percentage of wave and current energy to pass, creating a partially sheltered environment behind the screen. Wave screens typically extend throughout the elevation in which wave energy is anticipated to occur, though they may in some cases be extended to the seafloor. The openings in and below the wave screen facilitate current and sediment movement.

Surge Barrier

Surge Barriers are large, expensive structures that span the mouth of a harbor or the width of a river. Typically open to allow vessel traffic and water flow, they can be closed during storm periods to act as a barrier to surge and waves.

3.2.2 Complimentary Shoreline Strategies

A number of complimentary shoreline strategies were evaluated by the project team. These strategies were not meant to act alone, but rather act in concert with the primary strategies to maximize the reduction in risk to storm events.

Raise Elevation

Increasing the elevation of the shoreline acts as a barrier to storm surge. Increased elevation can be achieved in a variety of ways including hard structures (sea walls, revetments) or softer structures, such as dunes, beach nourishment or filling upland areas.

Revetment Edges

Revetments are hard structures used to stabilize and prevent further shoreline erosion. Revetments are typically made of stone or concrete and may be dumped or placed.

Living Edges

Living edges are shorelines that are stabilized to prevent further shoreline erosion through natural means, such as vegetation.

Dry Buffer

A dry buffer acts by increasing the upland width of the shoreline, increasing the distance over which waves must propagate before impacting key areas.

Wet Buffer

A wet buffer acts similarly to a dry buffer, except that this zone is located within the width of the intertidal/surf zone. Waves are forced to break in the shallower waters, reducing the size of waves and associated energy before the waves are able impact upland assets.

3.3 Scenarios

Three study scenario options were developed and later presented at the first stakeholder meeting (see section 4) to frame the remainder of the study and set the parameters for the two designs to be modeled in future phases of the project. Full size images of each scenario are included in Appendix D.

3.3.1 Option 1: Compare on-shore and offshore techniques.

Option 1 Scenario A: Maximize shoreline strategies for wave reduction and erosion control (shoreline elevation, revetment, living edges, dry buffer, wet buffer)

Option 1 Scenario B: Maximize in-water strategies for wave reduction and erosion control (breakwater types, wave screen, submerged vegetation)

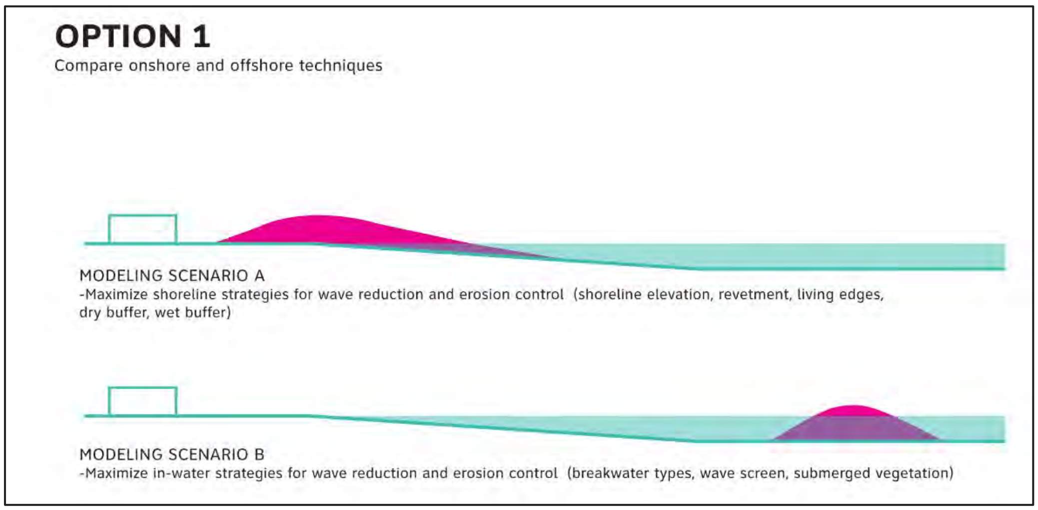

Figure 3-1: Option 1 Sections

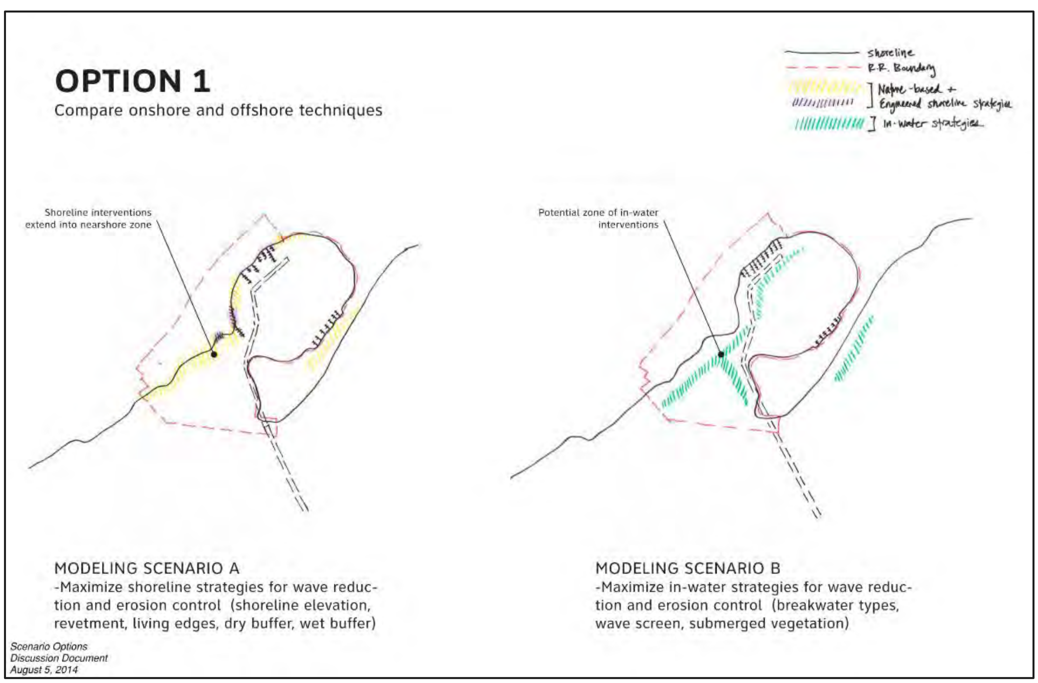

Figure 3-2: Option 1 Plans

3.3.2 Option 2: Compare localized vs. harbor-scale offshore protection scenarios

Option 2 Scenario A: Localized system of in-water techniques for wave reduction and erosion control (breakwater types, wave screen, submerged vegetation)

Option 2 Scenario B: Harbor-scale in-water intervention for wave reduction and erosion control (large scale breakwater, wave screen, submerged vegetation, channel stabilization)

