Appendix E
Natural Resources
(Part 3)

Appendix E-6
Living Breakwaters Design Modeling Report

LIVING BREAKWATERS

30% DESIGN MODELING REPORT

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version	Date	Notes
1.0	March 16, 2016	Baseline Modeling Report - Preliminary Draft.
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Appendix A – 30% Design Modeling Results Report
Appendix B – SBEACH and CSHORE Simulations

LIST OF ACRONYMS

ADCIRC	ADvanced CIRCulation numerical model
ADCP	Acoustic Doppler Current Profiler
CSHORE	Cross-SHORE beach erosion model
FEMA	Federal Emergency Management Agency
GENESIS	GENEralized model for SImulating Shoreline change
GEV	Generalized Extreme Value
LiDAR	Light Detection and Ranging
MHW	Mean High Water
MLLW	Mean Lower Low Water
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NYCDOITT	New York City Department of Information and Technology
NYSDEC	New York State Department of Environmental Conservation
PFIRM	Preliminary Flood Insurance Rate Map
REFDIF	REFraction DIFfraction numerical model
SBEACH	Storm-induced BEAch Change beach erosion model
SWAN	Simulating WAves Nearshore wave transformation model
TSPP	Tottenville Shoreline Protection Project
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WIS	Wave Information Studies

GLOSSARY OF TERMS

Astronomical Tide: Tidal levels resulting from gravitational effects from the sun and moon.

Backshore: Upper part of the active beach, above normal reach of high tides.

Bathymetry: Measurement of water depths for a given area.

Beach: Deposit of non-cohesive material situated on the interface between dry land and a large expanse of water.

Beach Profile: Cross-section taken perpendicular to the shoreline. Shows elevation change across offshore, swash, beach, and backshore zones.

Berm: Horizontal plateau on the beach face.

Bluff: High steep bank or cliff.

Breakwater: Offshore structure aligned parallel to the shore that provides protection from wave activity.

Cross Shore: Perpendicular to the shoreline.

D_{50} Sediment Size: Median particle diameter.

Depth of Closure: Offshore limit at which wave energy begins to have a negligible effect on shoreline change.

Diffraction: Multi-directional spreading of waves when entering a sheltered region.

Downdrift: Direction of predominant sediment movement.

Dune: Small hills or ridges of accumulated sand.

Extratropical Storm: Storm with cold air at its core that derives energy from release of potential energy when cold and warm air interact (Nor'Easters).

Foredune: Dune feature (beach slope fronting the dune) closest to the water.

Groin: Shore-protection structure extending roughly perpendicular from the shoreline.

Hindcast: Retrospective forecasting of waves using measured wind and wave information.

Hydrodynamics: Dealing with the motion of fluids.

Longshore: Parallel to the shoreline.

Neap Tide: Tides that rise and fall the least as a result of the moon being in quadrature.

Nearshore: Zone extending seaward from the shoreline including the breaker and swash zones.

Offshore: Direction seaward of the shore.

Onshore: Direction landward of the shore.

Orthoimagery: Image of the Earth's surface from satellite or airborne sensors.

Overwash: Part of the wave run-up that runs over the crest of a dune and does not flow directly back to the ocean. The effect of overwash is carrying sediment landwards.

Refraction: Effect by which the direction of a wave changes upon entering shallower water.

Return Period: Statistical period of time between occurrences of a given event. E.G. a 10-year storm event is a storm that produces surge elevations that occur on average once every 10 years.

Run-up: Vertical height above stillwater elevation that the rush of water up a beach reaches after the breaking of a wave.

Shoaling: Effect by which the height of a wave increases upon entering shallower water.

Significant Wave Height: Average height of the highest one-third of waves for a given wave climate.

Spectral Model: Wave model that simulates the sea surface as a spectrum of waves of varying frequencies.

Spring Tide: Tides that rise and fall the most as a result of a new or full moon.

Stillwater Elevation: Water surface elevation without wave action.

Storm Surge: Water elevation increases due to reduced atmospheric pressure, the onshore advection of water by winds, and wave setup by breaking waves.

Storm Tide: Storm surge plus astronomic tide without wave action.

Synthetic Storm: Hypothetical storm created using combinations of storm parameters from the historical storm record. Because severe storms are infrequent, the historical record does not capture all plausible combinations. Synthetic storms capture this variability statistically sampling historical storm parameters to create a suite of storms used in model simulations.

Swash Zone: The area of the shoreline where wave breaking occurs, extending from the limits of wave rundown and wave runup relative to the mean water level.

Tidal Flushing: Replacement of the water in an enclosed area by action of tidal currents.

Time Series: Series of values of a quantity obtained at successive times. Wave and surge time series are wave height and surge elevations at regular intervals (e.g. 1 hour) throughout the entirety of a storm event.

Transect Profile: See Beach Profile.

Tropical Storm: Storm with warm air at its core that derives its energy from the latent heat released when water vapor condenses into liquid.

Wave Direction: Direction from which the waves are coming.

Wave Height: Vertical distance between the crest (high point) and trough (low point) of the wave.

Wave Length: Distance between two successive wave crests.

Wave Period: Time required for two successive wave crests to pass a fixed point.

Wind Direction: Direction from which the wind is coming.

INTRODUCTION

PROJECT OVERVIEW

The Living Breakwaters project is an innovative implementation of coastal green infrastructure that aims to increase physical, ecological, and social resilience. The project is located in the waters of Raritan Bay (Lower New York Harbor) along the shoreline of Tottenville and Conference House Park in southern Staten Island. The Living Breakwaters, as currently proposed, consist of an approximately 1-mile-long system of breakwaters, with reef habitat enhancements.

The goals of the Living Breakwaters project are three-fold:

1) To reduce coastal risk through decreasing exposure to wave action and associated erosion along the shoreline in Tottenville.

2) To enhance habitat functions and values supporting local ecosystems through the creation and improvement of near shore and coastal habitat.

3) To foster stewardship, recreational use, and educational use of the coast and nearshore through increased awareness, access, and participation.

MODELING OVERVIEW

To inform the design and the benefits of the Living Breakwaters, an understanding of the wave conditions and the shoreline response to the project are required. Additionally, understanding of the hydrodynamics and water circulation patterns will aid in understanding any potential water quality impacts of the breakwater system. In the following sections, the modeling and analysis performed to develop baseline wave conditions, shoreline response, and tidal currents are described. Some of these models were then used to evaluate potential breakwater alternative scenarios. An outline is summarized below:

- **Wave Transformation Modeling** – Development of nearshore wave conditions by transforming wave conditions in the offshore to the nearshore using the Simulating Waves Nearshore (SWAN) wave transformation model.

- **Shoreline Change Analysis** – Development of historical shoreline positions from orthoimagery to inform critical areas of shoreline change, and to provide data for which shoreline change modeling can be calibrated and validated.

- **Shoreline Change Modeling** – Long-term shoreline change modeling using the GENEralized model for SImulating Shoreline changes (GENESIS) with simulation results calibrated and validated to the historically observed shorelines presented in the Shoreline Change Analysis section. The model was used to screen alternative scenarios and to assess the 30% design scenario.

- **Design Wave Transformation Near Breakwaters –** Modeling of the transformation of design wave conditions in proximity to the Living Breakwaters using the REFraction DIFfraction (REFDIF) wave model.

- **Storm Induced Beach Profile Response Modeling –** Modeling of beach profile change in the project region outside the Tottenville Shoreline Protection Project (TSPP) using the Storm-induced BEAch CHange (SBEACH) and Cross-SHORE (CSHORE) beach erosion models.
- **Water Circulation Modeling –** A tidal circulation model will be used to assess preliminary potential water quality impacts using the 2D hydrodynamic mode of the Delft3D-FLOW model.

The results presented in the sections identified above will inform baseline wave conditions, water circulation, and shoreline change behavior for the without-project conditions. These baseline results will also help inform the performance of proposed Living Breakwaters layouts and geometries by optimizing their design to achieve the goals of reduced erosion and reduced wave exposure. The alternative scenarios (with-project) will also be modeled, and the results compared to the baseline conditions (without-project).

Modeling efforts have focused on advancing the breakwater layout for the selection of a 30% design preferred scenario. Initial efforts examined scenarios designed to evaluate the impact of breakwater length, spacing, and distance from shore on long-term shore change (erosion and accretion). Wave climate in the lee of the proposed breakwaters were also examined during these initial scenarios. Further simulations were then performed on potential breakwater system configurations to determine system performance at storm wave attenuation and erosion reduction/reversal, and to evaluate various layout options. Aided by these results a 30% design scenario was developed.

This report builds on and supersedes the Baseline Monitoring Report.

WAVE TRANSFORMATION MODELING

In the project area no long-term measured or modeled wave records exist. To support the design layout and geometry of the Living Breakwaters, the long-term wave climate in the nearshore adjacent to the potential Living Breakwaters alignments was developed. This section discusses the use of the SWAN wave transformation model to transform U.S. Army Corps of Engineer (USACE) wave hindcast data from the entrance of New York Harbor to the project area. From the long-term wave climate data, return period wave statistics are estimated which can further assist the design team in advancing the design and layout of the Living Breakwaters. Additionally, the long-term wave climate will form the boundary conditions to the shoreline change modeling presented in the Shoreline Change Modeling section.

SWAN MODEL OVERVIEW

The Simulating WAves Nearshore (SWAN) wave transformation model has been applied for the determination of wave condition estimates in coastal areas by a global community of researchers and engineering consultants. The model is frequently updated with the most current developments from the research community. The current version, used in this study, is version 41.01 (SWAN, 2006).

For wave transformation modelling in Lower New York Bay and Raritan Bay, the SWAN model is capable of simulating the important wave processes that govern the generation and transformation of waves from offshore to nearshore adjacent to the project site. The following relevant wave processes are simulated in SWAN:

- Wind-wave generation (wave growth due to winds)
- Shoaling (increase in wave height as waves enter shallower water)
- Refraction (change in direction of waves caused by changing water depth)
- Energy changes due to bottom friction, wave breaking, whitecapping, and wave-wave interactions

SWAN is a spectral model that allows concurrent modeling of higher-frequency, locally generated wind waves and lower-frequency waves that are generated farther offshore. SWAN is also capable of simulation in a parallel computing environment, which is important for long-term wave climate estimates.

The intent of the current wave simulation is to transform 30 years of hourly wave data offshore to usable wave climates at the project site. The following sections describe offshore wave data, water levels, wind forcing, and other model parameters used in the simulation. The results of the 30-year wave transform are then presented along with return period wave statistics that will help support design of the Living Breakwaters.

MODEL INPUTS

OFFSHORE WAVE DATA

Hourly hindcast wave data were available from 1982 to 2012 at the USACE's Wave Information Study (WIS) station #63126 (Jensen, 2010). The station location is shown on Figure 1. Station #63126 is the closest hindcast data available for Staten Island. The hourly wave condition data from WIS station #63126 were applied at the offshore boundary of the SWAN model for transformation to the Living Breakwaters project site.

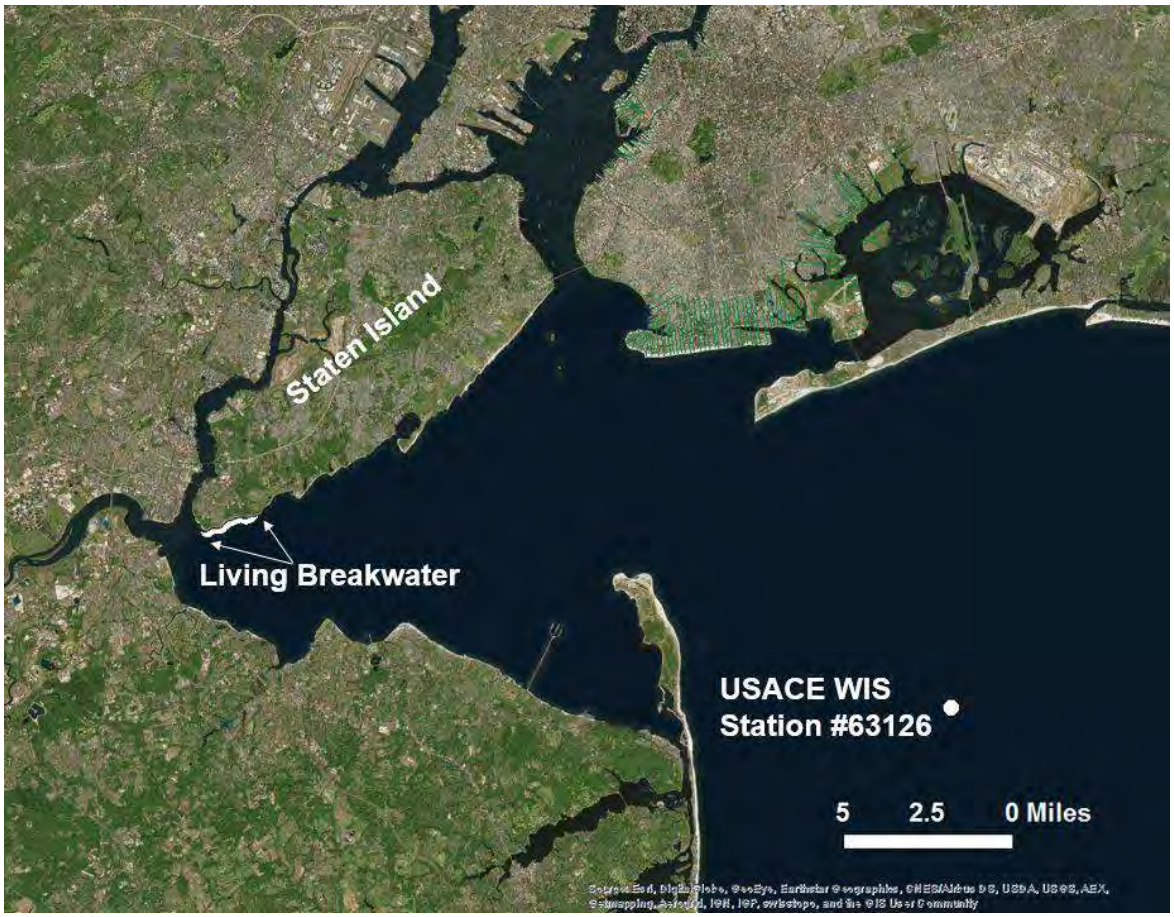

Figure 1. Location of USACE WIS station #63126 hourly wave hindcast data.

WATER LEVELS

Water level variation due to astronomical tide and storm surge was included in the wave model. Inclusion of water level variation improves wave transformation modeling, especially in the nearshore areas close to the Living Breakwaters. Water levels measured at the National Oceanic and Atmospheric Administration's (NOAA's) Sandy Hook station #8531680 were available over the 30-year simulation period. The NOAA Sandy Hook station, shown on Figure 2, is the closest to the project site.

Figure 2. Location of water level measurements at NOAA's Sandy Hook station #8531680.

WINDS

Long-term wind measurements were available at the following locations adjacent to the project site:

- John Fitzgerald Kennedy (JFK) Airport
- Newark Airport
- Sandy Hook
- Bergen Point

These locations are shown on Figure 3.

A comparison between each of the four measurement sites was made to determine if a better modeling approach would be to perform a spatial interpolation to define a spatially varying wind field or to simply apply a spatially uniform wind field. To compare each measurement location, all wind data were adjusted to the standard 10-meter elevation using the 1/7th power law (USACE, 1984) and to an over-water equivalent using a 0.85 coefficient (Simiu et al., 2007).

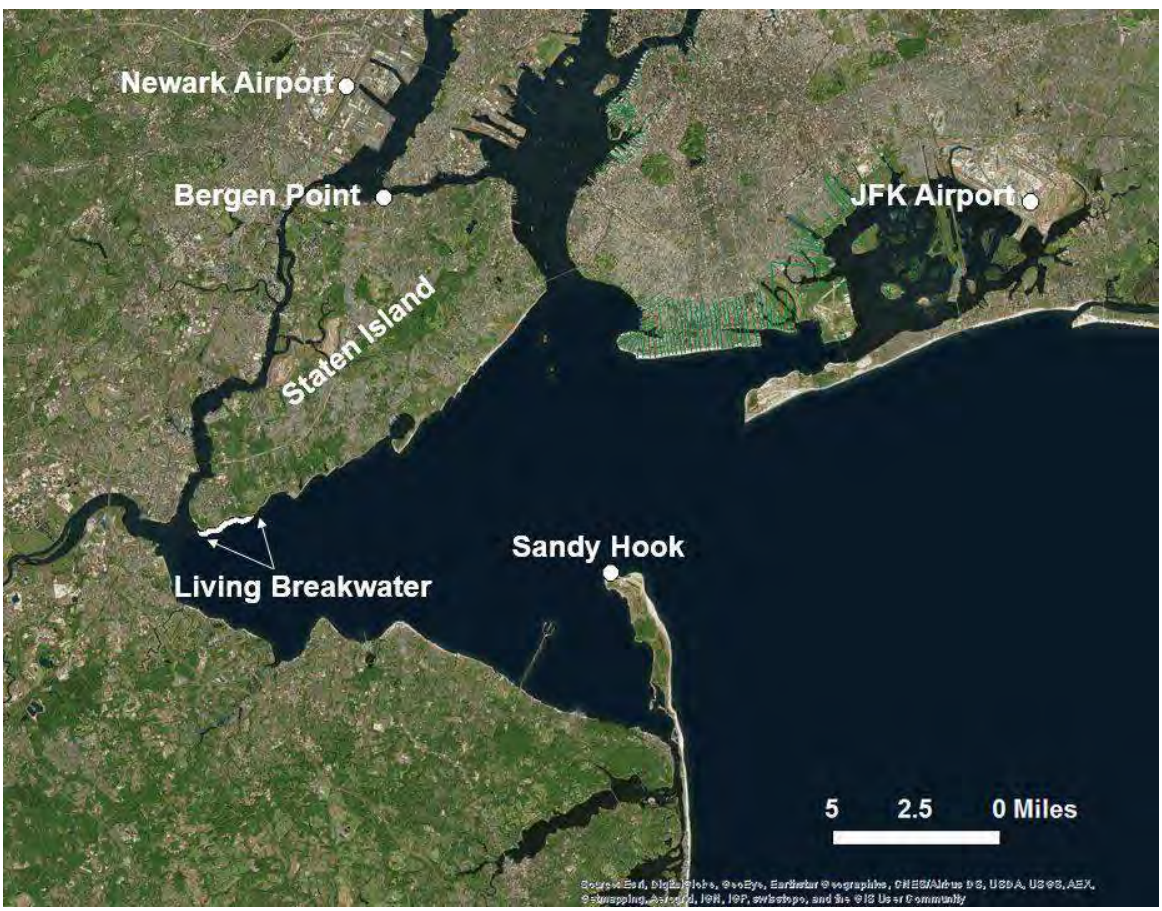

Figure 3. Location of nearest wind measurement locations: Newark Airport, JFK Airport, Sandy Hook, and Bergen Point.

As an example, Figure 4 compares measured wind data for the month of January 2012. Because of the general correlation of wind speed and direction between the four measurement locations, the wind field from the Newark Airport gage was selected for use in the SWAN model. As will be discussed in the Comparison to Measurements section, it was found that Newark Airport winds resulted in the best reproduction of SWAN-simulated waves relative to actual wave measurements.

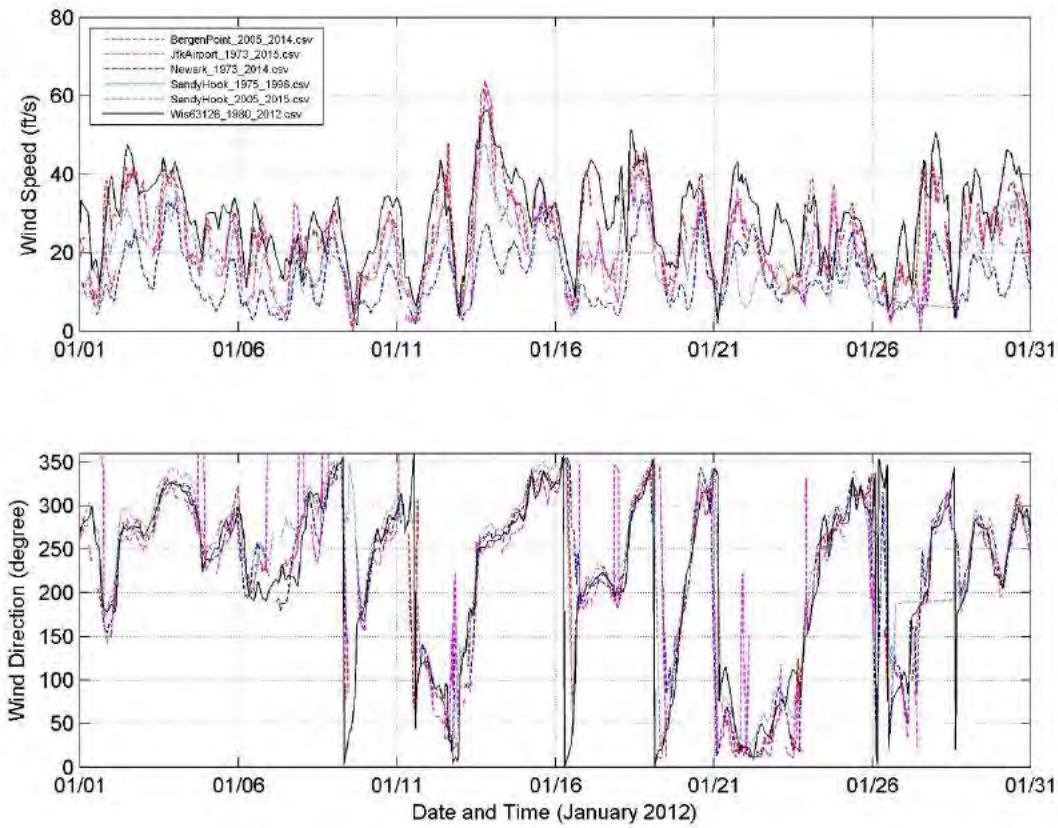

Figure 4. Comparison of wind measurements at four nearby locations during January 2012. Top image: wind speed in meters per second. Bottom image: wind direction in degrees clockwise from north.

BATHYMETRIC GRID

The computational grid for the SWAN model is shown on Figure 5. A 300-meter rectangular grid is refined in the nearshore areas to 50 to 100 meters. The bathymetric and topographic information assigned to the computational grid was the same developed as part of the Federal Emergency Management Agency's (FEMA's) Region II coastal analysis performed for New York City and New Jersey (FEMA, 2014a). Nearshore data in the vicinity of the Living Breakwaters obtained by multi-beam bathymetric and beach transect survey superseded FEMA's information within the survey limits (Hill International, 2015; MFS, 2015).

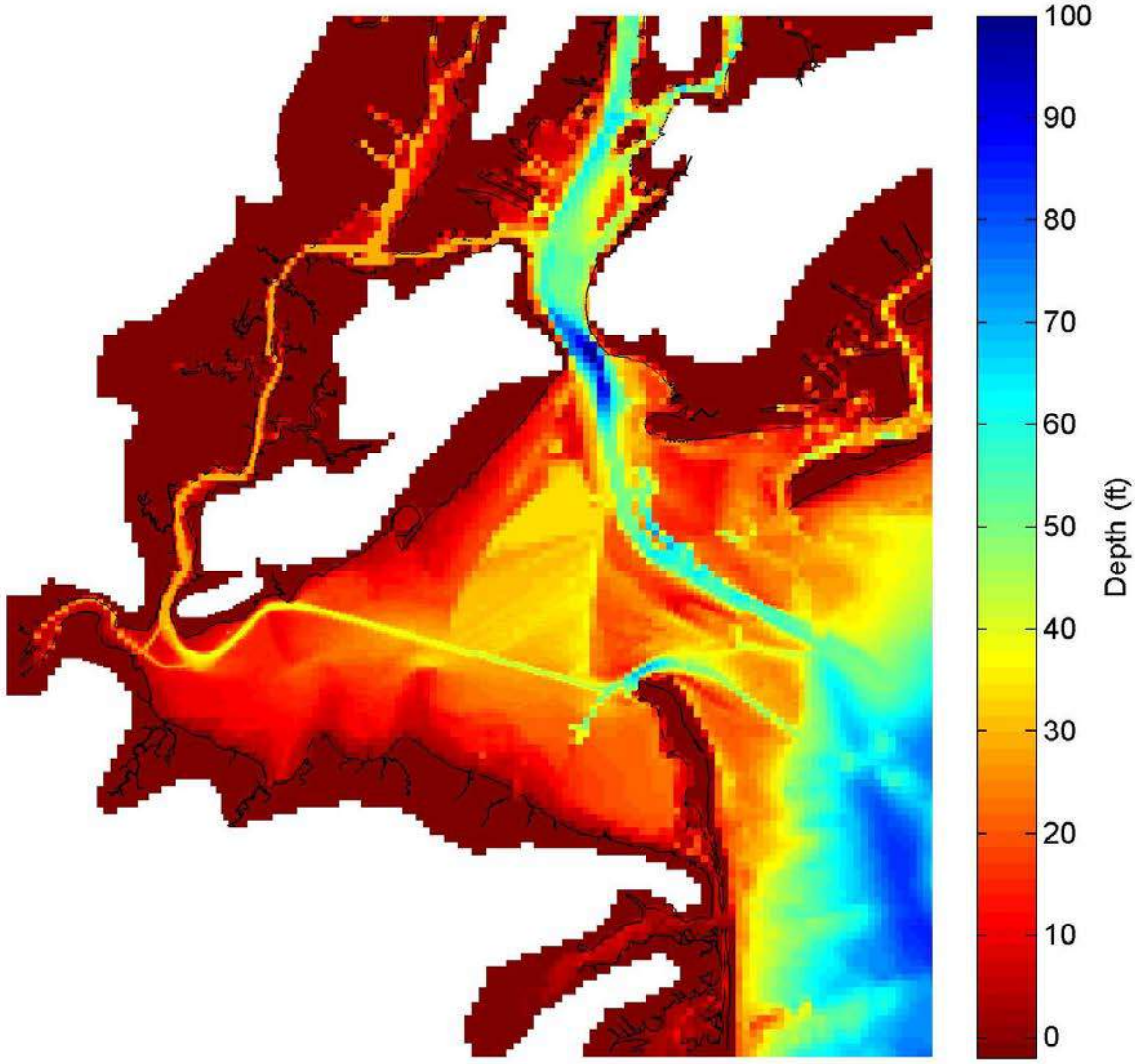

Figure 5. Bathymetry/topography (in feet) included in the SWAN model.

SIMULATION RESULTS

COMPARISON TO MEASUREMENTS

Simulation results from the SWAN model were validated against wave measurements made by an Acoustic Doppler Current Profiler (ADCP) deployed by Rutgers University from January 2012 to April 2012 (Roarty, 2016). The ADCP measurement location is shown on Figure 6.

Figure 6. Location of Rutgers ADCP measurements relative to the Living Breakwaters project site.

A comparison of measured versus simulated wave height (significant wave height), wave period, and wave direction is shown on Figure 7 for January 2012. During the comparison of simulated to measured wave heights, it was determined that Newark Airport winds resulted in the best match.

Figure 8 compares measured to simulated wave heights (significant wave height) for the full period of the Rutgers ADCP measurements.

In general, the simulated wave conditions match the measured wave conditions well. Short spikes in wave period and wave direction were observed in the Rutgers ADCP data. Given that no additional data filtering was performed on the data received from Rutgers, it is unclear if the source of short spikes in the measurement record is real observations or measurement noise that requires filtering. Ship wakes could play a role in producing wave period and wave direction spikes, especially considering the proximity of the Rutgers ADCP to navigation channels.

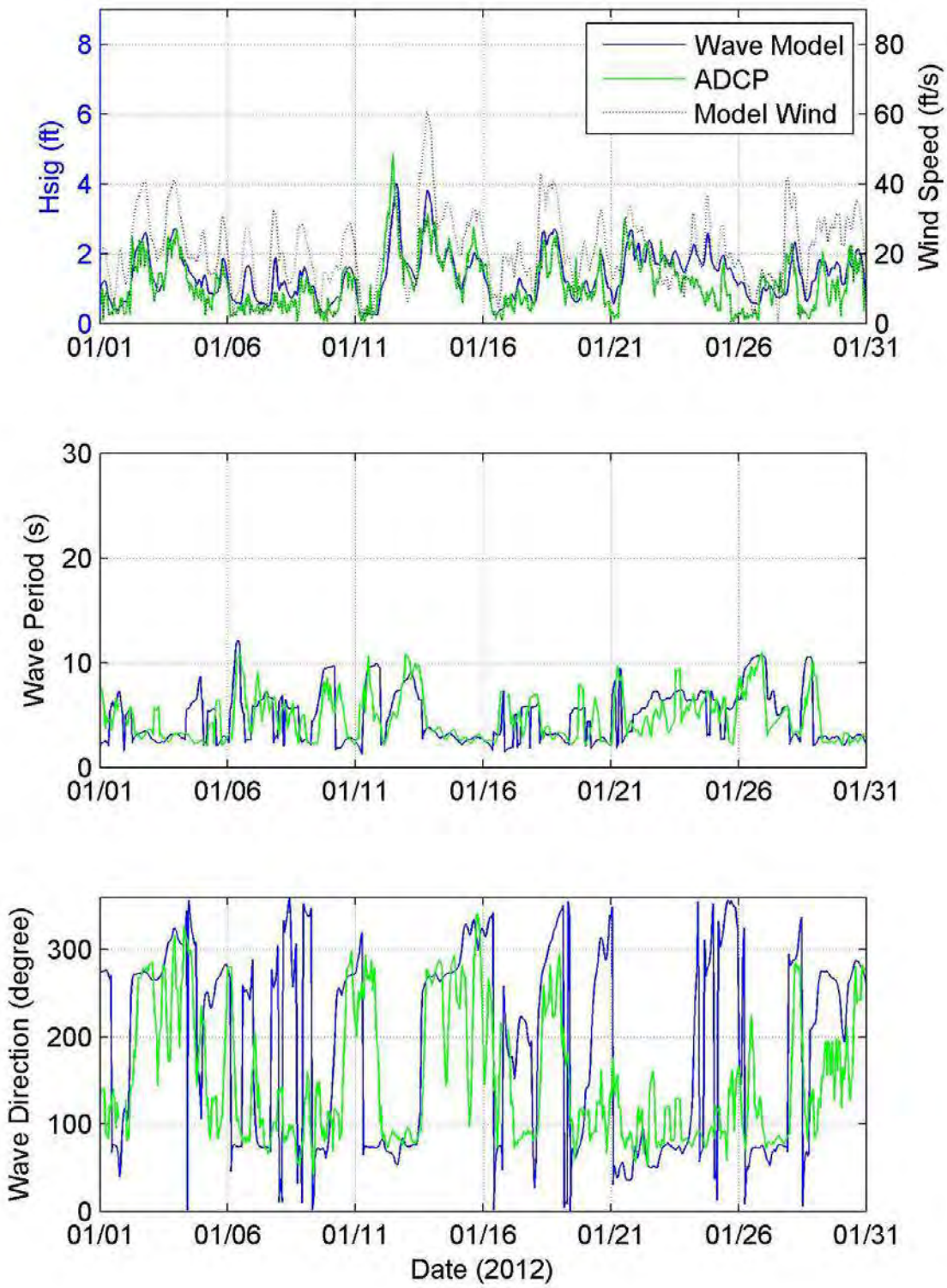

Figure 7. Comparison of simulated versus measured wave conditions for January 2012 at the Rutgers ADCP measurement location. Significant wave heights (top), wave periods (middle), and wave direction (bottom) in degrees clockwise from north.

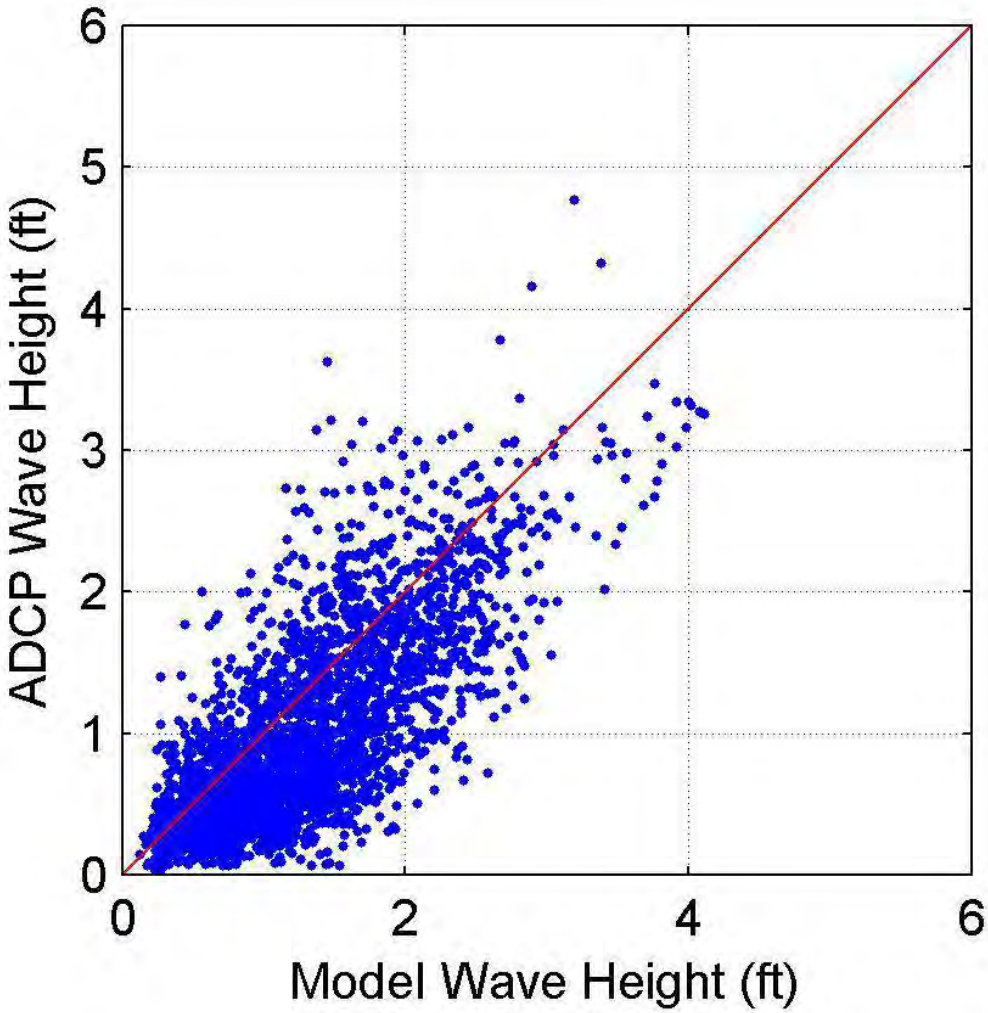

Figure 8. Comparison of model wave height to Rutgers ADCP wave height measurements between January and April 2012. The red line indicates a 1:1 match between measured and modeled wave heights.

NEARSHORE WAVE RESULTS

Wave transformation results were extracted in the vicinity of the potential breakwater alignment at eleven primary locations and eleven secondary locations. The primary locations are in the approximate limits of where breakwater alignments are proposed. Secondary locations are at the nearshore limit of the existing navigation channels. These extraction locations are summarized on Figure 9.

Figure 9. Wave transformation result locations.

p – indicates primary locations inside the proposed breakwater alignment.
s – indicates secondary locations adjacent to the navigation channels.

The 30-year, hourly wave data are summarized as wave roses at each of the primary locations, p1 through p11, on Figure 10. At eastern-facing locations, p3 through p11, the dominant wave direction is from the east nearly 20% of the time. The majority of waves are less than 0.4 meters (1.3 feet), with storm events resulting in wave heights in the 0.4 to greater than 1 meter (1.3 to greater than 3.3 feet) range from the east. At southern-facing locations, p1 and p2, Figure 10 demonstrates that the dominant direction shifts toward the southeast.

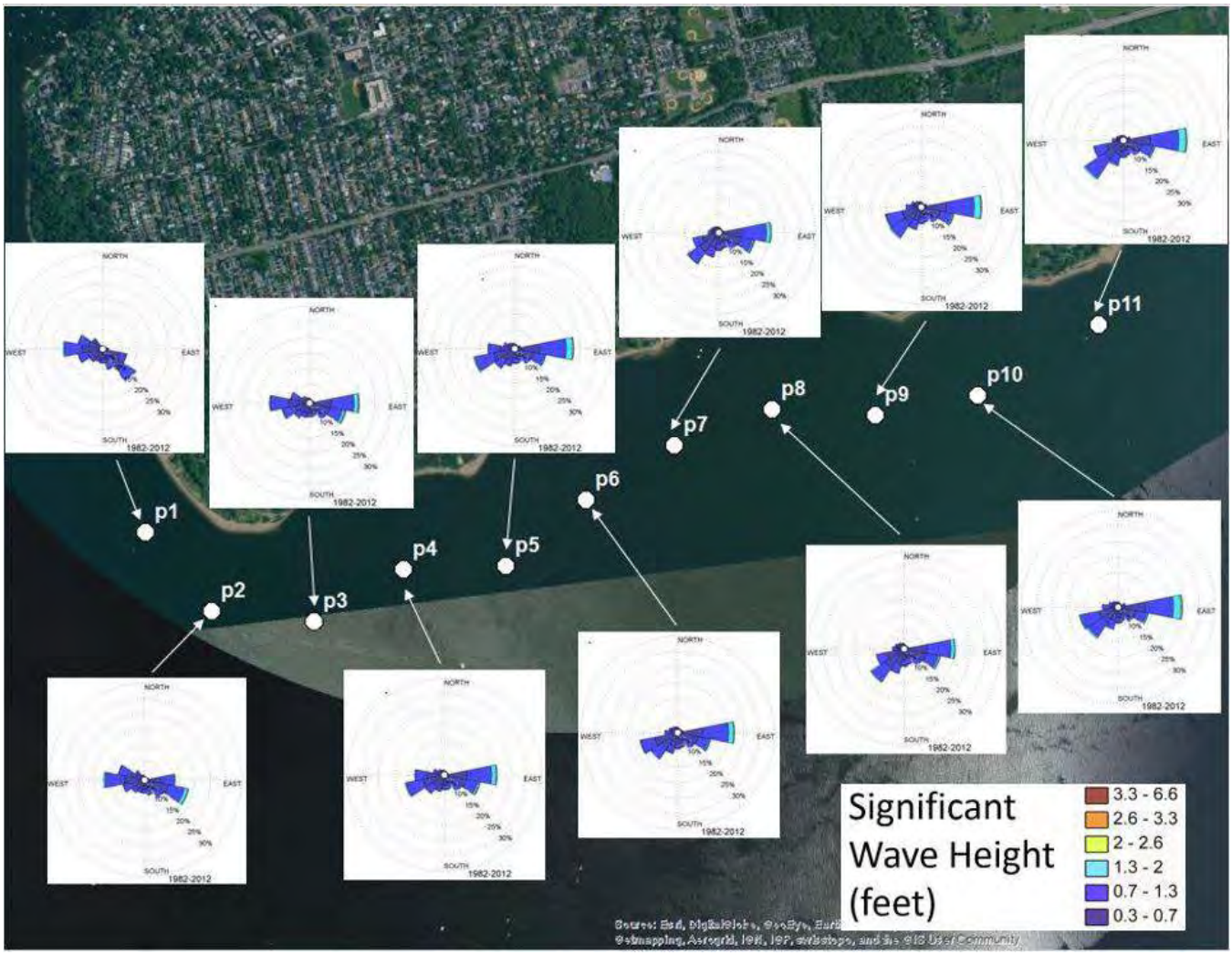

Figure 10. Wave roses of the 30-year hourly wave transformation results at primary locations p1 through p11. Significant wave heights in meters.

The wave transformation results at the secondary reporting locations, adjacent to the navigation channels, are shown on Figure 11. As was noted for the preliminary locations, for eastern-facing locations the dominant wave direction is from the east. For relatively southern-facing locations, the dominant wave direction shifts toward the southeast and southwest.

The wave field direction during a storm event was compared to the FEMA Preliminary Flood Insurance Rate Map (PFIRM) simulation results for the October 2005 event (FEMA, 2015). The FEMA PFIRM analysis was performed using the SWAN model as well. Figure 12 confirms an easterly direction for incoming wave directions in the vicinity of the Living Breakwaters site. Further comparisons of the wave transformation results to FEMA PFIRM results will be made in the Return Period Wave Conditions section.

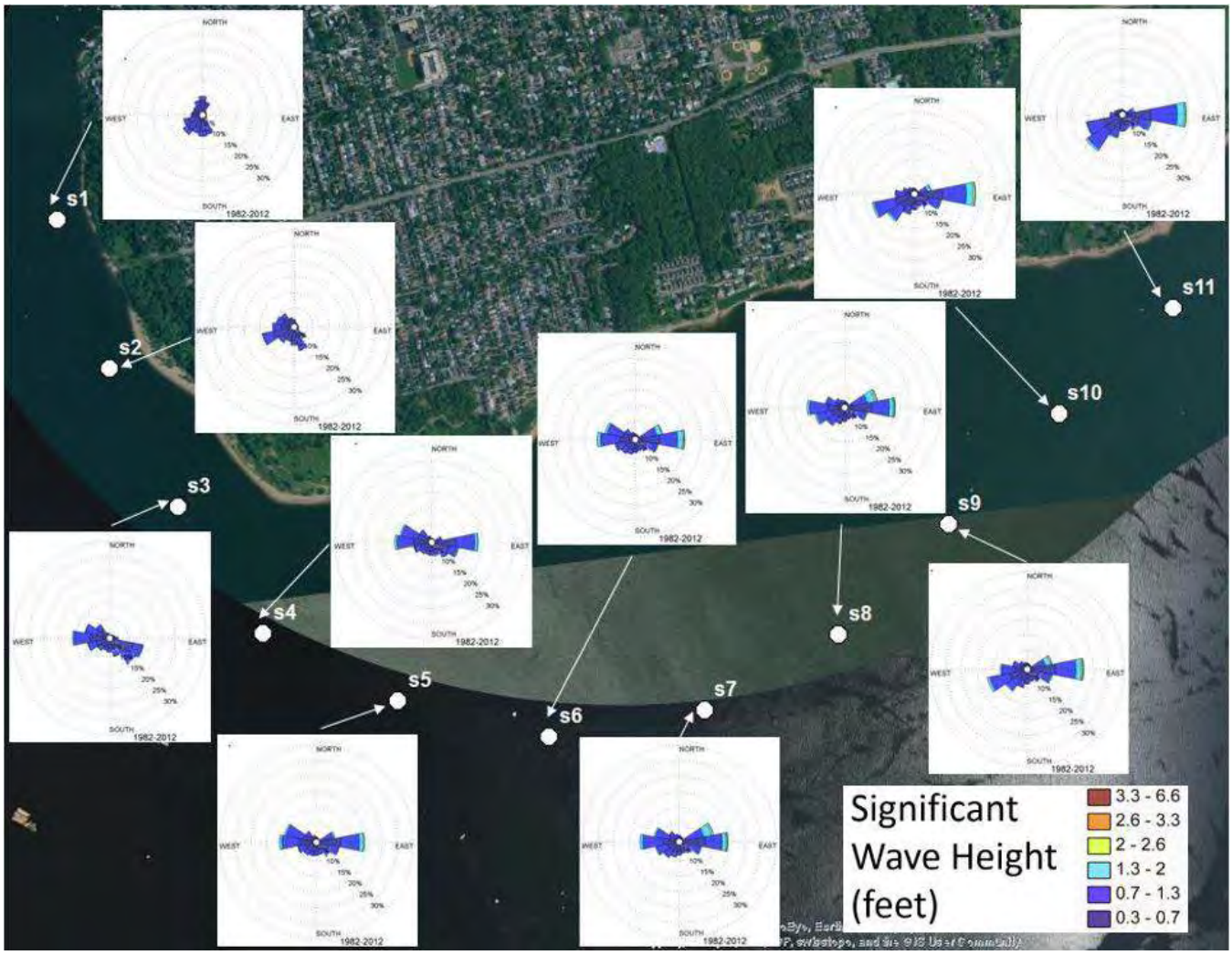

Figure 11. Wave roses of the 30-year hourly wave transformation results at secondary locations s1 through s11. Significant wave heights in meters.

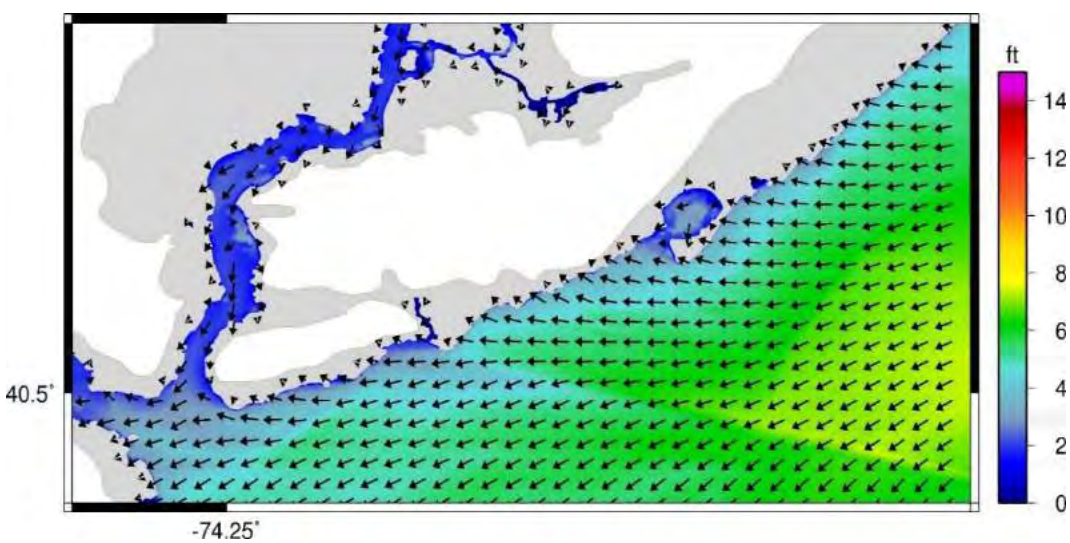

Figure 12. Wave directions during the FEMA PFIRM October 2005 event.

Waves arrive at the project site predominately from two general directions: ocean generated swells enter Raritan Bay past Sandy Hook from the East-Southeast (90- 120 degrees from North) and locally generated wind waves travel across the bay to the project area from the Southwest (195-240 degrees from the North). Over 70% of the waves observed over the past 30 years come from these two directional bands. The highest waves are driven on shore by storm events, which may come from any direction. However, analysis of wave conditions at the project site from the transformed wave hindcast data show that over the 30 year period, the largest significant waves come from the east and southeast. For the thirty years of modeled wave data 100% of the hourly significant waves over three feet in height came from the easterly to southeasterly direction and 56% of waves over 1.5 feet came from this direction.

RETURN PERIOD WAVE CONDITIONS

Location p6, shown on Figure 9, was selected as a primary location, central to the breakwater layout, for analysis and comparison of wave statistics. Return period wave conditions help to inform design conditions at the breakwaters site and to compare model outputs to studies performed by others in Raritan Bay. To estimate representative return wave periods, the transformed 30-year hourly wave data were used.

Annual maximum wave heights from each year of the simulation period (1982 to 2012) were used to estimate return period wave conditions. The Weibull, Gumbel, and Generalized Extreme Value (GEV) distributions were fit to the transformed annual maximum wave data. Comparing the best-fit from each of the three distributions, it was determined that the Gumbel distribution provided the best return period wave statistics for the transformed 30-year hourly wave data.

The wave heights for various return periods determined using the Gumbel distribution are summarized in Table 1. The wave heights shown in Table 1 were compared to the FEMA PFIRM values (FEMA, 2015). To develop the FEMA PFIRM significant wave height return periods, peak storm tide and the coincident significant wave height (at peak storm tide) were extracted from the 189 storm events that formed the FEMA PFIRM coastal analysis (30 historical extratropical storms and 159 synthetic tropical storms). FEMA PFIRM wave data were extracted at a location very close to the SWAN extraction location p6 in a water depth of -7.5 feet mean sea level.

A correlation between return period storm tide and return period significant wave height was developed from the FEMA PFIRM data as shown on Figure 13. An example determination of the 100-year wave height using the correlation to the published 100-year storm tide is also shown on Figure 13. This procedure of determining return period wave heights from the published FEMA PFIRM return period storm tides was also employed by the USACE for the Raritan Bay and Sandy Hook Bay, New Jersey, coastal storm risk management study (USACE, 2015a).

The FEMA PFIRM return period significant wave height closely matches the Gumbel distribution of the 30-year transformed wave data for all return periods, as shown in Table 1. The FEMA PFIRM return periods are approximately 3% to 10% less than the return periods of the Gumbel distribution over the range of return periods that are compared.

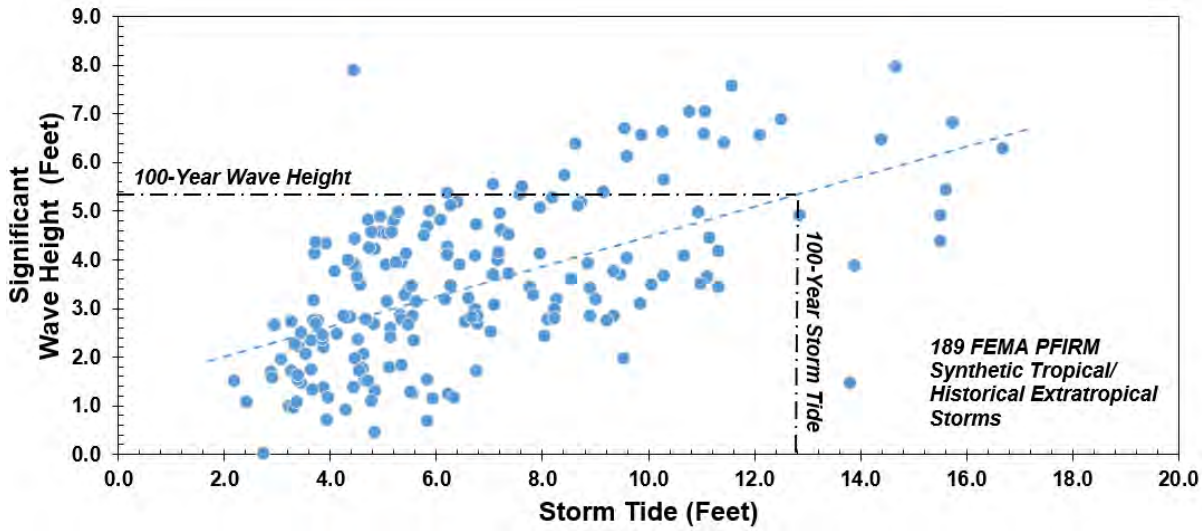

Figure 13. Significant wave height versus storm tide for each of the 189 synthetic tropical and historical extratropical storms of the FEMA PFIRM coastal analysis. Estimate of 100-year wave height at the published 100-year storm tide is shown (FEMA, 2015).

An additional comparison was made between wave condition return periods estimated from the 30-year transformed wave data at the location of the Rutgers ADCP site to return period wave conditions reported by the USACE (CERC, 2001). The Rutgers ADCP location correlates with validation of the SWAN model outputs and is in deep water similar to the USACE location (USACE reports the return period at -17 feet mean sea level west of Great Kills Harbor).

Table 2 shows the significant wave height return period correlation between the Gumbel distribution fit to the 30-year transformed wave data and the USACE study. The USACE study predicts higher return period significant wave heights for return periods less than the 25-year. However, the Gumbel distribution best-fit return periods are within 1% of the USACE study for the 50-, 100-, and 500-year return periods.

Table 1. Return period significant wave height for the Gumbel distribution best-fit to the 30-year transformed wave results at location p6. FEMA PFIRM return period significant wave heights for comparison (FEMA, 2015).