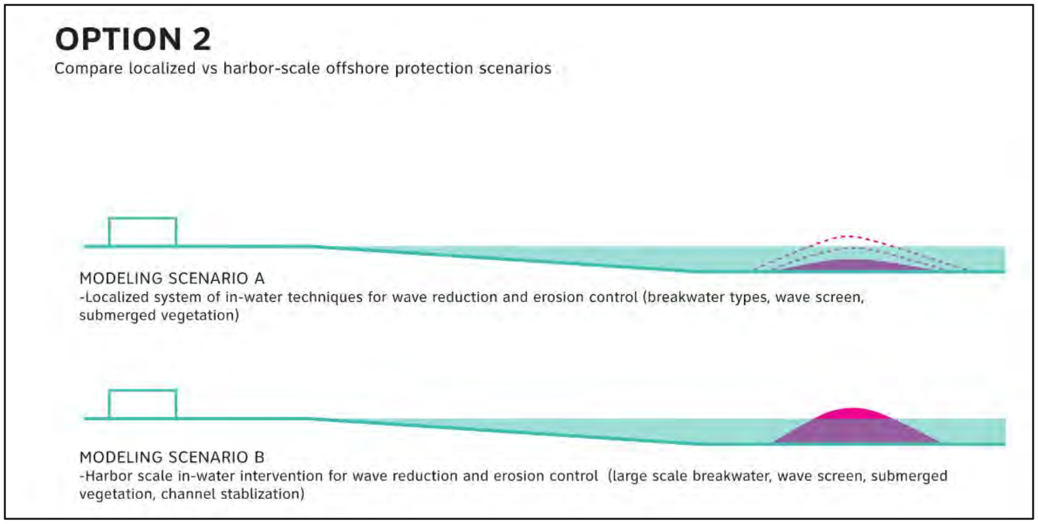

Figure 3-3: Option 2 Sections

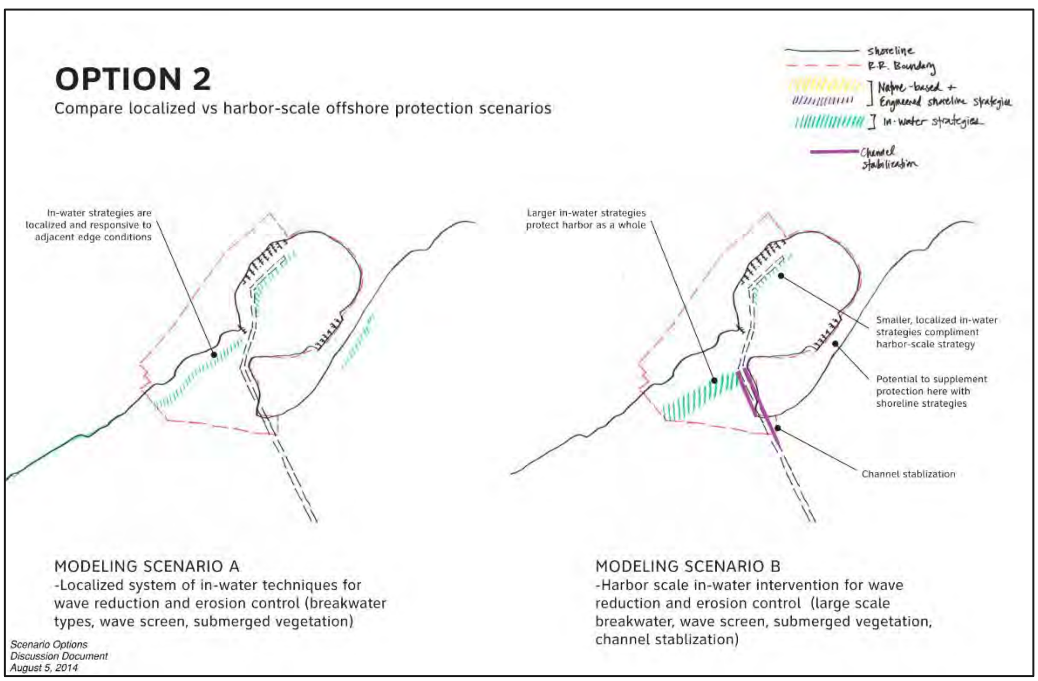

Figure 3-4: Option 2 Plans

3.3.3 Option 3: Compare variations of the layered approach with different emphasis on onshore/ offshore strategies

Option 3 Scenario A: Combine maximized shoreline intervention (shoreline elevation, revetment, living edges, dry buffer, wet buffer) and minimized in-water intervention for wave reduction and erosion control (breakwater types, wave screen, and submerged vegetation).

Option 3 Scenario B: Combine minimized shoreline intervention (shoreline elevation, revetment, living edges, dry buffer, wet buffer) and maximized in-water intervention for wave reduction and erosion control (breakwater types, wave wall).

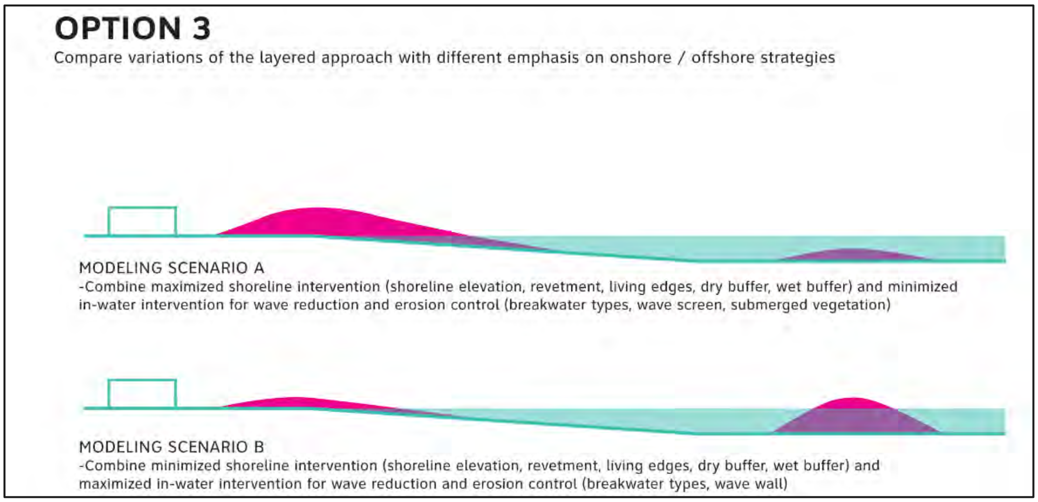

Figure 3-5:Option 3 Sections

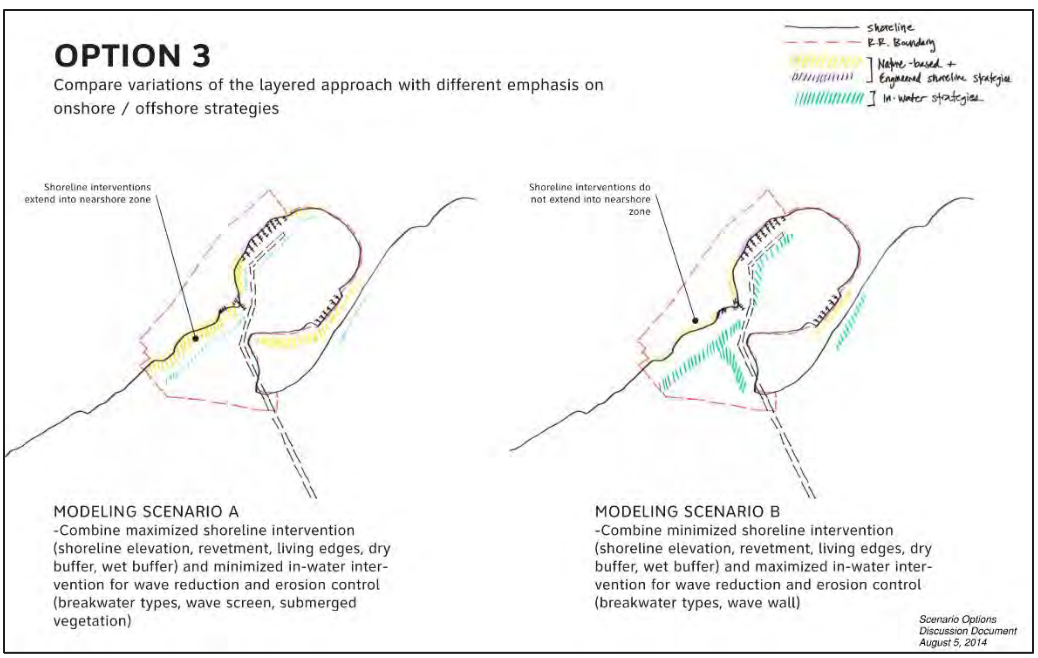

Figure 3-6: Option 3 Plans

4 Stakeholder Meeting

On August 5, 2014, the project team held a meeting at the New York City Office of Recovery and Resiliency (ORR) with project stakeholders which included representatives from: the New York State Department of Environmental Conservation (DEC), ORR, New York City Department of City Planning (DCP), National Park Service (NPS), New York City Department of Parks and Recreation (DPR), and New York State Governor's Office of Storm Recovery (GOSR). The meeting served to present the information collected in Task 2 and solicit feedback from the project stakeholders.

On August 14, 2014 the project stakeholders and project team met at DEC's office in New York to follow up on action items from the August 5th stakeholders meeting. Representatives of Department of Environmental Conservation (DEC), New York State Department of State, OCC|COWI and SCAPE were able to attend or call in to the meeting.

The purpose of the two meetings was to update stakeholders on the current status of the project, solicit input on potential intervention scenarios, and coordinate the field investigation (see section 5). Specific meeting topics included a review of project goals, specific boundaries, constraints and assumptions that guided the alternatives analysis, a discussion of types and features of shoreline protection strategies, use of an objective matrix to evaluate and assess shoreline protection strategies, the development of two recommended scenarios and planning for the field investigation. Meeting agendas, handouts and minutes are found in Appendix D.

5 Field Investigation

A field investigation along the shoreline and in the water was completed to identify basic site characteristics.

5.1 Shoreline Investigation

The Evaluation of Planned Wetlands (EPW) was developed as a rapid assessment procedure for determining whether or not a planned wetland restoration project has been adequately designed to achieve defined functional goals. For the Great Kills Harbor Breakwater Study, the wetlands in the area were evaluated using the EPW. There are six wetland functions, listed below, which provide the framework for the analysis and which were evaluated for this study.

- Shoreline Bank Erosion Control
- Sediment Stabilization
- Water Quality
- Wildlife
- Fish
- Uniqueness/Heritage

This methodology has been used around the NY Harbor over the past 20 years to analyze a variety of planned wetland projects and projects which could potentially impact wetlands. However, for the Great Kills Harbor Breakwater Study, a methodology was required to also evaluate the nearshore areas and the adjacent upland areas. Because there is no set methodology commonly used around the NY Harbor for these different systems, the EPW evaluation was modified to include nearshore and upland areas, using the framework outlined below.

Table 5-1: Upland Assessment Functions

Erosion Control & Sediment Stabilization	**Uniqueness/Heritage**	**Wildlife**
Disturbance at site Surface Runoff from off site Plant Cover Slope	Endangered species Rarity Unique Features Historical/archaeological significance Natural Landmark Park, sanctuary Scientific research site	Disturbance of wildlife habitat Gross contamination Vegetation Strata o layers o condition of layers o spatial pattern of shrubs/trees Vegetation Cover o cover types o ratio o interspersion o undesirable species Physical Features o shape of edges o wildlife attractors

For the littoral zone / nearshore areas, the following functions were assessed:

Table 5-2: Littoral Zone / Nearshore Area Assessment Functions

Erosion control	**Sediment**	**Water Quality**
Fetch Surface runoff Boat traffic Slope Submerged Aquatic Vegetation (SAV)	Disturbance SAV	Disturbance Substrate Substrate- slope characteristics Depth
Fish	**Uniqueness/Heritage**	
Disturbance at site Substrate SAV Fish cover/attractors Water quality Nutrient/contaminant sources Dissolved Oxygen Water temperature	Endangered species Rarity Unique features Historical or archaeological significance Natural landmark Park/sanctuary Scientific research site	

5.1.1 Field Assessment Methodology

The landward field investigation was conducted by an ecologist. The ecologist was briefed on the overall study objectives prior to the start of field work, and cautions were provided regarding sun burn, poison ivy, insect bites, feral animals, and other potential encounters. While in the field, the ecologist possessed a cell phone, Ipad and camera, site maps and EPW reference material.

The ecologist used the "Evaluation for Planned Wetlands (EPW): A Procedure for Assessing Wetland Functions and a Guide to Functional Design" (by Candy Bartoldus, Edgar Garbisch and Mark Kraus, Environmental Concern Inc., 1994), with some modifications to account for additional upland and nearshore areas, to determine the general baseline of the area.

The number of assessment areas was determined prior to the field investigation and based on the actual study area. Prior to the fieldwork, a map for each assessment area was developed, and included soil, geology, topographic, wetland and surface water information. The team also had information on tidal predictions obtained from www.saltwatertides.com.

Field data was collected and photos of each site were taken, with observations made in wetland areas, surrounding upland areas up to the first developed road or building, and in the intertidal areas along the shoreline. Surface water connections were located and potential flow pathways determined.

Water quality data was obtained from New York City's Department of Environmental Protection's *2010 New York Harbor Water Quality Report*, as reported below.

> **Classification:** This area of the harbor is classified for bathing and other recreational use (SB). Portions of those waters are also designated for the permitted use of shellfishing (for relay to cleaner waters, but not direct consumption), having a stricter use classification of SA.
>
> **Fecal Coliform:** In 2010, sanitary water quality as estimated by fecal coliform (FC) had the lowest values in the Lower New York Bay–Raritan Bay as compared to other waterbodies around New York City. Summer averages for FC numbers show that these waters meet and surpass NYS Standards for this area. Three of five stations had geometric means less than 20 cells/100 mL (an order of magnitude below State Standards). The FC concentrations for these waters show significant decline from the mid-1980s to the present time. While FC concentrations for surface waters were always below 200 cells/100 mL, average FC levels reached a low of 3 cells/100 mL in 1999. The levels have remained at or below 11 cells/100 mL since then. These improvements have allowed for the opening of all NYC public beaches since 1992 and the lifting of wet weather swimming advisories.
>
> **Dissolved Oxygen:** Most of dissolved oxygen (DO) values for surface and bottom waters in Lower New York Bay– Raritan Bay complied with the NYS DO Standard of 5.0 mg/L for bathing waters during the summer of 2010. Summer average DO values in these waters have been one of the highest among the harbor area since 1970. The average DO measurements in summer 2010 were 7.6 mg/L in surface waters and 7.2 mg/L in bottom waters, similar to 7.6 mg/L and 7.0 mg/L in summer 2009. Average summer DO concentrations have increased from 6.1 to 7.2 mg/L for surface waters, and from 5.2 to 7.0 mg/L for bottom waters from 1970 to 2010. Most of the improvement is attributed to improved water quality due to loading decreases of sanitary waste over the years into Arthur Kill and the Raritan River.

5.1.2 Existing Site Conditions

The existing site is located within the neighborhoods of Eltingville and Great Kills, which are located within the northernmost section of Staten Island's South Shore.