Significant Wave Height (Feet)		
Return Period	**Gumbel**	**FEMA PFIRM**
2 Year	**2.8**	**--**
5 Year	**3.6**	**--**
10 Year	**4.0**	**3.9**
25 Year	**4.7**	**4.3**
50 Year	**5.1**	**4.9**
100 Year	**5.6**	**5.3**
500 Year	**6.6**	**6.4**

Wave data near location p6 in a water depth of approximately -7.5 feet mean sea level.

Table 2. Return period significant wave height for the Gumbel distribution best-fit to the 30-year transformed wave results at the Rutgers ADCP location. USACE return period significant wave height for comparison (CERC, 2001).

Significant Wave Height (Feet)		
Return Period	**Gumbel**	**USACE 2001**
2 Year	**5.2**	**5.8**
5 Year	**6.0**	**6.5**
10 Year	**6.6**	**7.1**
25 Year	**7.4**	**7.5**
50 Year	**7.9**	**7.9**
100 Year	**8.5**	**8.4**
500 Year	**9.7**	**9.7**

SWAN data at Rutgers ADCP station. USACE at -17 feet mean sea level, west of Great Kills Harbor.

CONCLUSIONS

The SWAN wave transformation model was used to develop wave climate data in the vicinity of the Living Breakwaters project site. Thirty years of offshore wave, wind, and water level data were modeled and transformed to the project site. Results from the modeling effort compared favorably to the Rutgers ADCP measurements. The model results were also used to calculate return period wave conditions for the project site. These local wave climate data were then used to support subsequent modeling efforts and to help design layout geometry of the Living Breakwaters.

SHORELINE CHANGE ANALYSIS

A historical shoreline change analysis was performed based on orthoimagery available between 1978 and 2012, covering the range of the wave hindcast (1982 to 2012). The high water position for each orthoimage was delineated, allowing the long-term rate of change to be inferred. From the analysis, the locations where the largest shoreline change have occurred are presented. Related to the areas of largest shoreline change, the influence of existing shoreline structures is also discussed. The section concludes with the presentation of the effects of Hurricane Sandy on the shoreline.

ORTHOIMAGERY-BASED HISTORICAL SHORELINES

The historical shoreline position was determined using orthoimagery provided by the New York City Department of Information and Technology (NYCDOITT). Orthoimagery was available for the time periods shown in Table 3 covering the range of the wave hindcast (1982 to 2012). It can be seen that in some cases the exact date of imagery collection was unavailable or the orthoimagery was collected over multiple days.

Table 3. Orthoimagery collection dates.

Orthoimagery Date
11/03/12
3/30/2012 - 4/6/2012
4/1/2010 - 4/10/2010
3/10/2008 - 5/14/2008
04/2006
04/20/2004
04/14/2001
04/1996
1978

Shoreline position is developed from the orthoimagery by tracing the color change in the sand that results from the most recent high tide. Figure 14 provides an example of the high water shoreline. For each of the available orthoimages, the high water position was used to consistently define the shoreline position. The advantage to using the high water line is that orthoimagery will always be collected at or below the most recent high tide; therefore, the high water line can always be delineated (USGS, 2010).

Figure 14. Example determination of the recent high water shoreline position.

Figure 15 and Figure 16 present the high water shorelines in 1978 and March 30 to April 6, 2012. The rate of shoreline change over time was estimated between these two shorelines at a transect spacing of approximately 500 feet, with adjustments to capture rates at key areas and to avoid overlap with existing shoreline structures. Comparing rates of change over the largest temporal range in the available orthoimagery reduces uncertainty in the estimated rates of shoreline change, as will be discussed further in the Uncertainty Estimates section.

The rates of shoreline change exceed 1 foot per year mostly adjacent to Conference House Park, with the greatest shoreline erosion rate at 3.5 feet per year (±0.4 feet per year). This rate of erosion is consistent with the long-term erosion rates in the same part of the shoreline reported by Nordstrom et al. (1990) at 4.5 feet per year between 1911 and 1987.

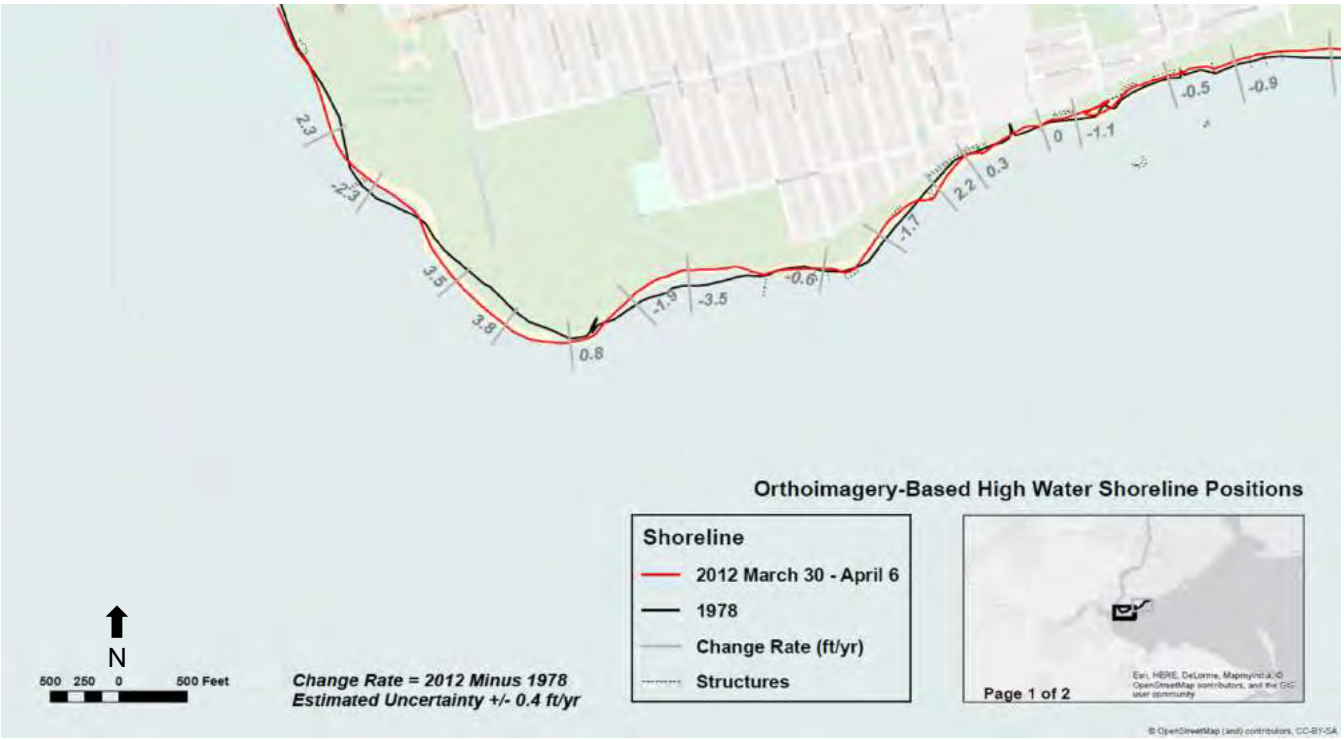

Figure 15. Shoreline change with rates in feet per year at the transects shown. Rates calculated as 2012 position minus 1978 position; negative rates indicate erosion and positive rates indicate accretion. (Image 1 of 2)

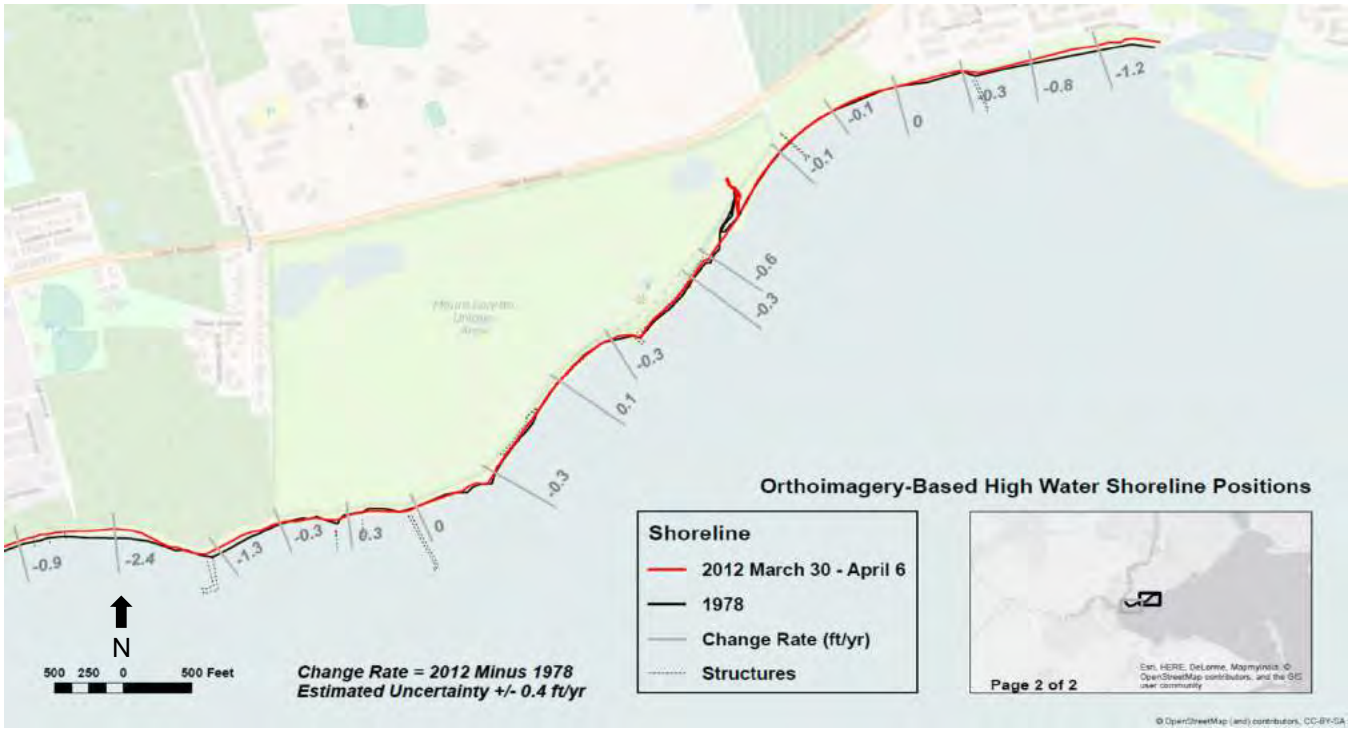

Figure 16. Shoreline change with rates in feet per year at the transects shown. Rates calculated as 2012 position minus 1978 position; negative rates indicate erosion and positive rates indicate accretion. (Image 2 of 2)

Most of the shoreline change rates moving to the northeast from Conference House Park along the shoreline are less than 1 foot per year, which is consistent with the results obtained by the USACE (2015b) and NYSDEC (1988). An exception is shown between Page Avenue and Richard Avenue where the long-term erosion rate is estimated at 2.4 feet per year (±0.4 feet per year). This area is downdrift of an L-shaped timber pile groin structure, which may have been a historic pier.

Areas of the most pronounced shoreline change are downdrift of existing groin structures, as shown on Figure 15 and Figure 16. Review of the orthoimagery indicates that many of the in-water shoreline structures were present from 1978 to 2012. A request for shoreline permits from the USACE and New York State Department of Environmental Conservation (NYSDEC) did not produce any permit records, likely indicating that many of the structures were installed before modern tidal wetland permitting requirements initiated in 1974.

Isolating the cause of the historical shoreline change rates from orthoimagery alone is constrained by an incomplete understanding of the physical mechanisms that influence the shoreline change. Temporally and spatially varying waves, water levels, and currents contribute to the observed shoreline change rates.

However, mean sea level rise is well-documented during the 1978 to 2012 period at NOAA's tide gage at Sandy Hook. Using the long-term mean sea level change rate at Sandy Hook along with the average beach slope reveals a long-term erosion of approximately 0.1 feet per year. This value is within the uncertainty of the analysis of 0.4 feet per year, indicating that either mean sea level rise is a small contributor to the overall shoreline change process or that an increase in mean sea level results is amplifying other processes that influence shoreline change such as waves, currents, and storm surge.

UNCERTAINTY ESTIMATES

Uncertainty in the position of the shoreline based on visual inspection of the high water line must be considered when interpreting shoreline change. Three relevant factors considered in the uncertainty estimates were:

- Consistent Georeferencing
- High Water Variation
- Wave Run-up Variation

The georeferencing uncertainty was estimated by comparing consistent shoreline structures between orthoimages. For example, a stormwater outfall headwall edge was observed in the 1978 image and compared to its location in the 2012 orthoimagery. The resulting uncertainty between images was estimated at ±1 foot. It should be noted that all images were previously georeferenced by NYCDOITT.

Due to the semidiurnal nature of astronomic tides in the New York City region and sensitivity to water level increases due to storm surge, high water variation was found to play a significant role in the uncertainty in high water shoreline position between orthoimages. Table 4 shows the most recent high water levels for the orthoimages that had reported dates.

Table 4. Orthoimagery date and recent high water elevation in feet NAVD88 (measured at NOAA's Sandy Hook station #8531680).

Orthoimagery Date	Recent High Water (feet NAVD88)
11/03/12	1.1
03/30/12	2.3
04/06/12	3.2
04/01/10	3.1
04/10/10	1.3
03/10/08	1.7
05/14/08	2.5
04/20/04	1.2
04/14/01	2.0

NAVD88 North American Vertical Datum of 1988.

For orthoimages that had a range of collection dates, the first and last days of those collections are shown in Table 4. For the nine dates listed in the table, the range of recent high water levels is approximately 2.1 feet. This is based on observed water levels at NOAA's Sandy Hook station #8531680. Because these are observed water levels, storm surge effects are included.

The plan view uncertainty that results from a vertical variation in the water level was estimated including the effects of shoreline slope. The average horizontal distance between 1.1 feet NAVD88 and 3.2 feet NAVD88 was estimated at 30 transects on the 2010 Light Detection and Ranging (LiDAR; NYCDOITT, 2012) and 2014 LiDAR (USGS, 2014) data. The average of these 60 estimates resulted in an uncertainty estimate of ±8 feet (in the plan view direction) due to vertical high water variation of 2.1 feet.

The wave conditions will vary depending on the day of collection of the orthoimagery, with the expectation that aerial flight dates will be made when weather conditions are not a safety risk (i.e. not storm conditions). Therefore, the wave transformation wave roses presented in the Nearshore Wave Results section were reviewed and a 0.2-meter (0.7-feet) wave height was used for wave run-up estimates.

The wave run-up was estimated using the method of Stockdon et al. (2006), which determined wave run-up as a function of deepwater significant wave height, beach slope, and deepwater wave length. Beach slope is calculated from the 2010 LiDAR and 2014 LiDAR data in the area between 1.1 and 3.2 feet NAVD88. Deepwater wave length was calculated for the SWAN peak wave period that correlated with the significant wave height. The wave parameters and wave run-up are summarized in Table 5.

Table 5. Summary of parameters used in estimating wave run-up using the relations of Stockdon et al. (2006).

Deepwater Significant Wave Height (feet)	Deepwater Wave Length (feet)	Beach Slope	Wave Run-up (feet)
0.7	35	0.125	0.5

The uncertainty due to georeferencing, high water variation, and wave run-up variation is then combined for a total horizontal uncertainty of ±9.5 feet, as summarized in Table 6. 86% of the uncertainty is due to variation in high water position. The shoreline position uncertainty rate between 1978 and 2012 is then estimated at ±0.4 feet per year ($\sqrt{9.5^2 + 9.5^2}/_{34\text{ years}}$) considering the propagation of uncertainty when rates are calculated between images. These uncertainty estimates are lower, but of the same order of magnitude, than those reported at the regional scale (USGS, 2010). Using the 0.125 beach slope estimate shown in Table 6, the plan distance uncertainty of ±0.4 feet per year correlates to ±0.05 vertical feet per year.

Table 6. Summary of horizontal uncertainty in orthoimagery-based high water shoreline positions.

Georeferencing	High Water Position	Wave Run-up	Total
±1 foot	±8 feet	±0.5 foot	±9.5 feet

HURRICANE SANDY SHORELINE RESPONSE

The effects of Hurricane Sandy on the shoreline were evaluated by comparing the March 30 to April 6, 2012, orthoimagery to the orthoimagery collected by NOAA on November 6, one week after Hurricane Sandy. The LiDAR data collected by the USGS on November 16 was also evaluated by delineating the high water line between mean high water, 2.4 feet NAVD88, and mean higher high water, 2.7 feet NAVD88 (NOAA Vertical Datum Transformation Tool, Version 3.4). A sample LiDAR-based high water shoreline position is shown on Figure 17.

The effect of Hurricane Sandy on the high water shoreline position, shown on Figure 19 and Figure 20, is small when compared to the long-term shoreline change rates presented in the Orthoimagery-Based Historical Shorelines section. The USACE reported that Hurricane Sandy transported material from the dunes and bluffs to the mean sea level position, but also reported changes in evaluation of the mean sea level position due to reflections in the LiDAR data. Additionally, the USACE compared the post-Sandy LiDAR data to the 2010 LiDAR data, which is a longer duration compared to the current analysis (USACE, 2015b).

Review of the November 6, 2012, orthoimagery does reveal that Hurricane Sandy created a significant amount of dune overwash in the Tottenville area. Overwash fans are observed from the dune into adjacent parks and into the neighborhoods as shown on Figure 18 near Page Avenue. It is unclear what portion of dune and bluff erosion was transported offshore in the cross-shore direction.

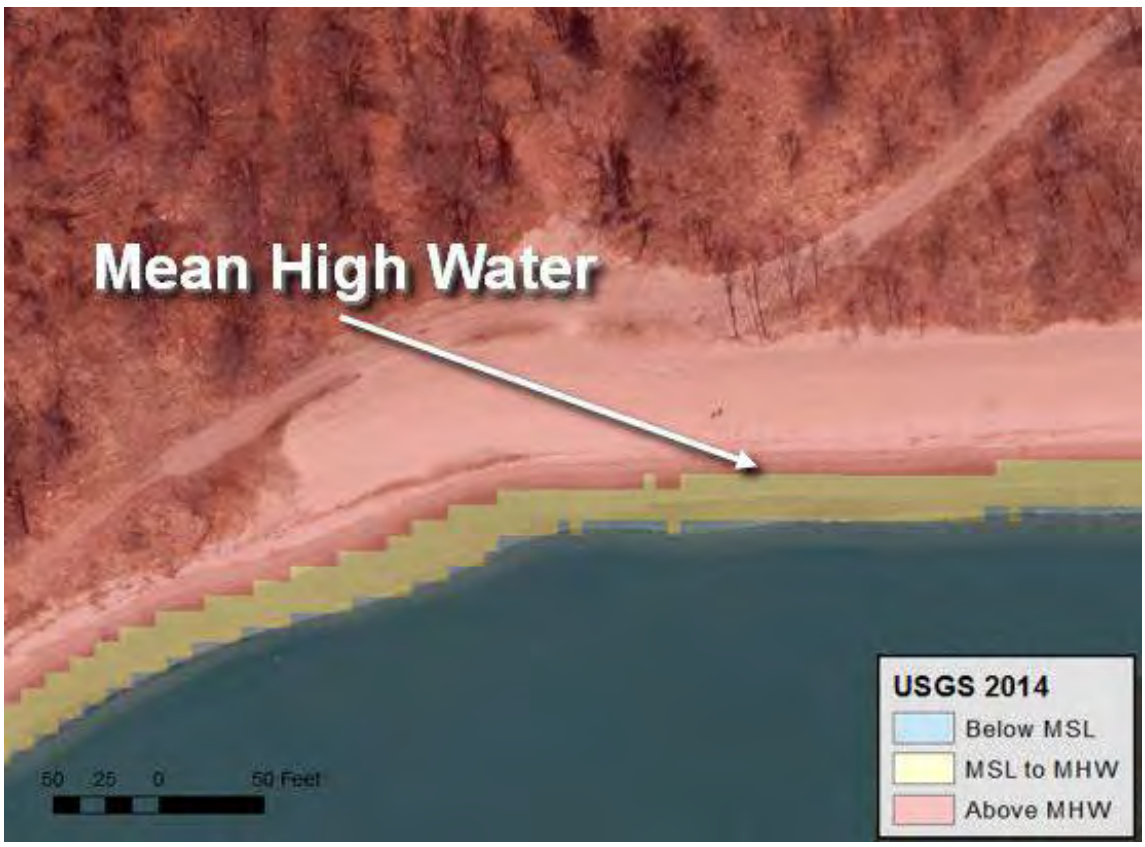

Figure 17. Shoreline position based on LiDAR position of the mean high water line.

Figure 18. Pre- and Post-Sandy aerial imagery demonstrating sand overwash near Page Avenue.

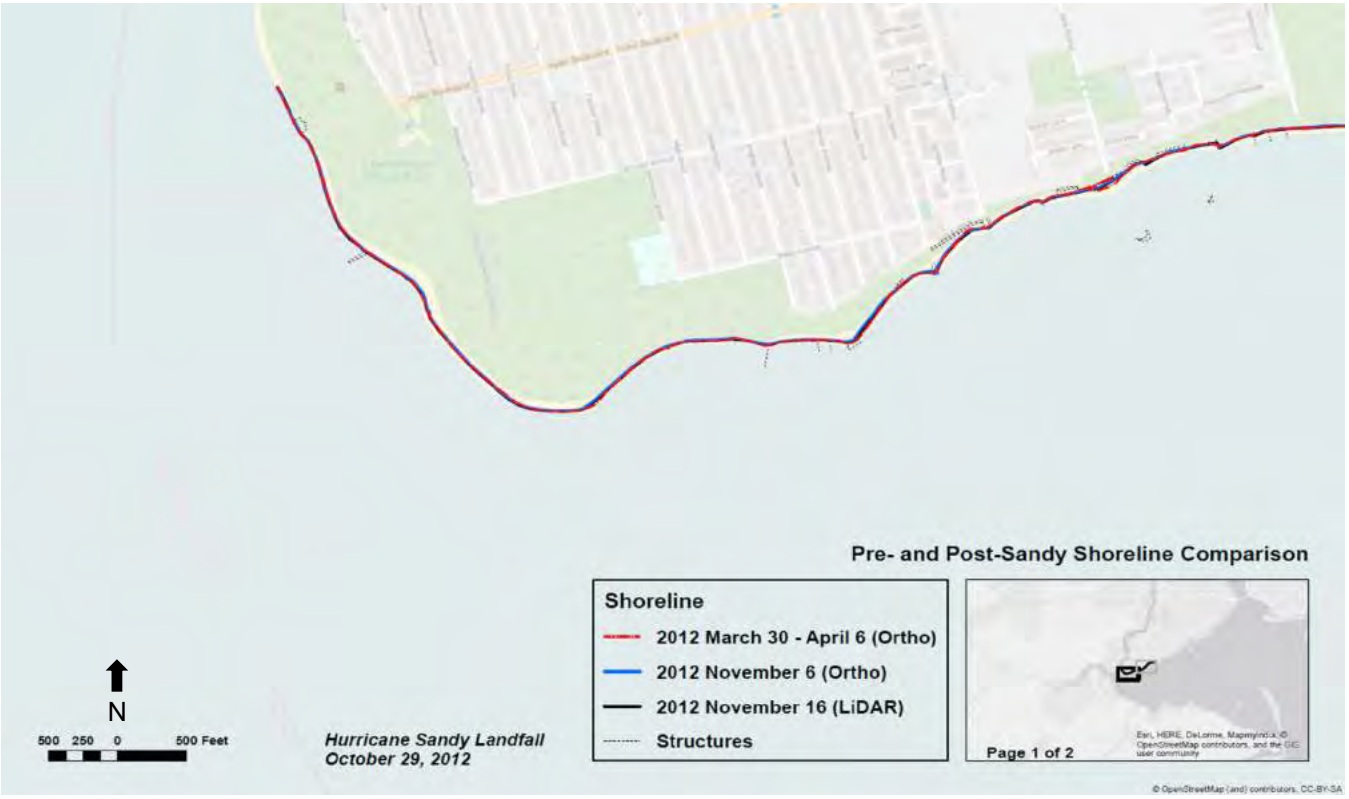

Figure 19. Pre- and Post-Sandy shoreline position comparisons. (Image 1 of 2)

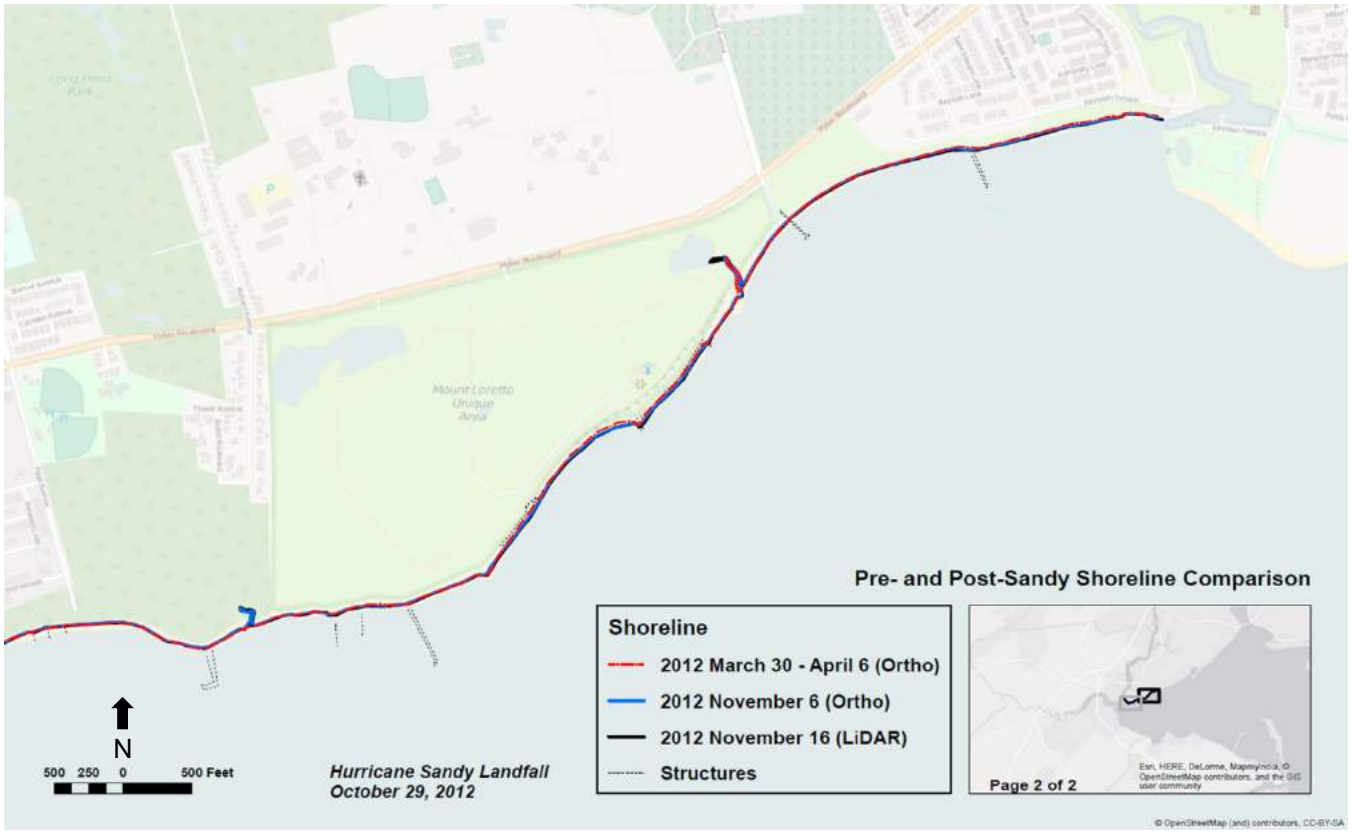

Figure 20. Pre- and Post-Sandy shoreline position comparisons. (Image 2 of 2)

SHORELINE CHANGE MODELING

Using the long-term nearshore wave climate conditions developed in the Wave Transformation Modeling section and the orthoimagery-based historical shoreline change described in the Shoreline Change Analysis section, a shoreline change model, using GENESIS, was developed. GENESIS is a commonly used and widely accepted shoreline change model, known as one-line model. The underlining assumption is that the cross-shore beach profile does not change with time, so that the active profile only moves parallel to itself, assuming the cross-shore profile is in long-term equilibrium. It simulates long term planform evolution of the shoreline in response changes in longshore sediment transport from incoming waves and coastal structures.

This section describes the model setup and calibration of results to the observed historical shoreline changes between 1978 and 1996. The calibrated model was validated to reproduce the shoreline changes between 1996 and 2012. The long-term (20 years) shoreline changes for the without-project, or baseline conditions, and 30% design breakwaters are then presented. The GENESIS modeling was performed over a 20 year period, which allows comparison of the various scenarios in development of the 30% design. The 20 year simulation period allows assessment of long term trends in shoreline change. While the proposed functional life of the project is 50 years, realistic prediction of 50 year shoreline position is beyond the reasonable expectation of the model. The GENESIS model is limited as to the length of wave record that can be simulated. For 30% design, use of a widely expected and relatively quick running model also allowed assessment and comparison of numerous alternatives over a 20 year simulation period.

GENESIS MODEL OVERVIEW

The GENEralized model for SImulating Shoreline change (GENESIS) model was developed by the USACE Engineering Research and Development Center as a tool to determine long-term evolution of the shoreline, including the effects of shoreline structures (Hanson, 1989). Model inputs include:

- Wave Conditions
- Sediment Characteristics
- Coastal Structure Layout and Geometry

With these inputs, long-term simulations of shoreline change are performed. The following sections discuss the selection of model inputs, the calibration and validation of simulated shoreline change to the observed shoreline change, and the estimated shoreline change under future without project (baseline) and future with-project conditions.

BASELINE MODEL INPUTS

WAVE DATA

Long-term wave condition data used in the GENESIS model were assigned from the SWAN model outputs described in the Wave Transformation Modeling section. Specifically, the wave conditions at location p8, shown on Figure 9, approximately 1,000 feet offshore of Bedell Avenue, were used as wave condition forcing in the model. The long-term wave rose at location p8 is shown on Figure 21. Wave conditions at location p8 were selected due to improved calibration and validation of GENESIS results.

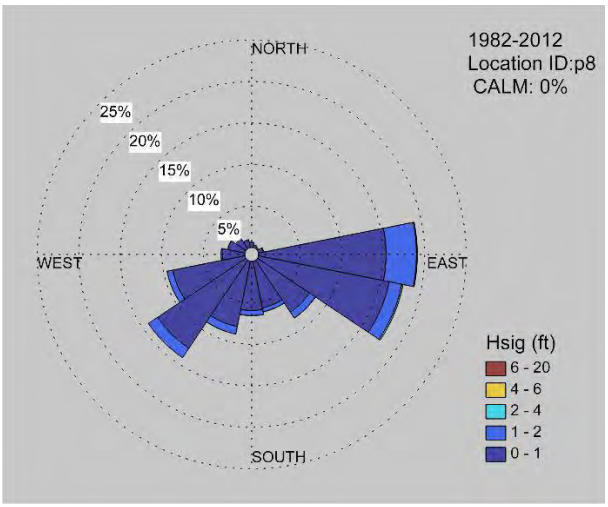

Figure 21. Long-term wave rose at SWAN model extraction location p8, which is approximately 1,000 feet offshore from Bedell Avenue.

WATER LEVELS AND SEDIMENT GRAIN SIZE

Water levels assigned to the model were based on the measured hourly water levels at the nearby NOAA Sandy Hook station #8531680. Sediment characteristics assigned in the model were obtained from initial grab samples taken close to the shoreline. The average D_{50} from the grab samples was measured at 0.35 millimeters (0.01 inch). This was the D_{50} used in the GENESIS model simulations. Note that this grain size is different from the average grain size determined once all the 30% design field data were collected which yielded an average D_{50} of 0.61 millimeters. This difference in D_{50} should not have a significant impact on the GENESIS results but is more critical to the beach profile change analysis. Further discussion of sediment grain sizes can be found in that section. The grain size was kept constant throughout all the GENESIS model runs to allow for direct comparison of the various scenarios. Additionally, sensitivity test simulations were preformed using both average D_{50} and showed almost no change to the resulting shoreline change. The GENESIS model is not highly sensitive to changes in grain size at 0.4 millimeters and greater.

BEACH PROFILE TRANSECTS

The cross-shore slope of the beach profile was assigned in the model based on the transect surveys performed by MFS (2015). These 23 cross-shore beach transects are shown on Figure 22. From these transects, a beach berm height of 1.0 meters (3.3 feet) was assigned along with a depth of closure of -6.0 meters (-19.7 feet).

The berm height elevation and the depth of closure were used to assign a cross-shore geometry to the model. The depth of closure is the offshore limit at which wave energy begins to have a negligible effect on nearshore shoreline change. At the Living Breakwaters site, the depth of closure generally correlates with the navigation channel.

SHORELINE STRUCTURES

Shoreline structures have a strong influence on the shoreline, as was presented in the Shoreline Change Analysis section. Therefore, all in-water structures were assigned as much detail as was available. For the majority of the structures, the site survey of structures performed by MFS (2015) provided sufficient detail of structure types, extents, and relevant elevations. For information not collected during the site survey, structure information was assigned through review of site photographs (MFS, 2015) and aerial imagery.

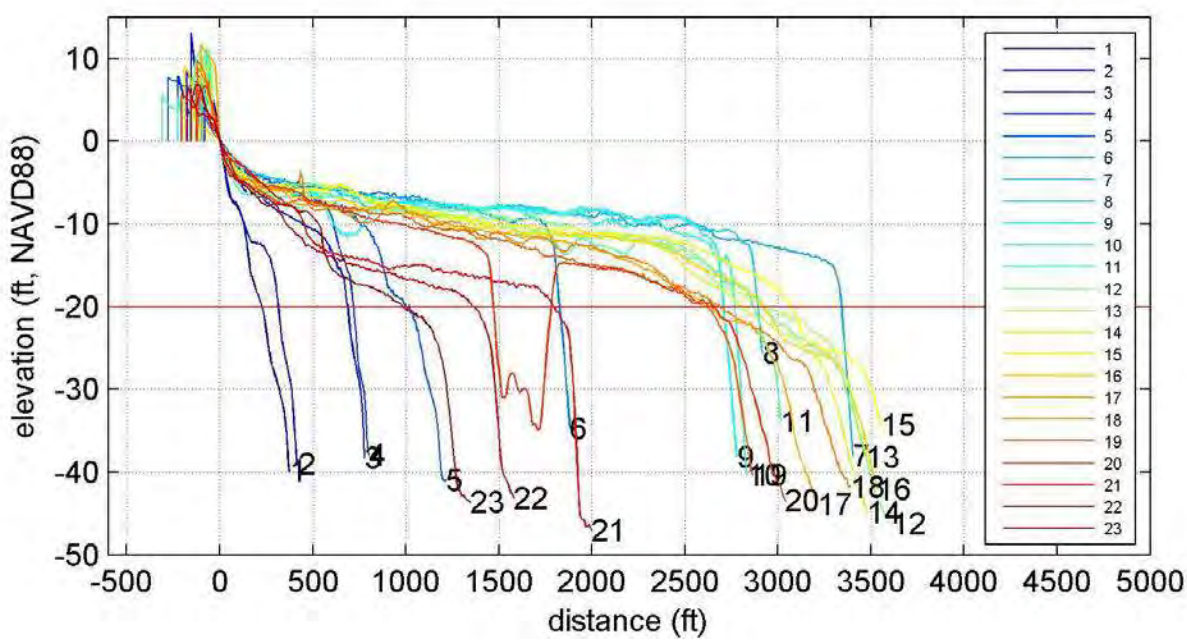

Figure 22. Cross-shore beach transects along the project length (MFS, 2015). Estimated closure depth of -6 meters shown by the horizontal red line.

BATHYMETRIC GRID

A computational grid was developed to extend offshore to the depth of closure and inland beyond the expected highest water elevations. The 10-meter (32.8-foot) rectangular grid extents are shown on Figure 23. The model grid extends from Conference House Park in the south to Butler Manor Woods in the north. Bathymetry was assigned to each grid cell using the multi-beam survey and the beach transect surveys performed in the Fall of 2015 (Hill International, 2015; MFS, 2015) and supplemented with data from the FEMA PFIRM coastal study (FEMA, 2014a).

Figure 23. Computational grid of the GENESIS model.

MODEL CALIBRATION AND VALIDATION

The historical shorelines described in the Shoreline Change Analysis section were used to calibrate and validate the performance of the GENESIS model. Calibration was performed for the shorelines between 1978 and April 1996, as shown on Figure 24. Results from each model run were compared with observed shoreline changes, with iterative adjustments to improve the model performance.

To achieve the results shown on Figure 24, the iterative calibration process resulted in the parameters shown in Table 7. The parameter K1 adjusts the rate of longshore transport influenced by obliquely incident waves and the K2 parameter adjusts the rate of longshore transport influenced by variations in wave breaking conditions along the shoreline (Hanson, 1989). The PERM parameter allows for sediment bypassing at structures perpendicular to the shoreline. A value of 0.6 assigned in the model accounts for permeability in the structure and the position of the structure relative to the water level. The PERM calibration parameter is not as sensitive as K1 and K2 in the model and was tested for sensitivity during calibration.

Using the calibrated model parameters, a validation simulation was performed between April 1996 and March 30 to April 6, 2012. The validation results, compared to observed orthoimagery-based shoreline change, are shown on Figure 25. The calibration and validation results demonstrate that the model is reproducing observed shoreline change behavior. Areas of the most significant shoreline change adjacent to Conference House Park, as discussed in the Shoreline Change Analysis section, are being reproduced by the model. Another area of significant historical shoreline change, northeast of Page Avenue, is also being reproduced by the model.

Table 7. Summary of GENESIS parameter values.

Parameter Name	Value
K1	0.55
K2	0.35
PERM	0.6

BASELINE SIMULATIONS

Using the calibrated and validated model parameters described above, a baseline 20-year simulation without-project was performed. For this simulation, the 1992 to 2012 water levels and wave conditions were used for the simulation. The results of the 20-year baseline simulation are shown on Figure 26.

Even with the assumptions and limitations of a 1-D model, GENESIS still should be able to predict the long term trends of shoreline changes. Figure 26 shows the modeled 20-year future shoreline change without project. The 20-year simulation, from 2015 to 2035, of the shoreline change rate was compared to observed rate in Figure 27. This analysis revealed that the computed shoreline change rates match the trend of observed rate reasonably well.

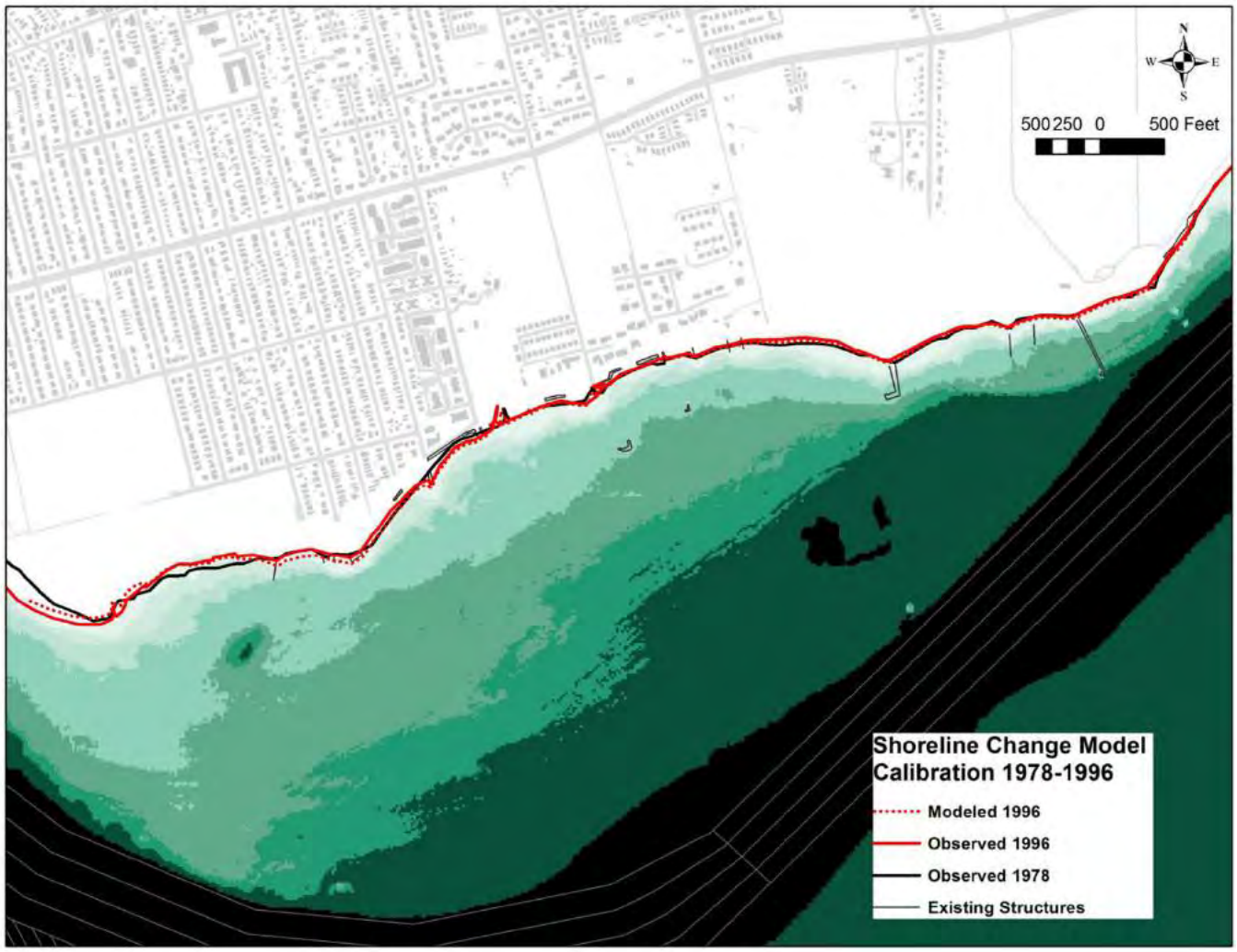

Figure 24. Shoreline change model calibration results comparing the observed shoreline in 1978 and the observed and modeled shoreline in April 1996.

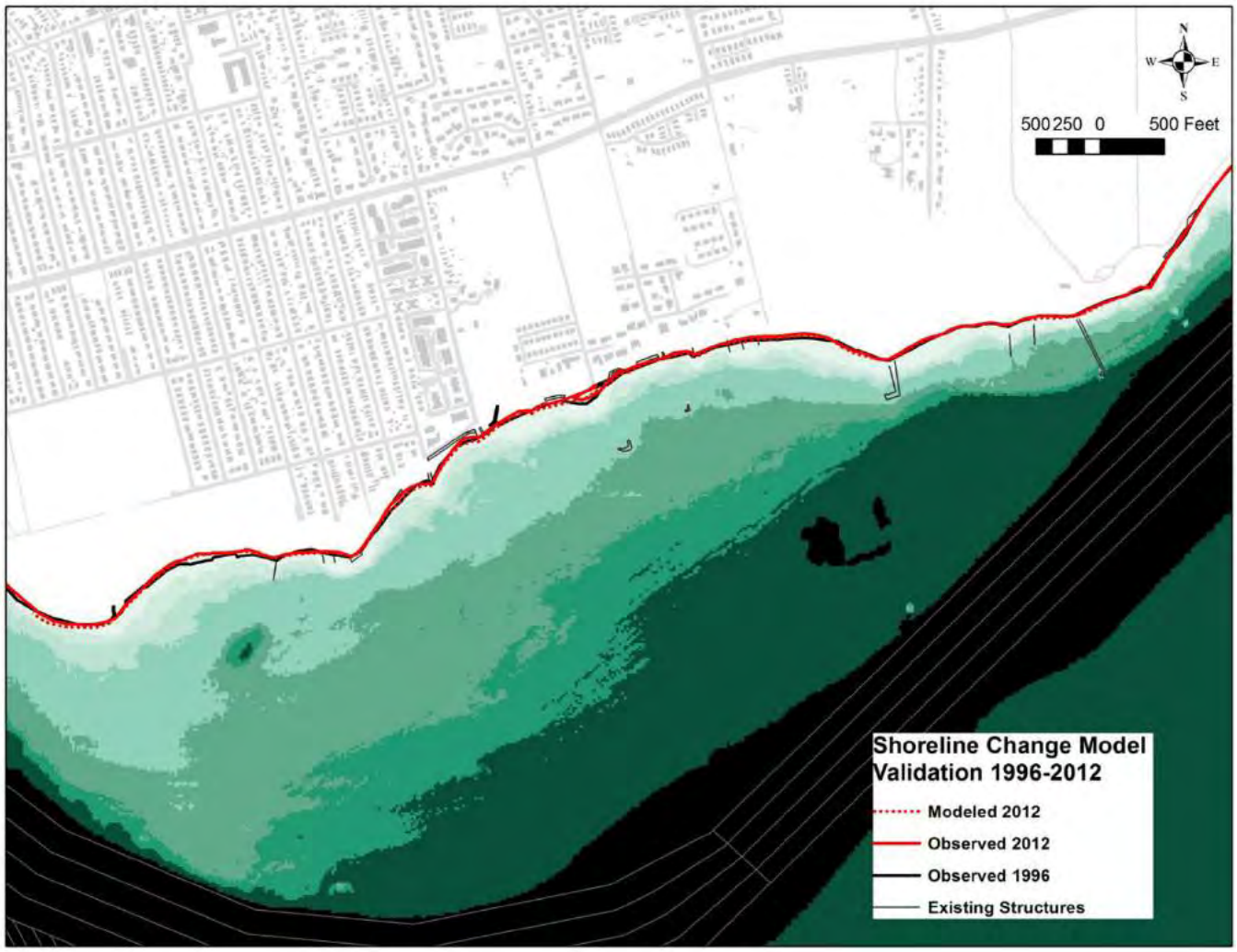

Figure 25. Shoreline change model validation results comparing the observed shoreline in April 1996 and the observed and modeled shoreline of March 30 to April 6, 2012.

Figure 26. Shoreline change under 20-year future without-project conditions. The initial shoreline of 2014-2015 is compared to the modeled shoreline in 2035.

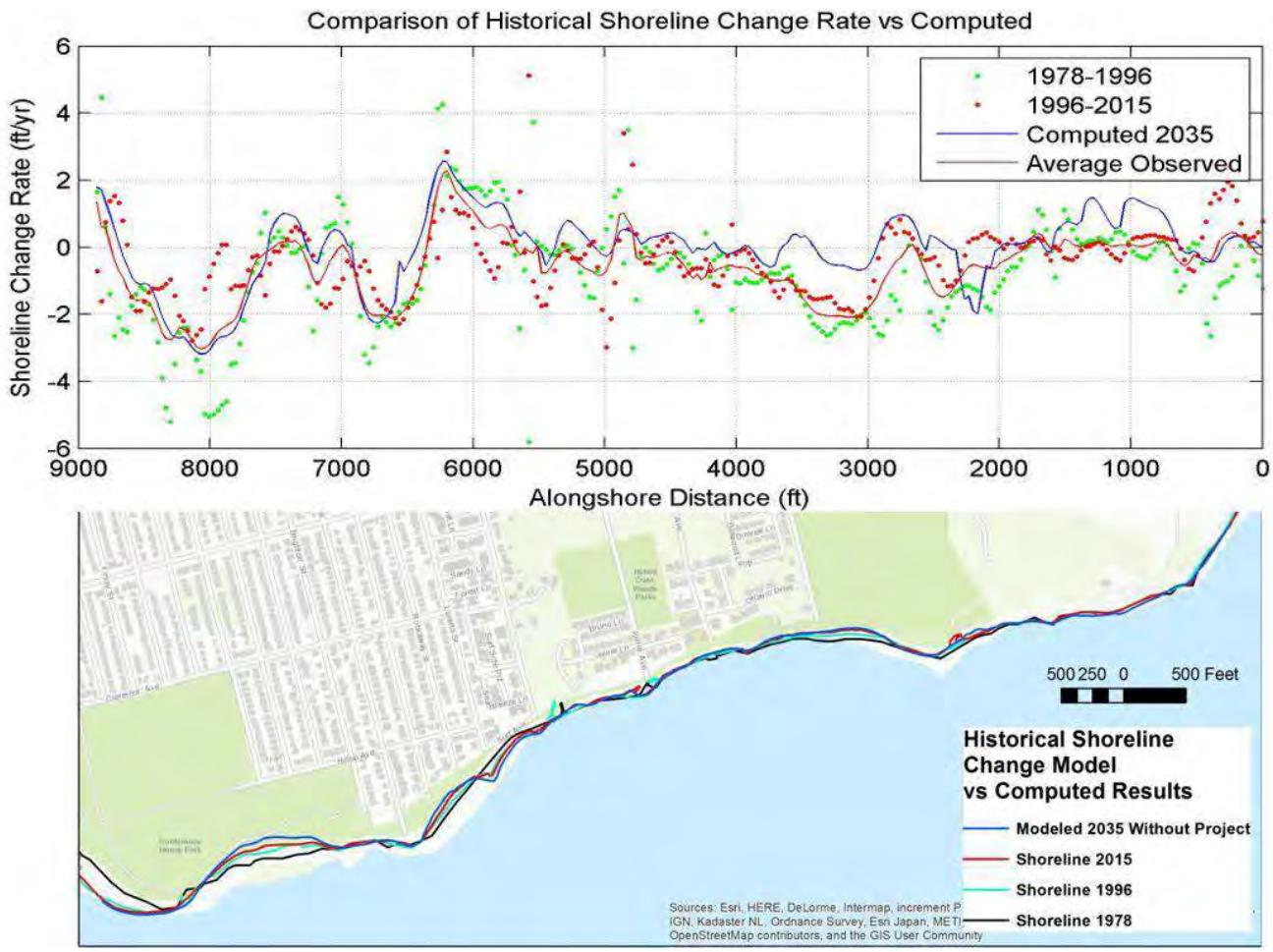

Figure 27. Comparison of computed shoreline change rates relative to observed shoreline change rates.

Figure 27 presents a comparison of the computed future shoreline change rates to the observed historic rates. This comparison revealed that in the southwestern portions of the site (south of Sprague Ave.) both the overall pattern and rates of shoreline erosion and accretion are likely to continue into the future, including the erosion rates of 1 to 2 feet per year between Loretto Street and Manhattan Street and between 2.0 and 3.5 feet per year in Conference House Park between Main Street and Wards Point. North of Sprague Avenue, the general pattern of erosion and accretion appear to remain the same, though rates of change simulated are slightly lower in the future than those historically observed. This may be due to adjustments of the shoreline over time as it attempts to reach a dynamic equilibrium.

30% DESIGN SIMULATIONS

In order to estimate the response of the shoreline to the breakwater layout of the 30% design scenario, the 10 breakwaters and targeted shoreline restoration were modeled for 20 years starting from the 2015 shoreline (MHW). The 30% design layout resulted from refinements and understanding of the breakwater system performance during 15 scenarios simulated by the GENESIS model. These scenarios are documented in Appendix A.

Figure 28 shows the shoreline response with the Living Breakwaters 30% design layout and shoreline restoration. The eastern pair of breakwaters are oriented to shelter the nearshore from the dominant wave direction while set far enough offshore to not completely arrest sediment transport. Sediment tends to accumulate along the shore on the eastern half of the project as the sediment transport gradient drops off with the reduction in wave energy due to the breakwaters. The simulated shoreline near Joline Avenue accretes up to 10 to 20 meters (30 to 60 feet). The addition of beach sediment for shoreline restoration builds the beach in an area where infrastructure is vulnerable and the breakwaters maintain the additional sediment in the region. The western-most breakwaters aid in holding the shoreline through areas of historical erosion at Conference House Park.

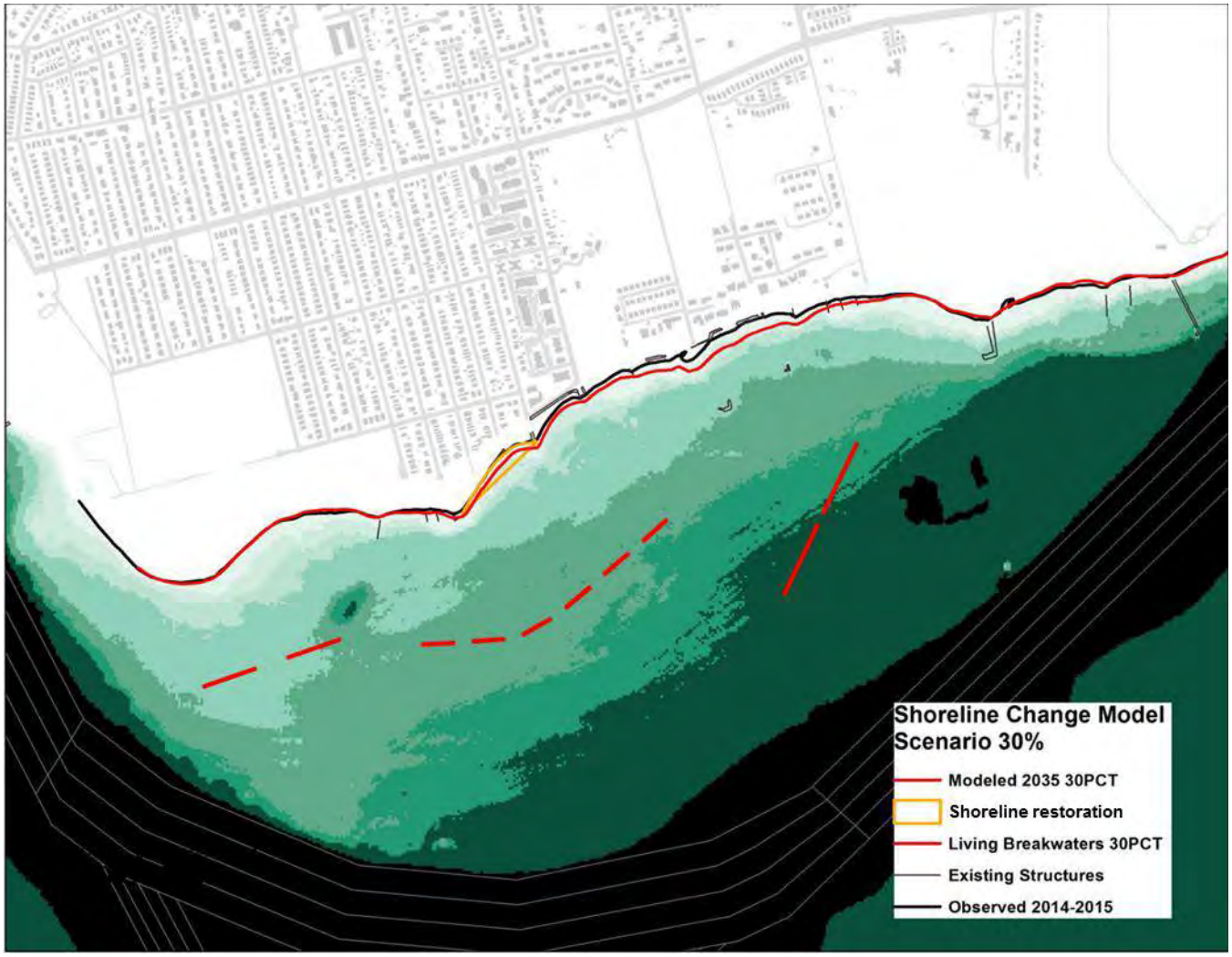

Figure 28. Shoreline changes of 20 years due to the proposed 30% design.

CONCLUSIONS

The GENESIS model was calibrated to shoreline change observed from 1978 to 1996 and validated to shoreline change observed from 1996 to 2012. The calibrated/validated model was then used to estimate future shoreline response, with and without Living Breakwaters. Without Living Breakwaters, the shoreline maintains erosion trends into the future that are similar to the historically observed. With the Living Breakwaters, the shoreline erosion is mitigated with extensive areas of shoreline accretion in the vicinity of the residential areas at most risk to storm damage.

Historical effects of sea level rise are included in the GENESIS model through the calibration parameters, however predicting future sea level rise effects on shoreline change is outside of the ability of the GENESIS model and is an area of active research nationwide. The GENESIS model is a 1-D model that assumes the cross shore profile does not change (it simply shifts landward and seaward but remains in a long term equilibrium shape). As sea level rises one of the impacts will be alternation of the cross shore profile as water levels rise shifting the shore position landward. With sea level rise there will be a complex interaction of the longshore and cross shore processes. The GENESIS model is not capable of representing these changes. When modeling predicted future shoreline change over long periods it should be noted that the model is intended to provide an understanding of overall trends and not predict specific shoreline future locations. The 30% design layout will be refined with more detailed modeling in the next phase.

DESIGN WAVE TRANSFORMATION NEAR BREAKWATERS

The transformation of the wave climate in the nearshore region close to the proposed Living Breakwaters alignments is important for understanding the Living Breakwaters performance relative to wave attenuation and optimizing its layout and geometry. This section describes the setup of the REFDIF model and the results of the wave transformation for baseline conditions (without the Living Breakwaters in place), and the results with the proposed 30% design in place.

REFDIF MODEL OVERVIEW

Close to a breakwater structure, wave refraction and diffraction are dominant processes. REFDIF is a coupled REFraction and DIFfraction wave model developed at the University of Delaware that is suitable for wave modeling near breakwaters. For this analysis, version 2.5 was used (Kirby et al., 1994). The REFDIF includes processes of wave refraction, diffraction, shoaling, and energy dissipation. REFDIF simulates wave propagation over nearshore bathymetry and around the structures allowing for the evaluation of the influence of variables such as water levels, wave directions, etc.

Incident waves are input at the project boundary and propagate through the model domain. REFDIF provides steady state monochromatic wave estimates by solving second-order nonlinear equations with a parabolic form. A limitation of the parabolic form technique is that wave directions cannot deviate at angles greater than ±30 degrees relative to the perpendicular of the boundary. Therefore, multiple computational grids must be developed for a range of approach wave directions. Additionally, REFDIF cannot model wave reflections or steep slopes (greater than 3 horizontal to 1 vertical). Because of the limitation on reflections, wave conditions on the wave approach side of the breakwaters should be interpreted with caution.

The model requires the following inputs:

- Wave height and wave period boundary conditions
- Side boundary conditions
- Computational grid/bathymetry
- Water level

These inputs are discussed further in the following section.

BASELINE MODEL INPUTS

WAVE DATA AND WATER LEVEL

Baseline simulations, without the Living Breakwaters, were performed for the combinations of wave conditions and water levels shown in Table 8. Wave conditions for each scenario were provided by the design team to inform performance under scenarios of interest for design and do not necessarily correlate with the wave return periods presented in the Wave Transformation Modeling section.

Table 8. Water levels and wave conditions for baseline simulations.

Water Elevation Event	Water Elevation (feet NAVD88)	Wave Height (feet)	Wave Period (seconds)
Mean High Water	**2.1**	**3.0**	**3.0**
FEMA PFIRM 1%-Annual-Chance	**12.9**	**5.3**	**5.0**

The wave conditions are applied perpendicular to the offshore boundary of the model. The following wave approach directions were analyzed for both of the events shown in Table 8.

- Southwest (225 degrees from N)
- East (90 degrees from N)
- Perpendicular (to general direction of shoreline, 150 degrees from N)

East and Southwest represent the most common wave directions and the perpendicular direction was also selected to assess the breakwaters wave attenuation capabilities.

BATHYMETRIC GRID

The computational grid was developed to extend well beyond the limits of the proposed Living Breakwaters layout zone. The computational grid was assigned a 5-meter (16.4-foot) spacing with a rectangular gird of 820 nodes by 940 nodes. The following data sources were used to assign bathymetry and topography to the computational grid:

- Bathymetry/NJ Topography - FEMA PFIRM coastal study (FEMA, 2014a)
- Bathymetry – Multibeam bathymetric survey and beach transects surveys in the vicinity of the initial Living Breakwaters alignments (Hill International, 2015; MFS, 2015)
- Topography – NYC 2010 1-foot LiDAR (NYCDOITT, 2012)

Figure 29 summarizes the water depths assigned to the computational grid, in meters NAVD88. The presence of the navigation channels is clear, forming the perimeter of the approximate Living Breakwaters alignment area with an assigned maintenance depth of approximately 10.7 meters (35 feet). Aside from the navigation channels, the majority of Raritan Bay within the computational domain is at a depth less than approximately 8 meters (26.2 feet).

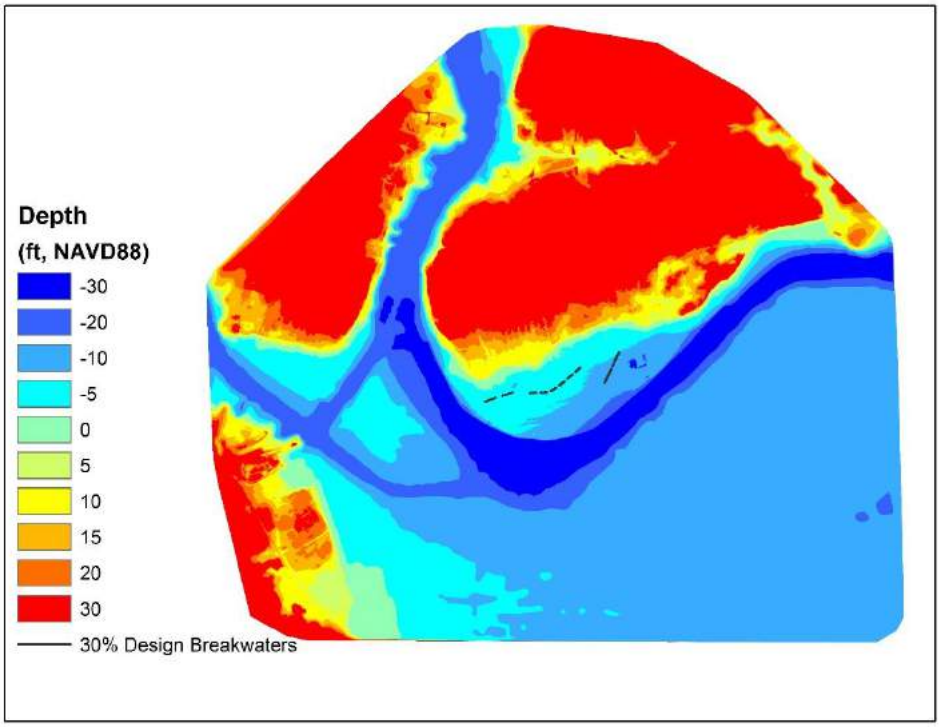

Figure 29. Computational depths in meters NAVD88 used in the REFDIF model.

BASELINE SIMULATIONS

The without-project simulations are illustrated by relative wave height (calculated wave height divided by incoming wave height imposed at the boundary) plots for each of the three wave approach directions on Figure 30 and Figure 31. Figure 30 shows the simulation results for the mean high water event with an imposed wave height of 3 feet and a wave period of 3 seconds. Figure 31 shows the simulation results for FEMA PFIRM 1% annual-chance event with an imposed wave height of 5.3 feet and a wave period of 5 seconds.

Each image shows a noticeable wave breaking line close to the shoreline, indicated by dark blue relative wave heights (close to zero). The breaker line advances landward for the increased water levels associated with the 1%-annual-chance event shown on Figure 31. Diffraction shadows are also clearly observed on the western side of the Staten Island peninsula for east and perpendicular wave directions during both water level events. These simulation results will form the baseline conditions to which with-project simulations are compared for each initial Living Breakwaters layout.

Additional insight into the transformation of waves in the nearshore area is shown on Figure 32. The wave crests and troughs are mapped for the 1%-annual-chance water elevation events. Wave transformation near the navigation channels, diffraction shadow zones on the western side of the tip of Staten Island, shoaling, and dissipation of waves close to the shoreline are clearly observed. SLR effects on the nearshore waves were simulated and the model results show the waves propagate further inland and the breaker line, indicated by dark blue color, were also pushed upland (See Figure 33 and Figure 34).

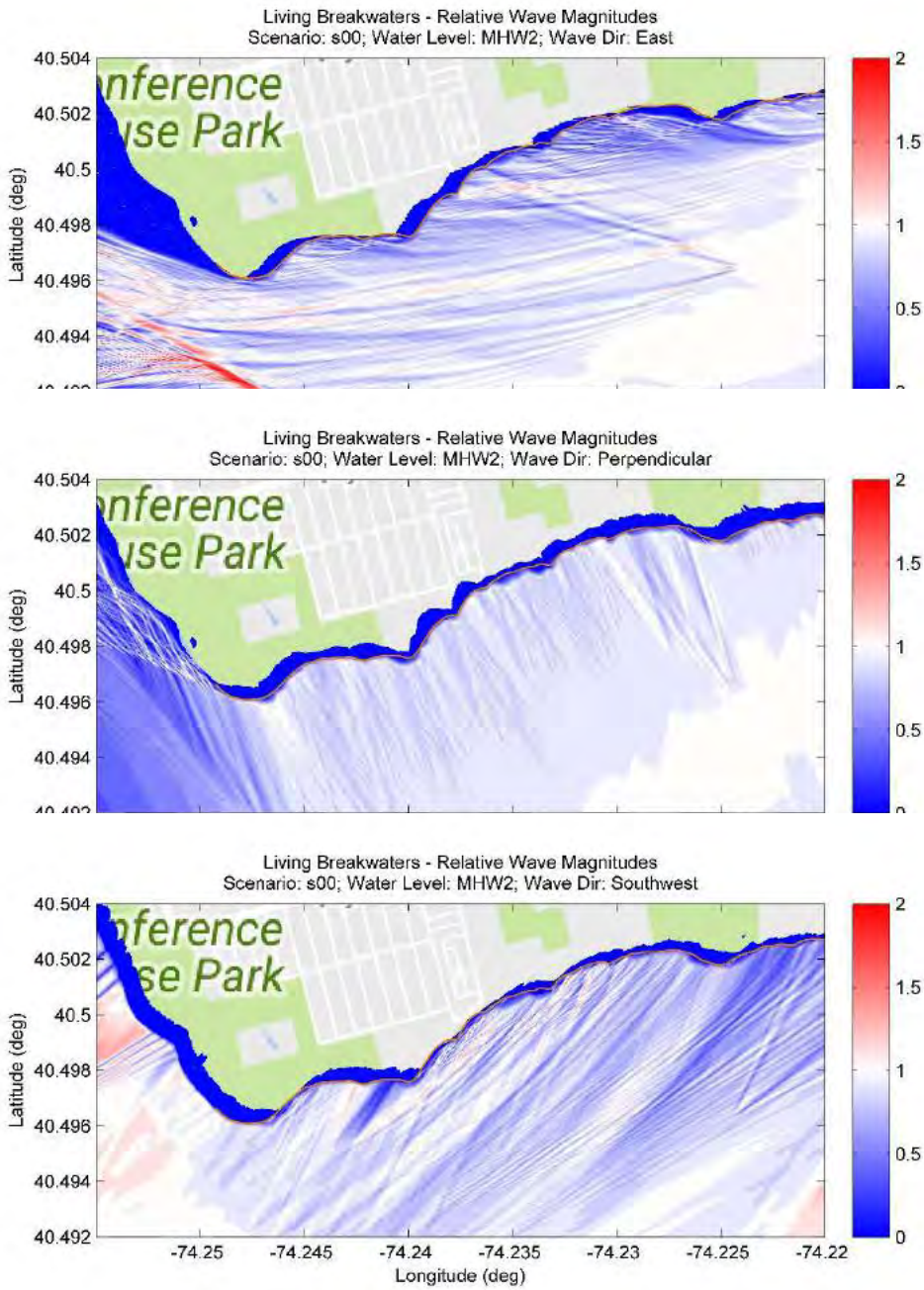

Figure 30. Relative wave heights in the vicinity of the potential Living Breakwaters alignment. Baseline simulations (without-project) for an incoming wave height of 3 feet, wave period of 3 seconds, and water level at mean high water (2.08' NAVD88). Top Image: east wave. Middle image: wave perpendicular to shoreline. Bottom image: southwest wave. Orange line is shoreline.

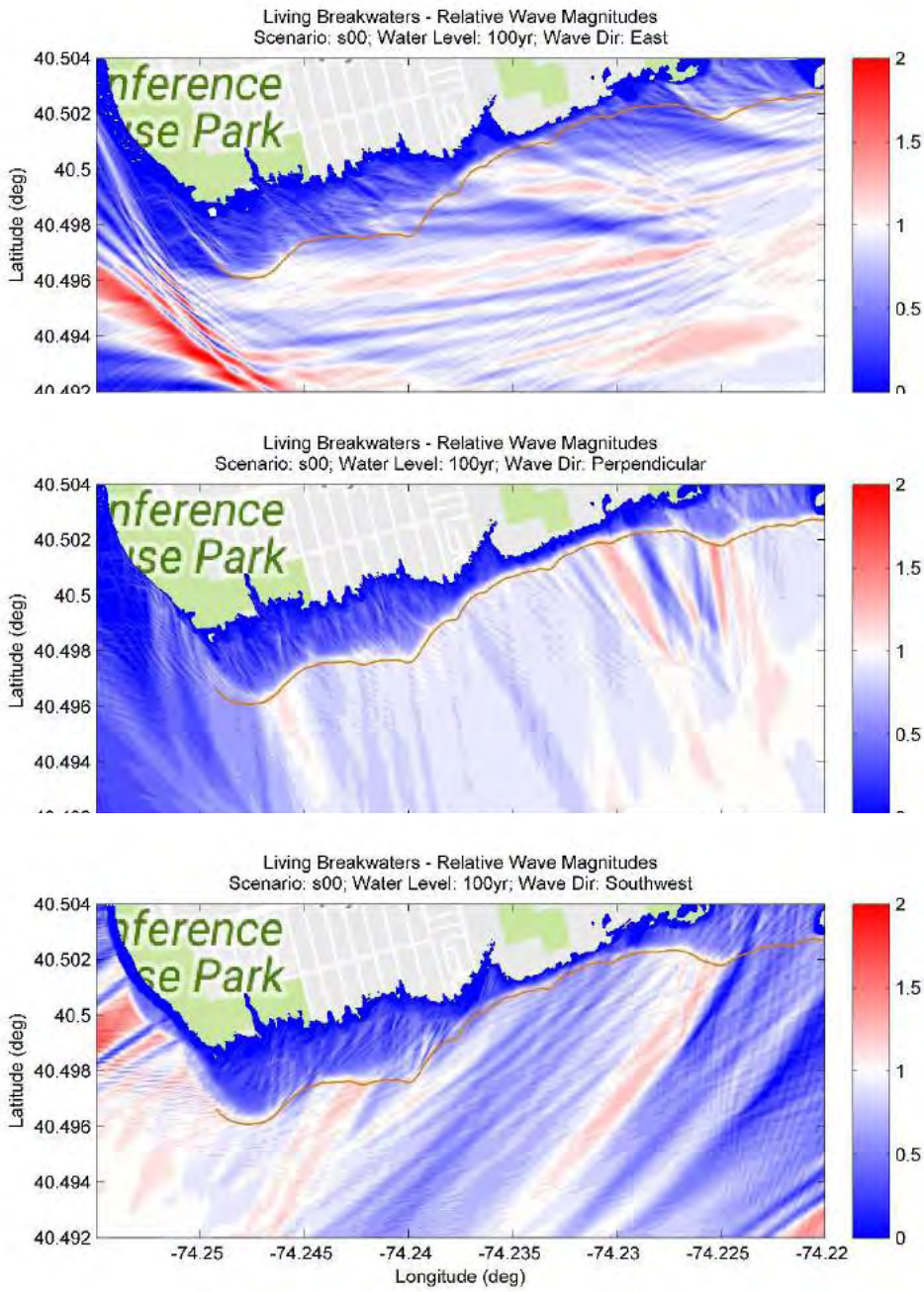

Figure 31. Relative wave heights in the vicinity of the potential Living Breakwaters alignment. Baseline simulations (without-project) for an incoming wave height of 5.3 feet, wave period of 5 seconds, and the 1%-annual-chance FEMA PFIRM water elevation (12.9' NAVD88). Top Image: east wave. Middle image: wave perpendicular to shoreline. Bottom image: southwest wave. Orange line is shoreline.

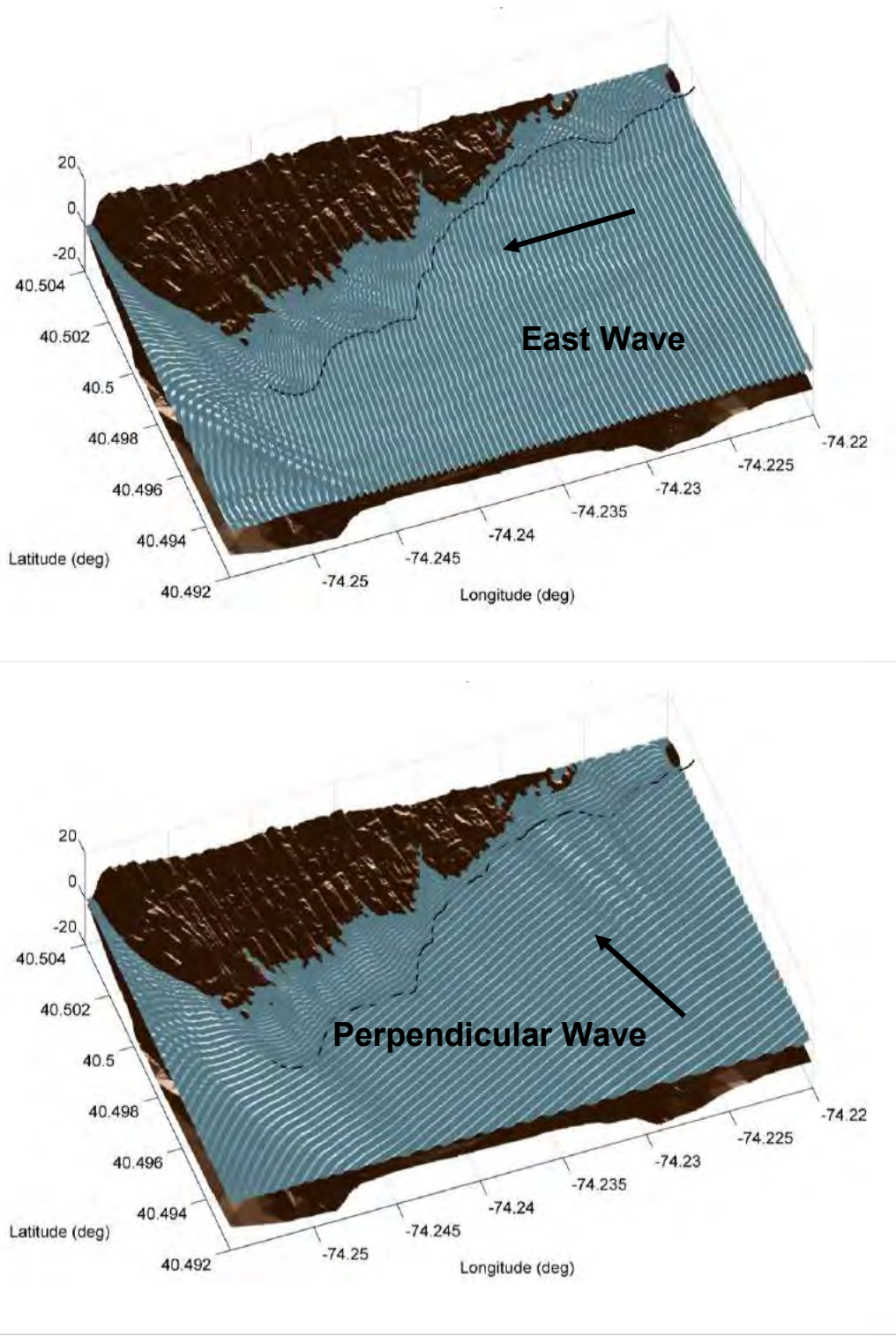

Figure 32. Wave crests and troughs near the potential Living Breakwaters alignment. Baseline simulations (without-project) for an imposed wave height of 5.3 feet, wave period of 5 seconds, and the 1%-annual-chance FEMA PFIRM water elevation. Top Image: east wave. Bottom image: wave perpendicular to shoreline.

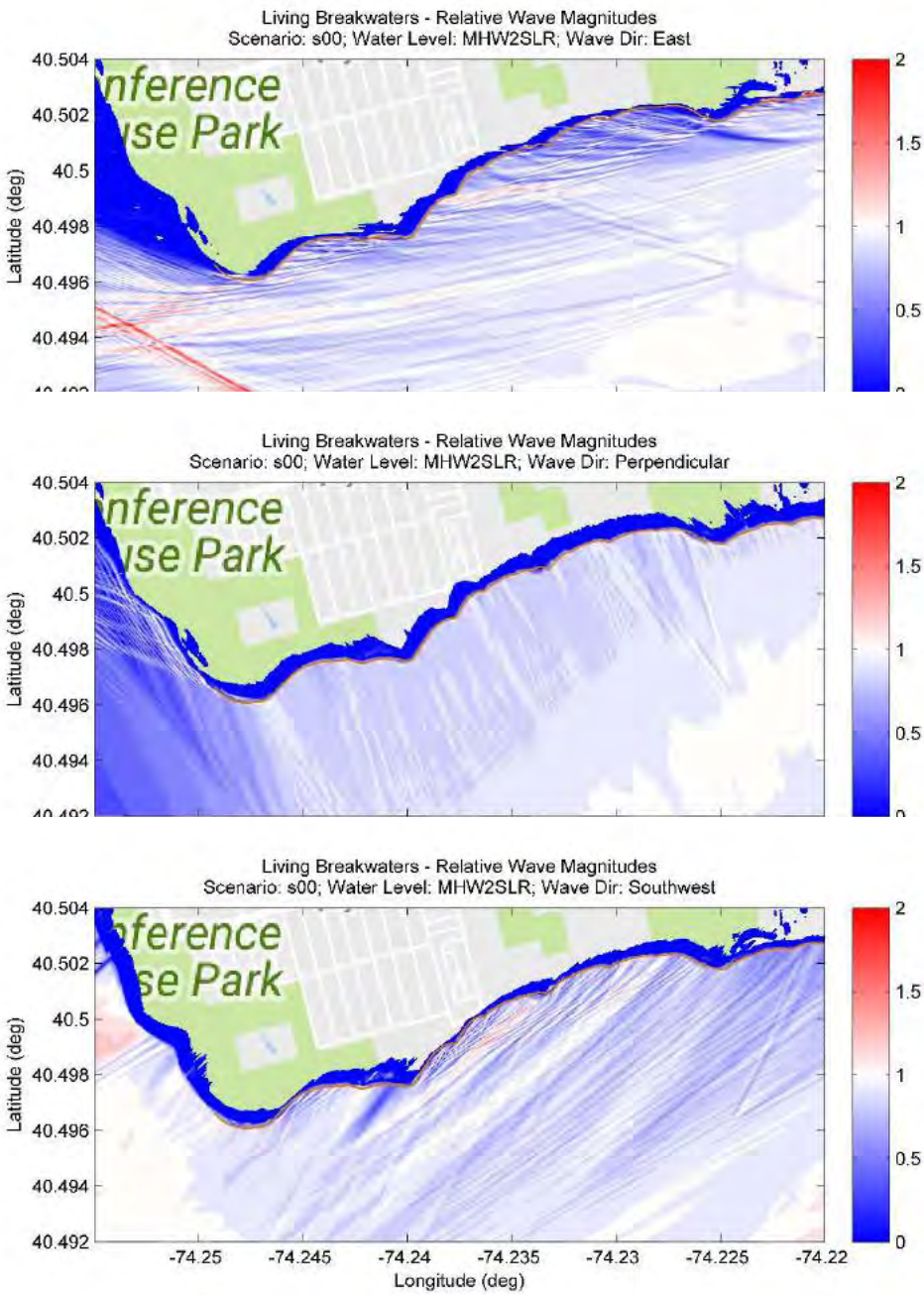

Figure 33. Relative wave heights in the vicinity of the potential Living Breakwaters alignment. Baseline simulations with SLR, without-project, for an incoming wave height of 3 feet, wave period of 3 seconds, and mean high water. Top Image: east wave. Middle image: wave perpendicular to shoreline. Bottom image: southwest wave. Orange line is shoreline.

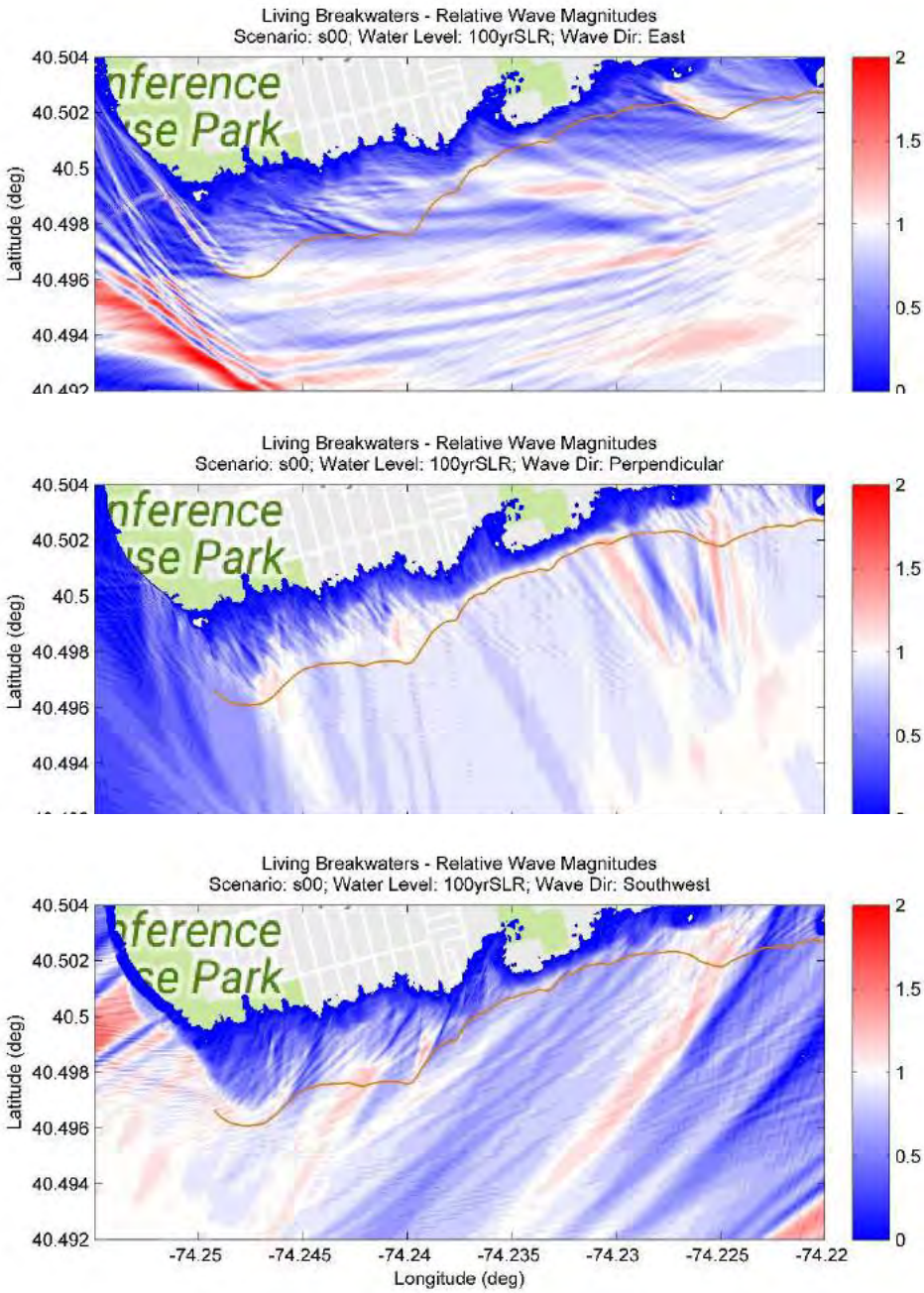

Figure 34. Relative wave heights in the vicinity of the potential Living Breakwaters alignment. Baseline simulations with SLR, without-project, for an incoming wave height of 5.3 feet, wave period of 5 seconds, and the 1%-annual-chance FEMA PFIRM water elevation. Top Image: east wave. Middle image: wave perpendicular to shoreline. Bottom image: southwest wave. Orange line is shoreline.

30% DESIGN SIMULATIONS

The 30% design simulation, including breakwaters and shoreline restoration, is summarized by relative wave height (wave height divided by incoming wave height imposed at the boundary) plots for each of the three wave approach directions on Figure 35 and Figure 36. Figure 35 shows the mean high water event with an imposed wave height of 3 feet and a wave period of 3 seconds. Figure 36 shows the FEMA PFIRM 1%-annual-chance event with an imposed wave height of 5.3 feet, and a wave period of 5 seconds.

Each image illustrates wave shadow areas created by breakwaters, wave penetration, and diffraction through the edge and gaps of breakwaters. The images also include a noticeable wave breaking line close to the shoreline, indicated by dark blue relative wave heights (close to zero). The breaker line advances landward for the increased water levels associated with the 1%-annual-chance event shown on Figure 36. Wave shoaling, refraction, and diffraction are also clearly observed from the propagation, crossing, and dissipation of wave rays at nearshore areas and around the breakwaters.

Design simulations were also run for the MHW with 30” of SLR and the 1% annual chance storm event with 30” of SLR (See Figure 37 and Figure 38). For these simulations, it was assumed that SLR would generate elevated water levels (stillwater elevations) but would not affect the storm wave height and period. The SLR simulations show the further penetration of waves and higher wave heights.

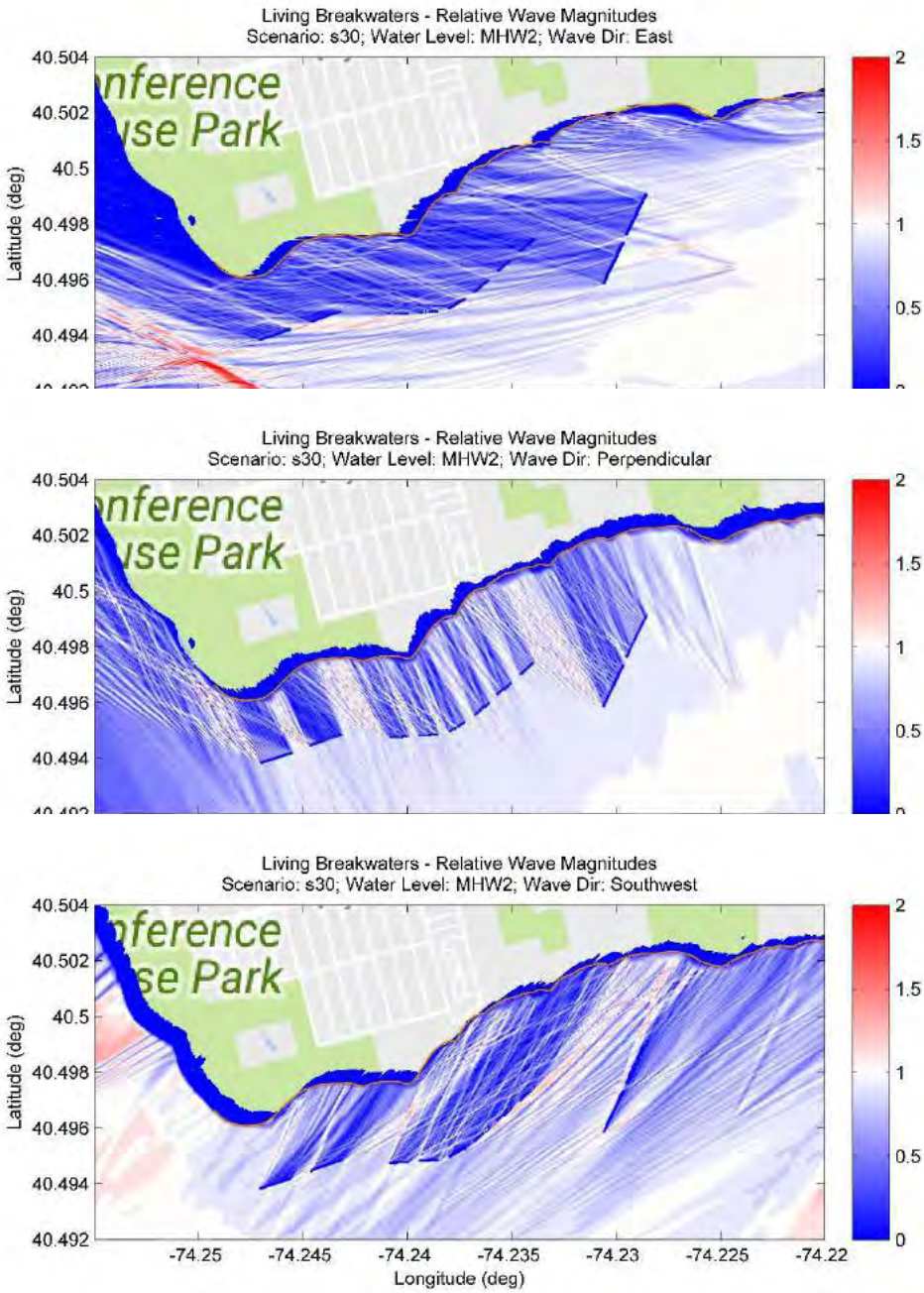

Figure 35. Relative wave heights in the vicinity of the potential Living Breakwaters alignment. 30% design simulations for an incoming wave height of 3 feet, wave period of 3 seconds, and mean high water. Top Image: east wave. Middle image: wave perpendicular to shoreline. Bottom image: southwest wave. Orange line is shoreline.

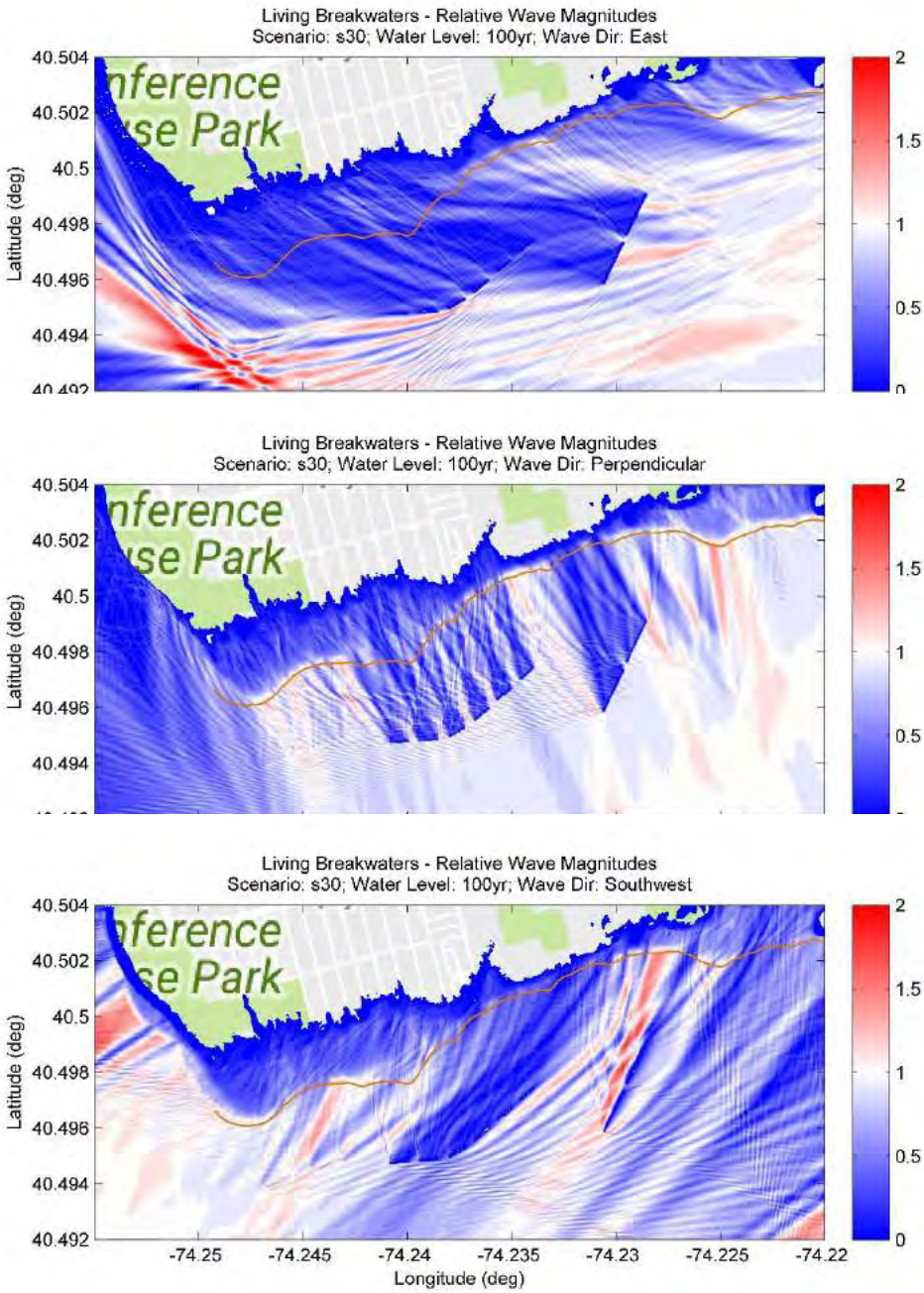

Figure 36. Relative wave heights in the vicinity of the potential Living Breakwaters alignment. 30% design simulations for an incoming wave height of 5.3 feet, wave period of 5 seconds, and the 1%-annual-chance FEMA PFIRM water elevation. Top Image: east wave. Middle image: wave perpendicular to shoreline. Bottom image: southwest wave. Orange line is shoreline.

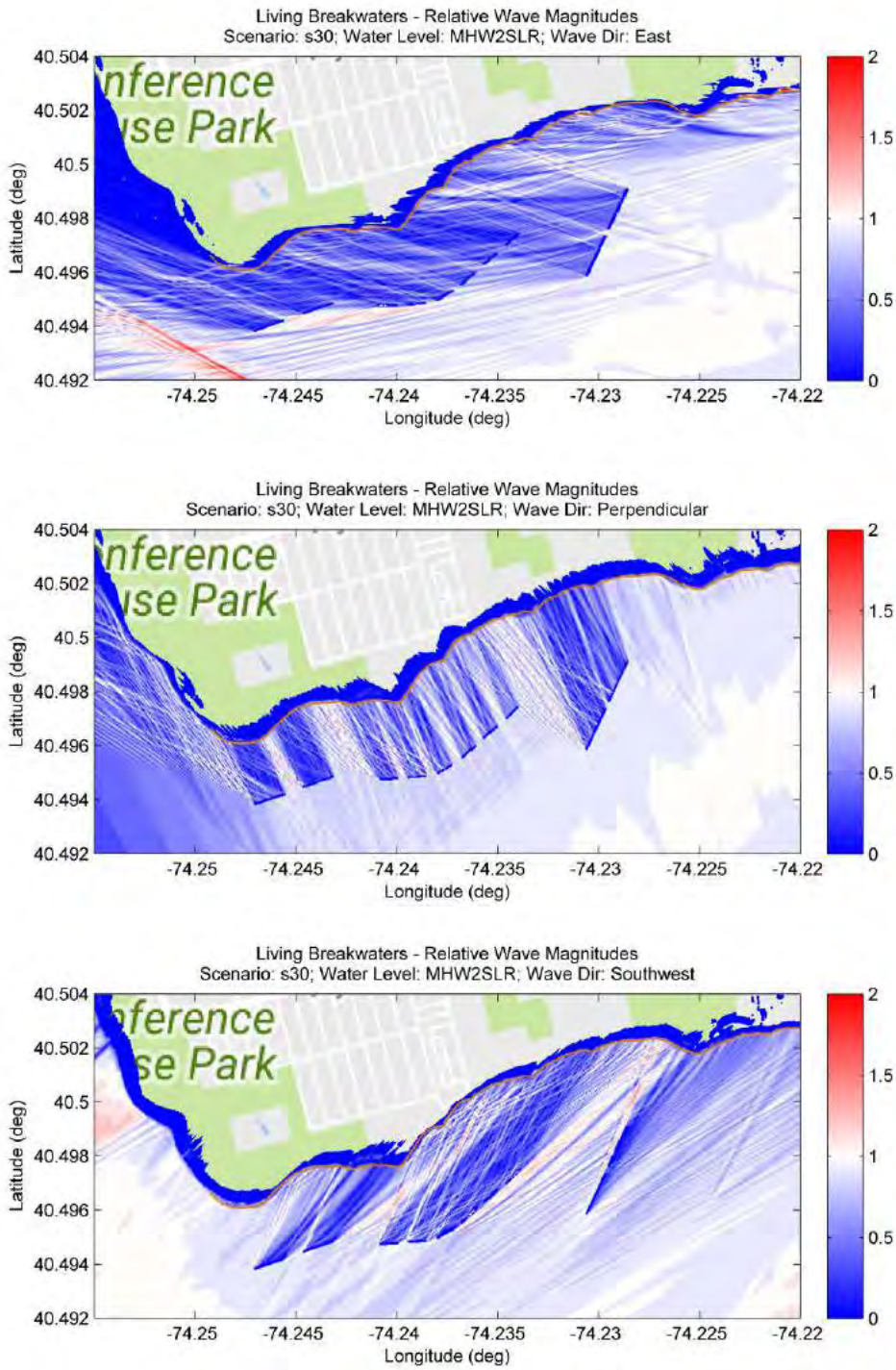

Figure 37. Relative wave heights in the vicinity of the potential Living Breakwaters alignment. 30% design simulations for an incoming wave height of 3 feet, wave period of 3 seconds, and mean high water with SLR. Top Image: east wave. Middle image: wave perpendicular to shoreline. Bottom image: southwest wave. Orange line is shoreline.

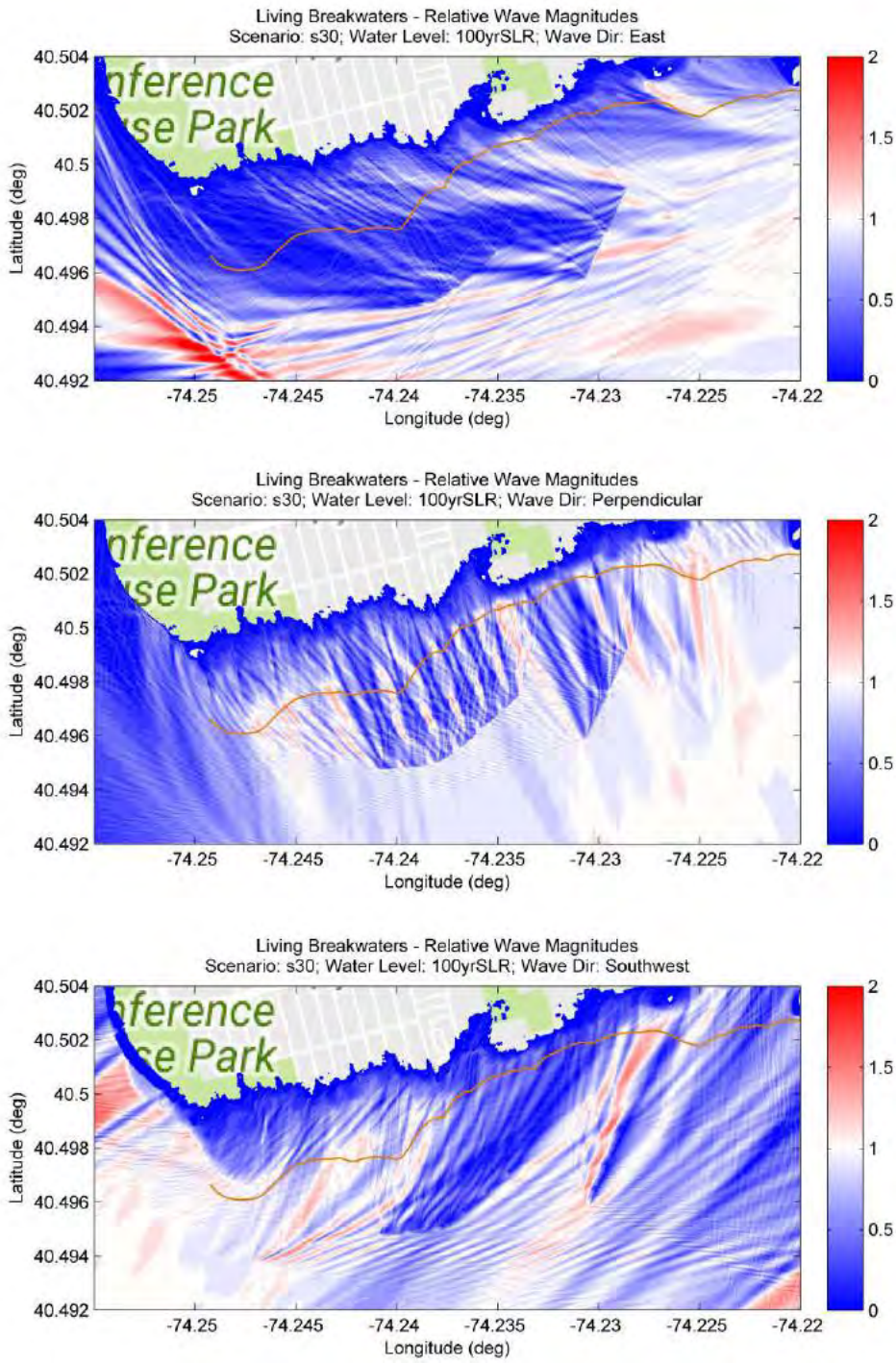

Figure 38. Relative wave heights in the vicinity of the potential Living Breakwaters alignment. 30% design simulations for an incoming wave height of 5.3 feet, wave period of 5 seconds, and the 1%-annual-chance FEMA PFIRM water elevation with SLR. Top Image: east wave. Middle image: wave perpendicular to shoreline. Bottom image: southwest wave. Orange line is shoreline.

ANALYSIS OF RESULTS

In order to better understand and preliminarily quantify the influence of the breakwaters on wave heights, average relative wave heights (or the percentage of incident wave height remaining) were calculated for regions near the project area. The locations of these regions are represented by the polygons shown on Figure 39. They were selected based on beach profile survey transect locations, breakwater layout, and cross shore beach change analysis locations.

Figure 39. Locations of polygons, transects, and relative wave heights for wave reduction calculation.

The average relative wave heights were calculated for each of the polygons shown in Figure 39 by averaging the relative wave heights located inside the polygons for each of the simulations run. The change in relative wave heights between the results with and without the project reflect the wave attenuation (wave height reduction) due to the breakwaters. The results of this analysis are presented in the tables on the following pages. Table 9, Table 10, and Table 11 present the wave reductions for each polygon along three incident wave directions for MHW both today and with 30" of sea level rise (SLR). It can be seen that the existing bathymetry reduces the incoming wave heights slightly (Table 9) and the addition of the breakwaters cause further reductions (Tables 10 and 11). Table 12, Table 13, and Table 14 present the same for the FEMA PFIRM 1%-annual-chance (100 year) event with an imposed wave height of 5.3 feet and a wave period of 5 seconds both with and without SLR. In each table the "relative wave height" is presented as the decimal percent of the wave height inputted at the model boundary. It should be noted that the project places greater focus on the area represented by polygon E for storm wave height reduction, as this is the zone within the project area with vulnerable on-shore assets in the FEMA PFIRM V zone and LiMWA. In other locations, while the shoreline has been subject to erosion, structures and infrastructure are

currently outside the FEMA PFIRM high energy wave zones. Only those polygons where wave height reductions were targeted or within the influence of the breakwaters are included in the summary below.

Wave Reduction Results at Mean High Water Level and 3 foot Wave Height

Table 9. Relative wave heights for baseline simulations (MHW).