To conduct the EPW analysis, the site was divided into 12 distinct areas as shown in Figure 5-1. The areas were broadly defined by the shoreline characteristics observed on site during field visits which occurred in September 2014. Existing conditions for each site are described below and photos of each section are located in Appendix C.

Figure 5-1: Upland and Littoral Zone Investigation Sections

5.1.3 Crescent Beach: Sections 1 – 4

Sections 1 through 4 collectively are known as Crescent Beach, which is located immediately south of the inner harbor along the southeast shoreline of Staten Island. The investigated area is bounded on the west by Tennyson Drive, on the east by Raritan Bay, to the south by a wooded area on the south side of Retford Avenue, and to the north by the Regalle Court condominiums.

The topography in this area ranges from small steep hills west of Tennyson Drive in the residential sections, to low-lying flat terrain along the shoreline. Areas along the shoreline have been filled over time with riprap, concrete, sand and other fill material.

The beaches in these sections are subject to twice daily tide fluctuations, and small gentle waves are a constant. The waters off of the beach are relatively shallow for some distance, approximately 1-5 feet below mean sea level. The substrate located offshore within this area generally consists of riprap, small gravel and sand. The waters are regularly used for recreational purposes such as fishing and boating.

Stormwater within these areas general flows from the higher elevated upland areas towards the bay through low points, generally located where streets end at the beach.

The nearshore area by Crescent Beach is a shallow area of the Lower Bay, partially protected by Crooke's Point except in the northernmost reach which is influenced by the regularly dredged navigation channel.

The adjacent shoreline is narrow, with development occurring immediately adjacent to the sandy beaches, often with bulkheads or riprap to armor the shoreline.

The benthic survey (Section 5.2) conducted for this project included a transect in this area. Close to the shoreline, the substrate at the base of the riprap revetment was found to consist primarily of varying sizes of gravel and cobblestones with sand sized fractions and shell hash embedded within the material. As the distance from the shoreline increases, the substrate becomes mostly sand with some silt and gravel and small areas of silt/clay. Similarly, as sand becomes more dominant in the substrate, the number of Northern quahog observed in the area also increases. The Northern quahog occurrence in this area is expected and likely to remain stable due to the water circulation patterns sweeping the area.

This shoreline section was further subdivided based on the observed dominant shoreline characteristics, as described below.

Section 1 is the southernmost section of Crescent Beach, and is located between Retford Avenue and Richmond Avenue. The shoreline consists primarily of sandy beach, located seaward of a concrete bulkhead, riprap or some other man-made hardened feature.

The land use within this section is largely low-density residential but is threaded throughout by open space. Open space areas include the beach areas along the eastern edge of the site, a small wooded area located at the end of Richmond Avenue, and the small wooded lot located just south of the site. Public access to the beach is available via a small path at the southern end of Tennyson Drive and at the end of Prol Place.

Around the nine homes located along the beach, the front yards consist primarily of mowed lawn and manicured landscapes, while the backyard areas are primarily covered with concrete and swimming pools.

The homeowners within this section have employed a number of techniques to armor their properties from the bay's waters, primarily using bulkheads and riprap. There was one small dilapidated dock located near the end of Prol Place.

Section 2 is located immediately north of Section 1, in the area between Richmond Avenue and Thornycroft Avenue. The shoreline is dominated by riprap along the shoreline, mixed with gravel and sand at the water's edge.

This area is located further east into the bay than Areas 1 and 3. Within this area, some of the residences still show signs of storm damage and a few appear unoccupied. Public access to the beach is available at the end of Oceanic Avenue.

The homes in the area are surrounded by mowed grass and manicured landscapes, with a number of trees located throughout. The topography within this area is relatively flat in the residential areas, sloping steeply to the water's edge.

Section 3, located between Thorneycroft Avenue and Glover Street, is dominated by the sandy beach located along the shoreline. The shoreline also includes a few small patches of tidal marsh vegetated with *Spartina alterniflora* and a few groins located in the northern stretch of the site. A sandy dune has been reconstructed along the western edge of the beach throughout most of this section. Large portions of the dune are unvegetated, but in the northern sections, the dune has been planted with beach grass.

At the end of Armstrong Avenue, a small park is located between Tennyson Drive and the shoreline. Few houses are located east of Tennyson Drive, and these are surrounded by mowed lawns and manicured landscapes. West of Tennyson Avenue, the land use is residential.

A large open space area, consisting of wetland and wooded areas, is located between Armstrong Avenue and Glover Street east of Tennyson Drive. The wetland is dominated by *Phragmites*.

The topography within this area is relatively flat, and most of the site is at a slightly higher elevation than the beach. There are a number of public access points where streets end at the beach.

Section 4 is the northernmost section of the Crescent Beach, running from Glover Street to Wiman Avenue. The shoreline area consists of a mix of concrete groins, riprap, sand and *Spartina alterniflora*–dominated tidal wetland.

The land use west of Tennyson Drive is residential, while east of Tennyson the land use is a mix of residential and open space. The open space areas contain a mix of trees. The homes have manicured lawns and gardens. Like Section 3, this area is relatively flat, with relief from a raised sand dune placed in between the houses and beach area. The dunes have been partially planted.

The shoreline is accessible by the public via a small path at the end of Wiman Avenue and at the end of Goodall Street.

5.1.4 Inner Harbor: Sections 5 – 10

Sections 5 through 7 are located within Great Kills Harbor but outside of the Great Kills Park – Gateway National Recreation Area while Section 8 through 10 are located within the Harbor and within the Park. The areas contain a diversity of natural and armored shorelines and are used for a diversity of purposes from recreation to boating to fishing.

The inner harbor contains areas of shallow waters and much deeper waters, largely dependent on whether the area has been dredged over time or not. The substrate located offshore is diverse, again depending on the depth of water and whether or not the area has been dredged. In shallow areas, the substrate is dominated by sand and tends to have a hard bottom. In the deeper waters, the substrate is dominated by silt, and is very soft. And near the riprap shorelines, stone and gravel tend to mix with the sand and silt.

The areas of natural shoreline, within sections 6 and 8 and around the boat ramp in section 9, are subject to twice daily tidal fluctuations. The bulkheaded and riprap shoreline areas are located above mean high water and are not subjected to the daily tidal action, however, these areas may be overtopped during storm events. Within the bulkheaded and riprap shoreline, stormwater generally flows from pipes to the harbor.

The waters are regularly used for mooring, clamming, boating, fishing and other recreational activities.

The Great Kills Harbor is a sheltered cove surrounded by parks and marinas. The depth and substrate within the inner harbor varies based on whether or not the area is dredged and whether or not the area is a site of sediment accretion or erosion. In areas of erosion, a hard sandy bottom is typically observed. In areas of accretion, an unconsolidated silt/clay is often found.

Two transects were investigated as part of the benthic survey (Section 5.2). The substrate along Transect #2 nearest to the shoreline consisted of a gelatinous, highly hydrated silt and clay, and exhibited anoxic conditions. The substrate along Transect #3 is directly comparable to that of Transect #2 once beyond the nearshore accumulation of the sandy and shell rich deposit, although Northern quahog occurred at a rare abundance level.

The hydrology of the area has been altered over time by:

- The filling of Crooke's Point which cut off some of the daily tidal circulation;
- The armoring of the shoreline in the form of bulkheads and riprap, disrupting the daily tidal influence to the shoreline; and
- The continued dredging of the harbor to maintain the navigation channel.