Polygon	Associated Transects	Relative Wave Height Today (MHW=2.08 NAVD88)			Relative Wave Height with 30" SLR (MHW=4.58 NAVD88)		
		East	Perpendicular	Southwest	East	Perpendicular	Southwest
C	6, 7, 8	0.94	0.93	0.97	0.91	0.87	0.95
D	9	0.95	0.91	0.74	0.94	0.88	0.81
E	10, 11, 12, 13	0.87	0.91	0.92	0.9	0.9	0.9
F	14, 15, 16	0.84	0.9	0.89	0.91	0.89	0.94
G	17, 18	0.9	0.93	0.83	0.92	0.91	0.88
H	19, 20	0.8	0.91	0.8	0.82	0.89	0.85

Table 10. Wave reductions for 30% design simulations (MHW).

Polygon	Associated Transects	Relative Wave Height			Average Change from Baseline
		East	Perpendicular	Southwest	
C	6, 7, 8	0.4	0.52	0.73	-42%
D	9	0.36	0.92	0.39	-36%
E	10, 11, 12, 13	0.45	0.66	0.56	-38%
F	14, 15, 16	0.52	0.94	0.48	-27%
G	17, 18	0.74	0.59	0.91	-15%
H	19, 20	0.8	0.91	0.71	-4%

Table 11. Wave reductions for 30% design simulations with SLR (MHW + 30").

Polygon	Associated Transects	Relative Wave Height			Average Change from Baseline	Average Change From 30% Design with no SLR
		East	Perpendicular	Southwest		
C	6, 7, 8	0.36	0.49	0.73	-42%	0%
D	9	0.43	0.9	0.35	-36%	0%
E	10, 11, 12, 13	0.46	0.64	0.61	-37%	1%
F	14, 15, 16	0.59	0.93	0.38	-30%	3%
G	17, 18	0.78	0.48	0.88	-21%	6%
H	19, 20	0.82	0.89	0.74	-4%	0%

Wave Reduction Results at 1% Annual Chance Water Level and Wave Height

Table 12. Wave reductions for baseline simulations (100 year).

Polygon	Associated Transects	Relative Wave Height			Relative Wave Height (with 30" SLR)		
		East	Perpendicular	Southwest	East	Perpendicular	Southwest
C	6, 7, 8	1.04	0.93	1.08	1.05	0.93	1.06
D	9	1.14	0.91	0.95	1.12	0.93	0.96
E	10, 11, 12, 13	0.96	0.94	0.77	0.96	0.94	0.81
F	14, 15, 16	0.75	0.93	0.70	0.81	0.94	0.75
G	17, 18	0.99	0.99	0.83	1	0.98	0.83
H	19, 20	0.85	0.86	1.04	0.83	0.88	1.01

Table 13. Wave reductions for 30% design simulations (100 year).

Polygon	Associated Transects	Relative Wave Height			Average Change from Baseline
		East	Perpendicular	Southwest	
C	6, 7, 8	0.5	0.92	1	-20%
D	9	0.23	0.94	0.88	-28%
E	10, 11, 12, 13	0.29	0.56	0.43	-51%
F	14, 15, 16	0.34	1	0.29	-35%
G	17, 18	0.76	0.43	0.9	-24%
H	19, 20	0.85	0.87	0.83	-6%

Table 14. Wave reductions for 30% design simulations with SLR (100 year + 30").

Polygon	Associated Transects	Relative Wave Height			Average Change from Baseline	Average Change From 30% Design with no SLR
		East	Perpendicular	Southwest		
C	6, 7, 8	0.43	0.94	1.03	-20%	0%
D	9	0.25	0.96	0.92	-26%	2%
E	10, 11, 12, 13	0.29	0.6	0.47	-49%	2%
F	14, 15, 16	0.73	1.02	0.23	-24%	11%
G	17, 18	0.8	0.57	0.9	-18%	6%
H	19, 20	0.83	0.87	0.76	-9%	-2%

CONCLUSIONS

The REFDIF wave transformation model was used to examine the wave climate in the nearshore region close to the proposed Living Breakwaters alignments. While breakwaters cannot lower the storm surge elevations, they can dramatically reduce the waves acting on the shoreline, which damage shoreline structures and are the driving force for erosion.

Comparing model results for relative wave heights with- and without Living Breakwaters demonstrate average wave height reductions of up to 51%. The largest wave reductions were in the region targeted for storm wave attenuation (polygon E) due to the concentration of residential infrastructure there. The effectiveness of the breakwaters is reduced with 30 inches of sea level rise allowing 2-11% increases in wave height but the Living Breakwaters still reduce wave heights up to 49%.

STORM INDUCED PROFILE RESPONSE MODELING

In addition to the long term shoreline change, shorter term storm-induced changes to the beach profile were investigated. Tropical and extratropical storms influence the beach profile over these short time frames, requiring a modified approach from the long term shoreline modeling described previously. For consistency with the TSPP team's approach, the SBEACH model (Larson, 1990) was first used to evaluate storm-induced beach profile changes.

However, as described in the following sections, calibration efforts demonstrated that SBEACH was not capable of accurately reproducing the beach profile response observed during the Hurricane Sandy event. As a result, an alternative storm-induced shoreline change model, CSHORE (Johnson, 2012), was evaluated as well. CSHORE performed significantly better than SBEACH at reproducing the observed Hurricane Sandy profile response. As a result, CSHORE was used for the full analysis of with- and without-project storm-induced beach profile change simulations. The results of these simulations are described in the following sections. Note that storm induced beach profile change was only modeled for areas outside the TSPP project area. The TSPP team is modeling and analyzing transects within the TSPP project area. .

SBEACH AND CSHORE MODEL OVERVIEW

Cross shore changes in the shoreline/beach profile due to a single storm event can be significant. Both the Storm-induced BEAch CHange beach erosion model (SBEACH) and the Cross-SHORE beach erosion model (CSHORE) were used to assess storm event response and changes to the beach profile. The models simulate cross-shore beach, berm, and dune erosion produced by storm waves and water levels. The models require the following inputs:

- Beach Profile Transects
- Wave Conditions
- Water Levels
- Sediment Characteristics

These inputs are discussed further in the following sections.

BASELINE MODEL INPUTS

BEACH PROFILE TRANSECTS

Simulations were performed at the transect locations shown on Figure 40. The location map shows 23 beach profile transects which are categorized as either inside or outside the TSPP limits, shown in purple. The analysis described herein focuses on the 10 beach profile transects (1-7 and 21-23) outside the TSPP.

Figure 40. Transect location map.

Transect surveys were performed in Fall 2015 and Spring 2016 (MFS, 2015). Both surveys ranged from -50 to +10 feet NAVD88 for all transects, and the seasonal differences at each transect were minimal. Given the high degree of overlap and similarity between the two sets of transects, running a separate analysis for Fall and Spring was not necessary. As a result, only the Fall 2015 transect profiles were used in the analysis. Transect surveys were combined with 2010 LiDAR (NYC, 2012) to supplement onshore topography to the inland extent of storm tide.

The ten combined transects have lengths between 1,000 and 4,000 feet. The transects begin offshore at a depth of -50 to -40 feet NAVD88 and extend onshore to an elevation of 10 to 40 feet NAVD88. Beach berm widths are

approximately 100 feet for most transects. Transects 1, 4, 21, and 23 have foredune features at an approximate elevation of 7 feet NAVD88. Transects 4 through 23 generally have dune features at approximately 10 feet NAVD88. Figure 41 shows the beach profile at transect 1, with all other profiles shown in Appendix B.

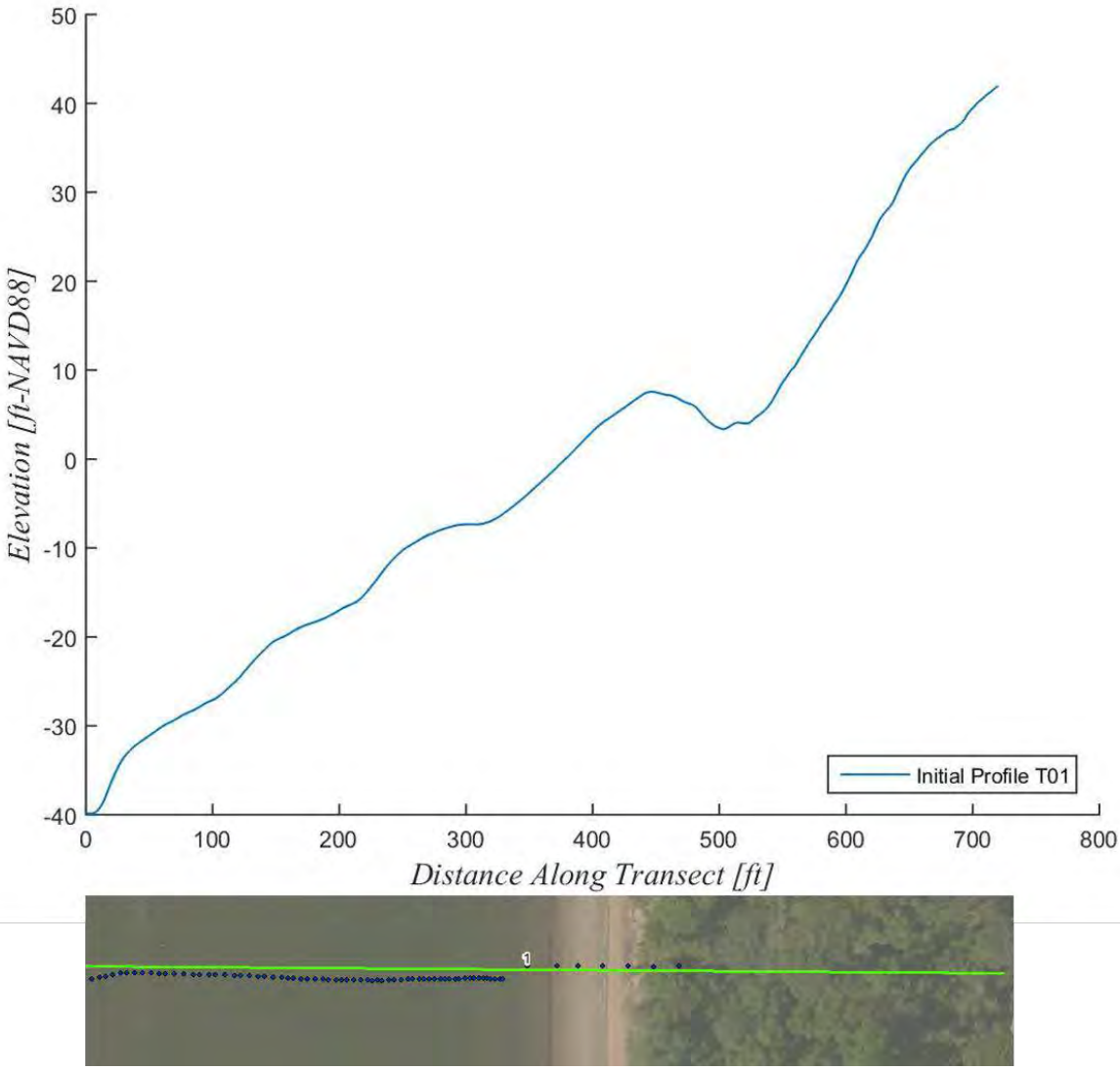

Figure 41. Beach profile at transect 1. Profiles supplemented with pre-Sandy LiDAR Onshore of the Fall 2015 transect survey. Recent orthoimagery at the transect shown for reference.

WATER LEVELS AND WAVE CONDITIONS

Storms representing the 10-, 25-, 50-, and 100-year FEMA PFIRM return period events and Hurricane Sandy were selected to be simulated. The four FEMA storms were selected from the full suite of 189 storms used by FEMA to develop the 2013 PFIRM (FEMA 2015). The individual storms that best matched the published FEMA PFIRM return period stillwater elevations were selected for analysis. Historical extratropical storms best represent the 10- and 25-year storm events, and synthetic tropical storms best represent the 50- and 100-year storm events, as shown in Table 15.

Using the FEMA PFIRM model inputs for these storms, each event listed in Table 15 was simulated in ADCIRC/SWAN to provide wave conditions and water levels during the storms that were used as inputs into the profile response modeling. The time series inputs provided by ADCIRC/SWAN include water levels, significant wave heights, and peak wave periods at regular time intervals for the full storm duration at the project site. For the Hurricane Sandy storm, the FEMA PFIRM ADCIRC/SWAN bathymetric grid was refined and simulated with available wind field and water level forcing conditions observed during the hurricane (City of New York, 2013). Simulation outputs were found to compare well with observed high water marks and time series of storm tides collected by the USGS in New York Harbor, including adjacent to the Living Breakwaters.

Table 15. Simulation events, their names, and associated peak stillwater elevation.

Event	Peak Stillwater Elevation (feet NAVD88)	Storm Name
10-Year	8.1	FEMA PFIRM “19620306”
25-Year	9.3	FEMA PFIRM “19921211”
50-Year	11.3	FEMA PFIRM “NJB_0003_012”
100-Year	12.7	FEMA PFIRM “NJB_0001_010”
Hurricane Sandy	12.9	Hurricane Sandy

To match each storm to a given return period event, the time series data of ADCIRC/SWAN model results were extracted from a nearshore location close to the project area (Figure 42). The extracted water level and wave height time series are shown on Figure 43 through Figure 47. The peak surge elevation from each storm is then compared to return surge elevations at the sample locations. Storms that most closely match the 10-, 25-, 50-, and 100-year return surge elevations were then selected. From the selected storms, wave and water level time series were extracted at locations near the offshore ends of the transects, shown on Figure 40. These wave and water level time series from the offshore transect location were propagated along the transect using the SBEACH and CSHORE profile response modeling.

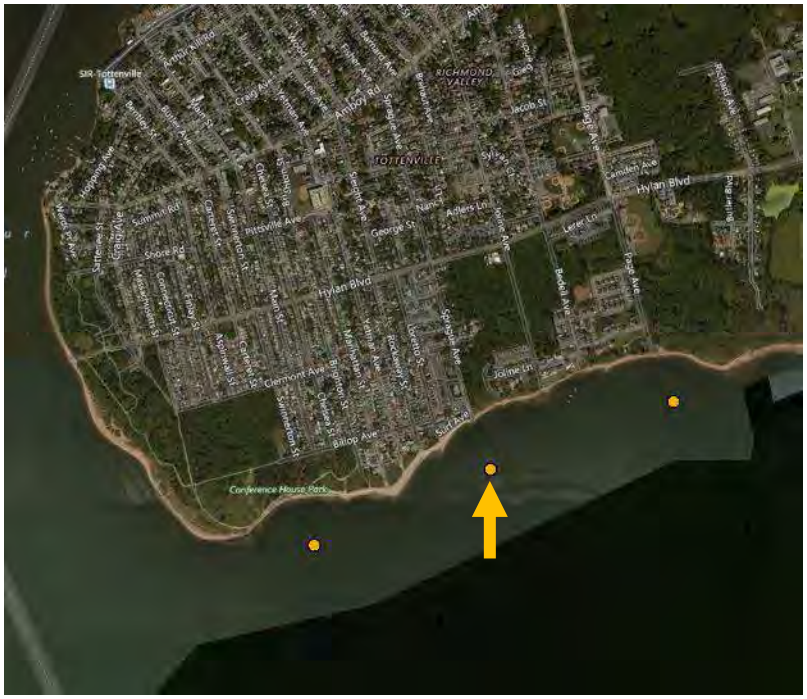

Figure 42. Nearshore extraction location, close to the project area, indicated by the arrow.

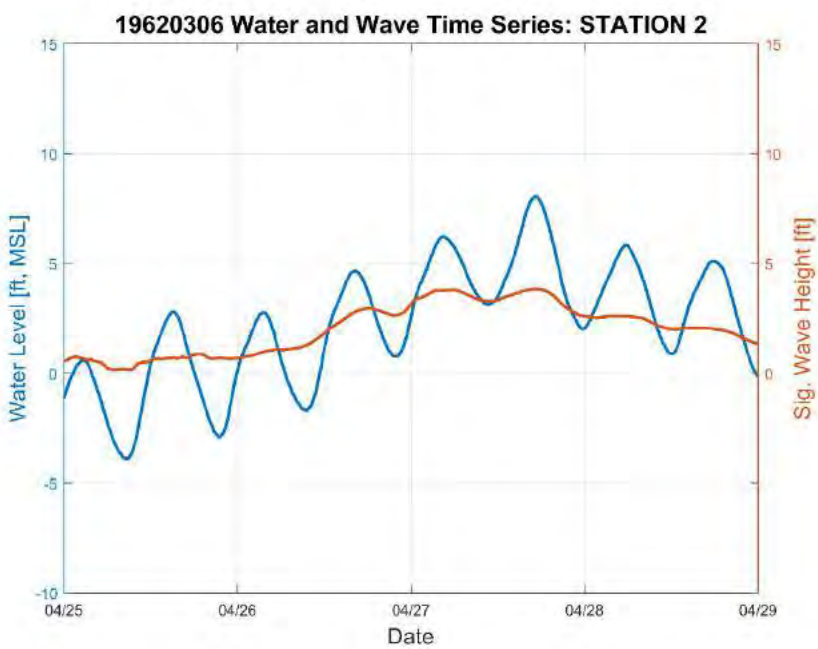

Figure 43. 10-year event storm tide and wave height time series.

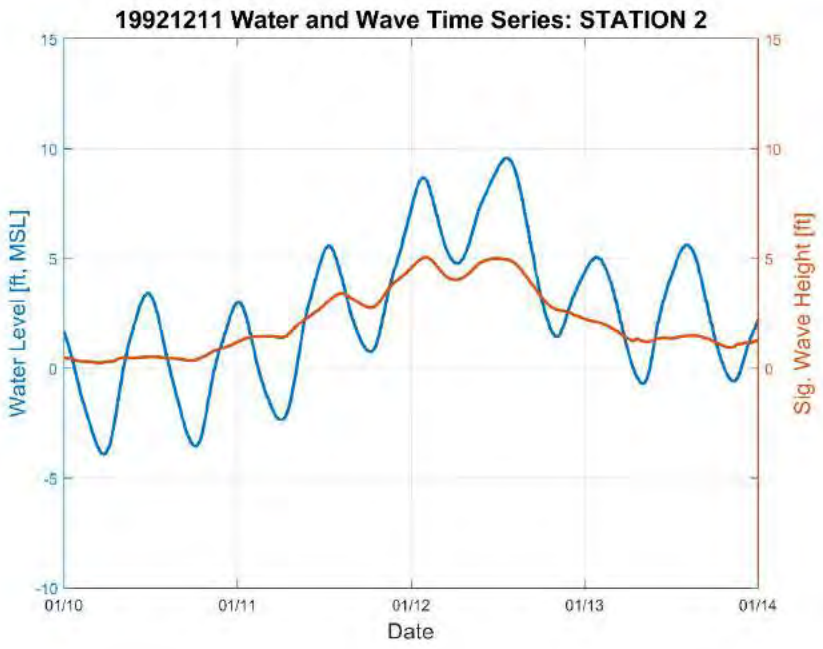

Figure 44. 25-year event storm tide and wave height time series.

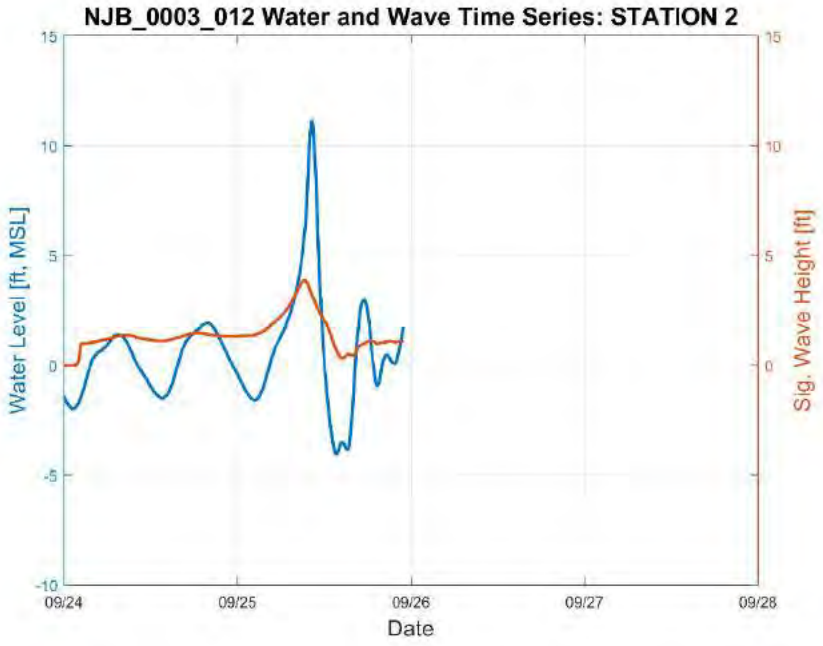

Figure 45. 50-year event storm tide and wave height time series.

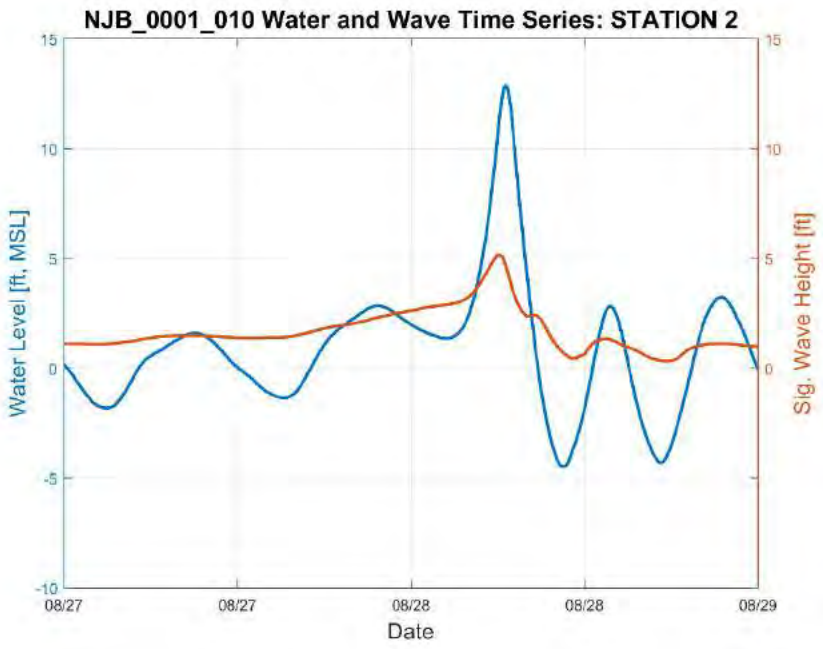

Figure 46. 100-year event storm tide and wave height time series.

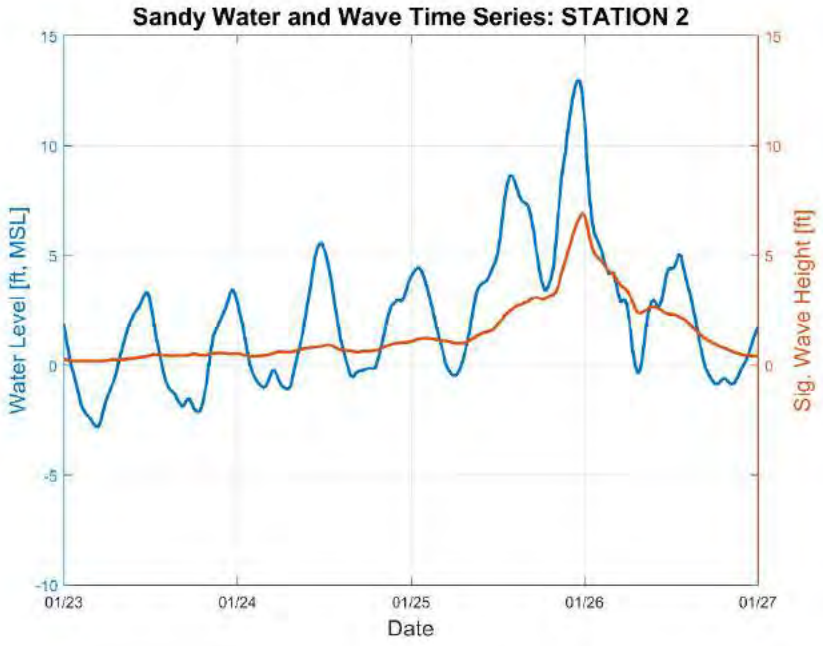

Figure 47. Hurricane Sandy storm tide and wave height time series.

SEDIMENT CHARACTERISTICS

Sediment surveys were completed throughout the project area during Summer 2015, Fall 2015, and Spring 2016 (MFS, 2015). The specific sediment surveys utilized in this analysis were:

- Fall 2015 Nearshore (MFS 11/15)
- Summer 2015 Offshore (Hill International 6/15)
- Spring 2016 Nearshore (MFS 5/16)
- Spring 2016 Offshore (Prudent Engineering 4/16)

Figure 48 shows an overview of sediment size from the Summer and Fall 2015 surveys, and Figure 49 shows the same overview of the Spring 2016 surveys. The average D_{50} measurement for both sets of surveys is 0.94 millimeters. However, this average D_{50} is influenced by surveys taken near the MLLW elevation in the surf zone where the sediment is considerably coarser. The average D_{50} for these MLLW measurements is 2.15 millimeters. The average D_{50} is 0.61 millimeters when you exclude those measurements and only include the offshore surveys and the beach surveys inland of MLLW. These average sediment sizes informed a range of D_{50} values that were tested during the calibration phase. Table 16 includes a summary of the sediment data.

Table 16. Summary of sediment survey data.

Location	Sediment Size (mm)		
	Fall	Spring	Average
Average MLLW	2.24	2.06	2.15
Average Nearshore including MLLW	1.05	1.07	1.06
Average Nearshore without MLLW	0.53	0.71	0.62
Average All	0.95	0.93	0.94
Average All without MLLW	0.56	0.67	0.61

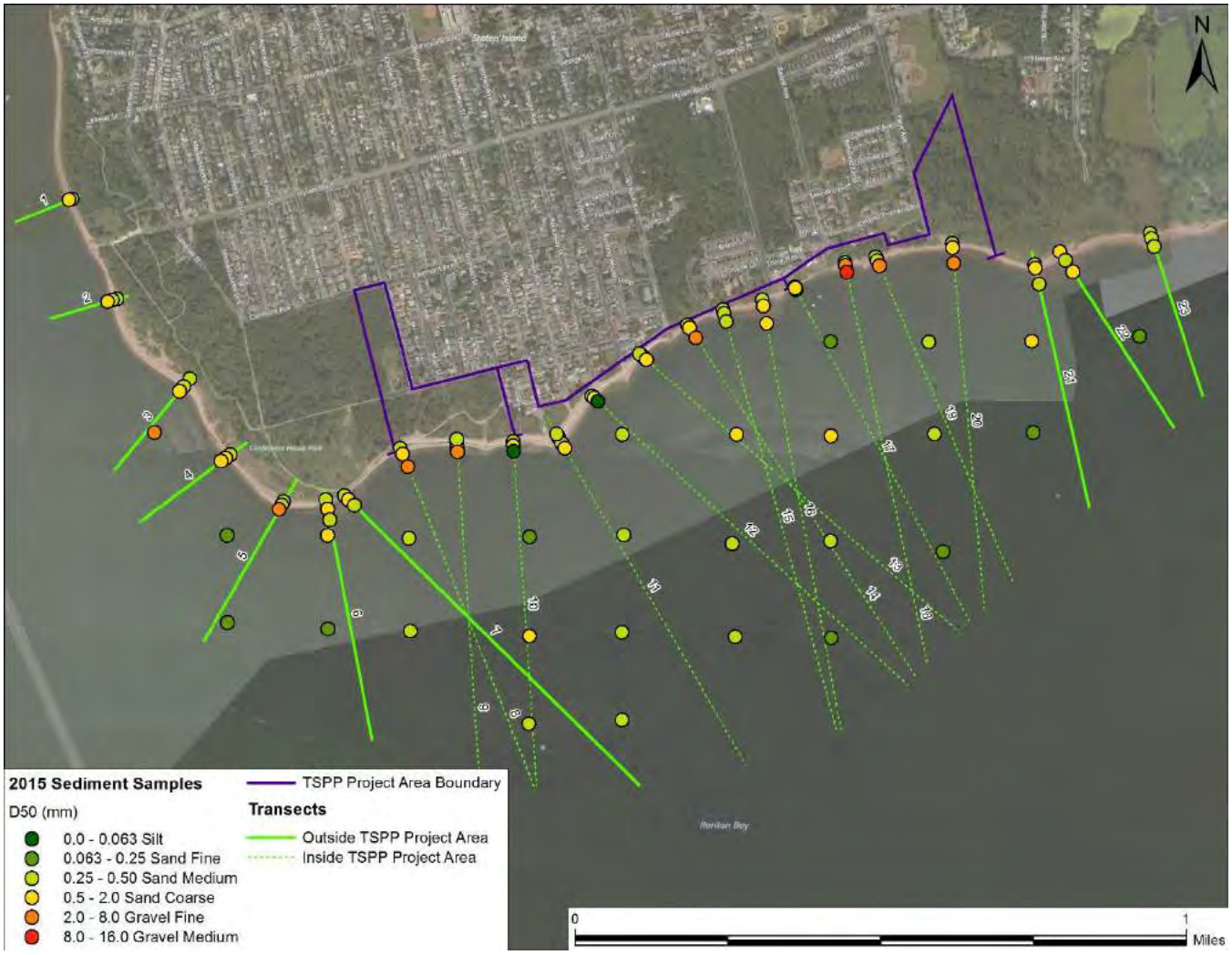

Figure 48. Summer and Fall 2015 sediment surveys.

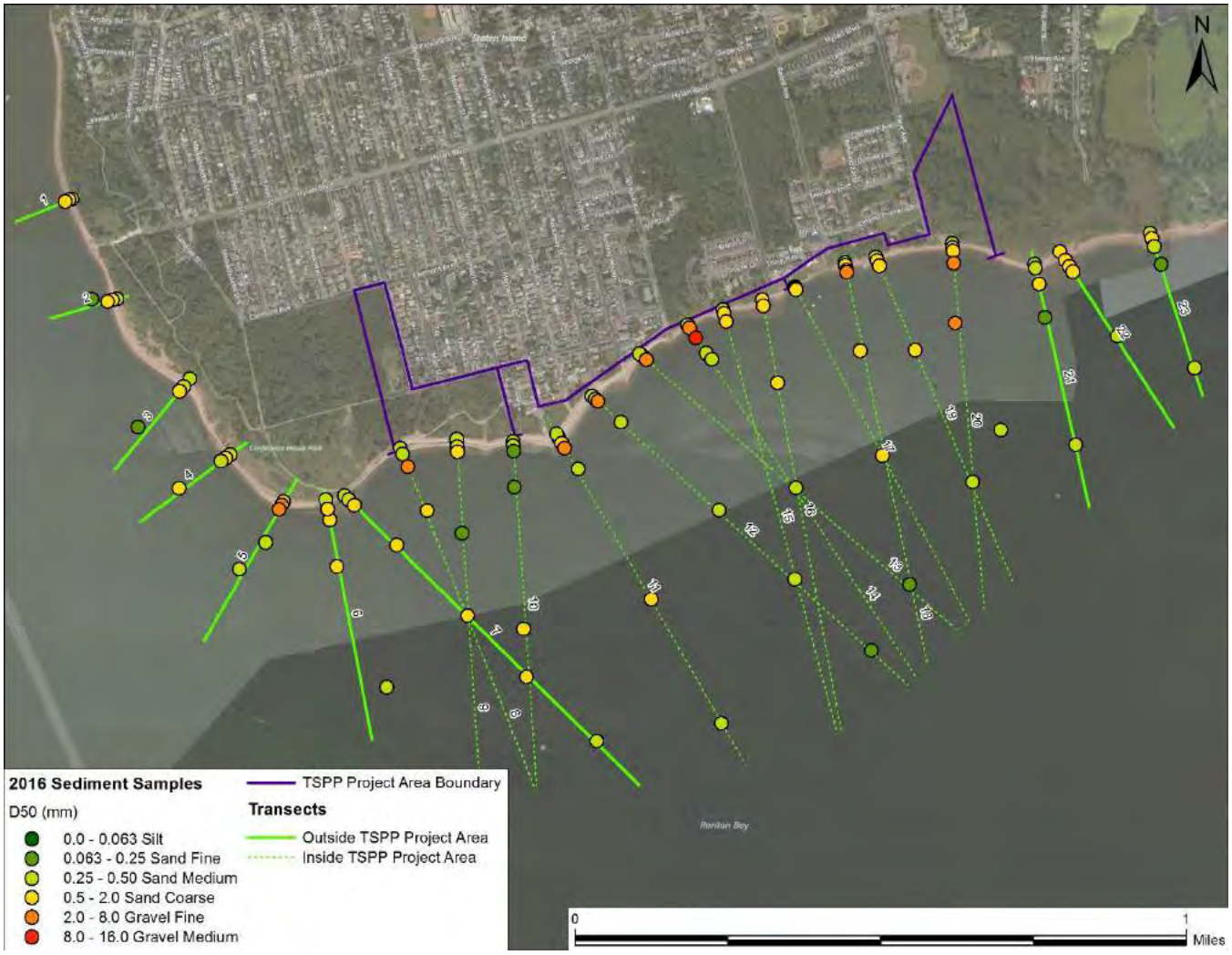

Figure 49. Spring 2016 sediment survey.

BASELINE SIMULATIONS

MODEL CALIBRATION

With no pre- and post-storm event beach surveys in the region available, data from Hurricane Sandy was used for calibration of the model. LiDAR pre-and post-Sandy were used in the analysis (USGS 2010; USGS 2014). Pre-Sandy LiDAR surveys were collected in Spring 2010. Hurricane Sandy made landfall on October 29, 2012, and Post-Sandy LiDAR surveys were completed two weeks later on November 16, 2012.There is a significant time between the pre- and post-storm LiDAR data, which is a possible source of error, but it represents the best available data. These transects are located throughout an undeveloped beach environment where beach profiles are not affected by man-made structures. Without outside influence, it is assumed that the change in the beach profiles is due to Hurricane Sandy. Given local MHW is 2.08 feet NAVD88, only LiDAR information above 2 feet NAVD88 was used due to interference from the water. Figure 50 shows the pre- and post-Sandy Lidar used for this analysis.

Pre- and post-Sandy orthoimagery collected by NOAA was also reviewed. These images provide detail regarding the extent of overwash caused by the storm. In most places the imagery shows where the beach sediment was carried onshore. The orthoimagery was compared to the LiDAR surveys to verify the changes observed between pre- and post-Sandy observations. The orthoimagery at each transect show some degree of sand overwash that is also evident when comparing pre- and post-Sandy LiDAR. However, LiDAR surveys for transects 5, 6, 7, and 23 also show some scour along the backshore region. And, orthoimagery for these scour areas look similar to the overwash areas. In both cases the orthoimagery show more sediment and less vegetation which can be caused by overwash covering the vegetation or by the loss of vegetation due to scour. As a result, orthoimagery can be used to confirm a change occurred, but is not reliable at predicting whether that change was a gain or loss of sediment. Figure 50 and Figure 51 show an example of the aerial imagery comparison done at the project site.

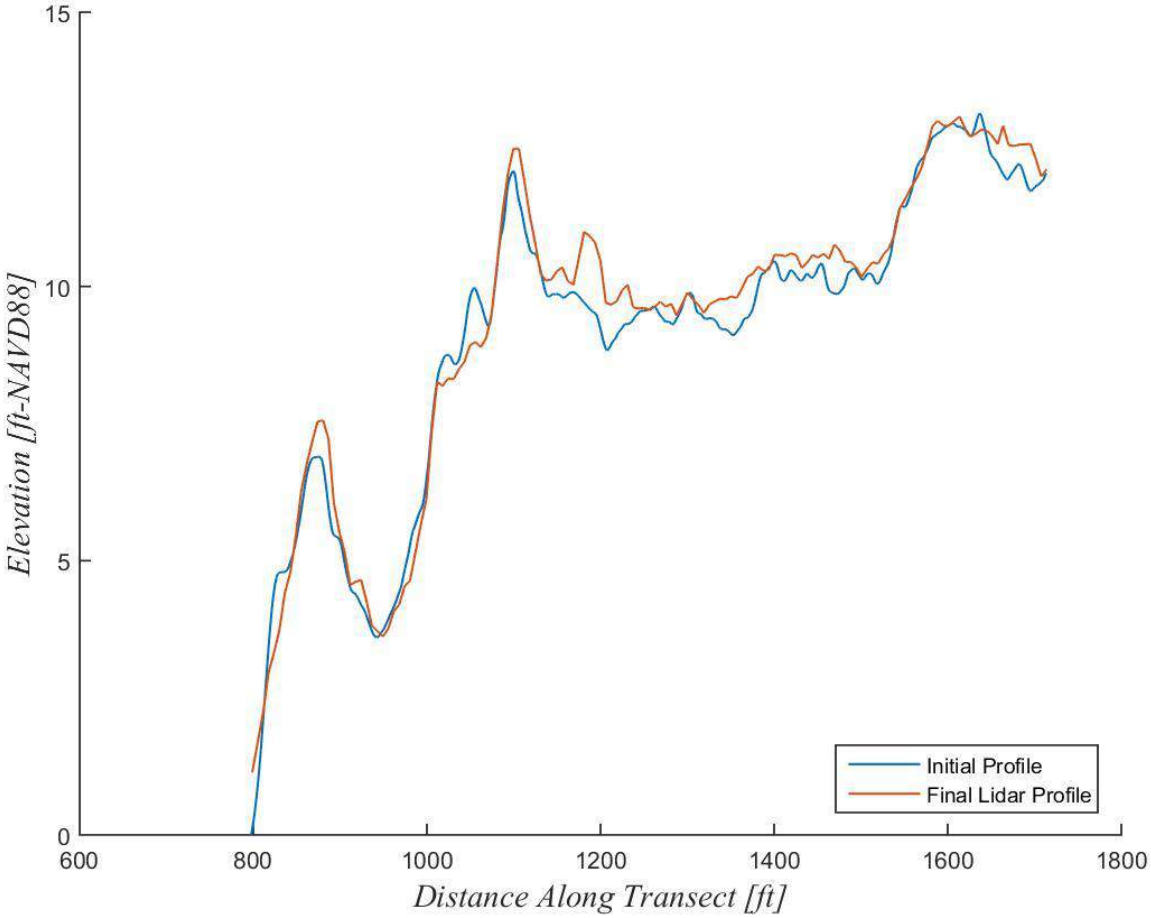

Figure 50. Pre- and post-Sandy comparison at transect 4. Line plot shows the initial (pre-Sandy) profile compared to the final (post-Sandy) profile. Underneath the line plot, the images include pre-Sandy orthoimagery (top) compared to post-Sandy orthoimagery (bottom). Comparison of the imagery shows some sand overwash covering the road in the middle of the image. The line plot shows that this change was indeed caused by additional sediment accumulation along the entire profile.

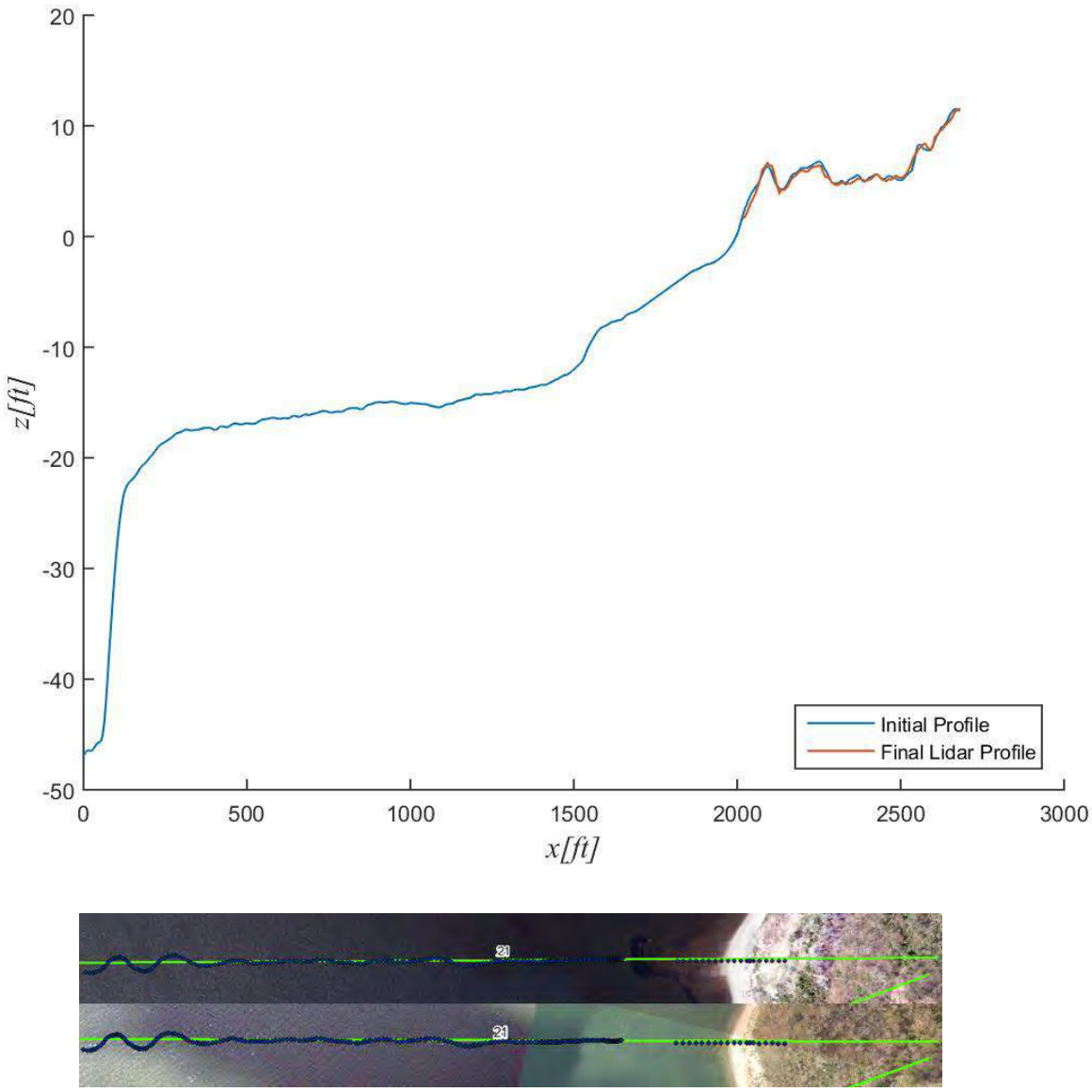

Figure 51. Pre- and post-Sandy comparison at transect 21. Line plot shows the initial (pre-Sandy) profile compared with the final (post-Sandy) profile. Underneath the line plot, the images pre-Sandy orthoimagery (top) compared to post-Sandy orthoimagery (bottom). Comparison of the imagery shows noticeable sand overwash caused by the storm. The line plot shows some erosion inland of the beach which is not immediately evident from the imagery.

The Hurricane Sandy storm and waves time series inputs were simulated for each of the 10 beach profile transects outside the TSPP project limits. When simulating results in SBEACH, the beach profiles, especially at dune features, showed more erosion than the post-Sandy Lidar surveys. Figure 52 and Figure 53 show the SBEACH results of the Hurricane Sandy event simulations at transects 4 and 21.

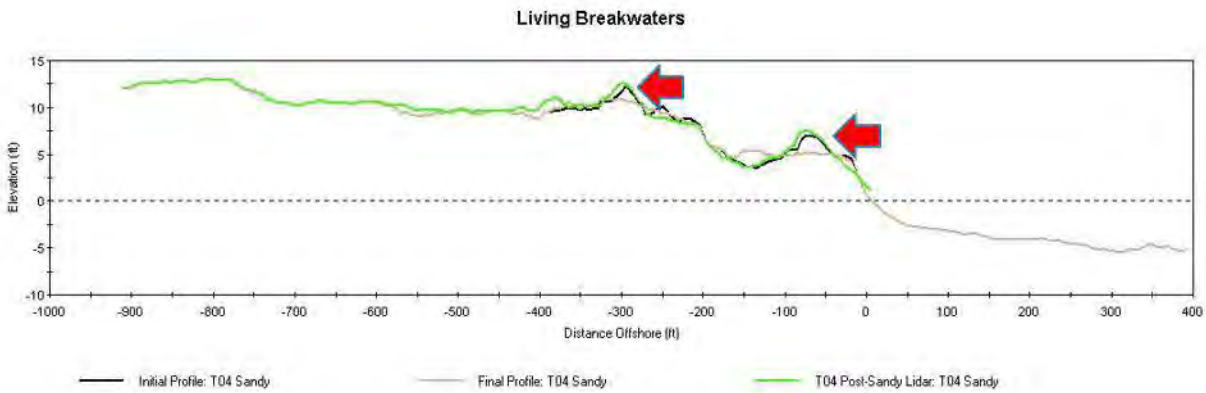

Figure 52. SBEACH model results for Hurricane Sandy at transect 4. Initial pre-Sandy profile shown in red. Final SBEACH profile shown in gray. Post-Sandy Lidar survey shown in green. Arrows point to large dunes where SBEACH results show considerable erosion relative to post-Sandy LiDAR.

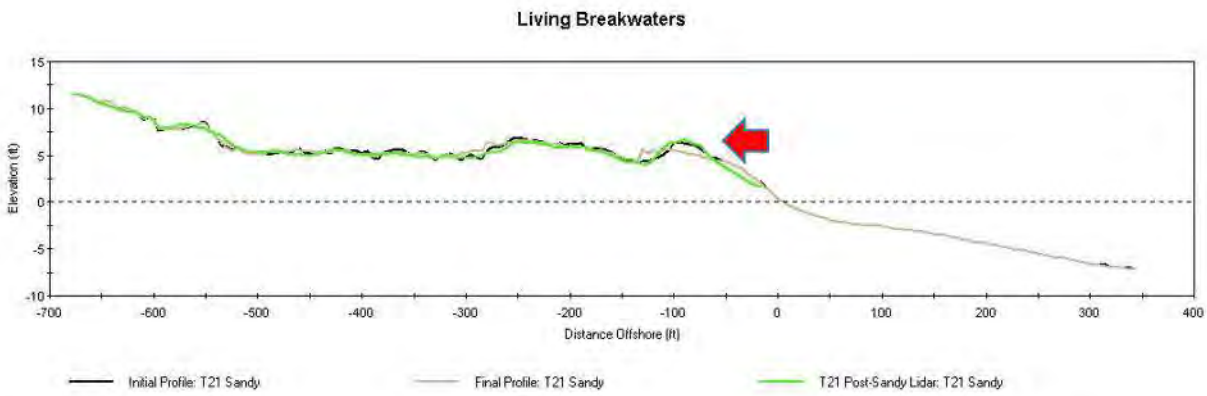

Figure 53. SBEACH model results for Hurricane Sandy at transect 21. Initial pre-Sandy profile shown in red. Final SBEACH profile shown in gray. Post-Sandy Lidar survey shown in green. The arrow points to a dune where SBEACH results show considerable erosion relative to post-Sandy LiDAR.

Multiple rounds of model calibration were completed to reduce the high degree of erosion created in the SBEACH simulations that did not match the observed events. Table 17 lists the default parameter values in SBEACH, and the parameter values that produced results most similar to the post-Sandy Lidar survey results shown on Figure 52 and Figure 53. The model results were most sensitive to the D_{50} and the maximum slope prior to avalanching parameters. A full range of D_{50}'s and avalanching parameters was tested, and the parameters that produced results most similar to the post-Sandy profiles are shown in Table 17. Even with these calibrated parameters, the best attainable results with the SBEACH model, shown on Figure 52 and Figure 53, do not match the dune response during the Hurricane Sandy event. In an attempt to achieve better calibration, the CSHORE model was used to simulate the Sandy event as well (USGS, 2014). This alternative was included because the CSHORE model has a more detailed description of storm-event physics and has more recent updates from the experimental literature.

Also, the model was used extensively for dune erosion in the NYC region as part of the most-current FEMA PFIRM study (FEMA 2015).

Table 17. SBEACH Parameters. Default values were used except where alternative values yielded results closer to physical observations during calibration tests.

Parameter Name	Default Value	Calibrated Value
Transport Rate Coefficient (K)	1.75×10^{-6} m^4/N	1.75×10^{-6} m^4/N
Overwash Transport Parameter	0.005	0.005
Coefficient for Slope-Dependent Term (E)	0.002 m^2/s	0.002 m^2/s
Transport Rate Decay Coefficient Multiplier (λ)	0.5	0.5
Water Temperature	20 C	20 C
Effective Grain Size	0.35 mm	1.0 mm
Maximum Slope Prior to Avalanching	45 deg	30 deg

* Further description of the parameters can be found in the SBEACH documentation (Larson 1990)

The Hurricane Sandy event was simulated in CSHORE model using adjustments from the default input parameters where needed. Table 18 summarizes the default and calibrated parameters in CSHORE, highlighting the sensitivity to D_{50} and Suspension Efficiency Due to Breaking. The CSHORE and SBEACH results for transects 4 and 21 during the Hurricane Sandy event are shown on Figure 54 and Figure 55, clearly indicating the improved response of CSHORE relative to SBEACH, especially at dune features. The results for the remaining transects can be found in Appendix C. With these results, CSHORE was advanced for all simulations using the calibrated parameters shown in Table 18.

Table 18. CSHORE Parameters. Default values were used with some exceptions where alternative values yielded results closer to physical observations during calibration tests.

Parameter Name	Default Value	Calibrated Value
Shallow Water Wave Breaking Parameter	0.8	0.8
Sediment Porosity	0.4	0.4
Average Sediment Size (D_{50})	0.3	0.61
Specific Gravity	2.65	2.65
Suspension Efficiency due to Breaking	0.005	0.002
Suspension Efficiency due to Friction	0.01	0.01
Suspended Load Parameter	0.5	0.5
Overtopping Suspended Load Parameter	0.1	0.1
Sediment Friction Angle Tangent	0.630	0.630
Bedload Parameter	0.001	0.001
Bottom Friction Parameter	0.015	0.015

* Further description of the parameters can be found in the CSHORE documentation (Johnson 2012)

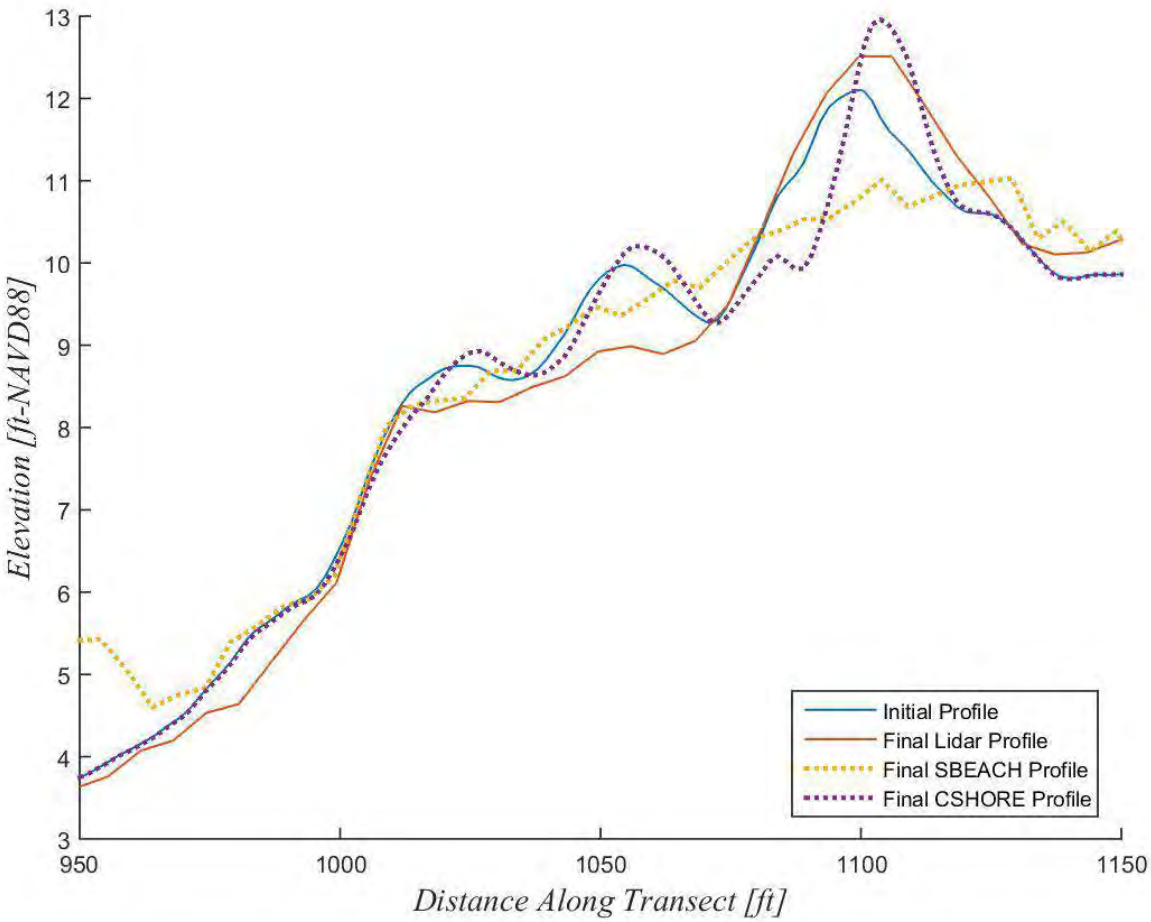

Figure 54. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 4. Final CSHORE Profile is much closer to Final Lidar Profile relative to SBEACH results.