This shoreline section was further subdivided based on the observed dominant shoreline characteristics, as described below.

Section 5 is located within the Port Regalle condominium site. The shoreline within this area is bulkheaded, and includes a marina and a paved public walkway along the upland shoreline. The topography is flat, the landscape is mowed and manicured, and the majority of the area is covered by impermeable pavement.

Section 6 is located immediately north of the Port Regalle site, within the 20-acre waterfront park called Seaside Wildlife Nature Park. This area is bounded to the south by Port Regalle, to the north by Cleveland Avenue, to the east by the waters of the inner harbor and to the west by Tennyson Drive and a fenced in area of open land and residential areas along Fitzgerald Avenue. The shoreline consists primarily of relatively wider stretches of tidal wetland and sandy beach, with some small sections of riprap.

The topography within the site is flat, and slopes gently down the shoreline to the water's edge. The area is primarily mowed, with small landscaped areas throughout the site. The adjacent harbor waters are shallow with a sandy substrate.

A boardwalk runs parallel to the shoreline, while paved paths circle the park. Passive recreation areas dominate the park uses to the south, while in the north section of the park a paved playground and parking area dominate the site.

Section 7 is bounded by the Seaside Wildlife Nature Park to the south, a small stream habitat to the north, the inner harbor to the east, and Mansion Avenue to the west. The site includes the Richmond County Yacht Club, Atlantis Marina, Mansion Marina and the Great Kills Yacht Club, their associated marinas, a number of restaurants and other smaller buildings, and paved parking areas. The shoreline is primarily bulkheaded except for a small area in the north, located between the Mansion Marina and Great Kills Yacht Club properties, which are undeveloped. The shoreline in this undeveloped area is a natural shoreline with gentle slopes and small pockets of tidal wetlands.

Section 8 is a small natural area containing a freshwater stream and adjacent wooded and tidal wetland habitats, located in Great Kills Park between the bulkheaded areas of Section 7 and 9. The stream flows southward along the eastern edge of Hylan Boulevard from areas offsite to the wooded area just north of the Waters Edge apartment complex, before draining to the inner harbor.

The waters off of Section 8 are shallow with a sandy substrate.

Section 9 consists of a bulkheaded shoreline in the western sections and a riprap section in the eastern sections of the site, which is located in the northernmost stretches of the inner harbor situated between the small natural area in Section 8 and the developed marina in Section 10 within Great Kills Park. There is one small section in the northeast section of the site that contains a riprap area, a stormwater drain pipe and a paved boat ramp for public boat access, with a paved parking lot located north of the boat ramp.

The remainder of the upland area in Section 9 located immediately adjacent to the shoreline contains open space dominated by grasses and a paved walkway. To the north of Section 9, the open area (which makes up roughly one half of Great Kills Park) is fenced and closed to the public due to an ongoing investigation related to radium contamination.

Section 10 consists of a bulkheaded shoreline located at the Nichols Great Kills Marina along the eastern edge of the harbor, west of Buffalo Street. The area is generally flat and the land narrow. The adjacent upland area consists primarily of paved parking areas with some small landscaped areas located throughout.

5.1.5 Great Kills Park – Sections 11 and 12

Sections 11 and 12, along with Sections 8-10, are located within Great Kills Park, which is one of three Federal parks that form the Gateway National Recreation Area. Great Kills Park was built mostly on fill and all of the shorelines within this area have been altered over time. The peninsula portion of the Park is surrounded by the inner harbor, the navigation channel and the outer harbor. The remaining park area is surrounded by residential and commercial developed areas.

The nearshore area off of Great Kills Beach is shallow in depth for some distance. As a result, the wave action tends to be small and gentle. The area is used extensively for recreation purposes, primarily swimming and fishing.

For the benthic survey (Section 5.2), a transect was conducted in this area. The substrate was found to be medium sand (finer than the sand observed off of Crescent Beach), with pea-sized gravel and shell hash in the intertidal and nearshore area, and fairly consistent throughout the site.

No live or loose shells of Northern quahog were found in this area, likely due to the westward net littoral drift of sediment.

Section 11 is the area known as Crooke’s Point, which runs from the harbor/marina area westward to the harbor inlet, and then around to its most eastward point where the inlet meets the bay. The area is triangular in shape, with Nichols Marina located to the northeast, and Buffalo Street running along the eastern edge, and the remaining edges surrounded by the waters of the harbor and the inlet. A dredged navigation channel runs parallel to the western shoreline, largely defining the characteristics of that shoreline.

The shoreline within the harbor is narrow and riprapped, and contains a narrow, shallow sandy bench offshore which quickly drops to deeper depths due to dredging. Adjacent to the area, the land contains a paved road way and parking lot. The vegetation that lines the roadway and parking lot is dominated by invasive herbaceous species like ragweed and wugwort, and tree species like Tree of Heaven.

At the inlet, the shoreline is sandy and relatively wider. There is evidence that during higher high tides, the water is cutting through the site, changing the general shape of the beach. Adjacent to this area is a dune system consisting of a variety of grass, herbaceous, shrub and tree species.

Just south of the inlet, the sandy beach is narrow. The area is regularly nourished with sand, and shows evidence of active erosion with steep sandy edges between the sandy beach and the adjacent upland dunes, as the site continues to adjust to the regular dredging and sand nourishment. A number of clam and oyster shells were observed along the sandy beach.

The waters between the navigation channel and the sandy beach are shallow, but quickly drop to depth at the channel.

The adjacent dunes are wide and contain a diversity of habitat, from wetland to maritime forest. Along the edges of the dune, particularly along Buffalo Street, the vegetation is dominated by invasive trees, shrubs and herbaceous species. But within the interior of the dunes, the habitat is dominated by native species.

The southern portion of Section 11 contains a much wider sandy beach, due to active sand deposition, although the southernmost tip of this section is heavily armored with riprap and has active areas of erosion.

The waters within Section 12 are primarily used for fishing and boating through the navigation channel.

Section 12 is characterized by its bay-side sandy beach and adjacent dune areas. The site is located east of Buffalo Street and Nichols Great Kills Marina, south of the Oakwood Wastewater Treatment Plant, north of the Great Kills Inlet and Section 11, and west of Lower Bay/Raritan Bay.

The sandy beach in this section is wide, and slopes gently to the water’s edge. Small sections of the beach are vegetated with beach grasses, but trucks regularly drive down the western edge of the beach leaving a swath of unvegetated sand parallel to the adjacent dunes. There are some beach grasses. The dune is a healthy system, with a diversity of grasses, herbaceous plants, shrubs and trees. A paved parking area is located just west of the beach and dune, and paths lead from the parking area through the dunes to the beach.

The beach is subject to twice daily tide fluctuations, and small gentle waves are a constant. The waters off of the beach are relatively shallow for some distance, approximately 1-5 feet below mean sea level. The waters in this section are regularly used for swimming, fishing and passive recreation.

The only erosion evidenced along the sandy beach was around the park’s beach house, located just west of Nichols Great Kills Marina and Buffalo Street. There are no dunes in this area and the adjacent uplands lie slightly lower in elevation than the dune areas, so stormwater tends to flow from the parking area and street towards the bay in this area.

5.2 Underwater Investigation

Figure 5-2: Underwater Investigation Diver Transects

On September 18, 2014, OCC divers and a marine biologist, accompanied by representatives of Biohabitats and SCAPE, completed a benthic survey of Great Kills Harbor inter and subtidal habitats. A detailed summary memo, including photographs, was prepared by OCC|COWI and has been included in Appendix C; select highlights from the underwater investigation are presented here. The study consisted of four shore perpendicular transects, detailed in Table 5-3, below.

Positioning was accomplished using the vessel mounted Differential Global Positioning System (DGPS). This positioning procedure facilitated locating the transect lines, video recording, sediment sampling and local conditions reporting.

Sediment samples were collected approximately quarterly along each transect, as well as at locations with a noticeable change in substrate character. The sediment samples were collected and sealed in plastic bags, carried to the support vessel, placed on a Number 40 mesh (approximately 0.5 mm) sieve, photographed with their transect and location number for subsequent identification (e.g. Transect 1, sample 1 is displayed as 1.1), sieved to eliminate the silts and clay fraction, and re-photographed with their identification number.

Table 5-3: Field Investigation Transects

Transect	Starting and Ending Coordinates	Length	Location
1	40^0 32.024' N, 74^0 08.978' W 40^0 31.882' N, 74^0 08.872' W	1,250 ft (381m)	Southeastward from the shoreline of Staten Island toward the southwestern end of the National Park Service's Crooke's Point
2	40^0 32.398' N, 74^0 08.238' W 40^0 32.760' N, 74^0 07.808' W	2,950 ft (900m)	Approximately mid-Great Kills Harbor to the shoreline bulkhead of the National Park Service's Great Kills Harbor Unit
3	40^0 32.112' N, 74^0 08.315' W 40^0 32.178' N, 74^0 08.315' W	400 ft (122m)	Begins at the riprap revetment along a small parking lot on the northwest side of Crooke's Point and extends northward into Great Kills Harbor
4	40^0 32.102' N, 74^0 07.820' W 40^0 32.058' N, 74^0 07.753' W	400 ft (122m)	Extends offshore from an area adjacent to the marked recreational bathing beach area within the Gateway National Recreation Area, Great Kills Park

Shellfish were identified in-situ by either the diver or the support team. If necessary, one or more individuals were brought to the surface, identified, photographed and returned to the waterway. Species abundance is classified according to the ACFOR acronym a simple, somewhat subjective scale of species abundance within a given area. It provides an indication of how many organisms are in a particular area/habitat since counting them is not practical. A subset of the area representative of the population is counted instead. The ACFOR scale is as follows:

- A – The species observed is "Abundant" within the given area.
- C – The species observed is "Common" within the given area.
- F – The species observed is "Frequent" within the given area.
- O – The species observed is "Occasional" within the given area
- R – The species observed is "Rare" within the given area.

5.2.1 Transect #1

The substrate at the base of the riprap revetment is comprised of varying sizes of gravel and cobblestones with sand sized fractions and shells along with shell hash as a top layer and embedded within the material. Near the shoreline, the gravel ranged from approximately 0.5" (0.625 cm) to cobblestones sizes of 3" (3.75 cm) upwards to almost 12" (30.0 cm) along their longest dimension. Beyond that point a gradual shift to smaller sizes occurred in the substrate. Midway along the transect line, approximately 600ft offshore, the substrate became predominately sandy silt with small to medium sized gravel present. Black discoloration of the sediment indicative of the presence of silt/clay and possibly organic material fractions was observed. From the mid-point of the transect to the shoreline, there were occasional Northern quahog however their presence was deemed “rare.” The population increased in direct relationship to the substrate composition. At the mid-point along the transect line, opposite a sunken barge, toward the offshore, the population of Northern quahog increased noticeably and quickly to a level where individuals were considered “frequent” to “common” along the transect line.

The Northern quahog occurrence in this area is expected and likely to remain stable due to the water circulation patterns sweeping the area. See Appendix C for sectional drawings of the field investigation transects.

5.2.2 Transect #2

At the landward end of the transect line the sediment is sand with some shell hash and organic detritus. Moving offshore, the substrate becomes primarily fine grained silts and clays with little compaction. At the mid-point along the survey, approximately 1,400 ft, the sediment reverted to sandy with silt/clay and some pea gravel. The sediment was compacted allowing little penetration. This reach appears to be less depositional which may reflect that it is somewhat shallower than the areas north and south of it where fine grained materials dominate the substrate composition. Observed shell hash was primarily from soft shell clams and Northern quahog. By three quarters along the transect line, the sediment had become predominately silt/clay again with little compaction and virtually no shell hash. Penetration of the substrate was easily made to more than 24" (67 cm) by hand. At the offshore end, the observed substrate was primarily sandy shell hash rich and compacted with some silt clay fractions. The inshore sediment sample was an unconsolidated fine sand/silt/clay with organic material and shell hash, either whole shell or just pieces representing assorted ages based on the shape and sizes of the pieces.

At the bulkhead, sediment grain sizes increased to be dominated by well compacted sandy sediment. Common mud whelks were observed. Ampelisca amphipods (tubes) population was prevalent approximately 33 ft (10m) from the bulkhead and decreased in population moving inshore. The *Ampelisca abdita* are the most common tube building amphipods seen colonizing recently deposited sediment in the region. Offshore, the diver reported the presence of complete razor clam, soft shell clam, and Northern quahog shells (empty) laying on the substrate surface and embedded within it. The razor clam shells were occasional to frequent and more than six (6) were observed in the divers field of vision during the first quarter of the transect survey. Their shell sizes ranged in length from approximately 3 to 4" (7.5 to 10.0 cm). The soft shell clam shells were frequent to common particularly in the offshore quarter of the survey. Northern quahog shells ranged from less than 0.2" to over 4" (0.50 cm. to over 10.0 cm) in length. There was no organic tissue present in any of the shells so date of demise was indeterminate. Live Northern quahogs embedded in the substrate were observed at approximately 0.5 to 0.7 per square foot (5 to 7 per square meter) (occasional to frequent) in this portion of the transect line.

The odor of hydrogen sulfide in the sediment samples and the lack of a visual oxygenated sediment layer (no "grey" color, only "black") indicate the lack of an oxygenation – reduction (Redox) potential profile in the collected sample. This condition indicates a depressed oxygen (hypoxic condition) or lack of oxygen (anoxic condition) in the sediments and overlying waters exists. Based on the strength of the hydrogen sulfide odor, limited number of living organisms along this transect as well as the presence of Northern quahogs on the substrate surface we suggest that an anoxic event was occurring. These events are often lethal, diminishing habitat values for species that seek to reside in an area throughout the year. The age of some of the Northern quahog found on the surface along transect line #2 indicate that a lack of oxygen condition was not an annual event. However, the 2014 event was lethal to virtually all organisms in the observation area.

5.2.3 Transect #3

Sample Transect #3 is approximately 400 ft (122 m) long; beginning at the riprap revetment along a small parking lot on the northwest side of Crooke's Point and extends northward into Great Kills Harbor. Michael Jennings of NEIWPCC was an observer on this transect line survey.