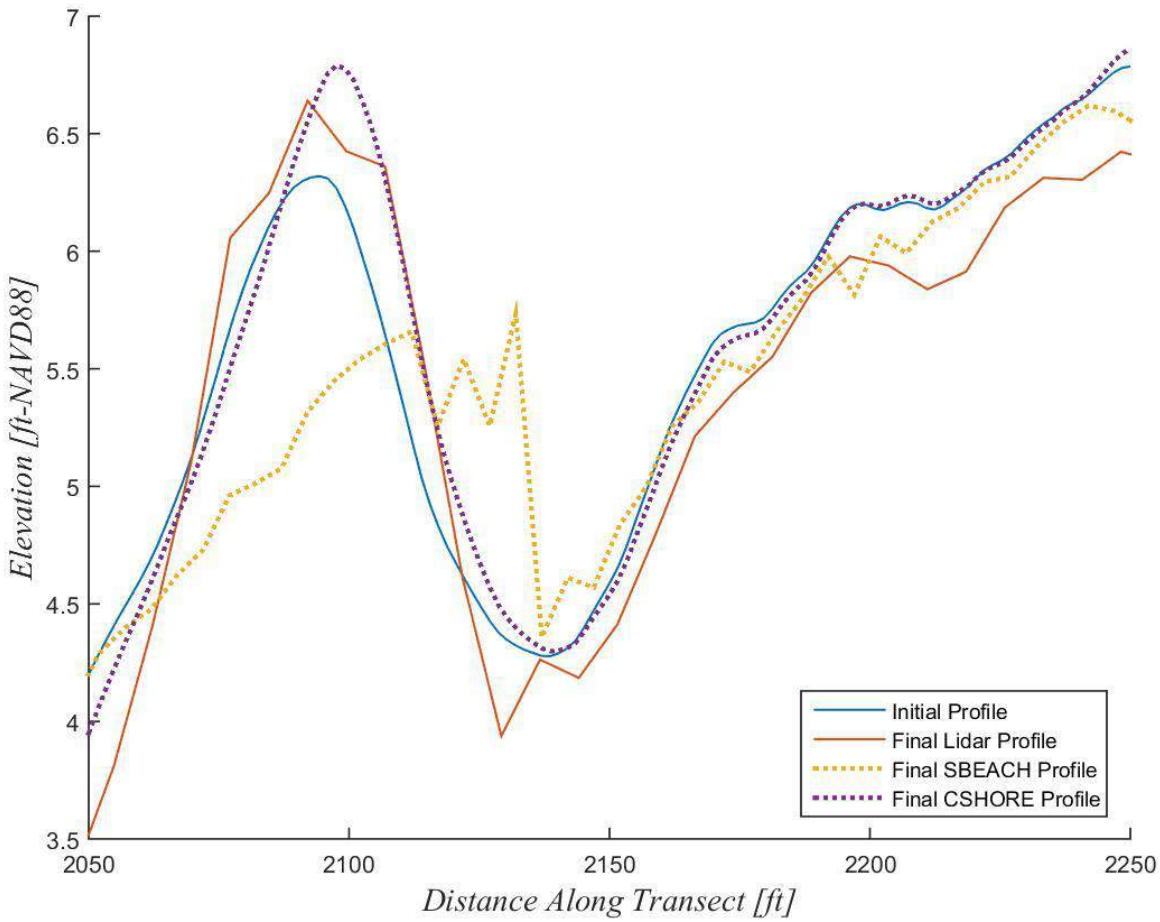

Figure 55. CSHORE and SBEACH model results for Hurricane Sandy at transect 21. Final CSHORE Profile is much closer to Final Lidar Profile relative to SBEACH results.

SIMULATION RESULTS – WITHOUT-PROJECT

Figure 56. Location map of beach profile transects. Transects 1-7 and 21-23 were modeled in CSHORE.

In addition to Hurricane Sandy, the CSHORE model was run for all four FEMA storms at the ten beach profile transects outside the TSPP project limits. The results for transects 1 through 5 show little or no change to the beach profile for any of the four FEMA storms. These transects are sheltered from the most direct wave exposure, explaining their muted shoreline response. Only during the Sandy simulations did these transects change noticeably due to the storm event.

Transects 6, 7, and 21 are more exposed and have more pronounced dune crests. These transects show increased erosion for most storms. In the CSHORE model, high frequency events (10- and 25-year storms) had lower surge elevations which allowed the wave activity to hit the beach directly and cause erosion. Low frequency events (50- and 100-year storms) had higher surge elevations which carried the wave activity over the beach region, leaving it unchanged. These results suggest higher frequency storms pose a greater risk to the beach region while lower frequency storms pose a greater risk to inland areas. And Hurricane Sandy, which had the greatest wave activity of the storm set, caused erosion along the beach despite the high surge elevation. Figure 57 shows the results for the four FEMA PFIRM events at transect 6. Figure 58 shows evolution of Transect 6 at four snapshots in time during the 25-year storm, demonstrating the influence of water level on the erosion of the dune features.

Transects 22 and 23 lack a pronounced dune crest, which is one of the more fragile parts of a beach profile. These dune crests get built up during calm periods, but are not able to withstand elevated surge and wave activity during storms. Without a large dune crest, transects 22 and 23 show a reduced storm response during the FEMA PFIRM storm event simulations as well as during the Hurricane Sandy simulation. Appendix D shows the results for the four FEMA PFIRM events at all the modeled transects.

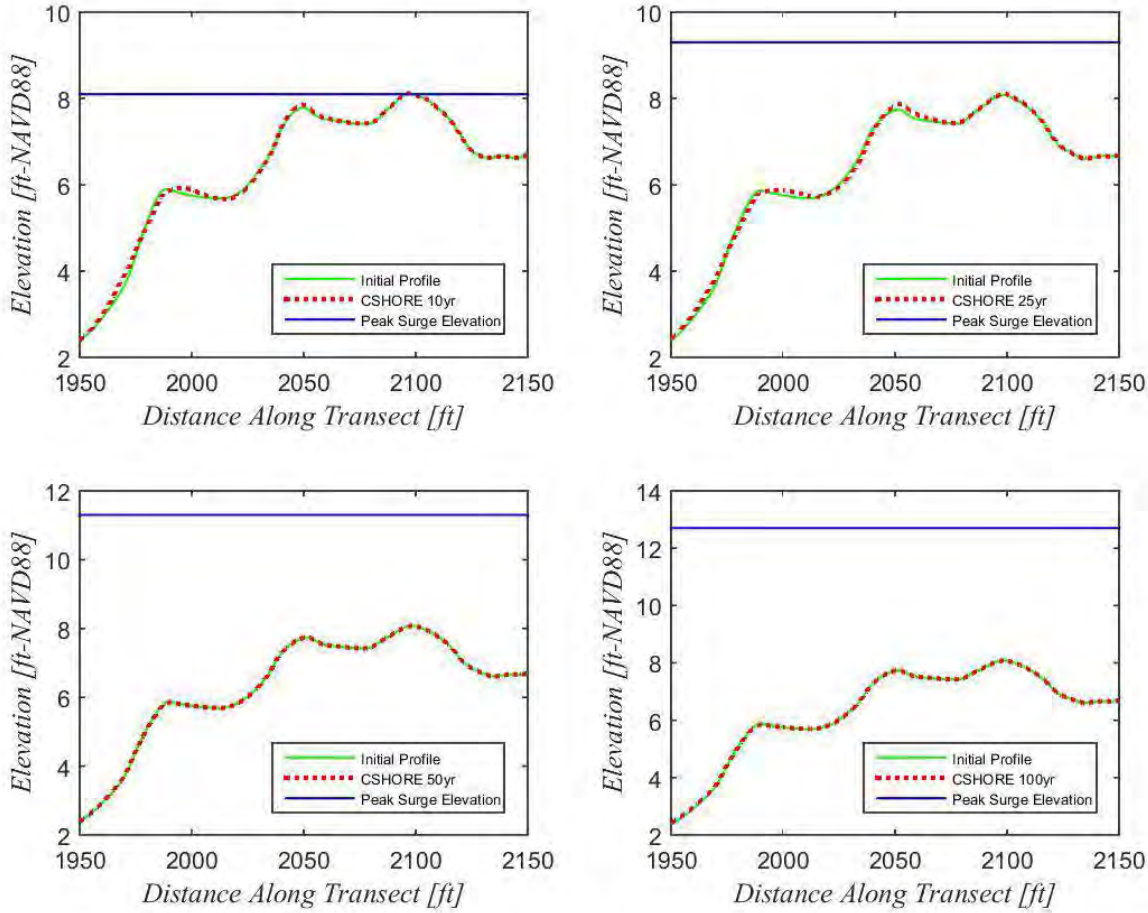

Figure 57. CSHORE results for 10-, 25-, 50-, and 100-year storm events at transect 6.

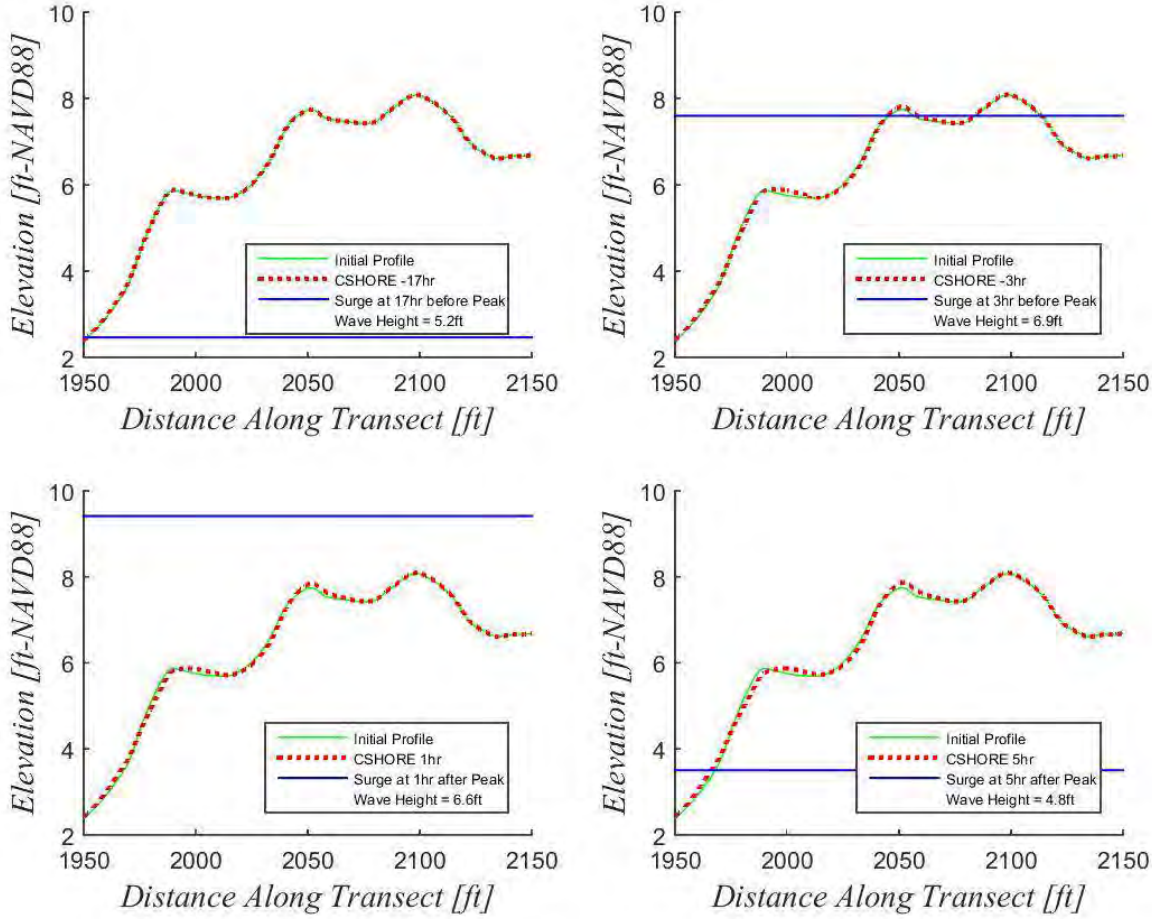

Figure 58. CSHORE results for 25-year storm event at Transect 6 at four times during the storm event.

30% DESIGN SIMULATIONS

CSHORE simulations were performed with the wave height reduction estimates from the REFDIF 30% design simulations with the Living Breakwaters for the 100-year FEMA PFIRM event. The reduction factor of 0.5 was applied for waves from the east at Transects 6 and 7 as shown in Table 11 (see RefDif Section). Other transects described in this section, transects 1-5 and 21-23, were not in the shadow zone of the Living Breakwaters so were not included in the with-project analysis.

The wave direction time series for the 100-year event was reviewed demonstrating that the majority of the storm waves approached from the east, allowing the reduction factor to be applied during most of the event. For wave approach directions within ±45 degrees from east, the reduction factor was linearly interpolated between 0.5 and 1.0 (i.e 0.5 at 0 degrees from east 0.75 at 22.5 degrees from east, and 1.0 at 45 degrees from east). Figure 59 shows the reduced wave height inputs used for the with-project simulations. Also note that these wave height inputs correspond to storm data at the offshore end of transects 6 and 7 (see Figure 40), and are therefore different from Figure 43 through Figure 47 which correspond to storm data closer to shore.

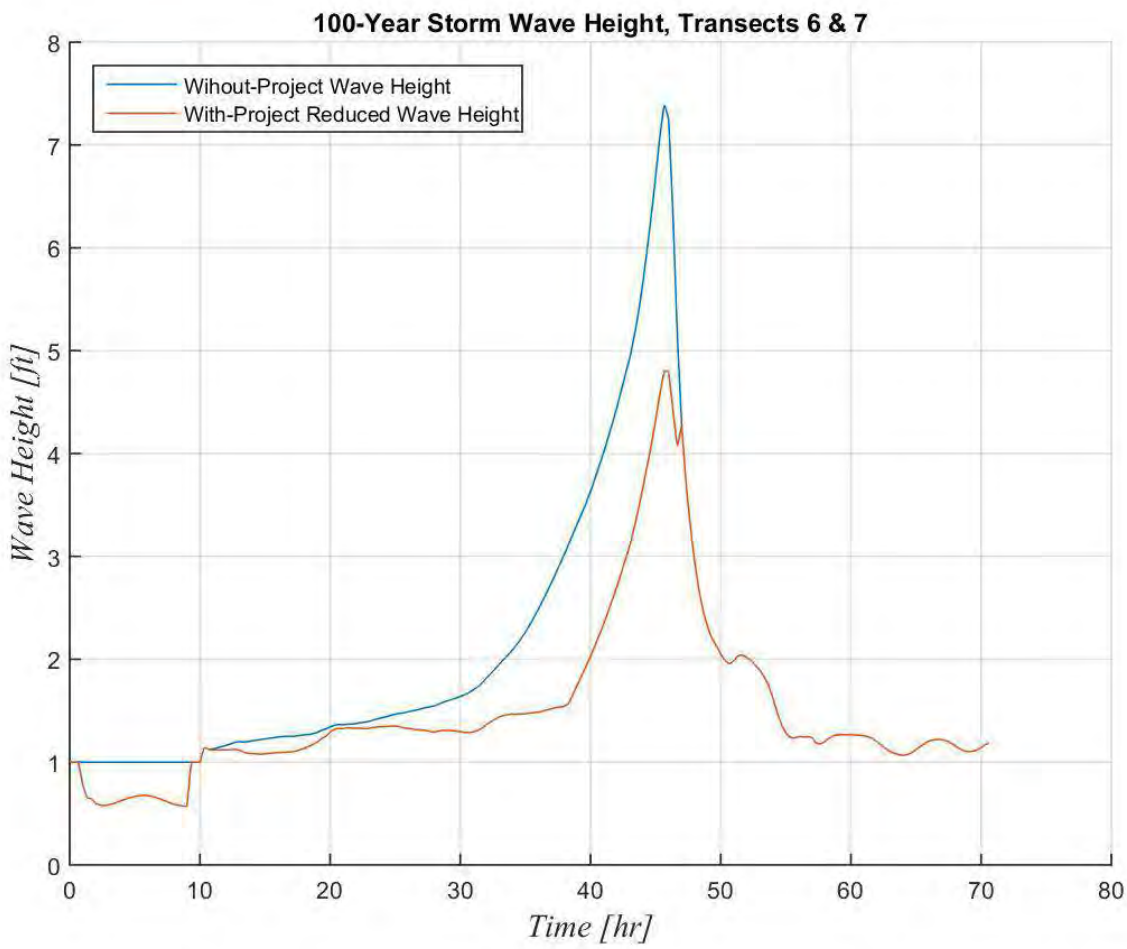

Figure 59. With-project (reduced) wave height compared to without-project (original) wave height for the 100-year storm event at transects 6 and 7.

Figure 60 shows transect 6 with-project results for the 100-year storm event, demonstrating a similar response to the without-project profile shown on Figure 57. The similar response with- or without-project is likely due to the fact that the storm tide elevation is significantly higher than the dune crest elevations. It is expected that the wave reductions resulting from the Living Breakwaters will have the most benefit to beach transects in the TSPP project area, which is outside the scope of this analysis.

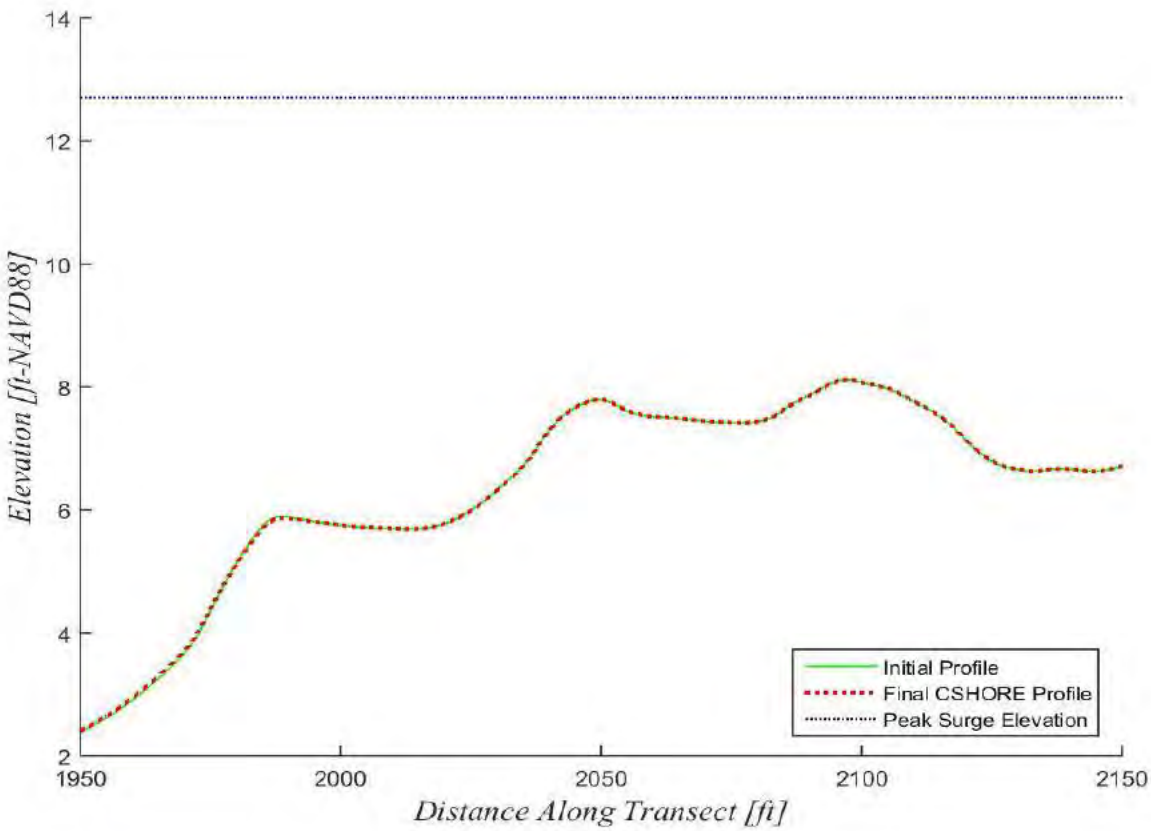

Figure 60. CSHORE results for transect 6 after the 100-year storm event using with-project (reduced) wave heights. No change was found along the profile because the high surge levels carried the wave activity above the beach profile.

CONCLUSIONS

In summary, the CSHORE model was used to simulate with- and without-project beach profile changes during the FEMA PFIRM 10-, 25-, 50-, and 100-year events at transects 1-7 and 21-23. The model parameters were based on a calibration effort using limited available data measured during Hurricane Sandy. The calibration effort also demonstrated that SBEACH was not capable of reproducing Hurricane Sandy response at the dune crests, requiring the use of CSHORE for all simulations. The limited availability of calibration data requires caution in the interpretation of the results presented in this section.

However, the current calibration results suggest that the beach profile does not respond significantly to large storm tide events outside of the TSPP project area, which is what was observed during Hurricane Sandy. These muted responses may be attributed to a large effective sand grain size and significant amounts of vegetation cover on the dunes and landward of the dunes. These results may also vary from results within the TSPP project area which may be more at risk of event based erosion.

WATER CIRCULATION MODELING

In studying alternatives for the Living Breakwater off the coast of Staten Island, it is important to recognize the effect such a structure would have on residence time and flushing of water and potential pollutants between the breakwater and the shore. In order to evaluate the potential impacts of the breakwater system on water quality, the time required for tidal flushing, or residence time, with and without Living Breakwaters was modeled using Delft3D-FLOW, a finite volume hydrodynamics model, and Delft3D-WAQ, a multidimensional water quality framework. This section describes the setup of the Delft3D-FLOW and Delft3D-WAQ models, the model validation procedures, and the influence of the Living Breakwaters on tidal flushing.

DELFT3D MODEL OVERVIEW

Delft3D is a globally-applied robust model used to assess hydrodynamics, water quality, and morphology. In this phase of design, it was used to simulate tidal currents and assess potential changes in flushing time. The movement of a conservative tracer was introduced in the lee of the living breakwaters and the flushing time was quantified with and without living breakwaters.

BASELINE MODEL INPUTS

The Delft3D-FLOW model bathymetry is shown on Figure 61 and was developed from the same bathymetric and survey information used in the wave transformation modeling. The grid is composed of regularly spaced 20 by 20-foot regular grid cells.

Three boundary conditions are applied at the open ocean to the east, the Raritan River, and Arthur Kill. Both the Raritan River and Arthur Kill use a zero-gradient Neumann boundary condition allowing for water to flow in and out. The eastern boundary is forced with water surface elevations extracted from simulations conducted using the FEMA ADCIRC model forced with tidal constituents from the 2001 ADCIRC harmonics database (FEMA, 2014b).

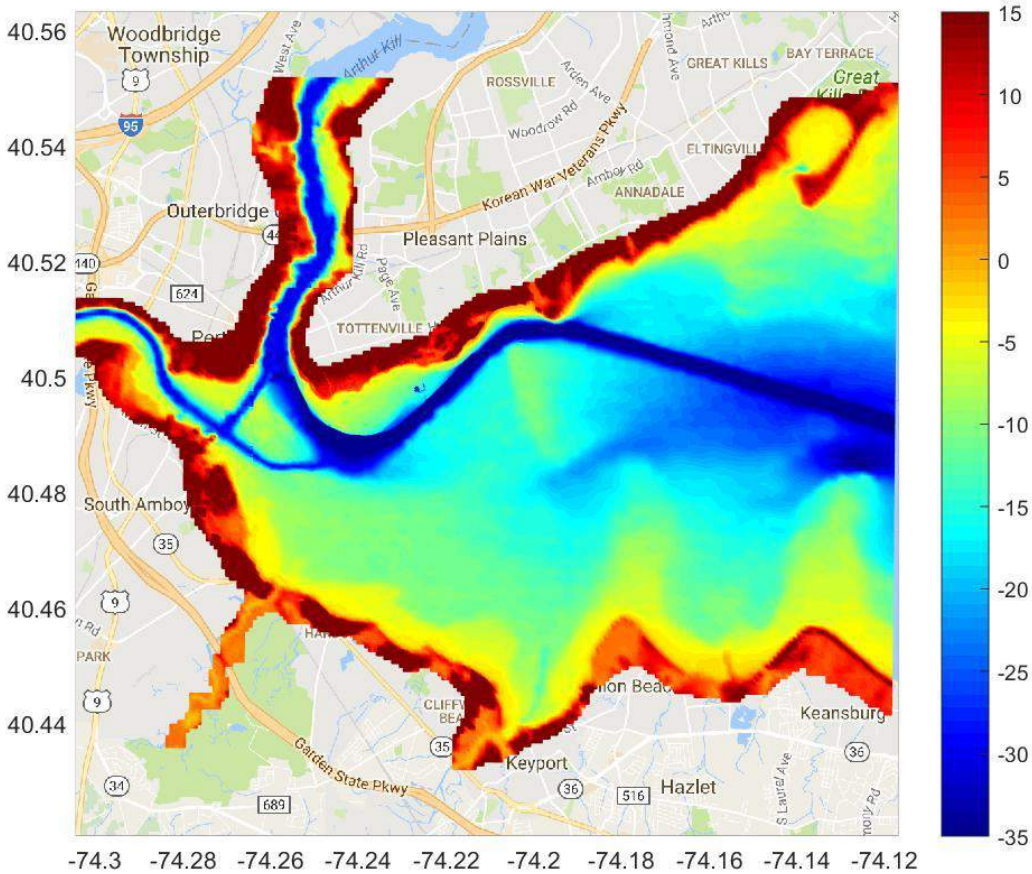

Figure 61. Delft3D model domain and bathymetric contours (feet NAVD88).

MODEL VALIDATION

To ensure the Delft3D-FLOW model was generating reasonable results, a series of validation exercises were conducted to compare computed water surface elevations and velocities to observations.

Unfortunately, only limited long term gage data is available throughout the region, so water surface elevation validation has been conducted using harmonics derived for NOAA subordinate stations, which can be converted to a time series of water surface elevations. Figures 62 through 67 show the comparison of water surface elevations between NOAA subordinate station computed elevations, ADCIRC, and Delft3D-FLOW. Comparisons are generally good in both phase and amplitude with only minor deviations. The largest deviations come during the neap tides while spring tides show excellent agreement.

In order to show that the velocities predicted by the model are reasonable, modeled output was compared to those measured by the deployed ADCP1. Figure 68 shows the comparison of surface velocities at ADCP1. Though Delft3D-FLOW is run in the two-dimensional depth averaged mode, an approximation to surface velocity can be made for comparison to the ADCP. Since wind forcing is not included in the model, an exact match is not expected and results are checked to ensure that reasonable velocities are modeled and that differences can be

understood. A plot of wind speed observations at Sandy Hook is provided to give reference for the discrepancy between the modeled and observed surface velocities. When taken in total, when the wind speeds are greater, the discrepancy between observed and modeled surface velocities is larger while when wind speeds are low, the discrepancy is generally much smaller, particularly on June 11, 2016.

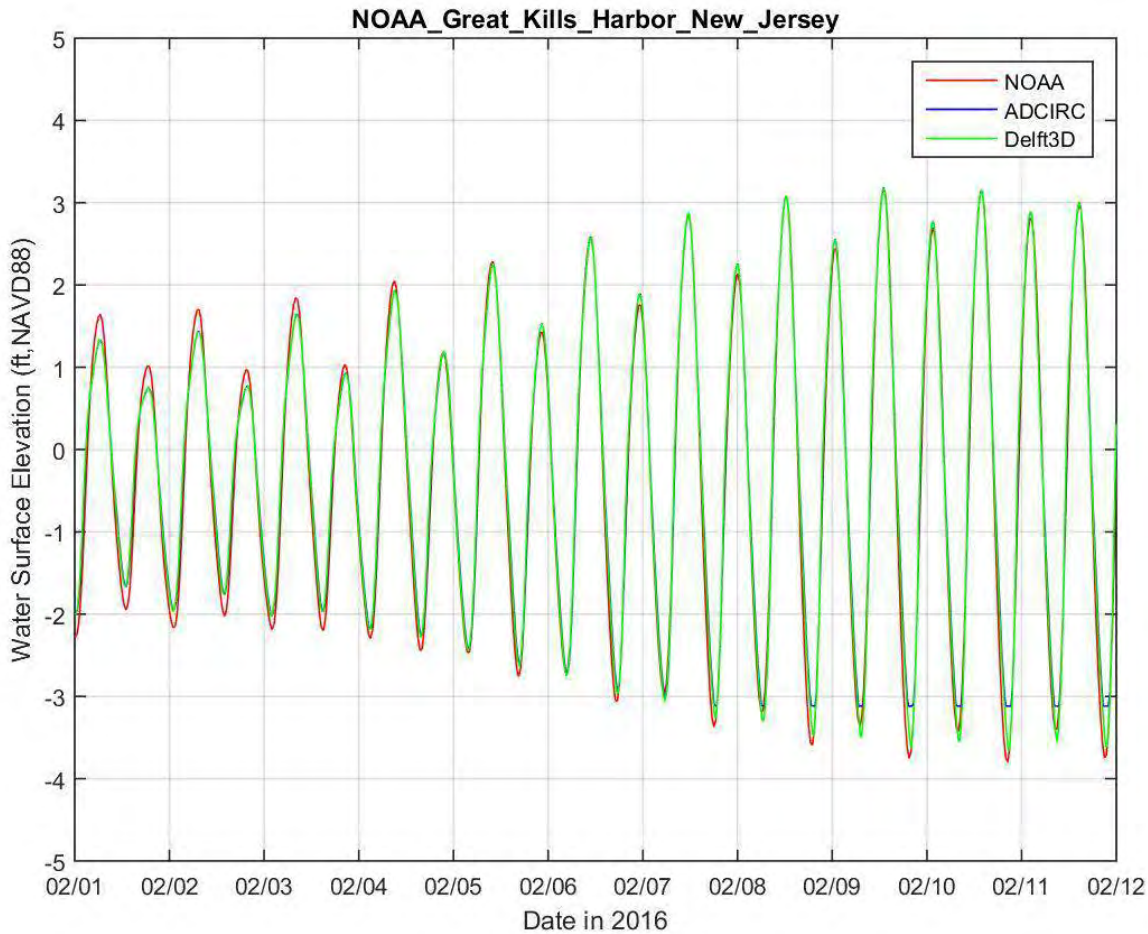

Figure 62. Comparison of water surface elevations (feet NAVD88) in Great Kills Harbor for February 2016 between the harmonics database, the FEMA ADCIRC model, and the Delft3D-FLOW model.

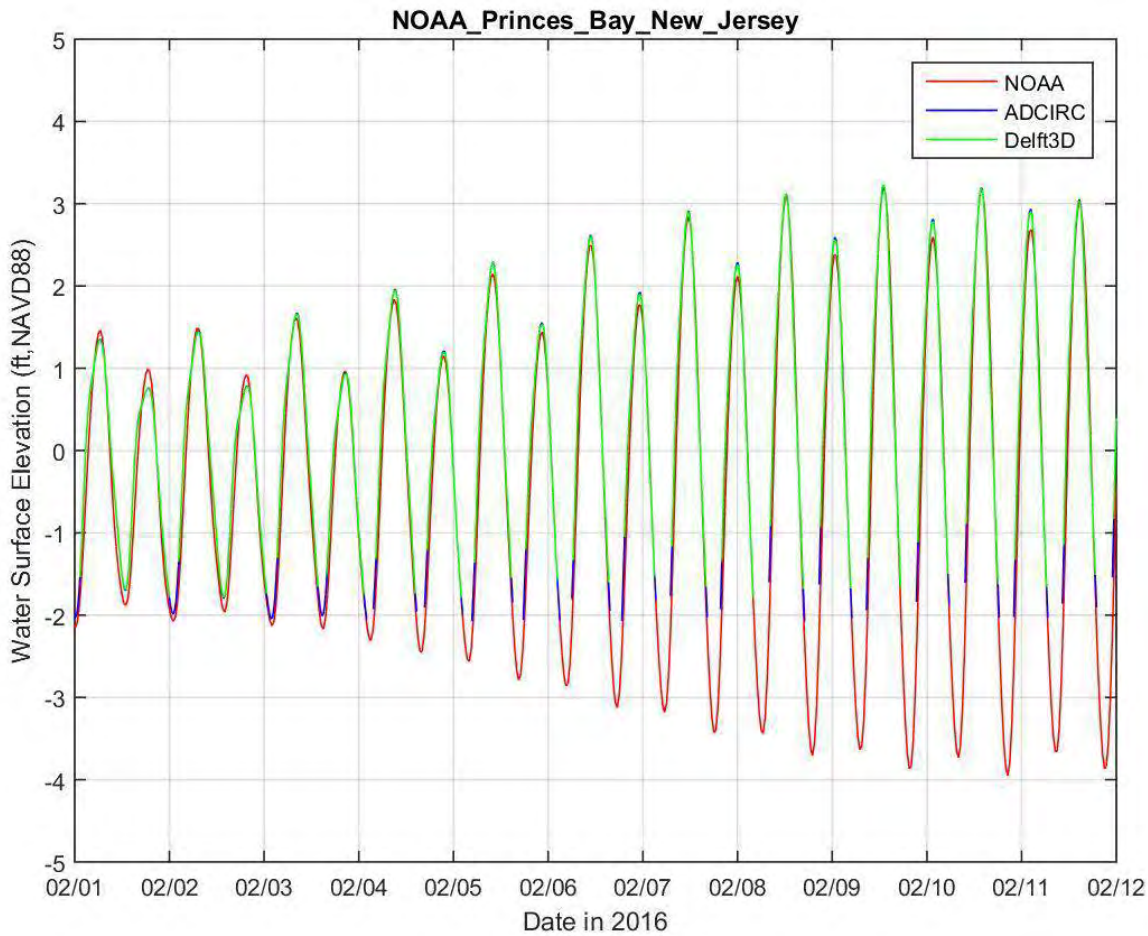

Figure 63. Comparison of water surface elevations (feet NAVD88) in Prince's Bay for February 2016 between the harmonics database, the FEMA ADCIRC model, and the Delft3D-FLOW model.

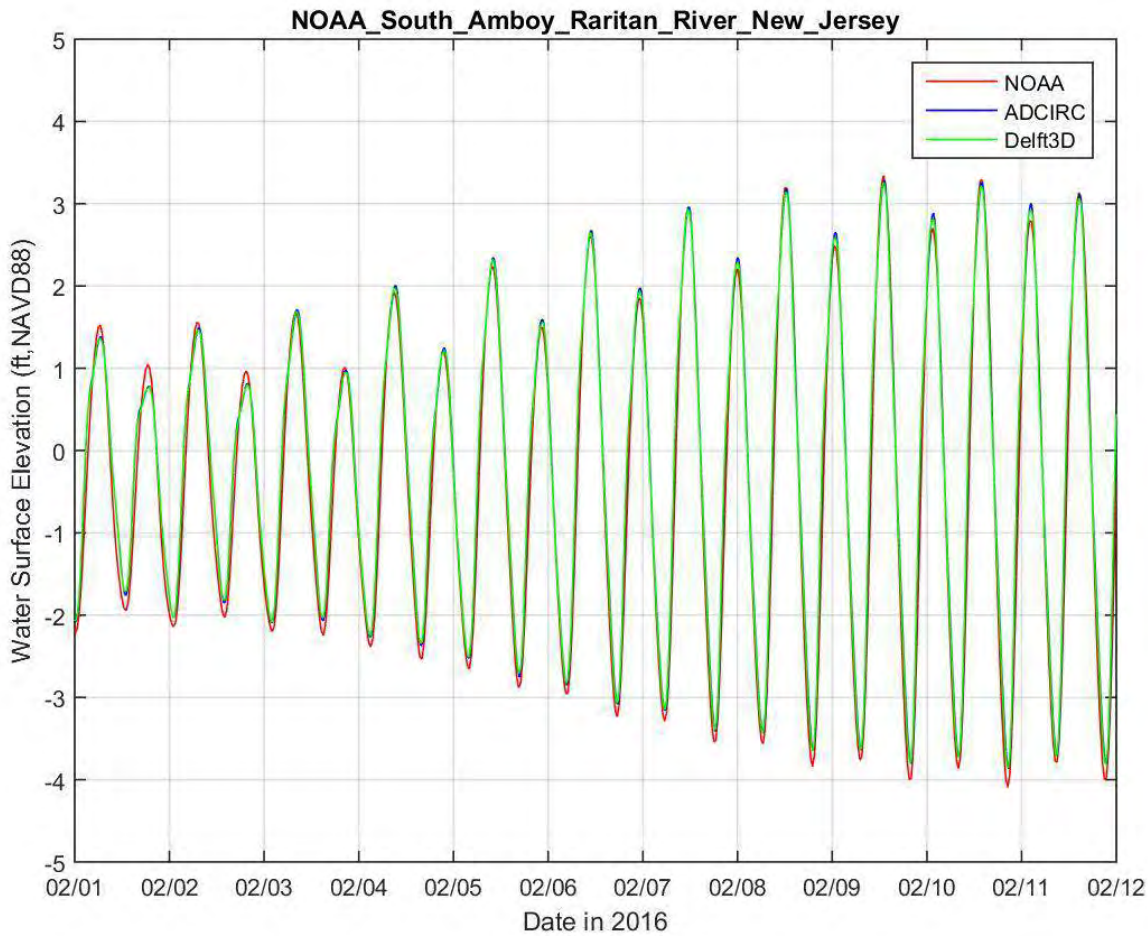

Figure 64. Comparison of water surface elevations (feet NAVD88) in the Raritan River for February 2016 between the harmonics database, the FEMA ADCIRC model, and the Delft3D-FLOW model.

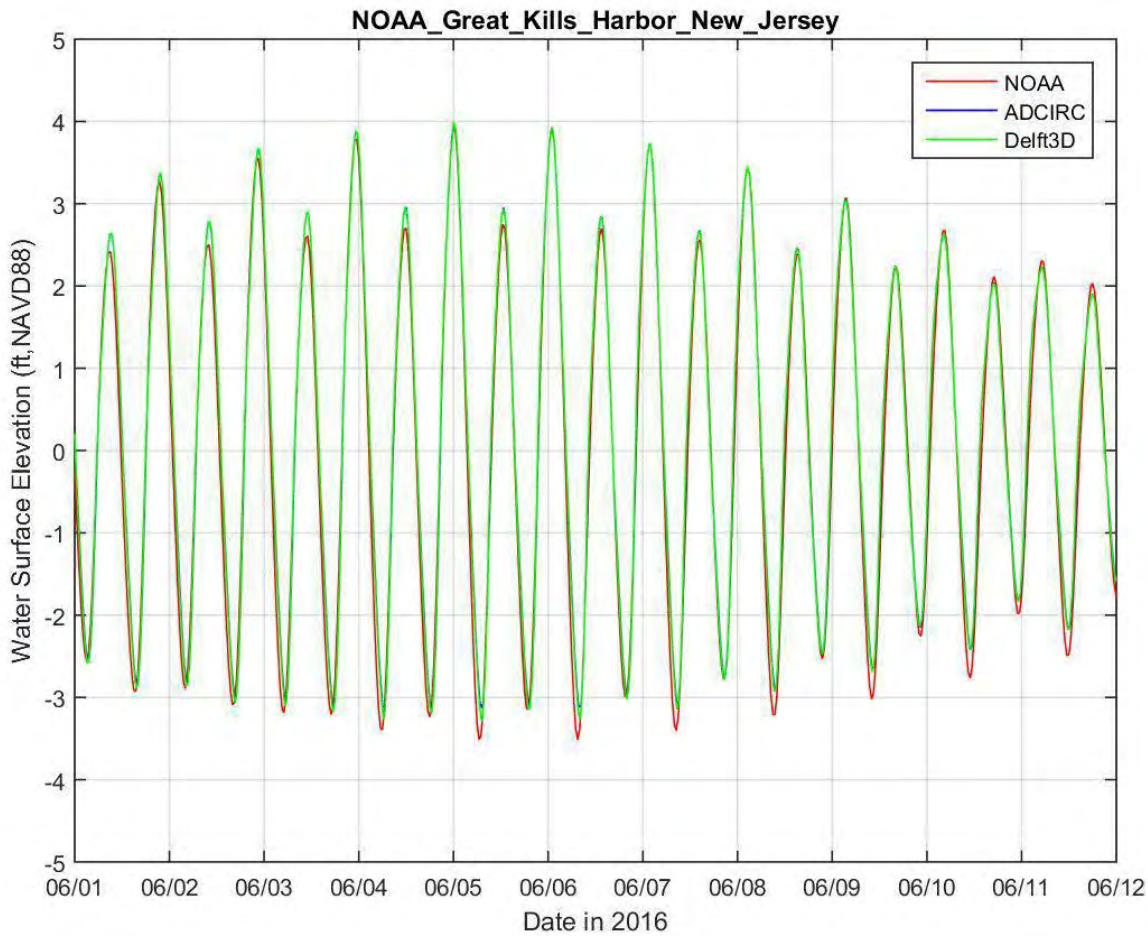

Figure 65. Comparison of water surface elevations (feet NAVD88) in Great Kills Harbor for June 2016 between the harmonics database, the FEMA ADCIRC model, and the Delft3D-FLOW model.

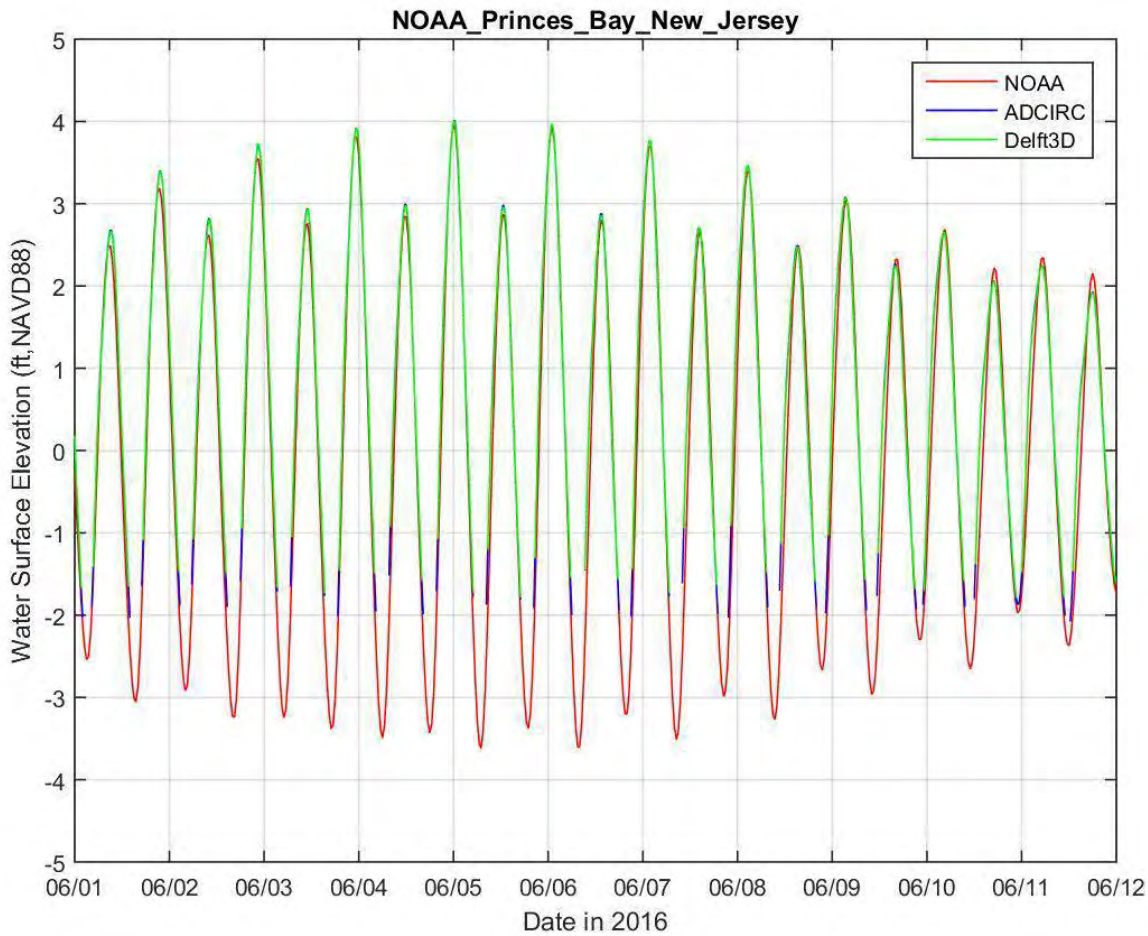

Figure 66. Comparison of water surface elevations (feet NAVD88) in Prince's Bay for June 2016 between the harmonics database, the FEMA ADCIRC model, and the Delft3D-FLOW model.

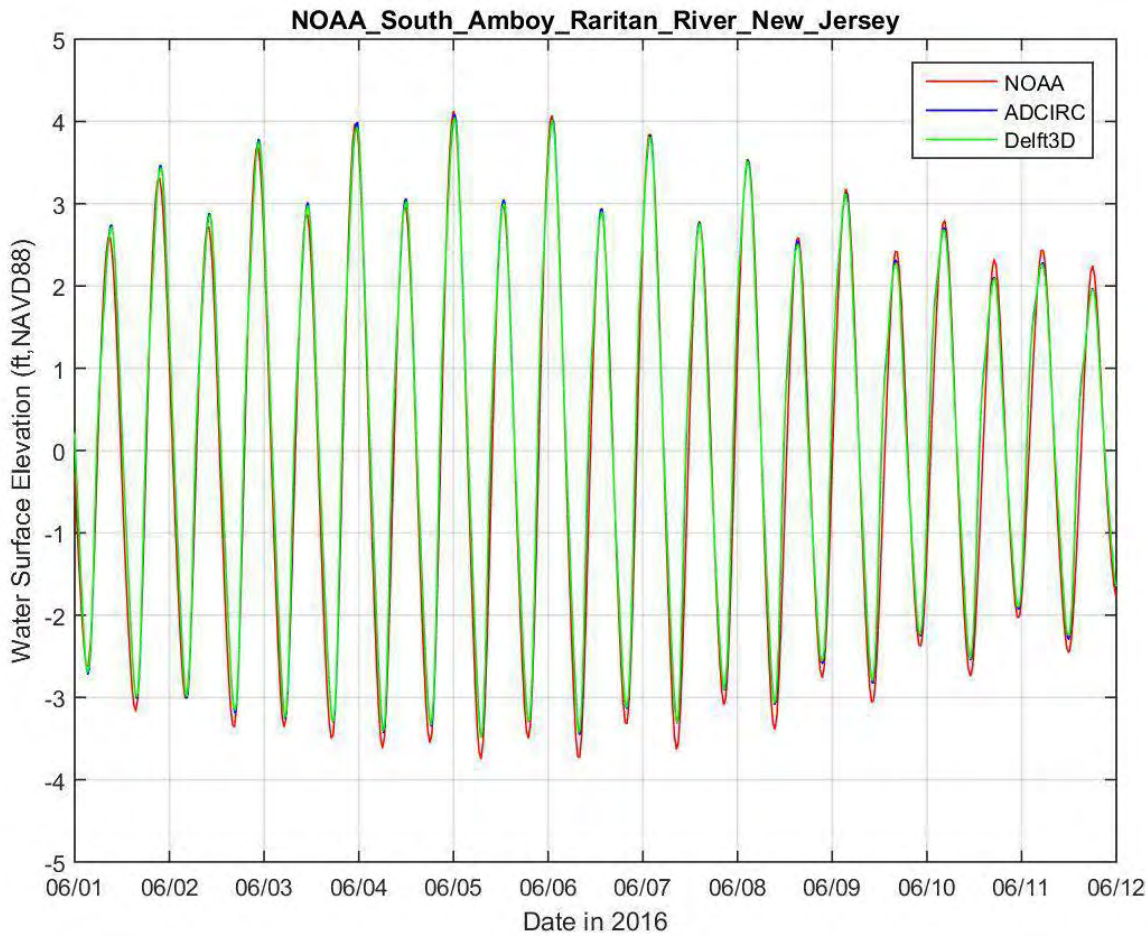

Figure 67. Comparison of water surface elevations (feet NAVD88) in the Raritan River for June 2016 between the harmonics database, the FEMA ADCIRC model, and the Delft3D-FLOW model.

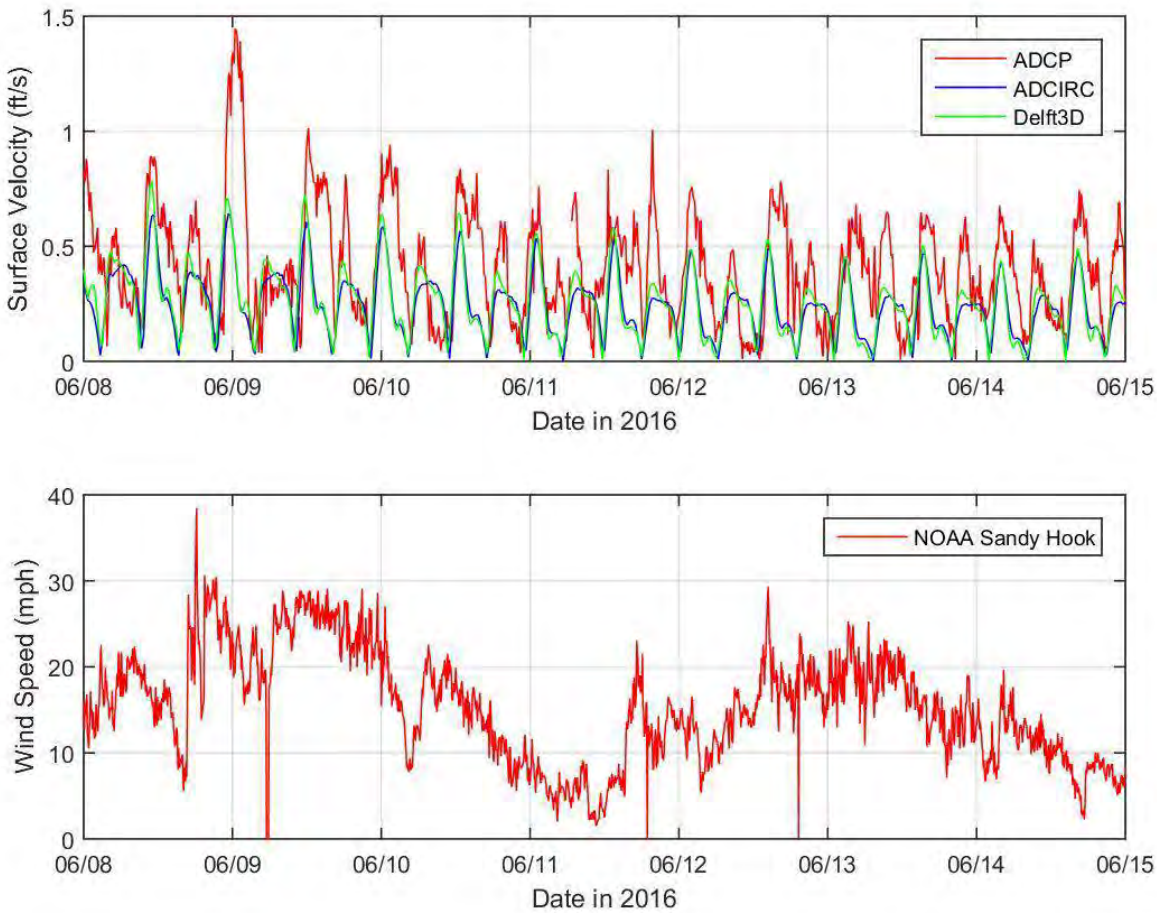

Figure 68. Comparison of observed and modeled surface velocities (top) and wind speed observations at Sandy Hook, NJ (bottom).