The nearshore area substrate reflected the probable migration of sandy material around Crooke's Point and into the Harbor. Sand is transported in a westerly direction by wave action until it falls into deeper water beyond the point. This sediment transport pattern has created a nearshore (inter and sub-tidal) zone of compacted sandy silt/clay with shells and shell hash mixed in on its surface and downward into the sediment. This condition extends offshore approximately 60 ft (18 m) from the toe of the riprap revetment at the base of the transect line. By approximately 80 ft (25 m) offshore, there is a marked shift to a substrate comprised of silty clay with some shell hash; the sediment can be penetrated more than a meter without encountering significant resistance. The substrate became more consolidated and an abundant population of *Ampelisca* amphipods carpeted the substrate with an occasional to frequent number of juvenile Northern quahog reported to be present. Beyond this point the substrate became progressively more unconsolidated and gelatinous (highly hydrated). The surface was populated by a large and continuous population of *Ampelisca* amphipods but beneath the amphipod tubes the sediment was basically soupy indicative of recent deposition. This substrate characteristic remained continuous to the end of the survey line.

Common mud snail (a.k.a. Eastern mud whelks, mud dog whelk, black dog whelk), [*Ilyanassa obsoleta* formerly *Nassarius obsoleta*] was found throughout the inner harbor transects except where the presence of the anoxia event was recorded. This was found in the inner half of Great Kills Harbor along Transect #2 beginning at 2,000 ft (600 m) from the inner bulkhead base of the survey and along the outer approximately fifty (50) ft of Transect line #3.

5.2.4 Transect #4

Sample Transect #4 is approximately 400 ft (122 m) long, extending offshore from an area adjacent to the marked recreational bathing beach area within the Gateway National Recreation Area, Great Kills Park. It is approximately 300 ft (90 m) westward of that marked swimming area. The substrate sediments throughout this transect are medium sand (finer than those with Transect #1) with "pea" sized gravel in the intertidal and nearshore area. The substrate remained relatively consistent throughout the transect survey. There is a significant amount of shell material throughout the inshore half of this transect line.

There were an occasional frequency level of hermit crabs observed along the survey area. The majority of them were wearing Common mud whelk shells. No live or loose shells of Northern quahog were found along this section of the transect line. This is to be expected as the net littoral drift of sediment is westward along the beach and occurs at a rate that causes the Federal Navigation Channel at the end of Crooke's Point to require regular maintenance dredging to maintain safe access and egress of Great Kills Harbor. The current dredging cycle is approximately ten years and volume is variable but always more than 100,000 cubic yards (75,000 cu. m) per event. As the result of Storms in 2011 and 2012 more than 250,000 cubic yards (190,000 cu. m) of sediment required relocation.

Wave or current induced shifting of sand along a seafloor is exclusionary for many species due to the abrasive action of the moving sand on exposed soft tissue. This abrasive environment reduces habitat value for benthic species and limits or precludes successful colonization by them. Evidence of the extent of the net westward drift is found in the USACE's dredging cycle rate for the entrance channel to Great Kills Harbor where it passes across the terminus of Crooke's Point. The fact that the maintenance dredging appears to cut through the accumulating shoal of sediment transported by littoral drift at the western end of Crooke's Point is evidence of the beach sediment instability. Moving across the channel, which was dredged earlier this year (2014), the bathymetric recorder on the survey vessel revealed a channel cut through the deposition shoal where water depths were shallower on either side of the dredged channel. Prior to work completed in 2014, the last recorded date of channel dredging was 2003.

Transect #4 crossed sediments that were visually similar to the initial characterization made on the actual beach face. The only difference was seen in the gravel to silt/clay ratio as one moved offshore. The offshore sediment sample is comparable to the nearshore sample with only a slightly higher amount of finer sand and silt/clay materials. The presence of the pea gravel and few shell fragments is reflective of more sorting of the sediment and indicative of wave induced erosion as would be expected on a beach that is exposed to ocean waves.

Throughout Transect #4, both visual and tactile searches for Northern quahog proved unsuccessful; no live individuals were found.

5.3 Field Investigation Conclusions

The Crescent Beach topography ranges from small steep hills in the residential sections, to low-lying flat terrain along the shoreline. Areas along the shoreline have been filled over time with riprap, concrete, sand and other fill material. The shoreline also includes a few small patches of tidal marsh vegetated with Spartina alterniflora. A large open space area, consisting of wetland and wooded areas, is located between Armstrong Avenue and Glover Street east of Tennyson Drive. The wetland is dominated by Phragmites. Farther north the shoreline area consists of a mix of concrete groins, riprap, sand and Spartina alterniflora–dominated tidal wetland.

The inner harbor contains areas of shallow waters and much deeper waters, largely dependent on whether the area has been dredged over time or not. The Seaside Wildlife Nature Park shoreline consists primarily of relatively wider stretches of tidal wetland and sandy beach, with some small sections of riprap. Farther along, the shoreline is dominated by bulkheads by a number of marinas, though some undeveloped properties contain small pockets of tidal wetlands.

Great Kills Park was built mostly on fill and all of the shorelines within this area have been altered overtime. The shoreline on the harbor side is narrow and with some locations riprapped, and contains a narrow, shallow sandy bench offshore which quickly drops to deeper depths due to dredging. A number of clam and oyster shells were observed along the sandy beach. The vegetation that lines the roadway and parking lot is dominated by invasive herbaceous species like ragweed and wugwort, and tree species like Tree of Heaven. The adjacent dunes are wide and contain a diversity of habitat, from wetland to maritime forest. Along the edges of the dune, particularly along Buffalo Street, the vegetation is dominated by invasive trees, shrubs and herbaceous species. But within the interior of the dunes, the habitat is dominated by native species.

The sandy beach on the ocean side slopes gently to the water’s edge. Small sections of the beach are vegetated with beach grasses, but trucks regularly drive down the western edge of the beach leaving a swath of unvegetated sand parallel to the adjacent dunes. There are some beach grasses. The dune is a healthy system, with a diversity of grasses, herbaceous plants, shrubs and trees.

The four (4) diver transect surveys revealed a broad spectrum of substrate types and habitation levels (use) by the Northern quahog target species.

The substrate along Transect #2 within the inner reaches of Great Kills Harbor indicates marginal to poor habitat for Northern quahog based on its substrate characteristics [gelatinous (highly hydrated) silts and clays] and water quality characteristics (anoxia). The substrate along Transect #3 is directly comparable to that of Transect #2 once beyond the nearshore accumulation of the sandy and shell rich deposit, although Northern quahog occurred at a rare abundance level.

The primarily sand substrate along Transect #4 shows evidence of net motion to the west. The substrate and associated habitat proved to be unsuitable for Northern quahog. Sediment motion typically causes a lack of organisms with soft bodies or appendages, verified here by the absence of such soft-bodied organisms collected along this transect.

Finally, there is the habitat and associated Northern quahog population found along Transect #1. Once seaward of the surf (wave breaking) zone along the shoreline where suspended sediment precluded visibility, a healthy and relatively large age range of Northern quahog sizes and individuals were found. Dispersive spawning enables the Northern quahog to utilize local currents to spread their larval young broadly. This increases the likelihood that some of the spawn will settle onto suitable substrates and grow. Observations within the shell litter and within the seabed reveal that Northern quahog reproduction is successful.

The existing habitat functions and values essential to Northern quahog survival appear to be localized in the area of Transect #1 (along and offshore of the area westward of Crooke's Point) and along portions of Transect lines #2 and #3. Although we found Northern quahog within Great Kills Harbor, many were dead or suffering from the effects of an apparent anoxia event.

A detailed summary memo of the underwater investigation is found in Appendix C.

6 Evaluation Matrix

6.1 Development

Development of the evaluation matrix progressed with the team providing discipline specific input on appropriate categories. General project alternatives were gathered from coastal protection strategies documented throughout the region. Final development for the criteria was performed in team workshop prior to discussion with the project stakeholders on August 5th, 2014.