RESIDENCE TIME MODELING SETUP

Hydrodynamics were computed for both February 2016 and June 2016 with and without the living breakwaters. These time periods were chosen since they corresponded to times when ADCP data were available. Also, one is the start of a neap tide cycle and the other a spring tide cycle. These hydrodynamic results are used to force the Delft3D-WAQ water quality simulation. It is assumed that the validated hydrodynamics are adequate predictors of tracer movement in the absence of data to validate the water quality model. A conservative tracer is placed into hydrodynamic simulations that have been running for 30 days, which allows the model to reach a dynamic steady state. Besides the movement of the tracer due to the water velocities, molecular diffusion is also included in the model to advect tracer.

Figure 69 shows the initial placement of the tracer slug. The slug is placed so that it encompasses the entire area enclosed by the breakwaters. The tracer is allowed to move throughout and exit the domain over the next 30 days of simulation. Flushing estimates are made by computing the mass of tracer remaining within the area originally defined on Figure 69. The time required to reach 50%, 37%, and 10% remaining concentration are reported in this

analysis, i.e. t_{50}, t_{37}, and t_{10}. The time required to reach 37% of the remaining concentration is used to represent the flushing time in the system. (Monsen, 2002)

Figure 69. Location of initial tracer slug (yellow hatch) relative to 30% design Living Breakwaters layout (red).

RESIDENCE TIME SIMULATION RESULTS

Figures 70 through 74 show snapshots of the tracer's movement in June 2016 over 5 days. Each left pane shows the simulation without breakwaters and each right pane shows the simulation with breakwaters. The tracer can be seen moving through and around the breakwaters. By day 5, the plume with and without breakwaters is very similar and most of the concentration has moved out of the study area in both cases.

Figure 75 and Figure 76 show the concentration of tracer in time as a percentage of its mass remaining in the study area. In general, the addition of breakwaters does not significantly change the flushing of the tracer and most of the substance leaves rather quickly. The changes to residence time are on the order of only a few hours. This information is summarized in Table 19.

Table 19. Summary of residence times computed by the water quality model.

	Feb-16			Jun-16		
Residence Time Metric (%)	Without Breakwaters (days)	With Breakwaters (days)	Change in Residence Time (hr)	Without Breakwaters (days)	With Breakwaters (days)	Change in Residence Time (hr)
t_{50}	1.26	1.35	2.16	0.33	0.49	3.84
t_{37}	1.88	1.82	-1.44	0.79	0.93	3.36
t_{10}	4.49	4.42	-1.68	1.97	1.99	0.48

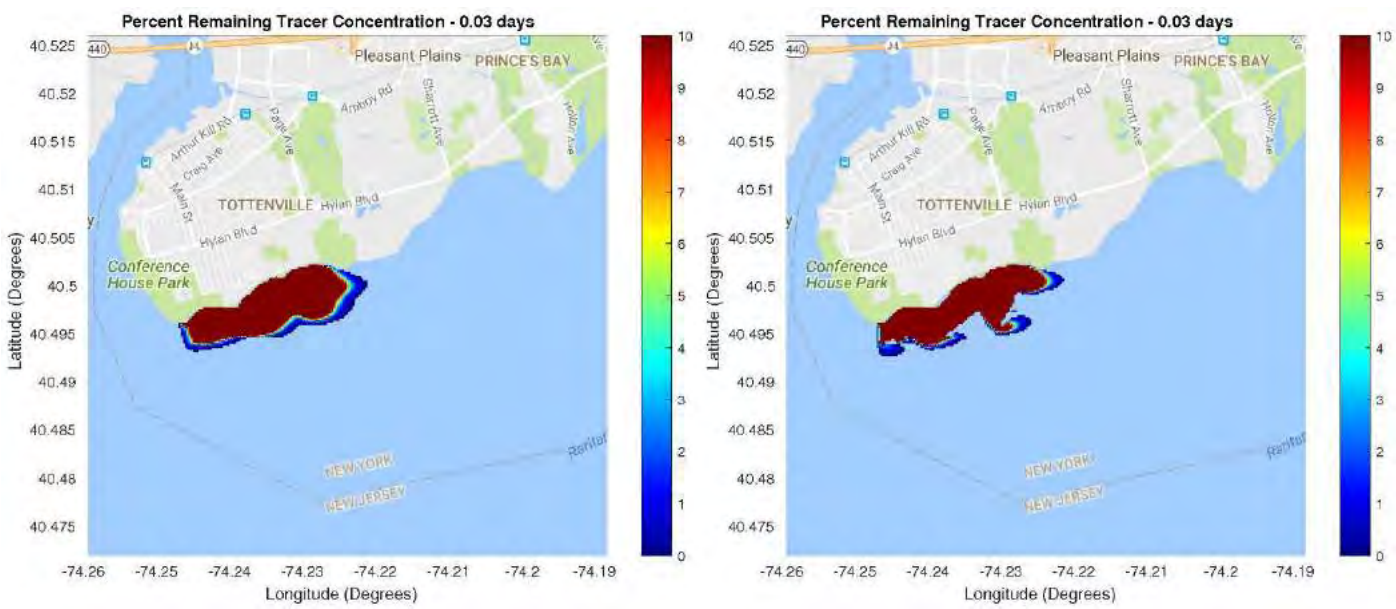

Figure 70: Water quality simulation of conservative tracer in June 2016, 0.03 days into simulation. Left pane without breakwaters and right pane with breakwaters.

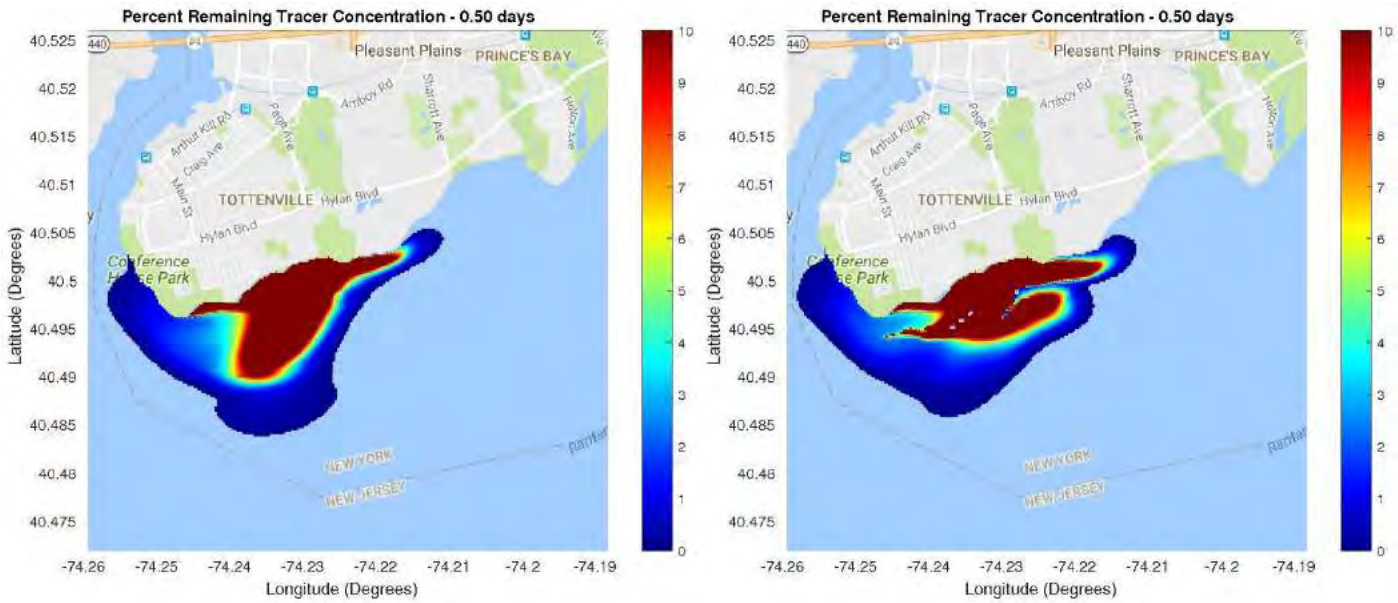

Figure 71. Water quality simulation of conservative tracer in June 2016, 0.50 days into simulation. Left pane without breakwaters and right pane with breakwaters.

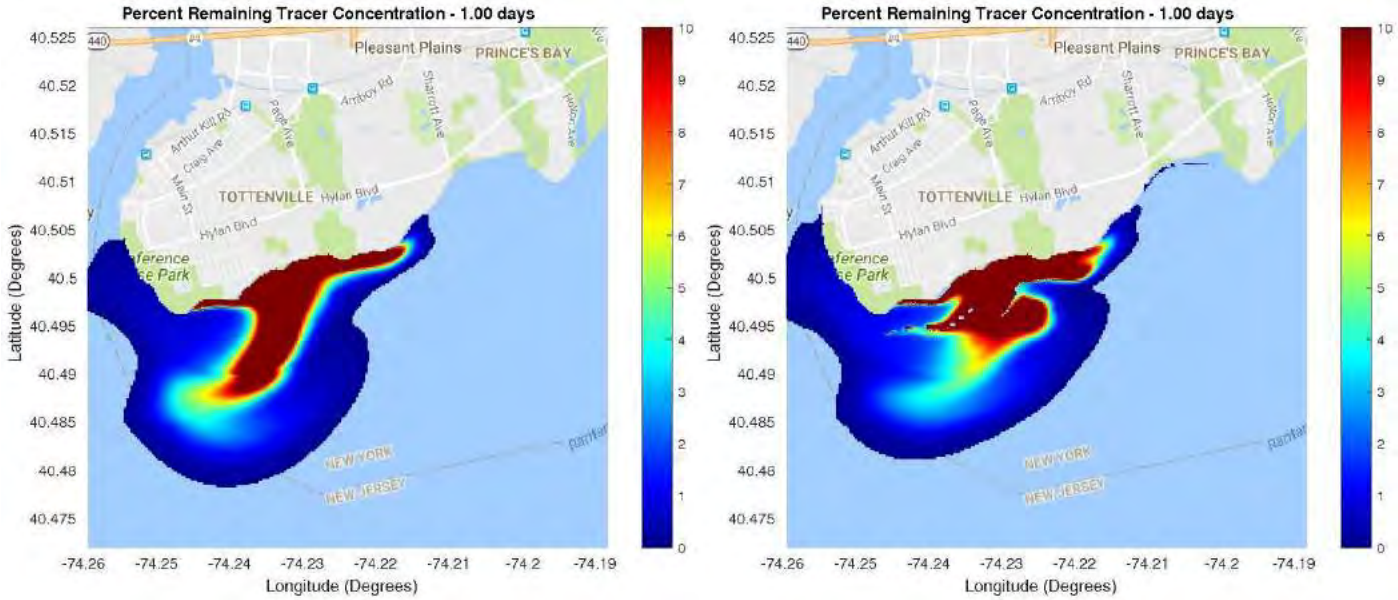

Figure 72. Water quality simulation of conservative tracer in June 2016, 1.00 days into simulation. Left pane without breakwaters and right pane with breakwaters.

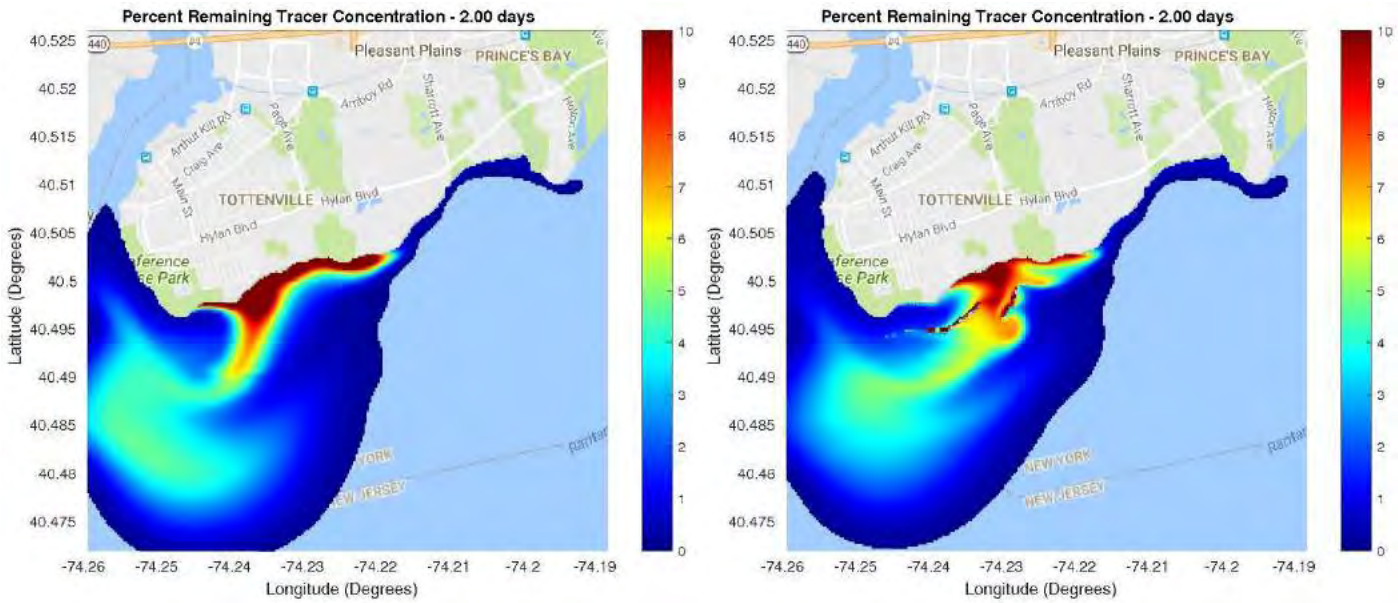

Figure 73. Water quality simulation of conservative tracer in June 2016, 2.00 days into simulation. Left pane without breakwaters and right pane with breakwaters.

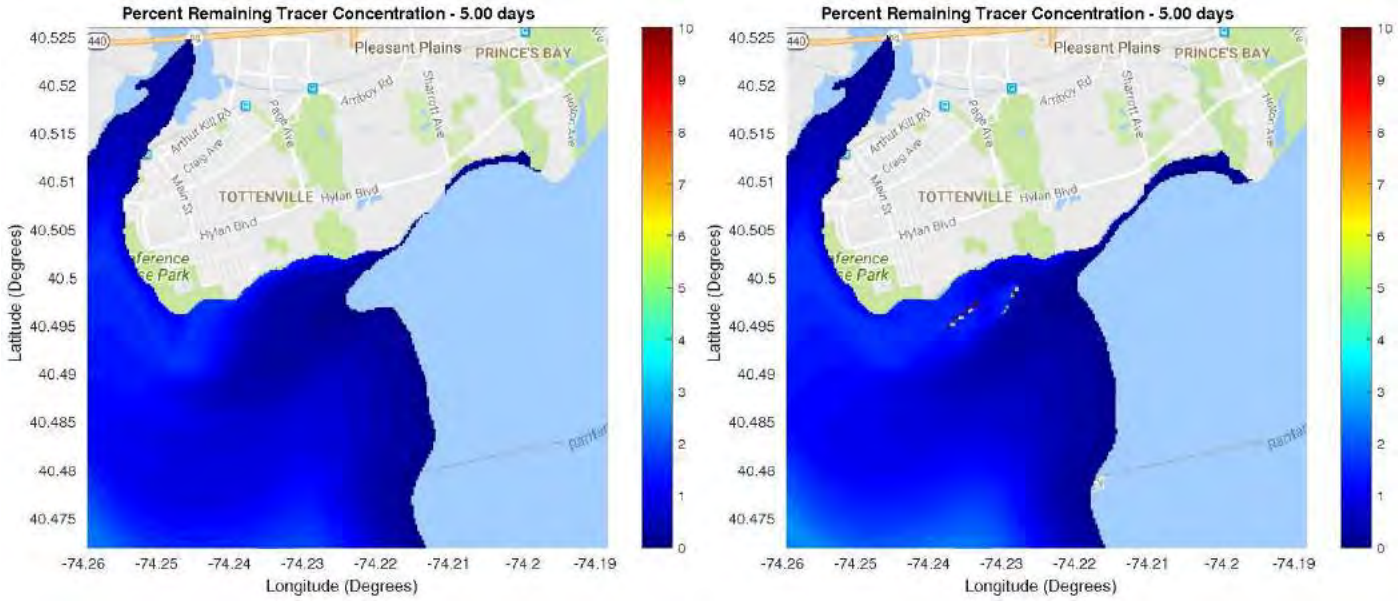

Figure 74. Water quality simulation of conservative tracer in June 2016, 5.00 days into simulation. Left pane without breakwaters and right pane with breakwaters.

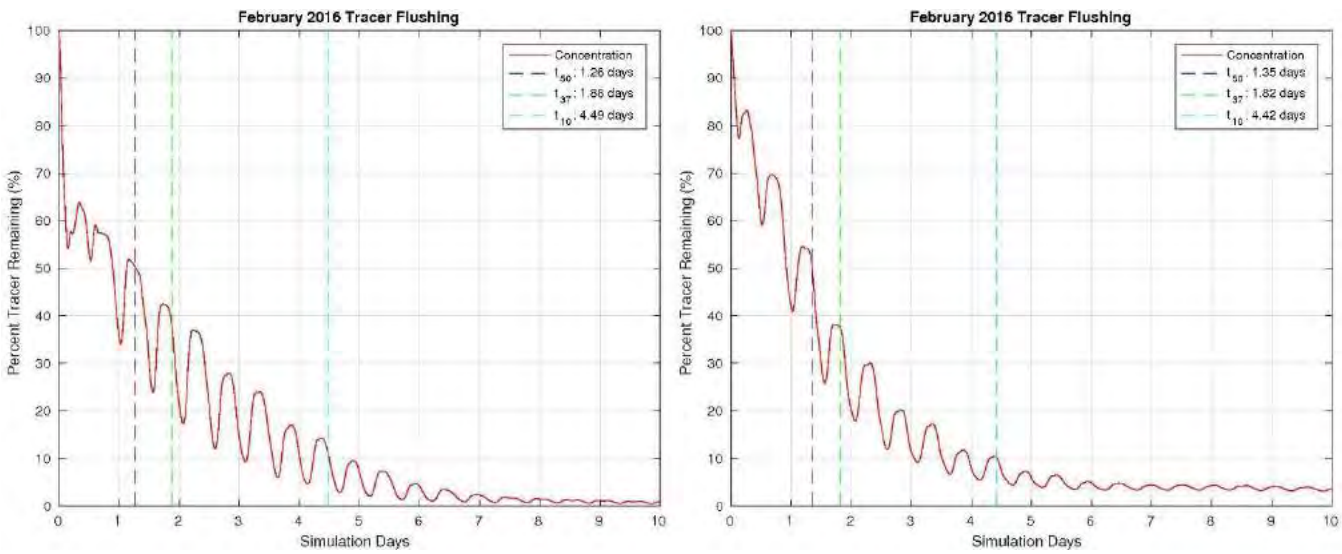

Figure 75. Comparison of concentration remaining in study area without breakwaters (left) and with breakwaters (right) for the February 2016 simulation.

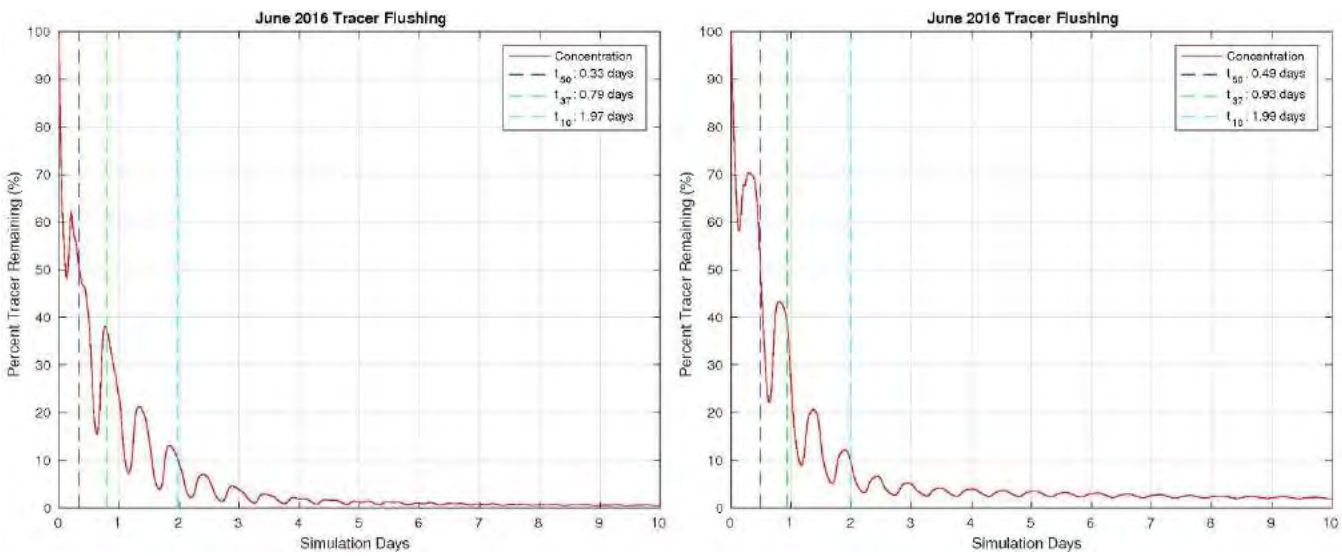

Figure 76. Comparison of concentration remaining in study area without breakwaters (left) and with breakwaters (right) for the June 2016 simulation.

CONCLUSIONS

Simulations indicate the concentration of tracer was less than 50% after less than 1.5 days and less than 10% remaining after 4.5 days for both the with- and without-project conditions. The results of the Delft3D water circulation model indicate minimal differences in the overall flushing times due to the presence of the breakwaters. Changes in residence times (time water remains in area shoreward of proposed breakwaters) were modeled as less than a few hours. Based on the modeling, the proposed breakwater design should have negligible, if any, impact on water quality in the project area relative to the existing conditions.

SUMMARY AND CONCLUSIONS

In support of 30% design of the Living Breakwaters modeling was performed to estimate project goals related to shoreline change, wave energy reduction, and maintained water quality flushing time. Wave transformation, shoreline change, storm induced beach profile response (cross shore change), and water circulation modeling were conducted.

Shoreline change modeling requires long-term wave data to achieve reasonable estimates. Since long-term wave data was not available in the immediate vicinity of the Living Breakwaters, a SWAN wave model was used to develop a 30-year (1982-2012) wave hindcast. This modeling transformed the offshore USACE WIS station wave hindcast available east of Sandy Hook together with local wind data and was validated with available wave measurement records in Raritan Bay.

Using this project vicinity wave hindcast data, shoreline change modeling was performed using the GENESIS model. The model was calibrated/validated using orthoimagery-based observed shoreline changes from 1978-2012. GENESIS was the primary tool to perform “what if” scenario evaluations of varying breakwater layouts allowing assessment of the potential impacts on shoreline change to help achieve the intended shoreline response goals of the project. The shoreline change model results demonstrated that the Living Breakwaters could be aligned to effectively reduce historical erosion rates and maintain the beach.

In addition to maintaining the beach, wave reduction is another goal of the Living Breakwaters. The REFDIF wave model was used to demonstrate the breakwaters were effective in attenuating wave energy and that a desired balance of shoreline change and wave protection to meet project goals could be achieved. Average wave height reductions of 38% to 51% were seen at the critical residential areas. Resiliency to sea level rise was also demonstrated with average wave height reductions in the same region ranging from 37% to 49% when including 30 inches of sea level rise.

Short-term shoreline response modeling during storms of significance was also performed. Limited LiDAR, wave, and water level data during Hurricane Sandy was used to calibrate the model. The calibration effort demonstrated that the SBEACH model was not capable of reproducing observed dune response during Hurricane Sandy. However, the CSHORE model was capable of reproducing dune response during Hurricane Sandy and was adopted for this analysis. Observed short-term shoreline response was muted during Hurricane Sandy, perhaps due to a relatively large effective sand grain size and/or due to the significant vegetation cover on and landward of dunes. CSHORE results with and without the Living Breakwaters each showed a muted response of the beach and dune features during the FEMA PFIRM 100-year event. This is consistent with the Hurricane Sandy response, which has characteristics similar to the FEMA PFIRM 100-year event. The CSHORE modeling was focused on shoreline areas outside of the TSPP project area, with the expectation that the TSPP team will perform similar short-term shoreline response modeling in the vicinity of the TSPP project area. Additional benefits of the Living Breakwaters on the TSPP project area may result from these simulations.

Flushing time behind the Living Breakwaters was evaluated with the Delft3d model. Simulations were performed during two months for which ADCP measurements were available to support model validation. Conservative tracer was released at the beginning of the each month in the lee of the Living Breakwaters and flushing time was

evaluated with and without Living Breakwaters. Results revealed no significant change in the residence time or tidal flushing with the Living Breakwaters in place.

In summary, the model simulations have demonstrated that the Living Breakwaters are effective at achieving the overall project goals to reduce historical erosion shoreline, maintain the shoreline and reduce wave energy in front of residential areas, and not have impacts on water quality flushing time. Although the modeling performed for 30% design was comprehensive for the current level of detail required, additional numerical and/or physical modeling with further physical detail will be performed at 60% design to further confirm the Living Breakwaters layout that achieves shoreline change, wave reduction, and habitat benefits without sacrificing water quality flushing times.

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APPENDIX A – 30% DESIGN MODELING RESULTS REPORT

LIVING BREAKWATERS

30% DESIGN MODELING RESULTS REPORT

Modeled Scenarios & Results (GENESIS, REFDIF, DELFT3D)

Date: 10/07/2016
Prepared by: ARCADIS
Reviewed by: **SCAPE**

VERSION	DATE	NOTES
1.0	08.01.2016	FIRST VERSION SUBMITTED FOR CLIENT REVIEW. THIS DRAFT ONLY INCLUDES RESULTS COMPLETED THROUGH 07.30.2016
2.0	10.12.2016	VERSION SUBMITTED AS APPENDIX TO 30% DESIGN MODELING REPORT

NAME	ORGANIZATION	DATE	COMMENTS PROVIDED?	COMMENTS INCORPORATED?

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Historic shoreline change and FEMA pFIRMs

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00: Baseline (future without project)

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SCENARIO 01: “HOLD THE SHORELINE”

SCENARIO 02: “STORM WAVE ATTENUATION”

SCENARIO 03: “TESTING FOR A TOMBOLO”

SCENARIO 04: “LEARNING FROM ROUND ONE

SCENARIO 05: “MODIFIED SCENARIO 4”

SCENARIO 06: “MINIMALIST APPROACH”

SCENARIO 07: “MINIMALIST APPROACH WITH SHORELINE RESTORATION”

SCENARIO 09

SCENARIO 10

SCENARIO 11

SCENARIO 12

SCENARIO 13

SCENARIO 14

SCENARIO 15

FINAL 30% DESIGN SCENARIO 66

Final 30% Design Scenario

Overall Take-Aways

INTRODUCTION

OVERVIEW

This document summarizes the numerical modeling performed to date on the Living Breakwaters breakwater design scenarios during 30% Design. The current version of this report and provides a summary of scenarios modeled and model results completed through 30% Design.

Numerical modeling performed to date has been for long-term shoreline change (using the GENESIS model),wave refraction and diffraction (using the REFDIF model), storm-induced profile response (using SBEACH and CSHORE models), and water circulation (using Delft3D model).

SUMMARY OF MODEL RESULTS (AS OF 10.06.2016)

- Modeling efforts have focused on advancing the breakwater layout for the selection of a 30% design preferred scenario. Initial efforts examined scenarios designed to evaluate the impact of breakwater length, spacing, and distance from shore on long-term shore change (erosion and accretion) and the wave climate in the lee of the breakwaters.
- Additional modeling simulations were performed on potential breakwater system configurations to determine system performance and evaluate various layout options at achieving project goals.
- The without project (baseline) and project (30% design) have been simulated with all models. For some models (GENESIS and REFDIF) multiple scenarios were simulated in the screening and development of the preferred scenario.
- The preferred layout is shown to advance and refine beyond 30% design.

MODEL ASSUMPTIONS AND STANDARDS

- Modeling Assumptions and Standards are outlined in the Project Assumptions and Standards Memo (currently being updated in collaboration with Stantec / RACE) and the 30% Design Modeling Report.
- Shoreline change modeling was performed using the GENESIS model and the wave climate assessed in the lee of the breakwaters using the REFDIF model. Storm induced beach profile change for the shoreline areas outside of the Tottenville Shoreline Protection Project area were assessed using the SBEACH and CSHORE models and water circulation/preliminary water quality were evaluated using the Delft3D model.

Living Breakwaters 30% Design
Summary scenarios modeled

Scenrio

Sc. #	Scenario name (if provided)	GENESIS	REFDIF MHW	REFDIF MHW +30" SLR	REFDIF 100yr	REFDIF 100yr + 30" SLR	Delft 3D	SBEACH	CSHORE
00	No Action	X	X		X		1	1	1
01	Hold the Shoreline	X	X		X				
02	Storm Wave Reduction	X	X		X				
03	Test for Tombolo	X	X		X				
04	"Dream Scenario"	X	X		X				
05	sc05	X							
06	sc06	X							
07	sc07	X							
08	"Permitting" Scenario								
09	sc09	X							
10	sc10	X							
11	sc11	X							
12	sc12	X							
13	sc13	X							
14	Preliminary Preferred Scenario	X	X		X				
15	Revised 30% Design Scenario	X	X		X				
-	30% Design Scenario (including shoreline restoration)	X	X	X	X	X	1		1

Notes & assumptions

water level used for all GENESIS Runs @ MHW was	2.08
water level used for all GENESIS Runs w/ SLRwas	4.58
MHW used for typical tides RefDif runs	2.10
Incident wave height for typical tides RefDif runs	3.00
Stillwater elevation for 100yr storm RefDif runs	12.90
Incident wave height for 100yr storm RefDif runs	5.30

RefDIF runs model only single wave directions at a time, the following wave directions (degrees from N) were modeled: E (90); Perpendicular to Shore (150); SW (225)
SBEACH / CSHORE were performed for 5 storm series (10, 25, 50, 100, Sandy); hydrographs were selected by ARCADIS based on FEMA storms and share with TSPP team
SBEACH / CSHORE are used to model event-based change at the shoreline and so only locations outside the TSPP project area were modeled; 7 transects:

HISTORIC ANALYSIS AND EXISTING INFORMATION

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW SPRING 2012

MHW 1978

OBSERVED BEACH GROWTH

OBSERVED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

OBSERVED HISTORIC SHORELINE CHANGE

1978 - SPRING 2012 (PRE-SANDY)

NY RISING

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SPRING 2012 MHW (PRE-SANDY)

FALL 2012 MHW (POST-SANDY)

OBSERVED BEACH GROWTH

OBSERVED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

OBSERVED EVENT BASED SHORELINE CHANGE

SPRING 2012 (PRE-SANDY) - FALL 2012 (POST SANDY)

NY RISING

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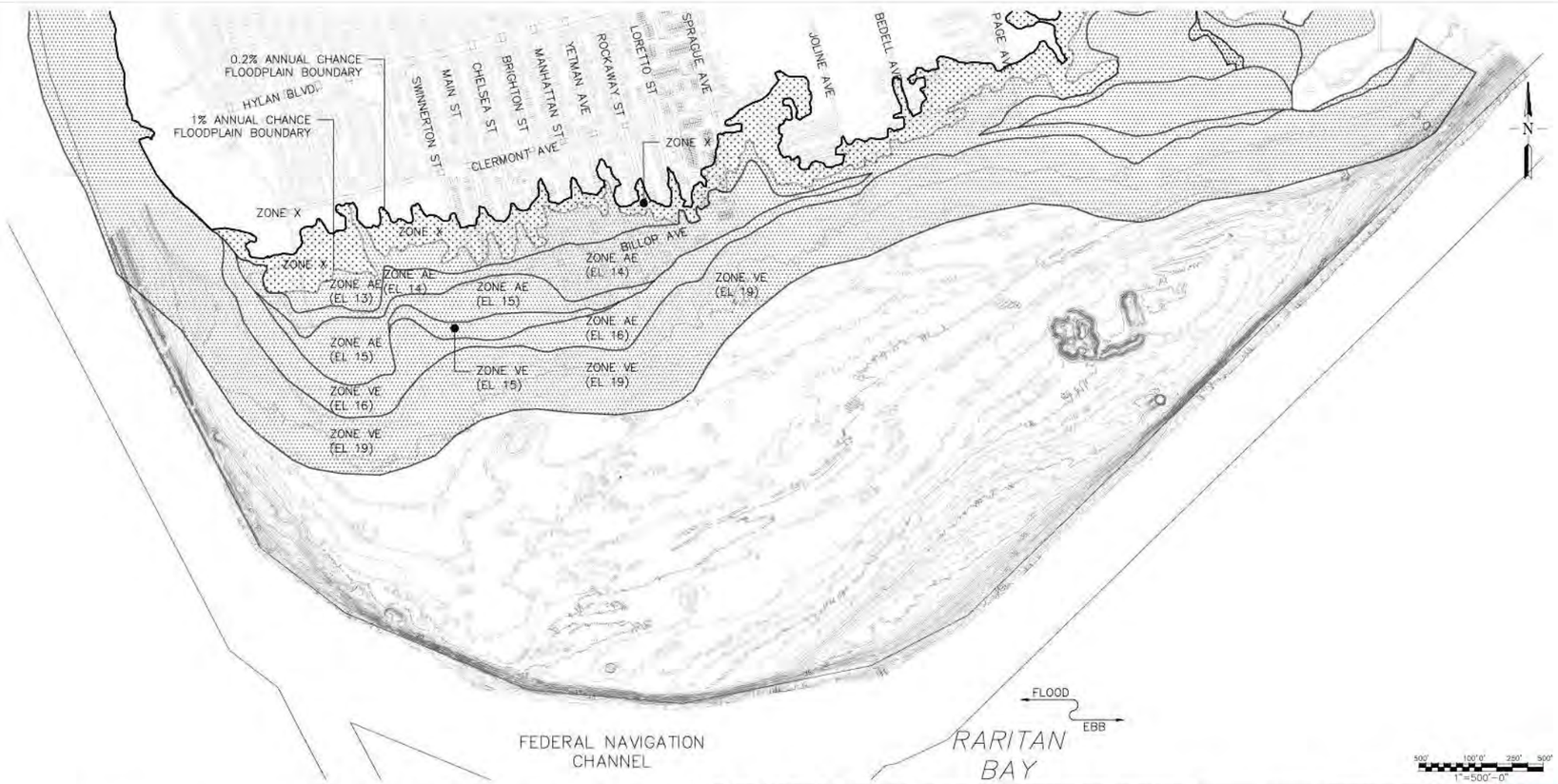

1 G-100 FEMA FLOOD INSURANCE RATE PLAN

LEGEND

SPECIAL FLOOD HAZARD AREAS SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS
OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

1% annual chance floodplain boundary
0.2% annual chance floodplain boundary
Floodway boundary
Zone D boundary
CBRS and OPA boundary
Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
Limit of Moderate Wave Action
513 — Base Flood Elevation line and value; elevation in feet*
(EL 987) — Base Flood Elevation value where uniform within zone; elevation in feet*
* Referenced to the North American Vertical Datum of 1988
15 — 15 Cross section line
23 — 23 Transect line
Culvert, Flume, Penstock or Aqueduct
Road or Railroad Bridge
Footbridge
87°07'45", 32°22'30" Geographic coordinates referenced to the North American Datum of 1983 (NAD 83), Western Hemisphere
4076000 N 1000-meter Universal Transverse Mercator grid values, zone 19
600000 FT 5000-foot grid values: New York State Plane coordinate system, Long Island zone (FIPSZONE 3104), Lambert Conformal Conic projection
DX5510 × Bench mark (see explanation in Notes to Users section of this FIRM panel)
● M1.5 River Mile

2 G-100 FIRM LEGEND N.T.S.

3 G-100 PRELIMINARY FLOOD INSURANCE RATE MAP

30% DESIGN SUBMISSION
NOT FOR CONSTRUCTION

FEMA PFIRM MAP

NY RISING

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HISTORIC SHORELINE CHANGE AND FEMA PFIRMS

Historic shoreline change analysis was performed based on orthoimagery available between 1978 and 2012, for a period covering the range of the wave hindcast data (1982 to 2012).

The rates of shoreline change exceed 1 foot per year mostly adjacent to Conference House Park west of Brighton Street, with the greatest shoreline erosion rate at 3.5 feet per year (±0.4 feet per year).

Most of the shoreline change rates moving to the northeast from Brighton Street along the shoreline are less than 1 foot per year. An exception is shown between Manhattan and Rockaway Streets where the rate is estimated at 1.7 feet per year (±0.4 feet per year) and between Page Avenue and Richard Avenue where the long-term erosion rate is estimated at 2.4 feet per year (±0.4 feet per year). This area is downdrift of an L-shaped timber pile groin structure, which may have been a historic pier.

Areas of the most pronounced localized shoreline change are downdrift of existing groin structures.

BASELINE (FUTURE WITHOUT PROJECT)

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PRUDENT ENGINEERING

MODELED 2035 MHW

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

BASELINE, FUTURE WITHOUT PROJECT

GENESIS RESULTS

NY RISING

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LOT-EK ARCHITECTURE
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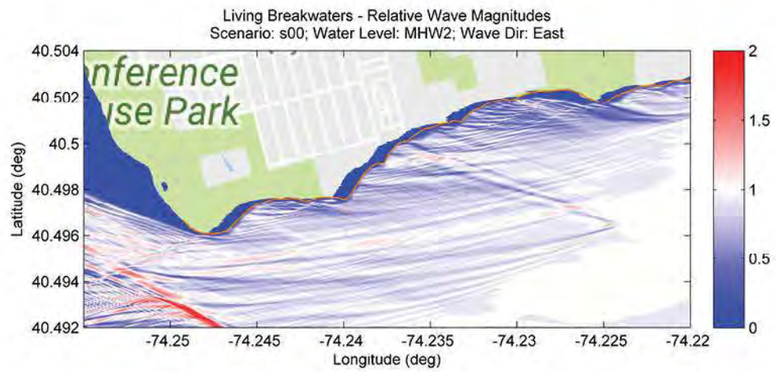
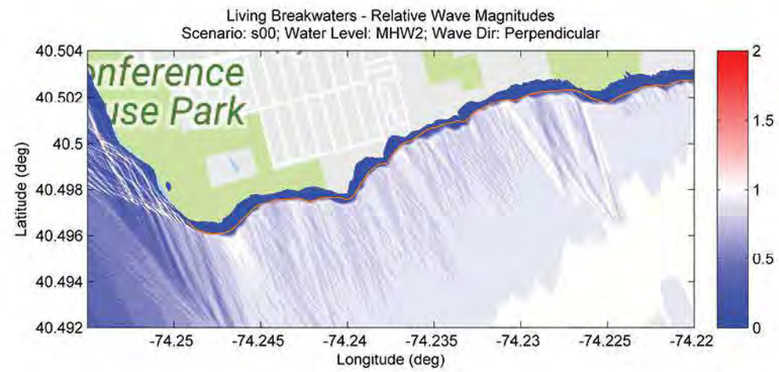
PRUDENT ENGINEERING

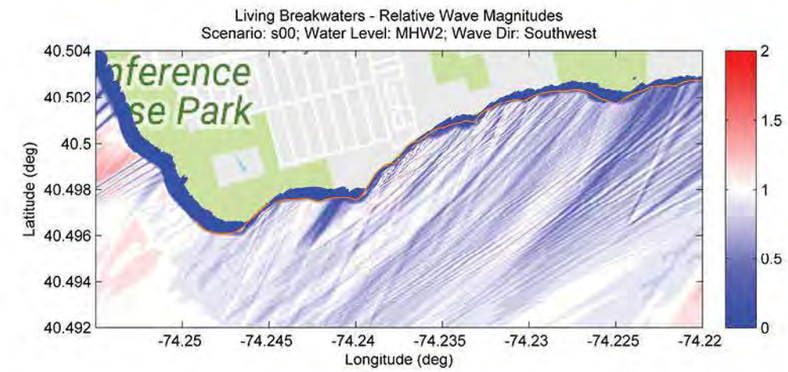
MHW | Input Wave Height of 3 feet | Waves from East



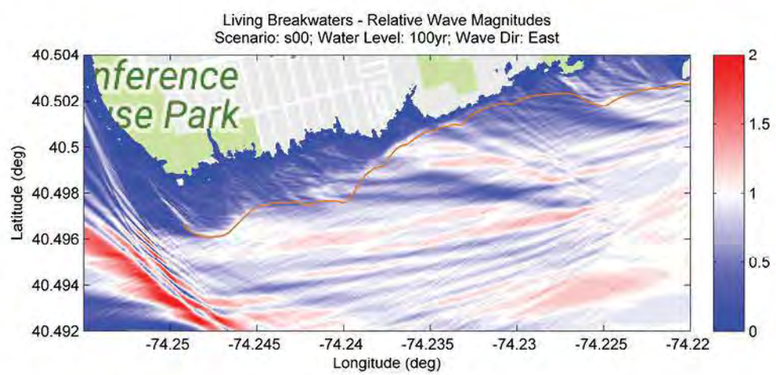
MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore



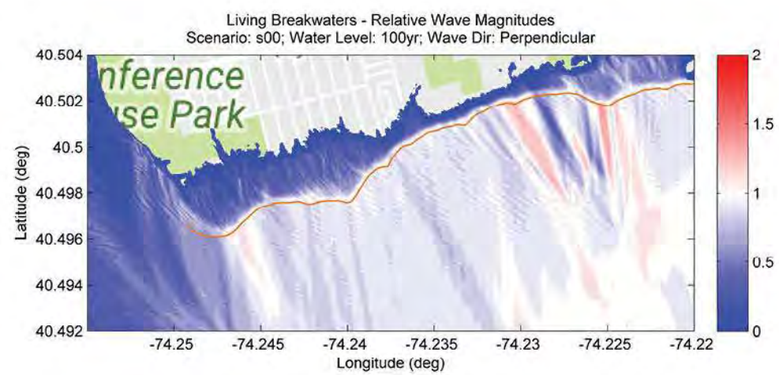
MHW | Input Wave Height of 3 feet | Waves from Southwest



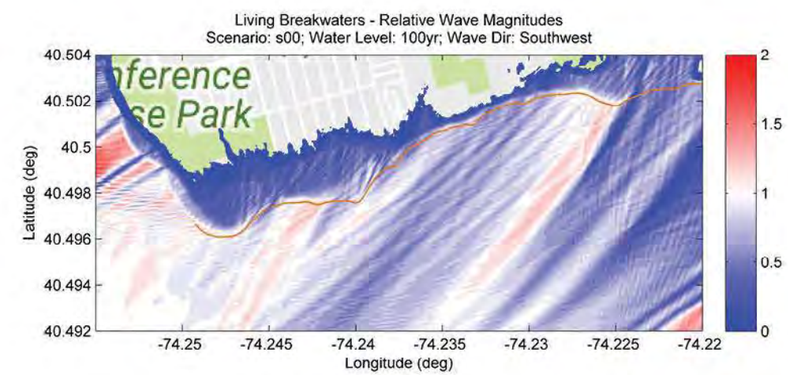
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore

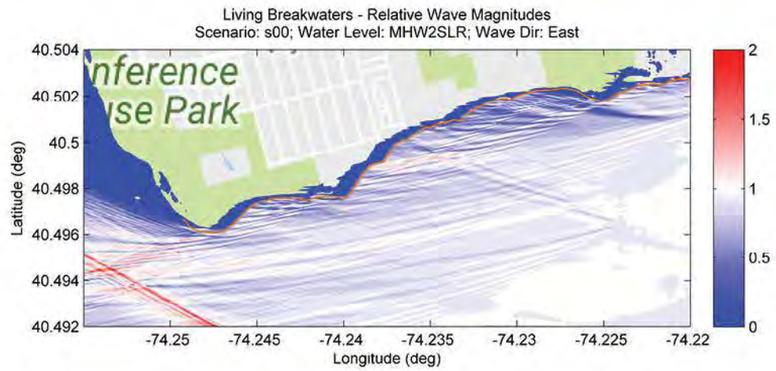


100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



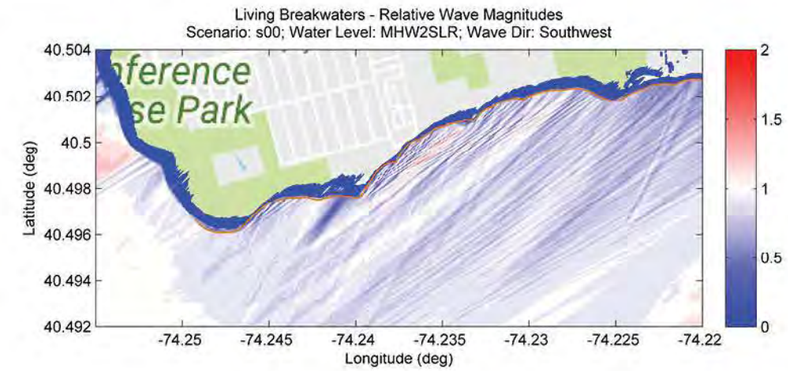
WAVE HEIGHTS SHOWN ARE RELATIVE WAVE HEIGHTS (MODELED WAVE HEIGHT/INCOMING OFFSHORE WAVE HEIGHT).