6.2 Evaluation Criteria

The matrix evaluation involved both qualitative and quantitative assessments. The qualitative assessment was compiled as a way to collect input from project participants regarding the functionality of the system. The qualitative assessment categories and brief descriptions are below:

- Description: Description of the alternative
- Alternative Variations: Alternative variations
- Vertical location: Where is the alternative located within the water column
- Horizontal location from shoreline: Where is the alternative located relative to the shoreline
- Habitat Creation: Opportunities to create habitat
- Habitat Disruption: Potential habitat loss & disruption concerns
- Relative Construction Costs: Relative construction costs

- Versatility: Ability to perform in multiple storm types and conditions
- Constructability: Applicability to existing site conditions
- Service Life & Maintenance: Projection of how long the system can be effective
- Notes: Additional Notes

The quantitative assessment involved assigned scores to the different assessment criteria. The scores were used to determine the alternative most favorable to a range of stakeholder priorities. The weighting and scoring is discussed below in section 6.3. The quantitative assessment criteria and brief descriptions are below:

- Feasibility: Feasibility to implement the strategy within the project boundaries. Strategies determined infeasible were not rated.
- Wave Energy: The influence of the alternative on wave energy
- Storm Surge: The influence of the alternative on storm surge
- Coastal Erosion Protection: Net coastal erosion protection considering both the local and downdrift shoreline
- Habitat Impacts: Net habitat impacts
- Societal / Economic Impacts (cost/benefit): Net impact on societal benefits both societal and economy (i.e. tourism, local fishing economy)
- Recreational Impacts: Net influence the alternative will have on local recreation (i.e. public access, boating, ...)
- Navigation Impacts: Net influence the alternative will have on navigation into and around Great Kills harbor
- Visual Impact: Net influence the alternative will have on the visual impact from the nearshore area
- Rating: Weighted rating
- Relative Ranking: Ranking

6.3 Scoring System

The scoring system is based on a matrix of weighted ratings. The individual rating for each criteria ranged from -3, Highly Negative/Consequence to +3, Highly Positive/Beneficial Influence or Consequence, as seen in Table 6-1.

Table 6-1: Matrix Assessment, Criteria Rating Scale

Value	Associated Description of Value
+3	Highly Positive/Beneficial Influence or Consequence
+2	Positive Influence
+1	Minor Positive Influence
0	Neutral (No impact)
-1	Minor Negative Influence
-2	Negative Influence/Consequences
-3	Highly Negative/Consequences

In addition to the ratings for each strategy, a weighting system was developed by the project team to emphasize relative importance/priority of each category. The weights were selected by the project team based on feedback from the stakeholders, knowledge of past projects, and professional judgment.

Weighted rankings were developed by multiplying the ranking score by the weighting factor. The maximum theoretical assessment value is 3.0.

The full results and scores are reported in the assessment matrix, included as Appendix B.

7 Conclusions and Recommendations

Based on the matrix analysis and stakeholder meetings, two modeling scenarios were agreed upon: (1) A breakwater on the ocean-side of Crooke's Point with a harbor-wide breakwater at the mouth of Great Kills Harbor; (2) Dune on Crooke's Point with smaller breakwaters / offshore interventions along Crescent beach and inside the harbor. These options will be advanced based on the remaining scope of this study.

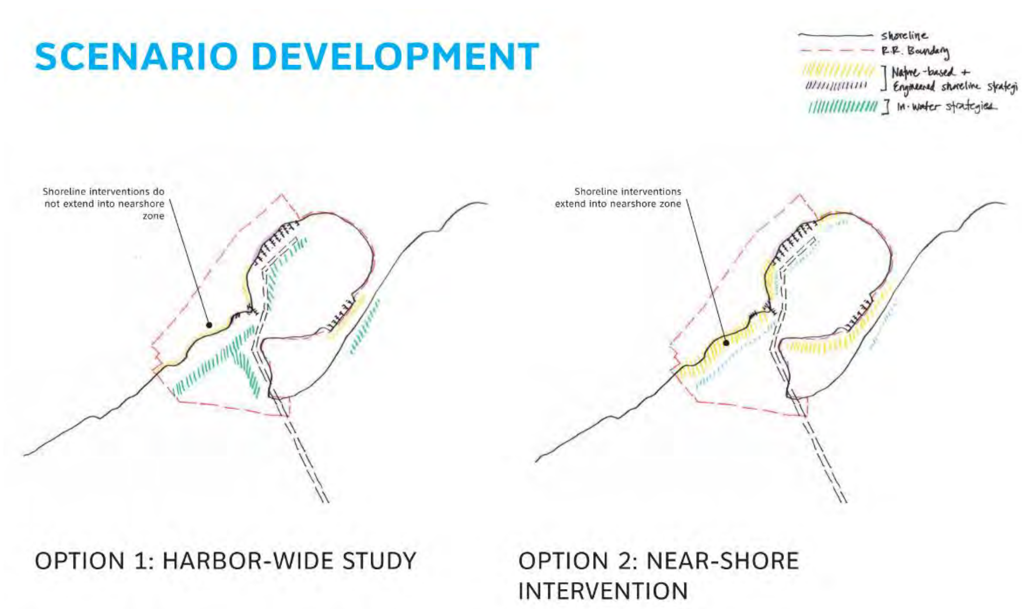

Figure 7-1: Modeling Scenario Development

It was agreed in the meeting held with the project stakeholders that all the breakwaters should be emergent (crest above Mean Higher High Water). A crest elevation of +11 ft (relative to NAVD 88) is thought to be effective for wave attenuation and is recommended for both modeling scenarios. Dunes were modeled at +14 ft.

Model scenario 1 is recommended to include a harbor-wide breakwater which will span the length of the risk reduction area along Crescent Beach and block direct wave propagation from offshore into the harbor ('L' shape). Wave diffraction through openings on a harbor-wide breakwater will likely be significant, therefore the structure is recommended without gaps. The distance from the shoreline is recommended at approximately ¼ mile to reduce the potential for wave regeneration in the lee of the breakwater. An additional breakwater on the ocean-side of Crooke's Point was also included to protect Nichols Marina. This breakwater is 1400 ft in length, located in front of the NPS facilities on Crooke's Point, and is located one tenth (1/10) of a mile from the shoreline.

Model scenario 2 is recommended to include a segmented breakwater along the length of the Crescent Beach risk reduction area. Empirical results of wave diffraction through breakwater lengths of approximately 250 ft with gaps suggest an 80 ft gap would be effective at attenuating waves while allowing some wave energy to pass through the breakwater line. This scenario would be located closer to shore (approximately 1/10 mile) to encourage sedimentation and reduce the potential for superposition of the diffracted waves in the lee of the breakwaters. Along Crooke's Point, a 600 ft constructed dune was proposed to connect the topographical high points.

The orientation of the Great Kills Harbor entrance suggests it is vulnerable from waves propagating from the south, typically occurring during nor'easters. The damage caused by Sandy was devastating, however nor'easters have the potential to occur at a higher frequency with a high potential for damage. It is recommended that, in addition to a Sandy-like storm, a nor'easter-type storm is modeled for each scenario.

Including effects of sea level rise, the following four storm cases are recommended for modeling the two scenarios in Task 3: (1) Nor'easter-type, (2) Nor'easter-type with 31" sea level rise, (3) Sandy-like storm, and (4) Sandy-like storm with 31" sea level rise.

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