MHW + 30" SLR | Input Wave Height of 3 feet | Waves from East

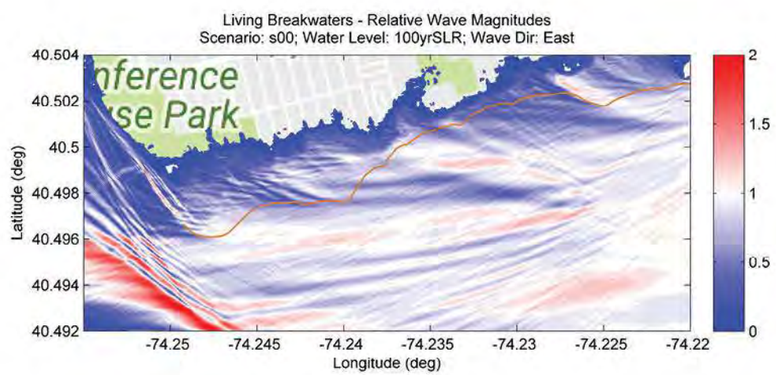


MHW + 30" SLR | Input Wave Height of 3 feet | Waves Perpendicular to Shore

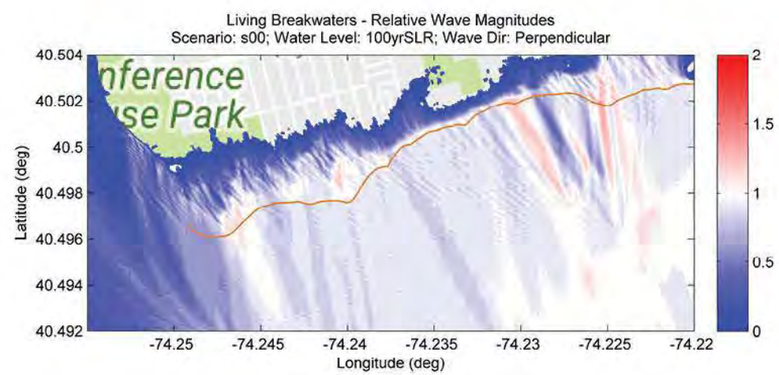
MHW + 30" SLR | Input Wave Height of 3 feet | Waves from Southwest



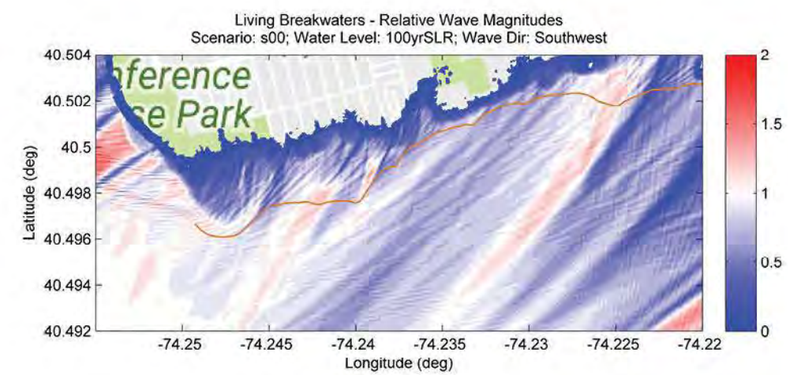
100 Year + 30" SLR | Input Wave Height of 5.3 feet | Waves from East



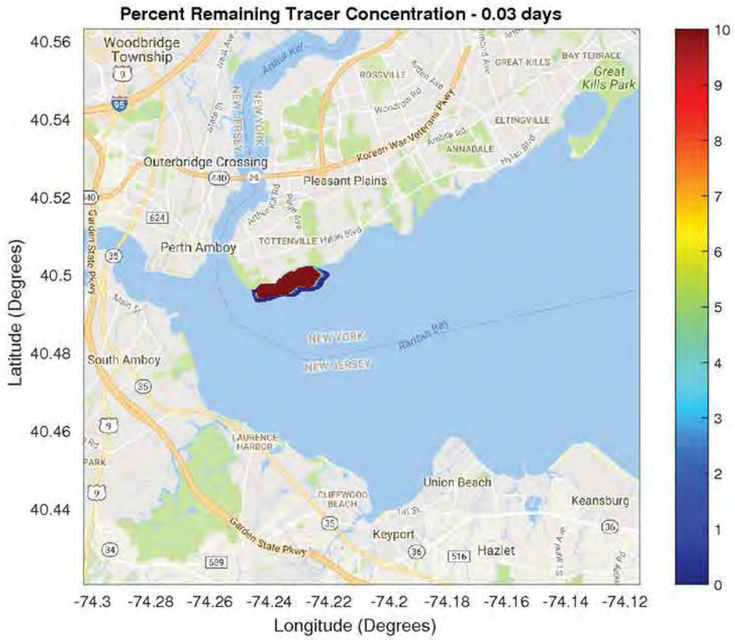
100 Year + 30" SLR | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore

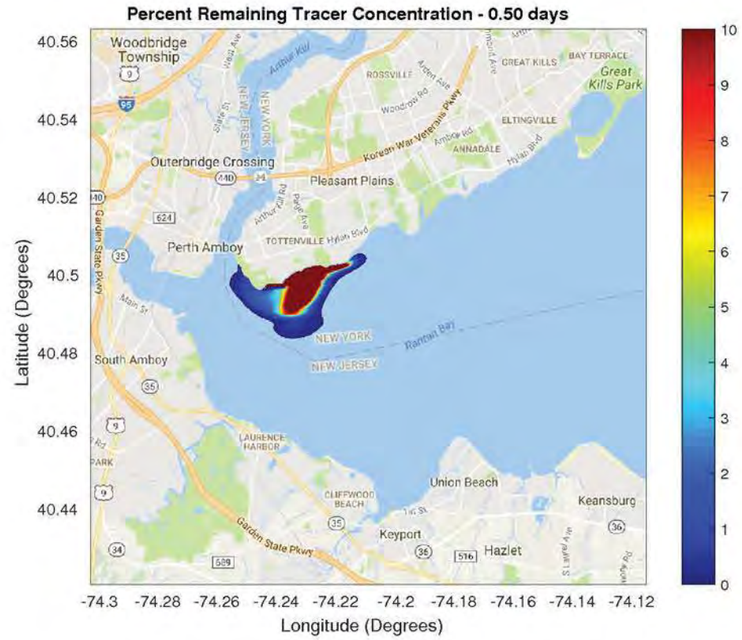


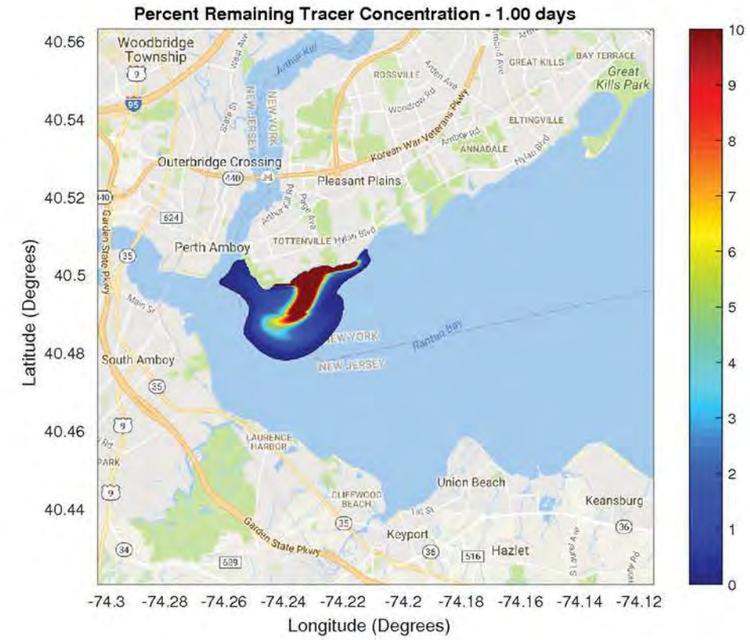
100 Year + 30" SLR| Input Wave Height of 5.3 feet | Waves from Southwest

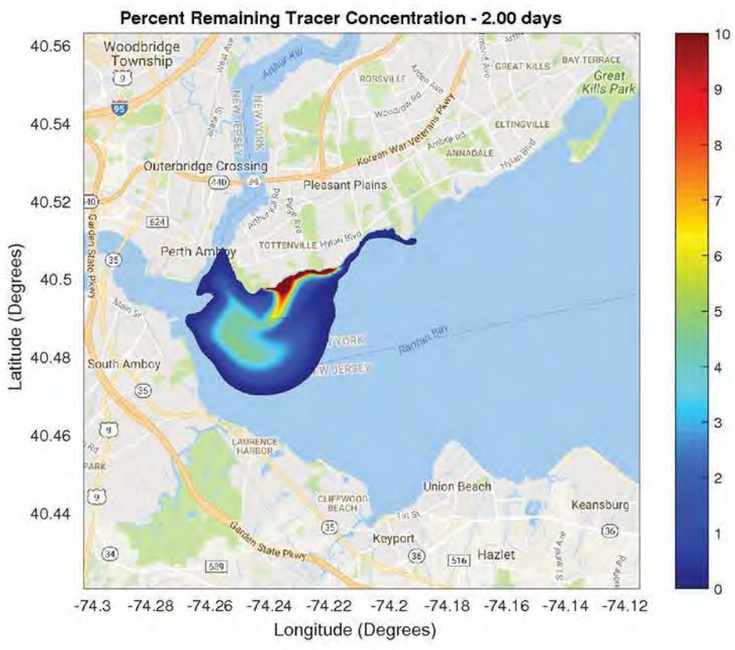


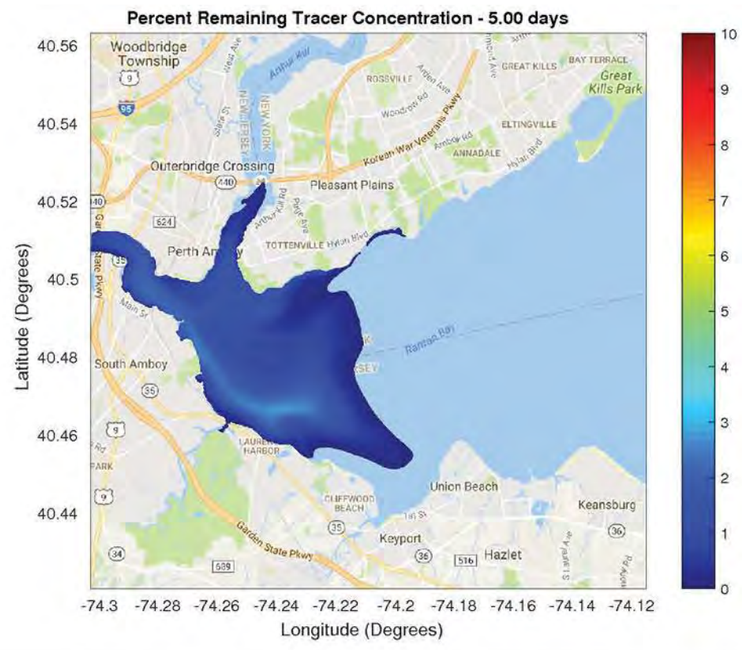
WAVE HEIGHTS SHOWN ARE RELATIVE WAVE HEIGHTS (MODELED WAVE HEIGHT/INCOMING OFFSHORE WAVE HEIGHT).











BASELINE, FUTURE WITHOUT PROJECT

DELFT-3D RESULTS

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

00: BASELINE (FUTURE WITHOUT PROJECT)

ASSUMPTIONS: SHORELINE CONDITIONS

- 2015 shoreline (which was a compilation of the 2015 TSPP survey, 2014 LiDAR in areas outside the survey, and the 2015 structures survey supplemented with aerial information) was used as starting point / baseline for shoreline change of the preferred alternative.
- Initial model simulations used the pre-Sandy 2012 shoreline developed from aerial photography as the initial shoreline based on the shorelines used in the calibration process and the data available at the start of the scenario modeling process (this initial shoreline was used for consistency of comparison until the preferred scenario was selected).
- Shoreline structures / conditions assumed to be as surveyed in fall 2015; baseline model results assume no alteration of existing shoreline structures.
- The shoreline is the surveyed MHW line defined as 2.08 ft. NAVD88 tidal datum at Sandy Hook. Outside the survey limits, MHW was delineated from post-Sandy USGS LiDAR(August 2014).

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- The overall trends in shoreline change remain similar. Southwest of Sprague Avenue, the future without scenario showed shoreline change rates for the next 20 years consistent with the severe (>1') rates seen over the past 30 years. Northeast of Sprague Avenue, the future without scenario showed somewhat reduced rates shoreline change for the next 20 years relative to the rates seen over the past 30 years.
- The complex (wavey) nature of this shoreline and large number of structures on the shoreline likely complicates shoreline change processes, making results more varied
- Changes in sea levels may also play a factor in the response of the shoreline. Currently the model simulation have used current mean sea level. This allowed for comparison between scenarios but the effects of varying sea level will be tested once the preferred scenario is advanced in the next phase of design. Simplified shoreline change models, such as GENESIS, are effective at evaluating trends in shoreline changes and impacts of shoreline and nearshore structures but do not fully represent the cross shore processes that are impacted by sea level rise. Sea level rise influences are further evaluated in this phase of modeling in REFDIF.

WAVE ACTION

- Both the channel and the northern depth anomaly (the hole), impact wave refraction and diffraction and can result in some increased wave heights.
- The beach itself is one of the best attenuators of storm waves (building beach and complimentary on-shore interventions may have best storm wave reduction benefits)

WATER QUALITY

- The tracer plume originating from the project area dissipates to less than a few percent concentration in less than 5 days.

DESIGN SCENARIOS

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
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2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 01

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW 2012

OBSERVED BEACH GROWTH

OBSERVED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

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0' 500' 1000' 2000'

SCENARIO 01

SCENARIO LAYOUT

NY RISING

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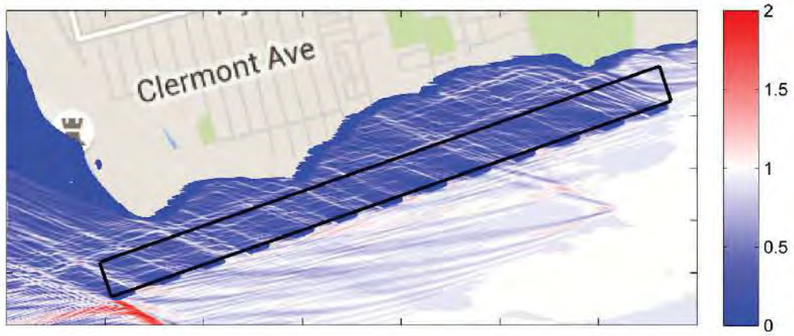
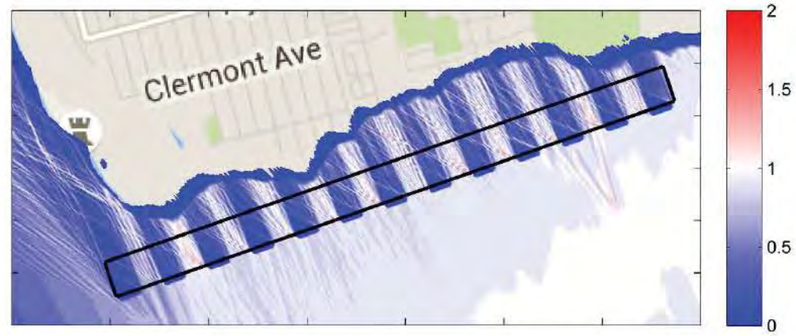
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

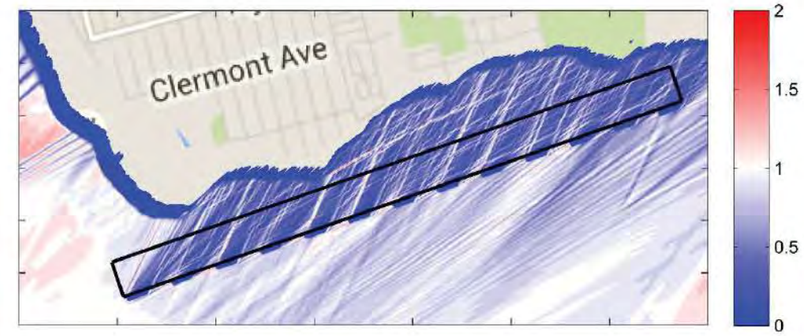
MHW | Input Wave Height of 3 feet | Waves from East



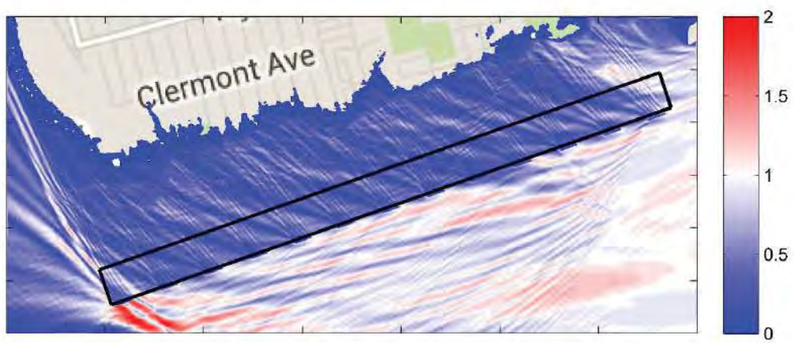
MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore



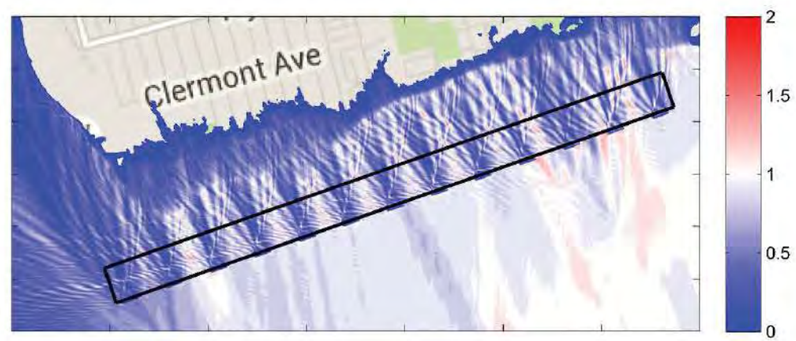
MHW | Input Wave Height of 3 feet | Waves from Southwest



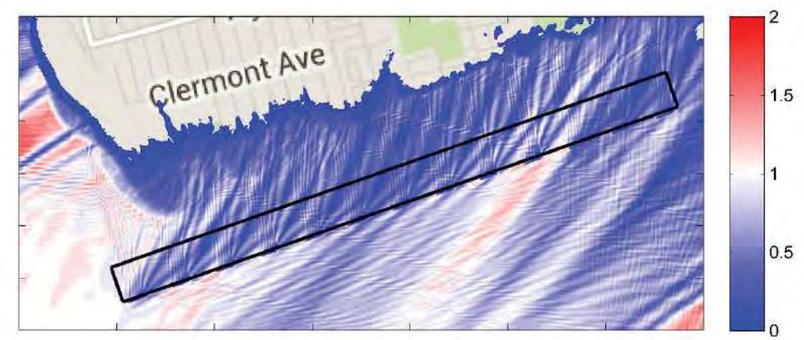
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



Wave heights shown are relative wave heights (modeled wave height/incoming offshore wave height).

SCENARIO 01: “HOLD THE SHORELINE”

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- System provided effective shoreline stabilization in almost all areas.
- Limited effect at furthest distance to shore (x=1,300 feet, L/x=.25, where x is distance from shore and L is breakwater length) Trapping of greater amounts of sediment ‘upstream’ appears to limit potential of sediment capture downstream, suggesting that this is not a high sediment system.
- Salient response at north end was surprisingly strong; may be the salient itself beginning to act to trap sediment behind it. => may not need to extend breakwaters all the way north to get salient effect there.

WAVE ACTION

- The wave shadow zone (area where we see wave height reduction) is larger when waves are oblique rather than head-on in relation to breakwater orientation

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
AREADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
RPS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 02: "STORM WAVE ATTENUATION"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
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SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 02: "STORM WAVE ATTENUATION"

GENESIS RESULTS

NY RISING

SCAPE TEAM

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OCEAN AND COASTAL CONSULTANTS
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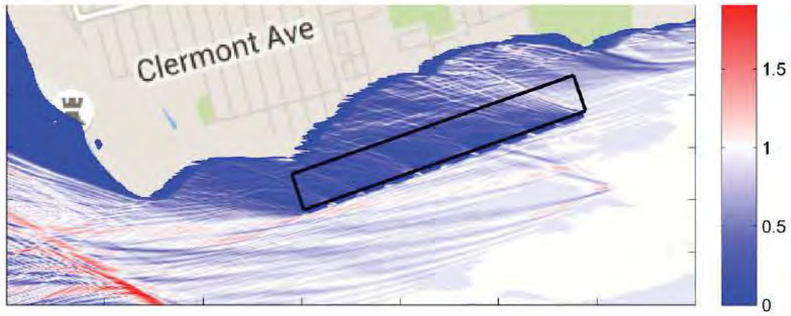
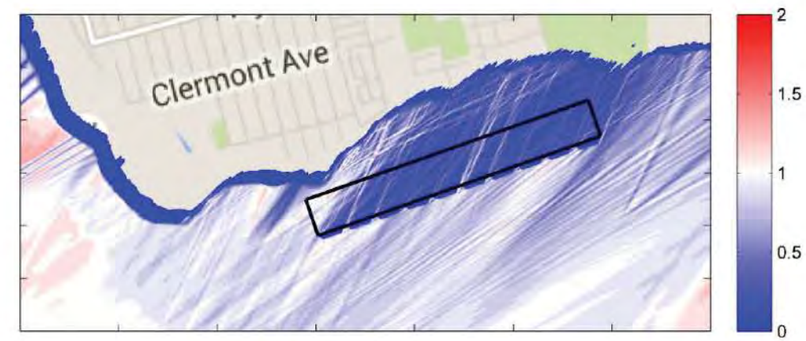
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW | Input Wave Height of 3 feet | Waves from East

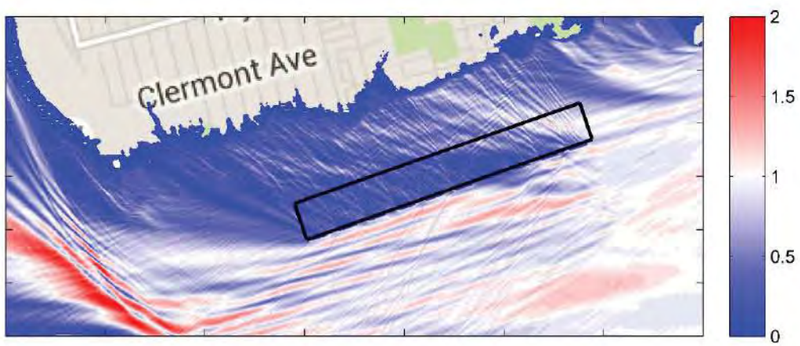


MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore

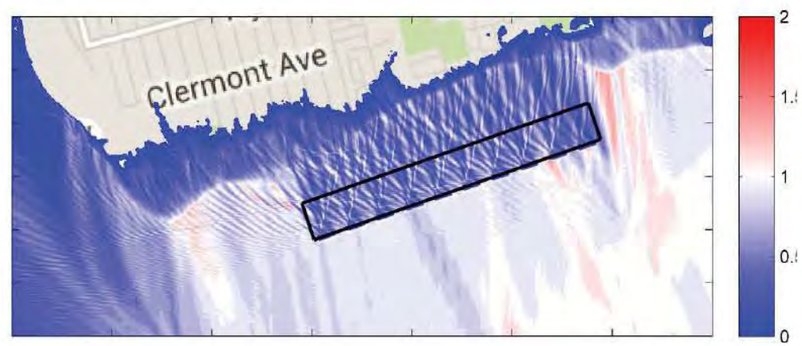
MHW | Input Wave Height of 3 feet | Waves from Southwest



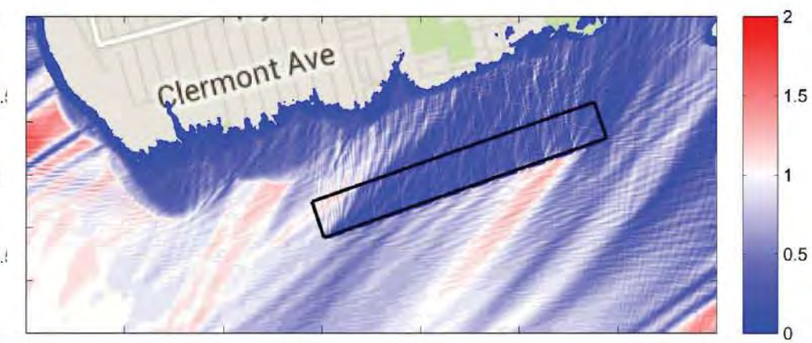
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



SCENARIO 02: "STORM WAVE ATTENUATION"

REF DIF RESULTS

SCENARIO 02: "STORM WAVE ATTENUATION"

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Breakwaters acted as a single unit in how they impacted shoreline change => Breakwaters with small gap width (30') or Wg/(L+Wg) (1/4) act like a single unit in salient formation
- If sediment is trapped 'upstream', but if nothing is done at the southern end, this could exacerbate erosion in Conference House Park => breakwater system will need to extend to the southwestern edge of Zone 2 to avoid further erosion in this zone.

WAVE ACTION

- Smaller gap widths allow fewer / lower waves to pass through.
- Again, the wave shadow zone (area where we see wave height reduction) is larger when waves are oblique rather than head-on in relation to breakwater orientation

SCENARIO 02: "STORM WAVE ATTENUATION"
MODEL TAKE-AWAYS AND LESSONS LEARNED

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
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CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 03: "TESTING FOR TOMBOLO"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
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CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 03: "TESTING FOR TOMBOLO"

GENESIS RESULTS

NY RISING

SCAPE TEAM

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OCEAN AND COASTAL CONSULTANTS
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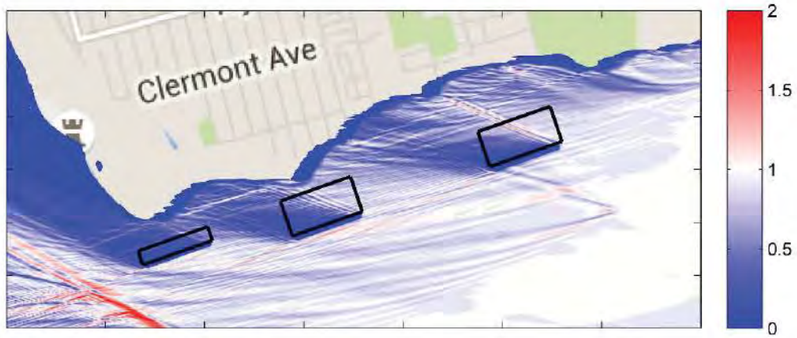
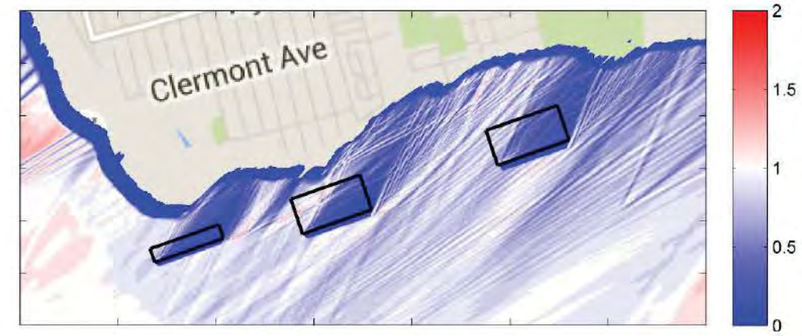
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW | Input Wave Height of 3 feet | Waves from East

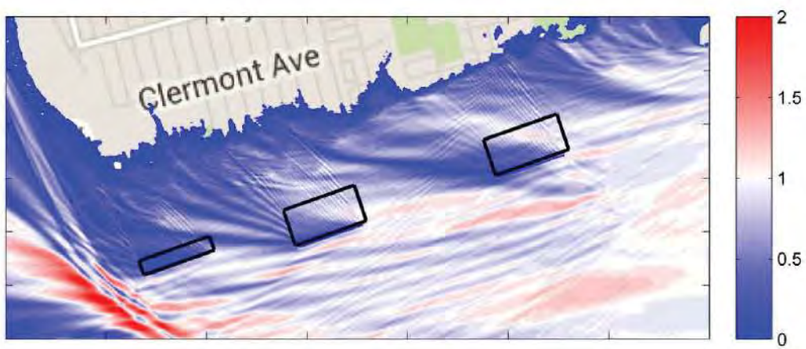


MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore

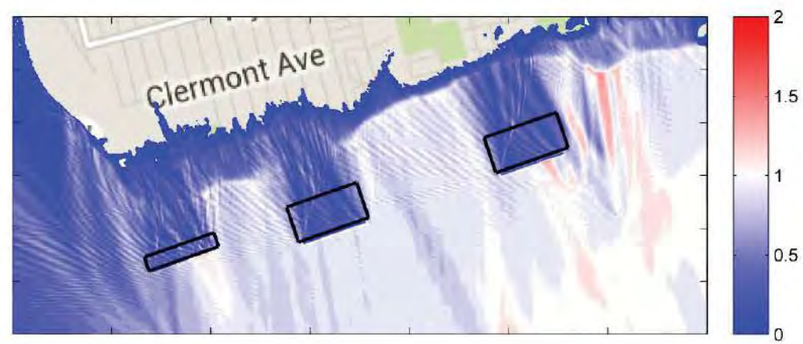
MHW | Input Wave Height of 3 feet | Waves from Southwest



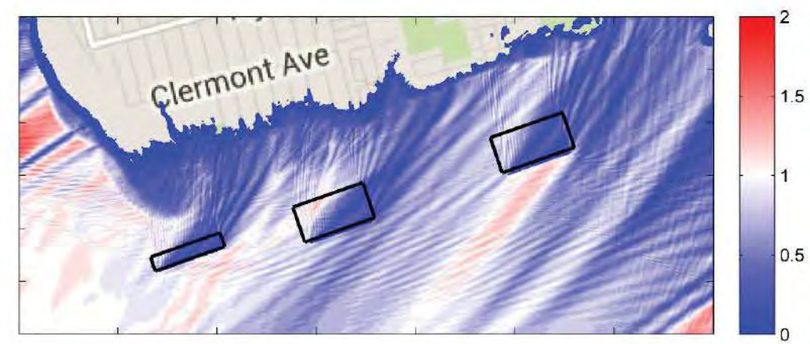
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



SCENARIO 03: "TESTING FOR A TOMBOLO"

REF DIF RESULTS

SCENARIO 03: "TESTING FOR A TOMBOLO"

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- The long breakwaters all show significant salient response.
- Shoreline response is not proportional to distance to shore (X) or the ratio of breakwater segment length to distance to shore (L/X), suggesting that other factors influence the scale of salient formation, including but not limited to amount of sediment in the system, amount of sediment trapped upstream, shape of shoreline, and existing coastal structures.
- It may be possible to create a tombolo, which would act like a terminal groin at the end of the system.

WAVE ACTION

- The wide spacing between breakwater segments means that there is little wave reduction in the gaps between them.
- The breakwaters themselves are effective wave attenuators.

NY RISING
SCAPE TEAM
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
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AREADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
RPS CONSULTING ENGINEERS
PRUDENT ENGINEERING

2012 MHW

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 04: "LEARNING FROM ROUND ONE"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
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SEARC ECOLOGICAL MARINE CONSULTING
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MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 04: "LEARNING FROM ROUND ONE"

GENESIS RESULTS

NY RISING

SCAPE TEAM

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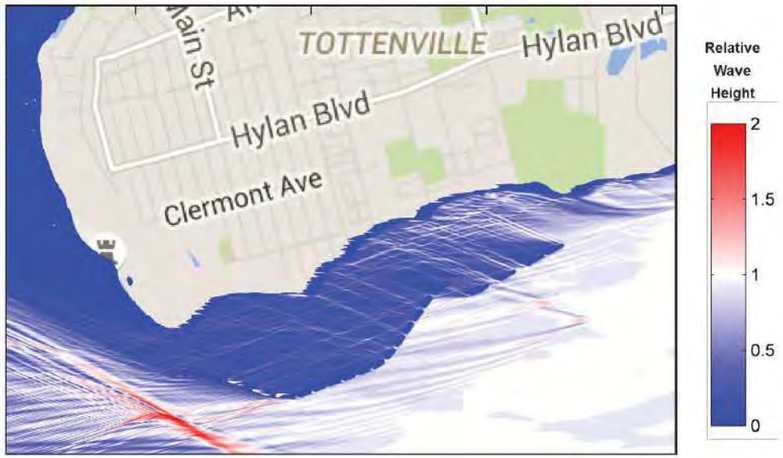
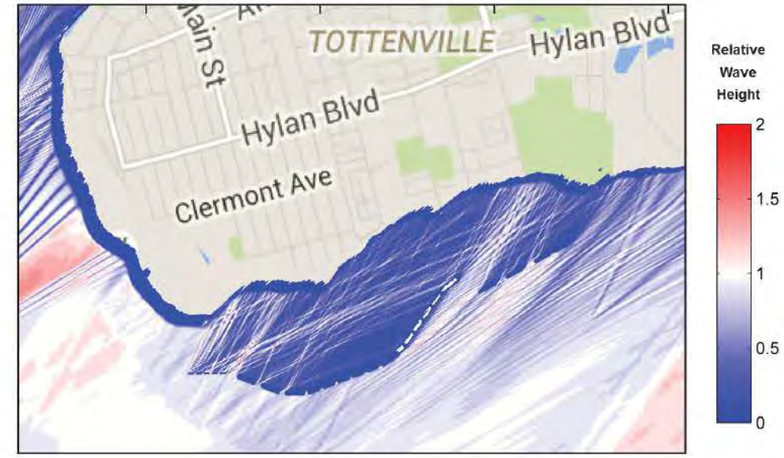
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW | Input Wave Height of 3 feet | Waves from East

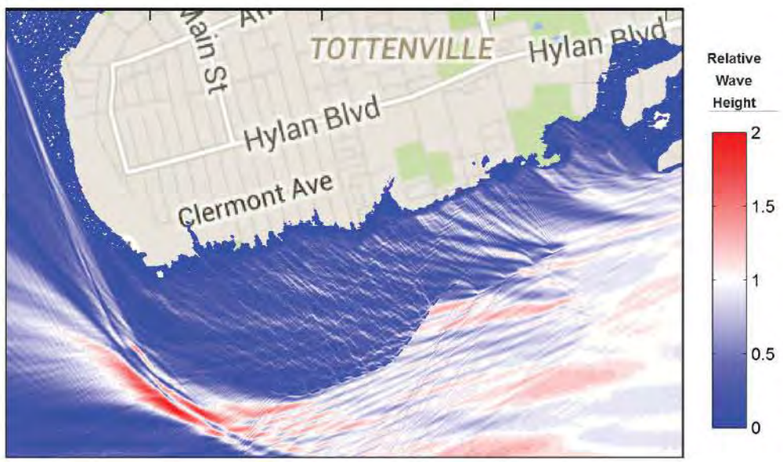


MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore

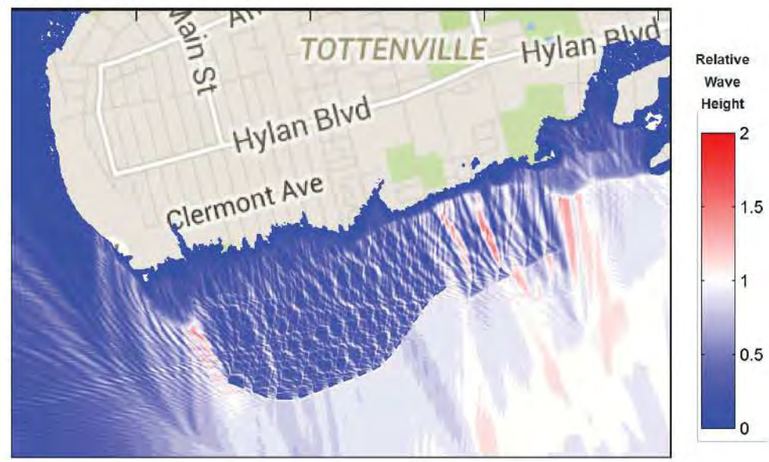
MHW | Input Wave Height of 3 feet | Waves from Southwest



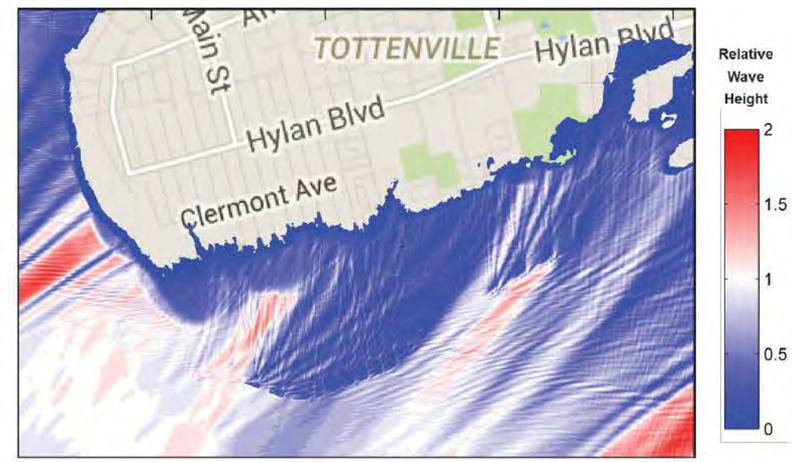
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



SCENARIO 04: "LEARNING FROM ROUND ONE"

REF DIF RESULTS

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
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SEARC ECOLOGICAL MARINE CONSULTING
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PRUDENT ENGINEERING

SCENARIO 04: "LEARNING FROM ROUND ONE

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Shoreline is stabilized along length
- Limited longshore sediment supply is trapped along northeast shoreline and does not reach Zones 2 and 3 where accretion is desired
- Varying breakwater layout for desired goals by region appears to have merit

WAVE ACTION

- Effective wave shadow zone throughout most of the project area (area where we see wave height reduction)
- Lower crested breakwaters on western edge show limited effectiveness in attenuating waves under higher water levels

OTHER

- Large footprint = costly, high impact

SCENARIO 04: "LEARNING FROM ROUND ONE"
MODEL TAKE-AWAYS AND LESSONS LEARNED

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED
SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
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CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 05: "MODIFIED SCENARIO 04"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
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MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 05: "MODIFIED SCENARIO 04"

GENESIS RESULTS

NY RISING

SCAPE TEAM

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OCEAN AND COASTAL CONSULTANTS
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SCENARIO 05: “MODIFIED SCENARIO 4”

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Shoreline is stabilized along much of its length
- Significant accretion between Manhattan St and Page Ave
- Some erosion continued in Zone 2
- Removing northeastern breakwaters allowed more sediment to move farther west along the shoreline
- Bringing breakwaters closer to shore increased shoreline accretion and wave protection

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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SCENARIO 06: "MINIMALIST APPROACH"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 06: "MINIMALIST APPROACH"

GENESIS RESULTS

NY RISING

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SCENARIO 06: “MINIMALIST APPROACH”

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Northeastern breakwaters were effective in retaining sediment and causing shoreline accretion
- Removal and lowering of southwestern breakwaters resulted in loss of protection and considerable erosion in conjunction with sediment trapping up drift

NY RISING
SCAPE TEAM
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PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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PROPOSED SHORELINE RESTORATION

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SCENARIO 07: "MINIMALIST APPROACH WITH SHORELINE RESTORATION"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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PROPOSED SHORELINE RESTORATION

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SCENARIO 07: "MINIMALIST APPROACH WITH SHORELINE RESTORATION"

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 07: “MINIMALIST APPROACH WITH SHORELINE RESTORATION”

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Shoreline restoration shifted shoreline outward in region of fill
- Shoreline restoration was relatively well retained
- Erosion of western part of shoreline was slightly reduced but still significant as in previous scenario (same breakwater layout sc06)

SCENARIO 07: “MINIMALIST APPROACH WITH SHORELINE RESTORATION”

MODEL TAKE-AWAYS AND LESSONS LEARNED

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 09

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 09

GENESIS RESULTS

NY RISING

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SCENARIO 09

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Moving the western and central breakwaters closer to shore enhanced shoreline protection.
- Having a breakwater in the middle of the western bay at the park reduced erosion of that region.
- Removal of southwestern breakwaters resulted in loss of protection and considerable erosion of Ward's Point in conjunction with sediment trapping up drift.

NY RISING

SCAPE TEAM

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MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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0′ 500′ 1000′ 2000′

SCENARIO 10

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

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SCENARIO 10

GENESIS RESULTS

NY RISING

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SCENARIO 10

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Repositioning of the central breakwaters improved shoreline shape and moving farther offshore into deeper water is likely to aid constructability without any noticeable loss in shoreline retention in the simulation.
- Moving of the southwestern breakwater resulted in accretion at the western point (Ward's Point) but significant erosion continued in the adjacent embayment.

SCAPE TEAM

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MHW 2012

ANTICIPATED BEACH GROWTH

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SHORELINE STRUCTURES

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SCENARIO 11

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

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SCENARIO 11

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 11

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Reducing the number of breakwaters in the central portion and moving the southwestern breakwater increased erosion especially in the adjacent embayment.
- Significant accretion at Ward's Point and between Manhattan St and Bedell Ave

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
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MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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PROPOSED SHORELINE RESTORATION

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0' 500' 1000' 2000'

SCENARIO 12

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
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PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

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0' 500' 1000' 2000'

SCENARIO 12

GENESIS RESULTS

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
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MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

SCENARIO 12

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Splitting the southwestern breakwater into two to provide protection to the point and embayment reduced erosion in the region, but erosion continued.
- Adding back a breakwater to the central section improved shoreline retention and protection between Bedell St and Page Ave
- Retained accretion between Manhattan St and Bedell St

NY RISING
SCAPE TEAM
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
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PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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SCENARIO 13

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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SCENARIO 13

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 13

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Moving the southwestern breakwaters and lengthening the breakwater at the southwestern point improved the modeled shoreline response shape; almost eliminated erosion in Zone 2
- Consistent beach accretion between Yettman St and Page Ave

NY RISING
SCAPE TEAM
SCAPE / LANDSCAPE ARCHITECTURE
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PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 14

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

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SCENARIO 14

GENESIS RESULTS

NY RISING

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MODELED 2035 MHW

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
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SCENARIO 14 (2015 MHW)

GENESIS RESULTS

NY RISING

SCAPE TEAM

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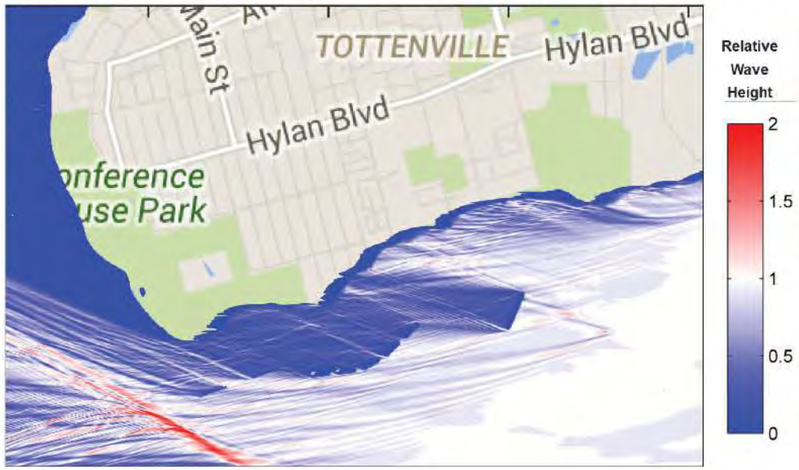
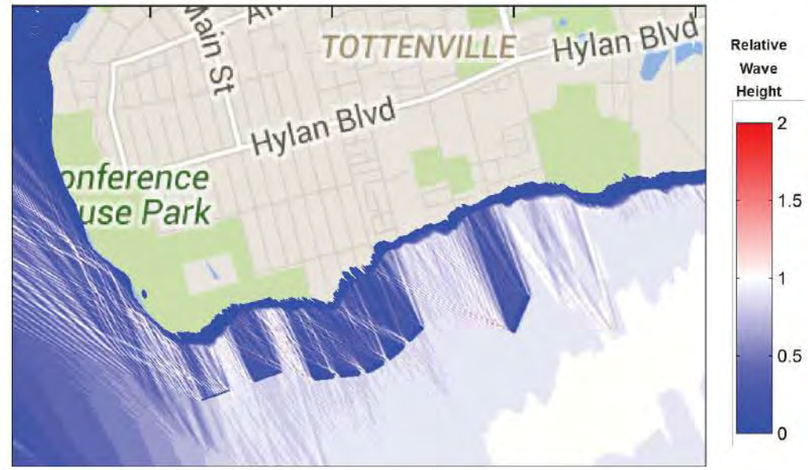
PRUDENT ENGINEERING

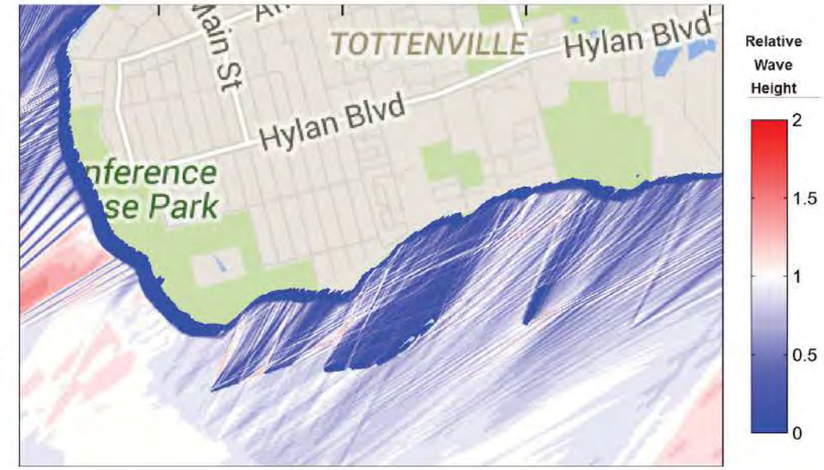
MHW | Input Wave Height of 3 feet | Waves from East



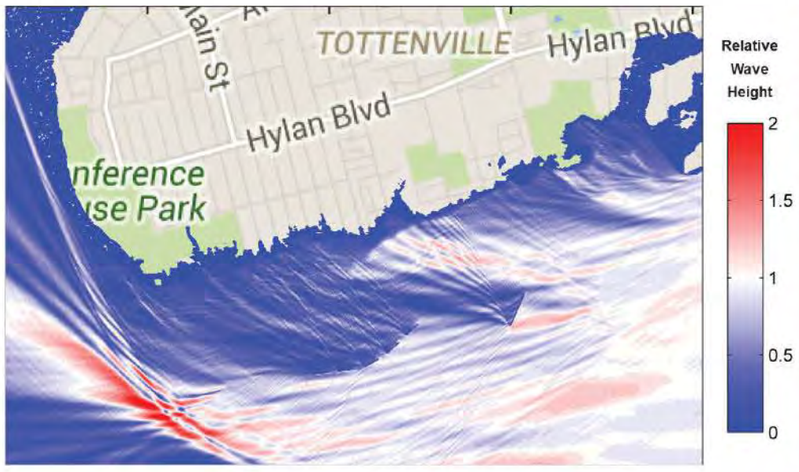
MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore



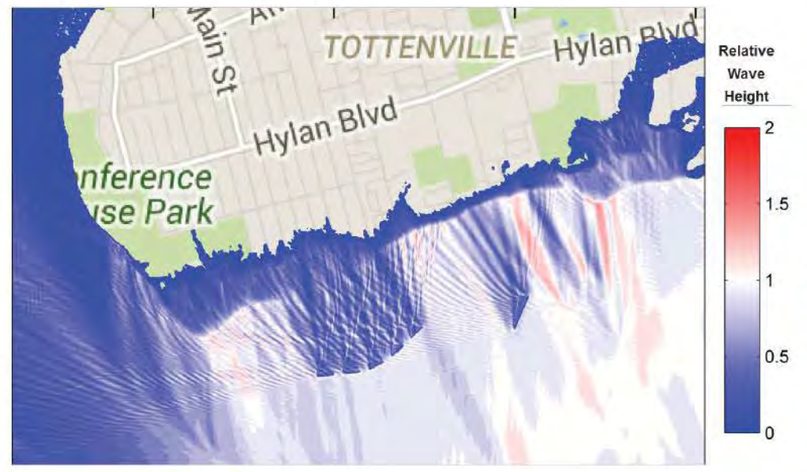
MHW | Input Wave Height of 3 feet | Waves from Southwest



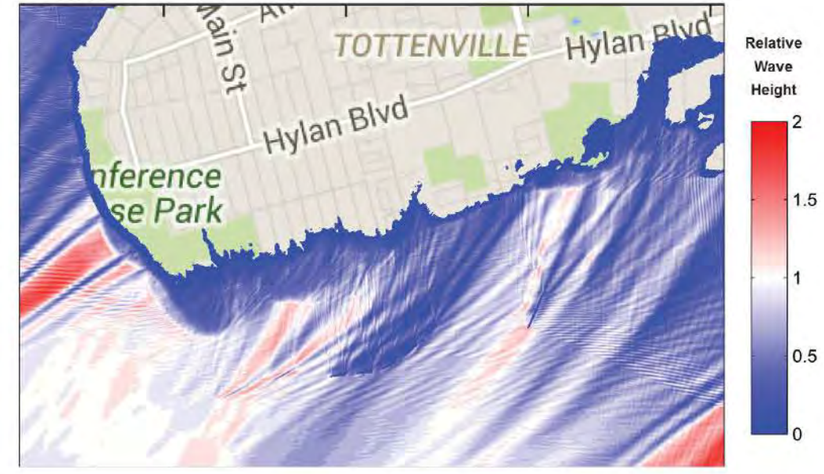
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



SCENARIO 14

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Similar to Scenario 13, refinement of southwestern breakwater location and lengthening of these breakwater segments improved modeled shoreline response, shoreline shape, sediment accretion, and sediment retention at the southwestern point and adjacent embayment.

WAVE ACTION

- Breakwaters provide effective wave shadow zones in their lee for area between Brighton St. and Sprague Ave. where vulnerable locations / assets are located for most wave directions. Some additional study may be required for waves from the east.
- Lower crested southwestern breakwaters show reduced effectiveness in attenuating waves under higher water levels. Note that storm wave attenuation has not been identified as a priority for this area, as vulnerable assets are not located in this area.
- Increased wave exposure in gap between northeastern and central breakwaters: the increased spacing and reduction of number of northeastern breakwaters was to attempt to balance between wave attenuation and sediment trapping. Further refinement of breakwater alignment may be required if storm wave attenuation for the northeastern area of the project area is a greater priority.

NY RISING
SCAPE TEAM
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
HARSON'S MANCKEBACH
ARCADIS
BEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
RPS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 15

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2035 MHW

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 15

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 15

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Similar to Scenario 14, addition of one more central breakwater and eastern breakwater to balance shoreline response with improved wave protection.
- Additional accretion to the northern eastern portion of the project shoreline due to the additional breakwaters. Some reduction in sediment available and accretion farther down the shore.

WAVE ACTION

- Breakwaters provide effective wave shadow zones in their lee for area between Brighton St. and Sprague Ave. where vulnerable locations / assets are located for most wave directions. Additional protection from waves from the east afforded by the additional breakwaters.
- Lower crested southwestern breakwaters show reduced effectiveness in attenuating waves under higher water levels. Note that storm wave attenuation has not been identified as a priority for this area, as vulnerable assets are not located in this area.

NY RISING
SCAPE TEAM
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
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AREADIS
BEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
RPS CONSULTING ENGINEERS
PRUDENT ENGINEERING

FINAL 30% DESIGN SCENARIO

SCAPE TEAM

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PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

2015 MHW

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

30% DESIGN SCENARIO

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2035 MHW

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

30% DESIGN SCENARIO

GENESIS RESULTS

NY RISING

SCAPE TEAM

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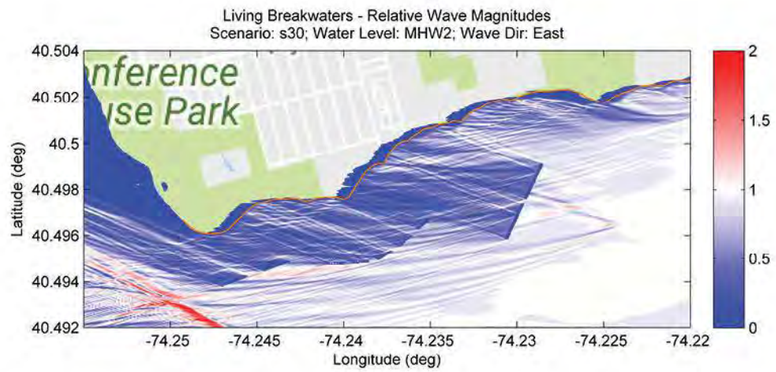
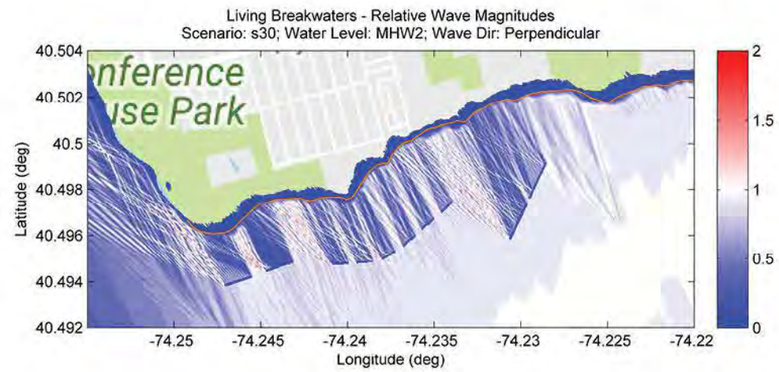
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

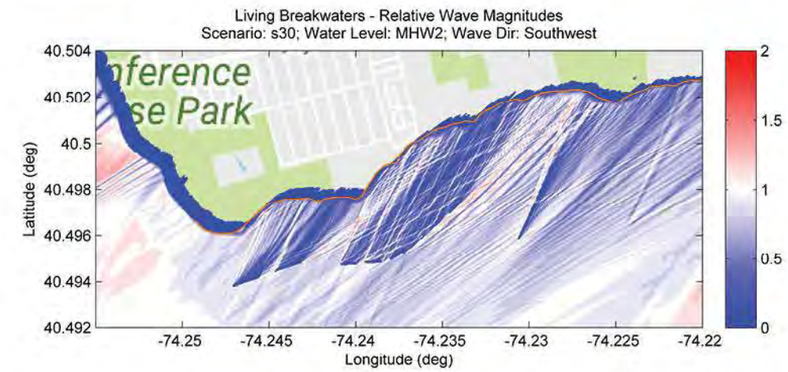
MHW | Input Wave Height of 3 feet | Waves from East



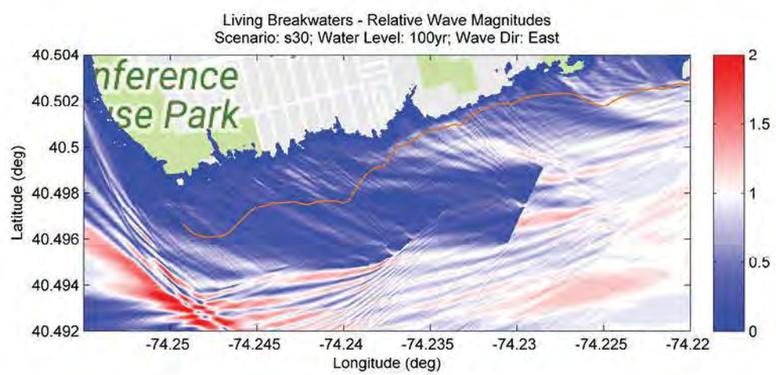
MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore



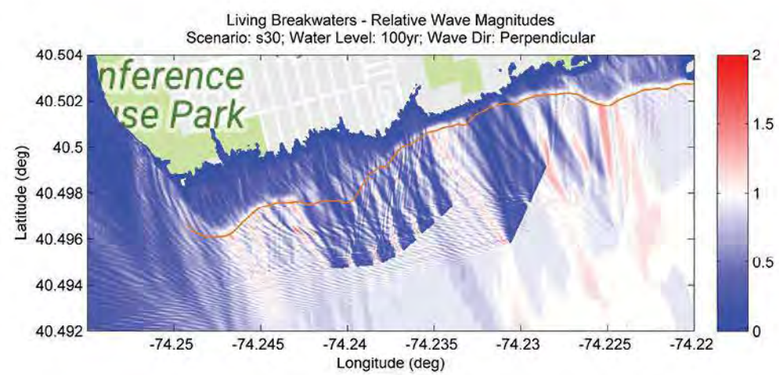
MHW | Input Wave Height of 3 feet | Waves from Southwest



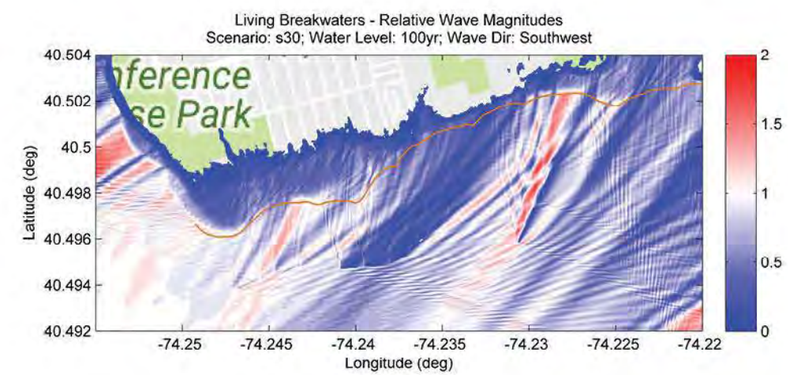
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore

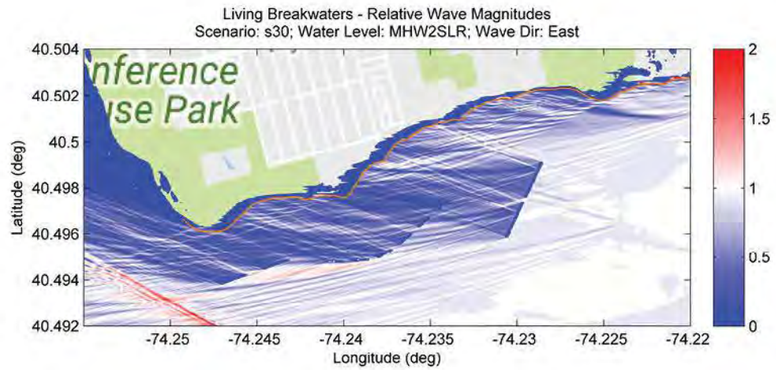


100 Year | Input Wave Height of 5.3 feet | Waves from Southwest

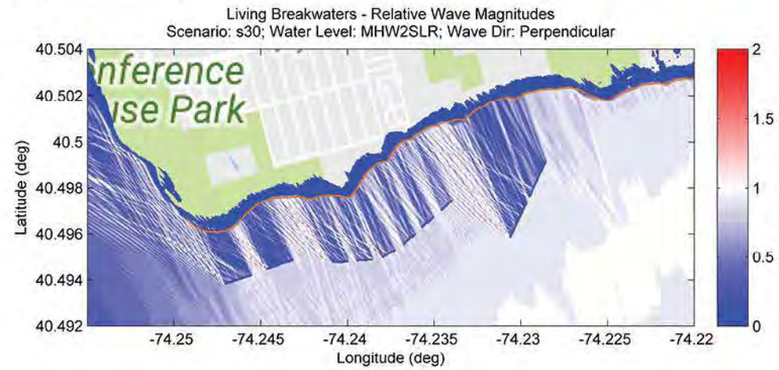


WAVE HEIGHTS SHOWN ARE RELATIVE WAVE HEIGHTS (MODELED WAVE HEIGHT/INCOMING OFFSHORE WAVE HEIGHT).

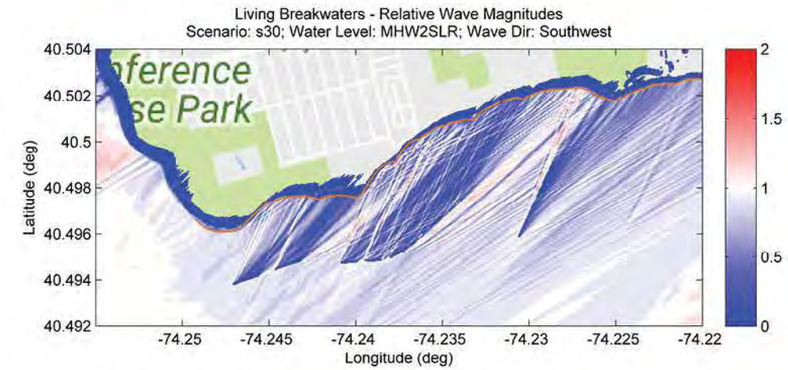
MHW + 30" SLR | Input Wave Height of 3 feet | Waves from East



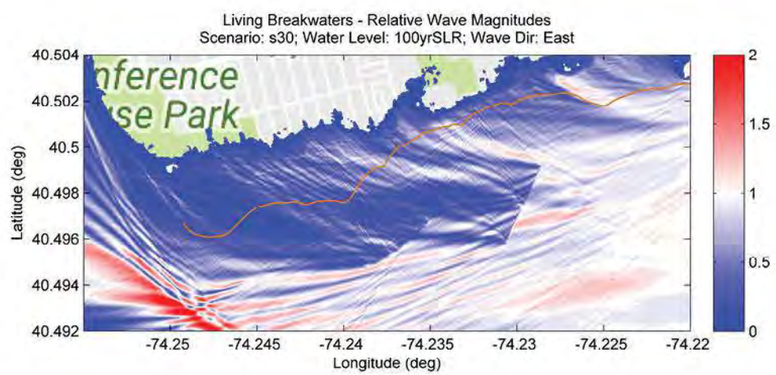
MHW + 30" SLR | Input Wave Height of 3 feet | Waves Perpendicular to Shore



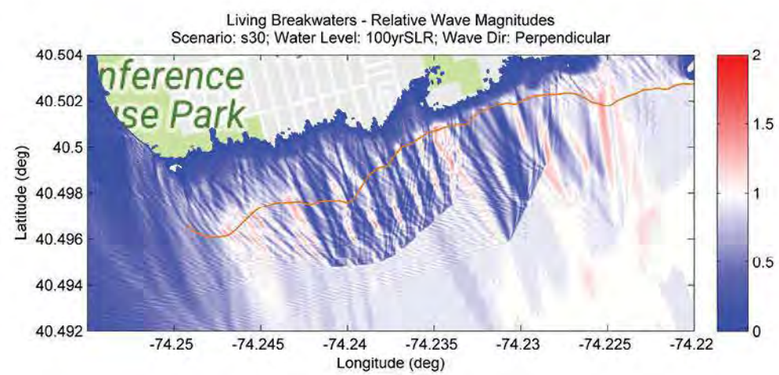
MHW + 30" SLR | Input Wave Height of 3 feet | Waves from Southwest



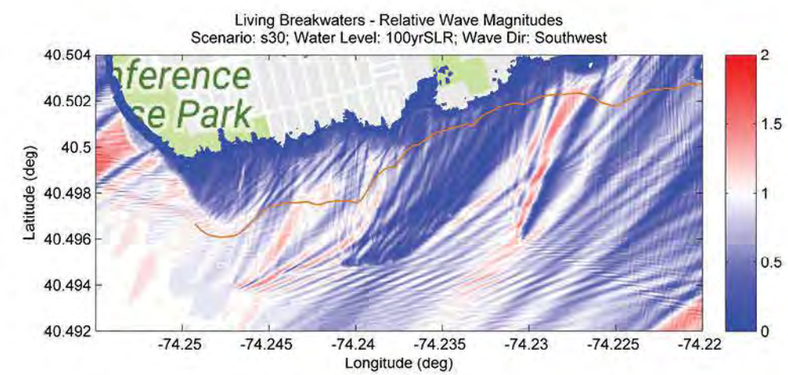
100 Year + 30" SLR | Input Wave Height of 5.3 feet | Waves from East



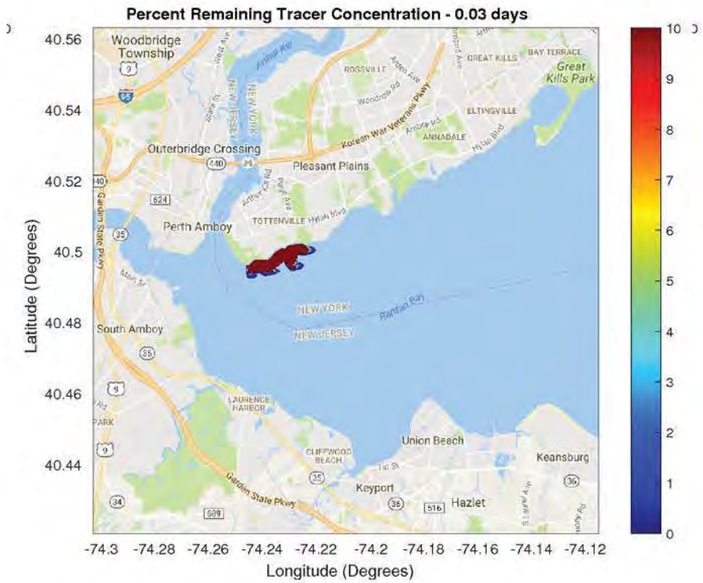
100 Year + 30" SLR| Input Wave Height of 5.3 feet | Waves Perpendicular to Shore

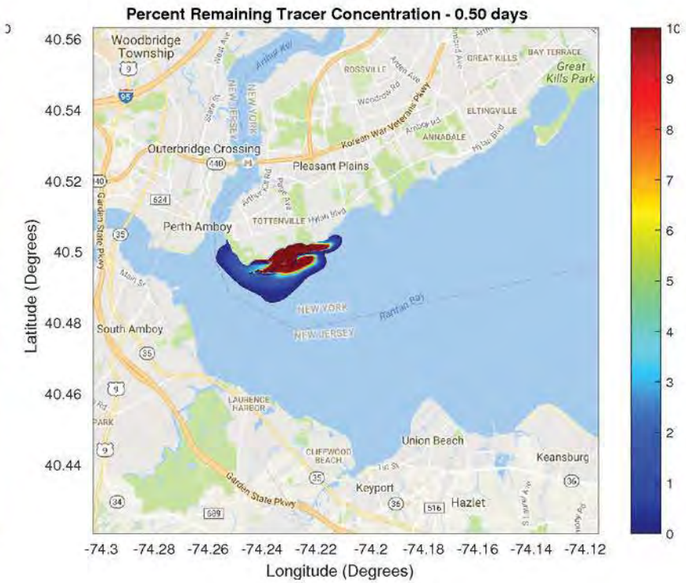


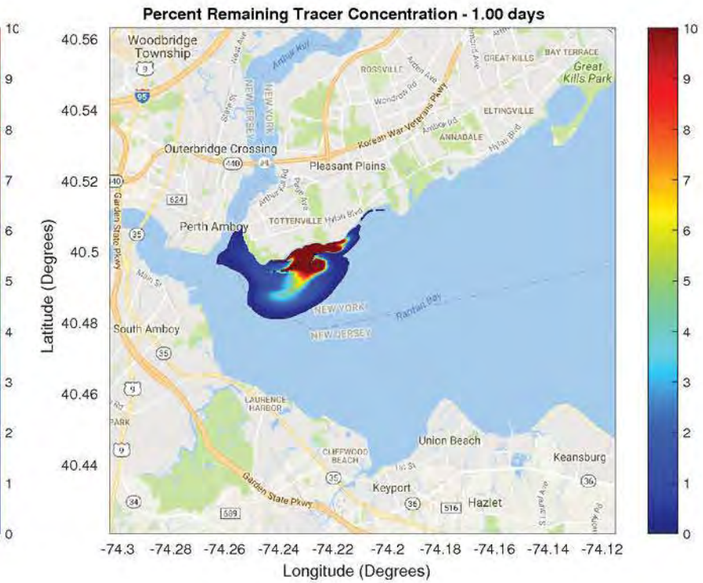
100 Year + 30" SLR| Input Wave Height of 5.3 feet | Waves from Southwest

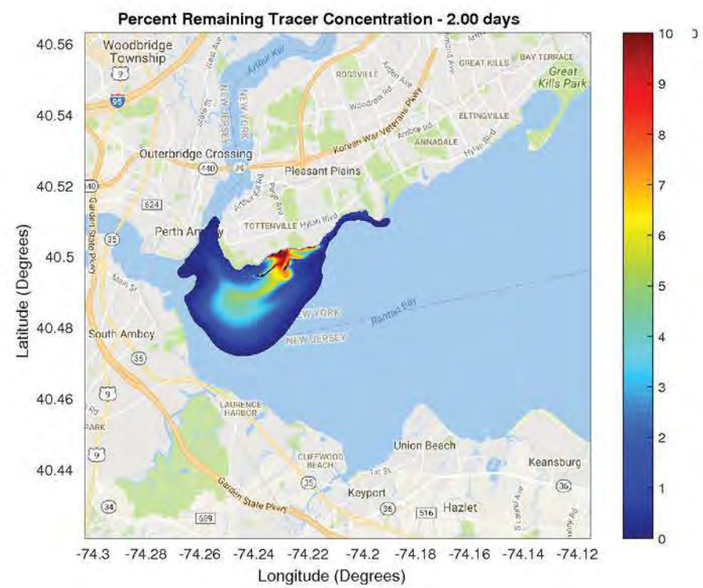


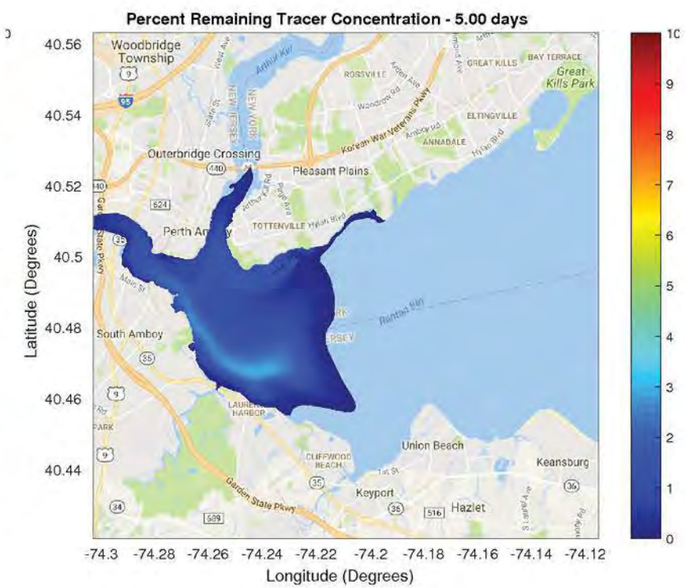
WAVE HEIGHTS SHOWN ARE RELATIVE WAVE HEIGHTS (MODELED WAVE HEIGHT/INCOMING OFFSHORE WAVE HEIGHT).











30% DESIGN SCENARIO

DELFT-3D RESULTS

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

FINAL 30% DESIGN SCENARIO

SUMMARY OF MODEL RESULTS

SHORELINE CHANGE

- Same as Scenario 15 with the addition of some shoreline restoration
- Beach is well retained and provides increased beach width over critical area of the shoreline
- Balance of shoreline response and wave protection

WAVE ACTION

- Same as Scenario 15.

WATER QUALITY

- No significant changes in residence time due to breakwaters

OVERALL TAKE-AWAYS

SHORELINE CHANGE

- Living Breakwaters spacing, gap width, distance to shoreline, and alignment iteratively tested to develop a preferred scenario.
- Living Breakwater System can provide effective shoreline stabilization in almost all areas.
- Breakwater distance from shore, length, gap width, and the relative ratios between them influence the shoreline behavior. Other factors influence the scale of salient formation, including but not limited to amount of sediment in the system, amount of sediment trapped upstream, shape of shoreline, and existing coastal structures.
- Trapping of greater amounts of sediment 'upstream' appears to limit potential of sediment capture downstream.
- "Opening" northeast breakwater area was required to allow updrift sediment to transport to zone 2 / zone 3.
- Southwestern breakwaters are required to stabilize historical erosion at Conference House Park.

WAVE ACTION

- With enough properly spaced breakwaters an effective wave shadow zone (area where we see wave height reduction) throughout most of the project area can be created.
- Smaller gap widths allow fewer / lower waves to pass through.
- Wide spacing between breakwater segments results in little wave reduction in the gaps between them.
- Use of lower crested breakwaters on western edge show limited effectiveness in attenuating waves under higher water levels, so are only being recommended where storm wave attenuation is not a priority (southeastern end of the project area)

WATER QUALITY

- No significant changes in residence time due to breakwaters

SHORELINE RESTORATION

- Shoreline restoration shifted shoreline outward in region of fill.
- Shoreline restoration was relatively well retained.

APPENDIX B - SBEACH AND CSHORE SIMULATIONS

INITIAL BEACH PROFILE TRANSECTS

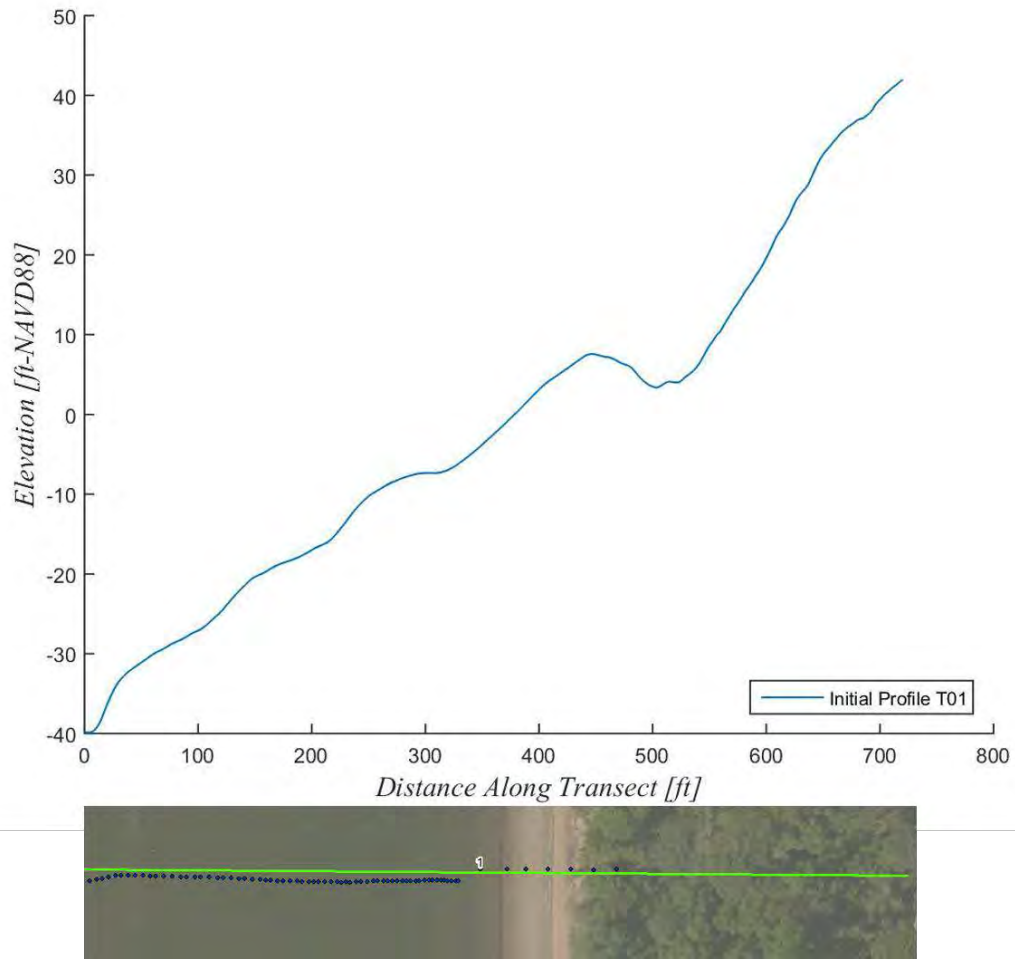


Figure 1. Initial beach profile and recent orthoimagery for transect 1.

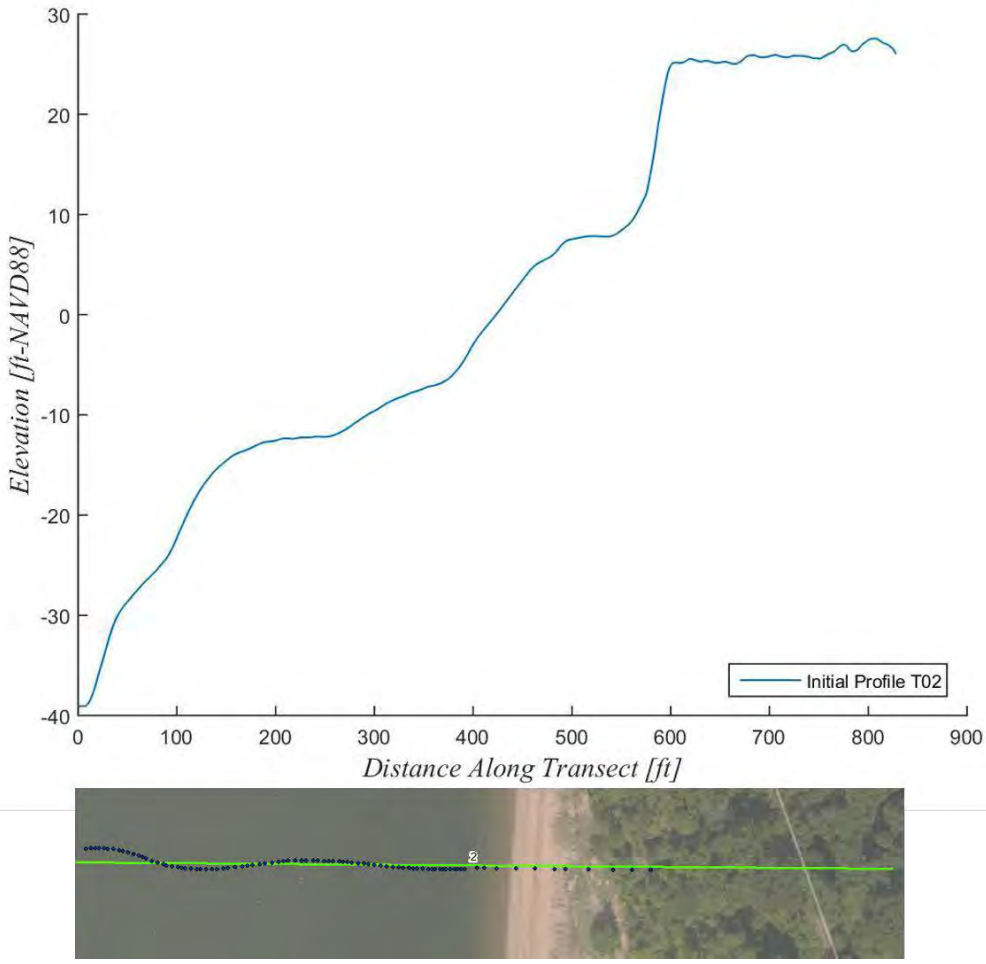


Figure 2. Initial beach profile and recent orthoimagery for transect 2.

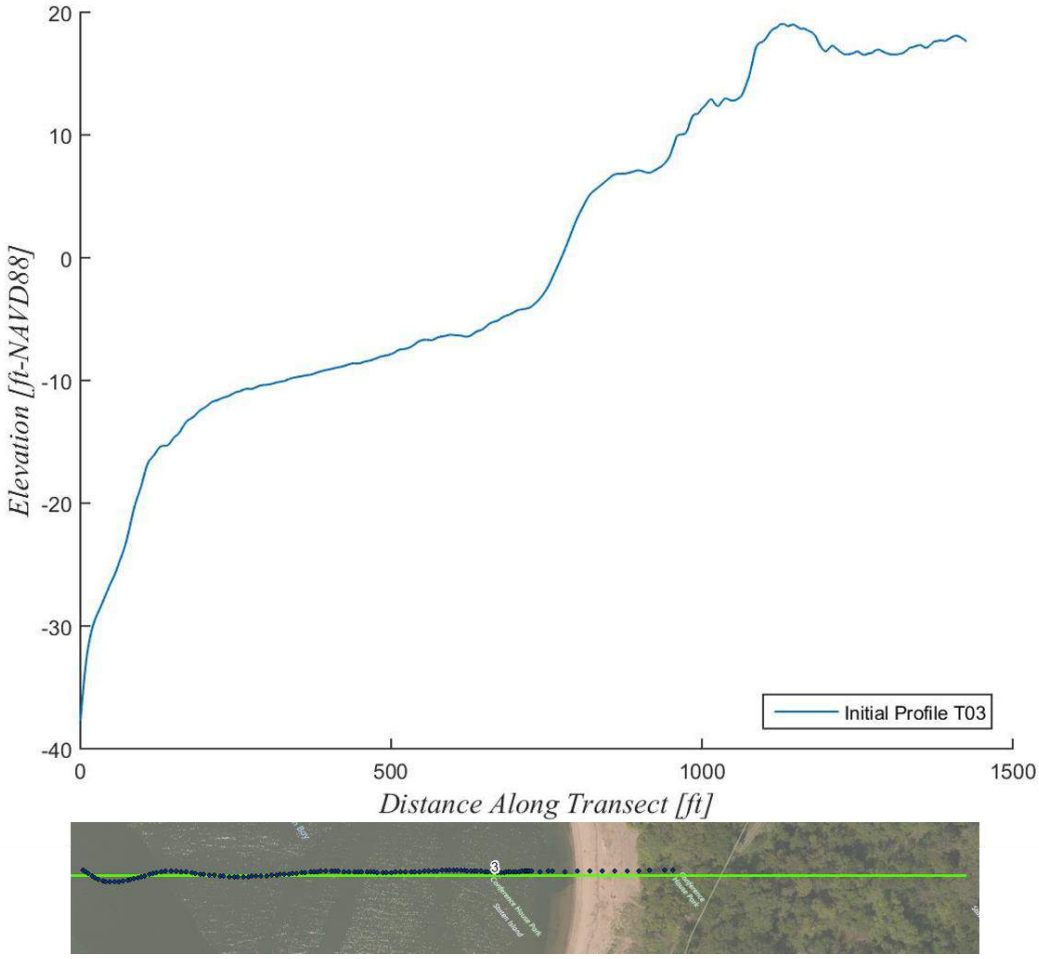


Figure 3. Initial beach profile and recent orthoimagery for transect 3.

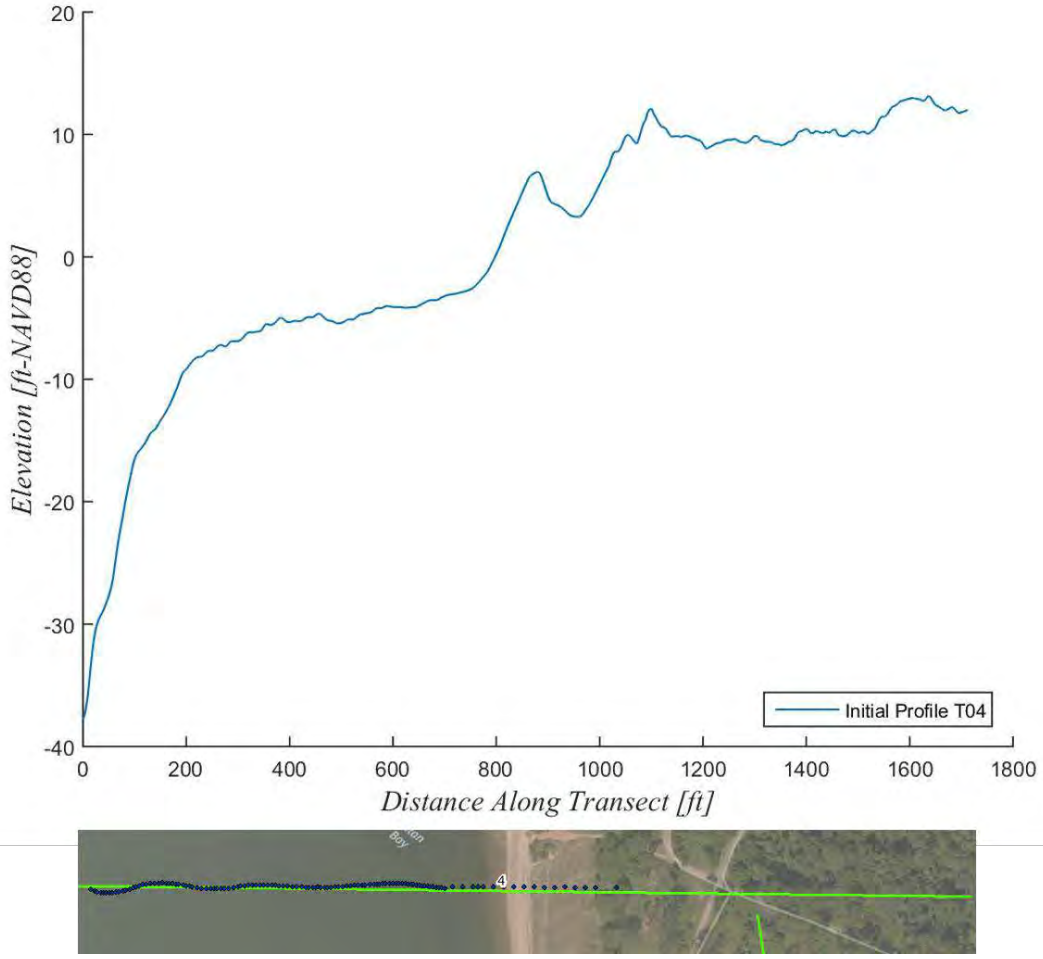


Figure 4. Initial beach profile and recent orthoimagery for transect 4.

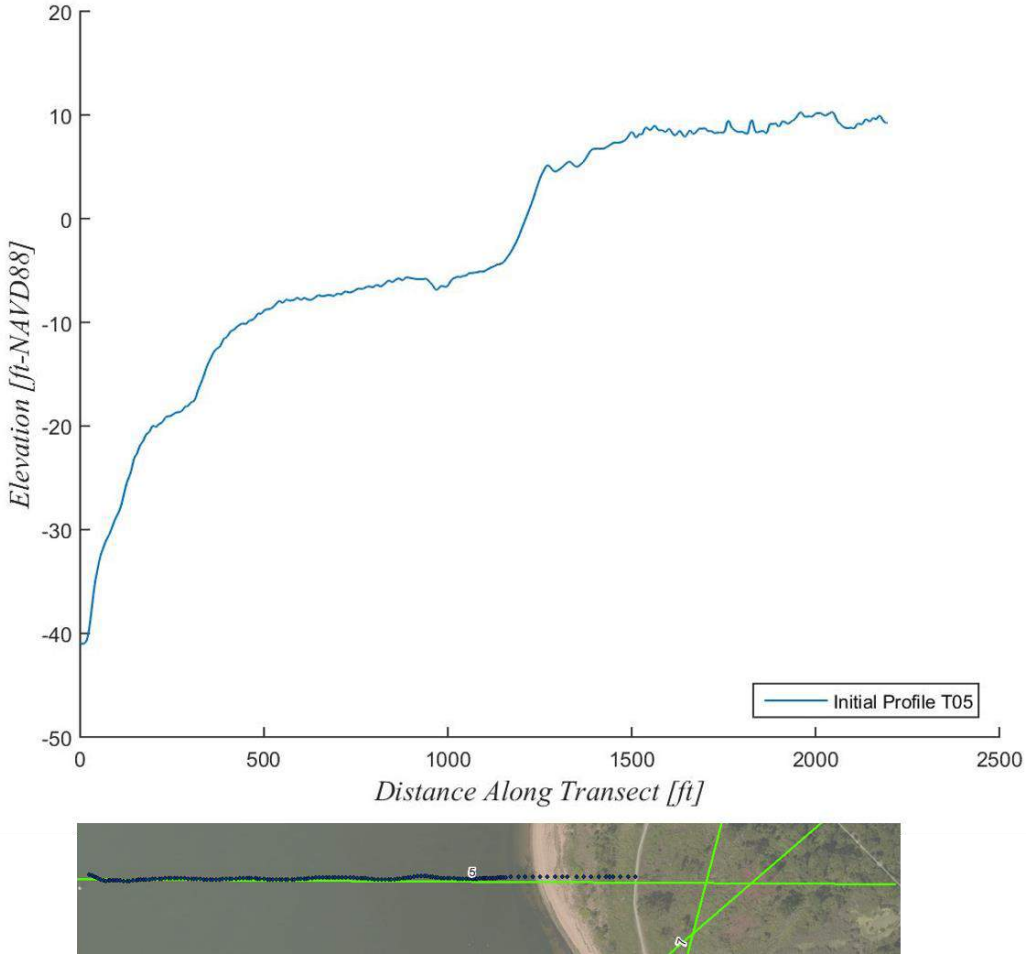


Figure 5. Initial beach profile and recent orthoimagery for transect 5.

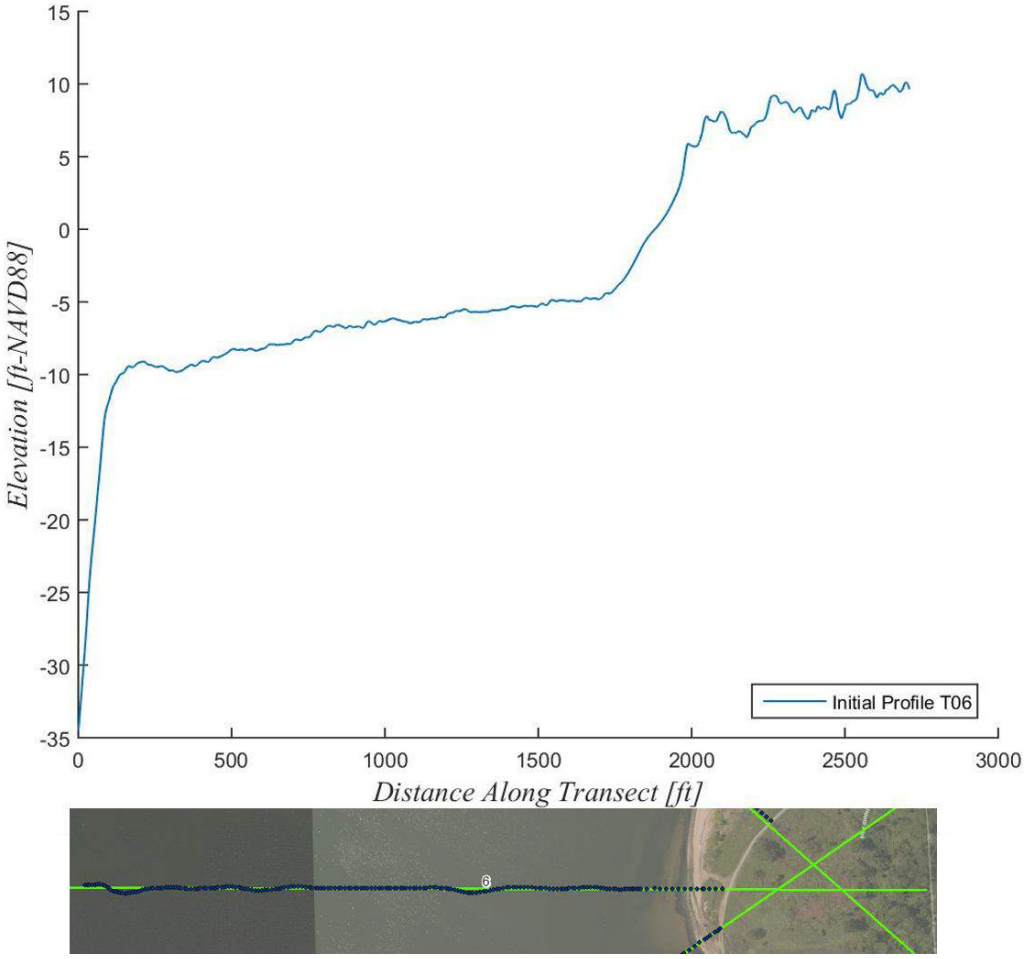


Figure 6. Initial beach profile and recent orthoimagery for transect 6.

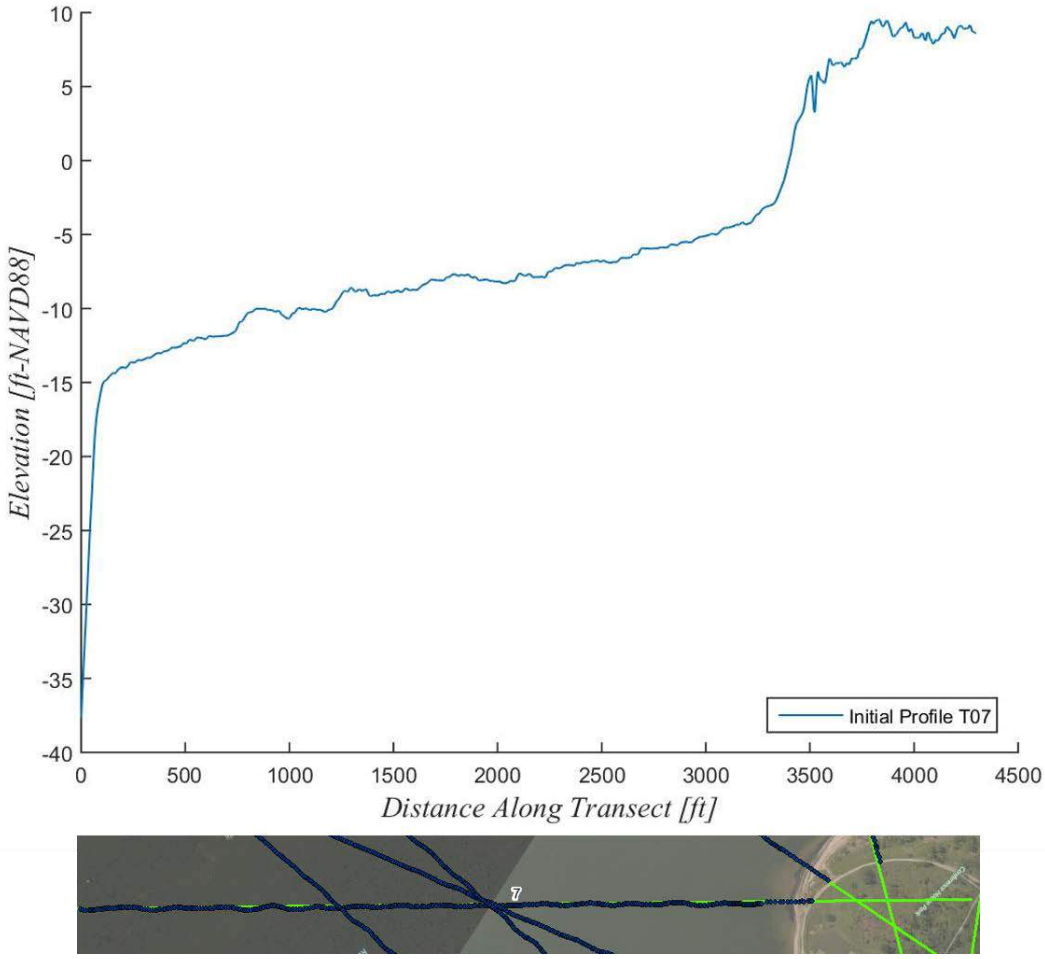


Figure 7. Initial beach profile and recent orthoimagery for transect 7.

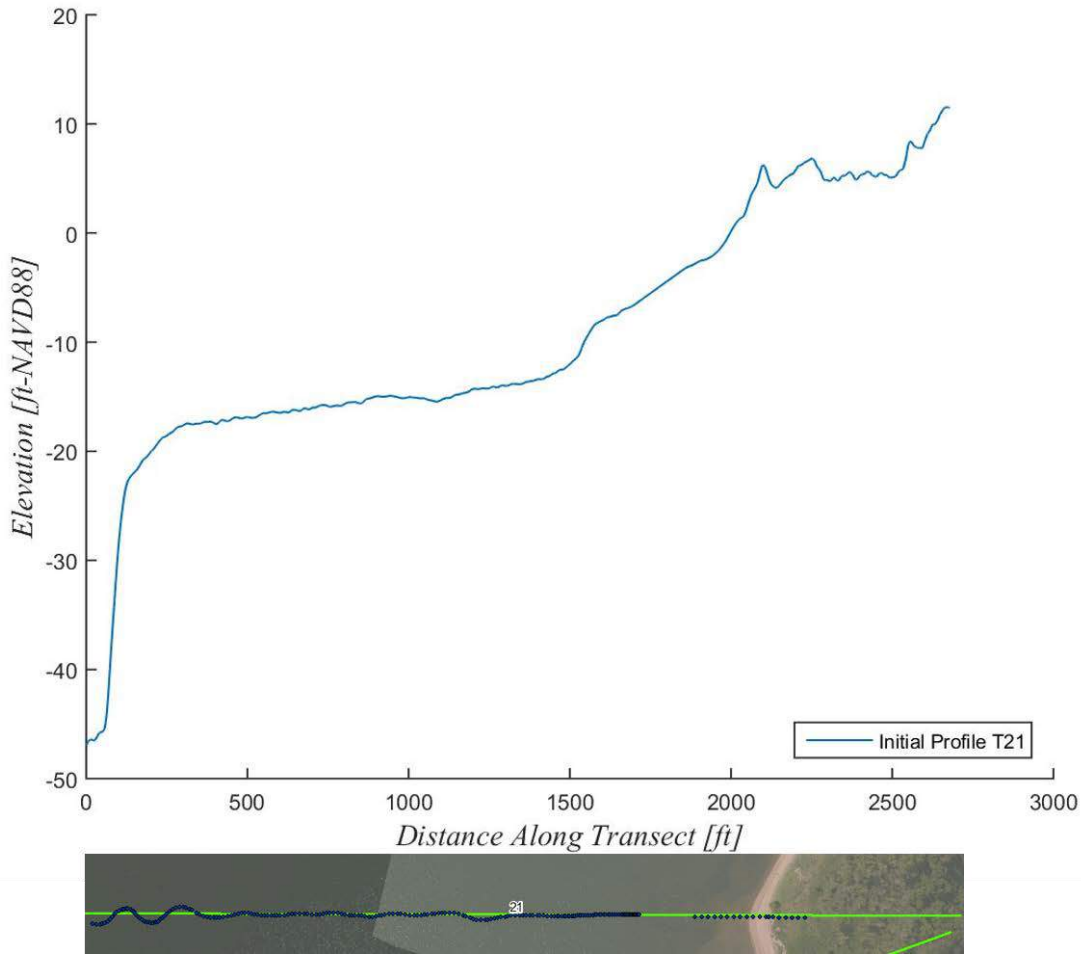


Figure 8. Initial beach profile and recent orthoimagery for transect 21.

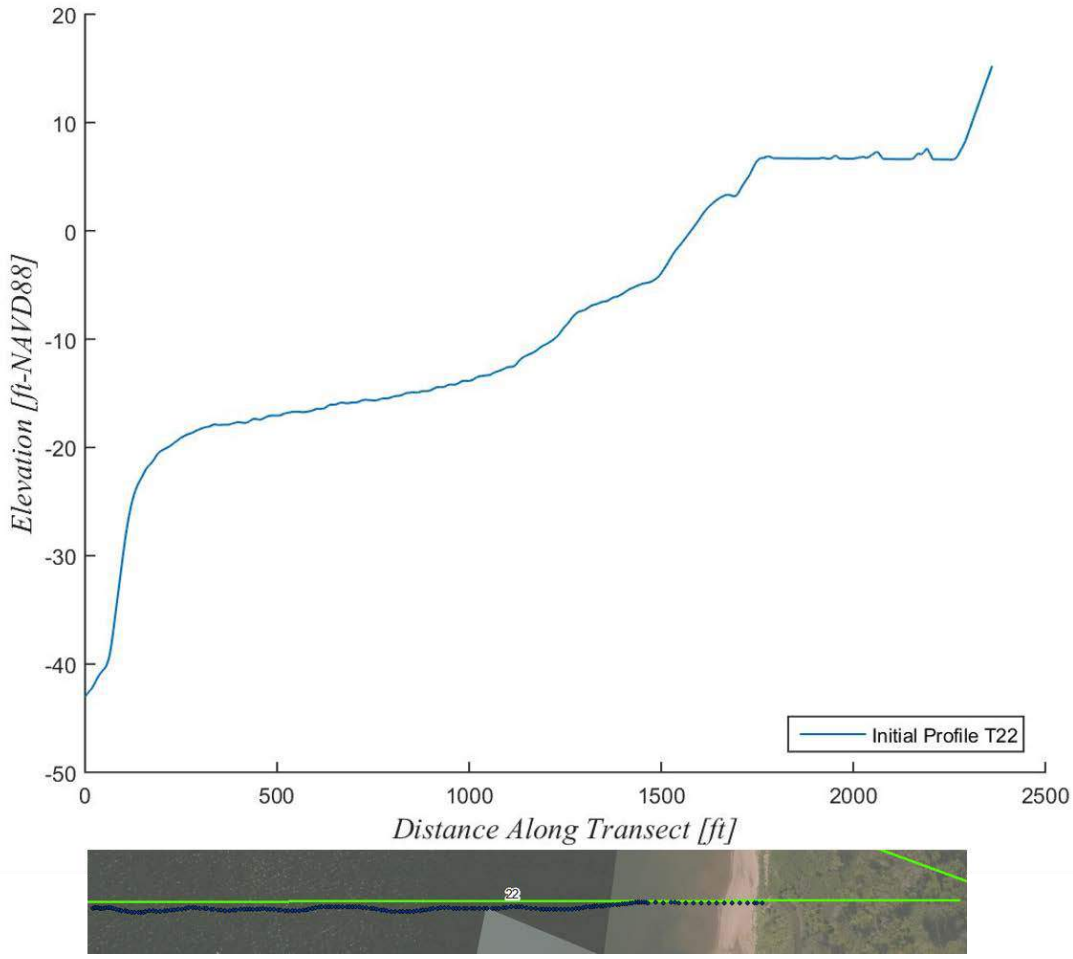


Figure 9. Initial beach profile and recent orthoimagery for transect 22.

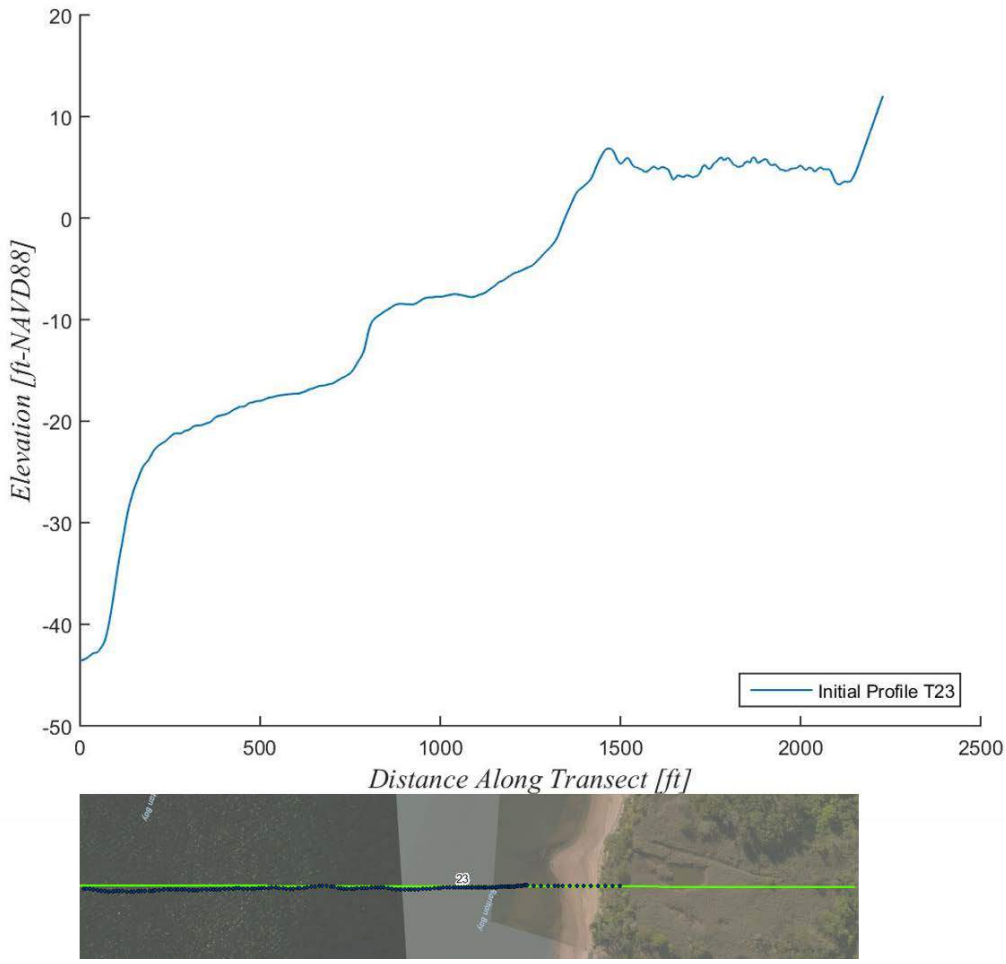


Figure 10. Initial beach profile and recent orthoimagery for transect 23.

SBEACH AND CSHORE SIMULATIONS WITH HURRICANE SANDY

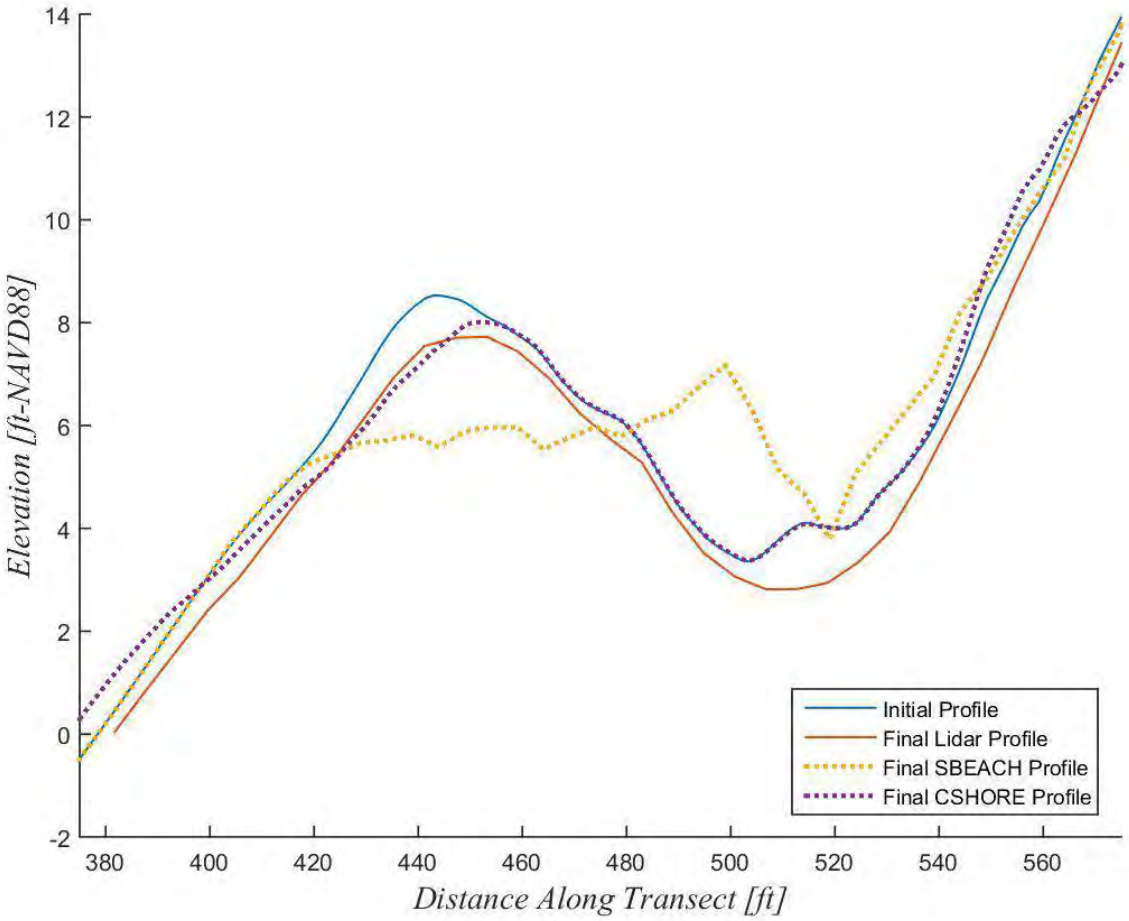


Figure 11. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 1.

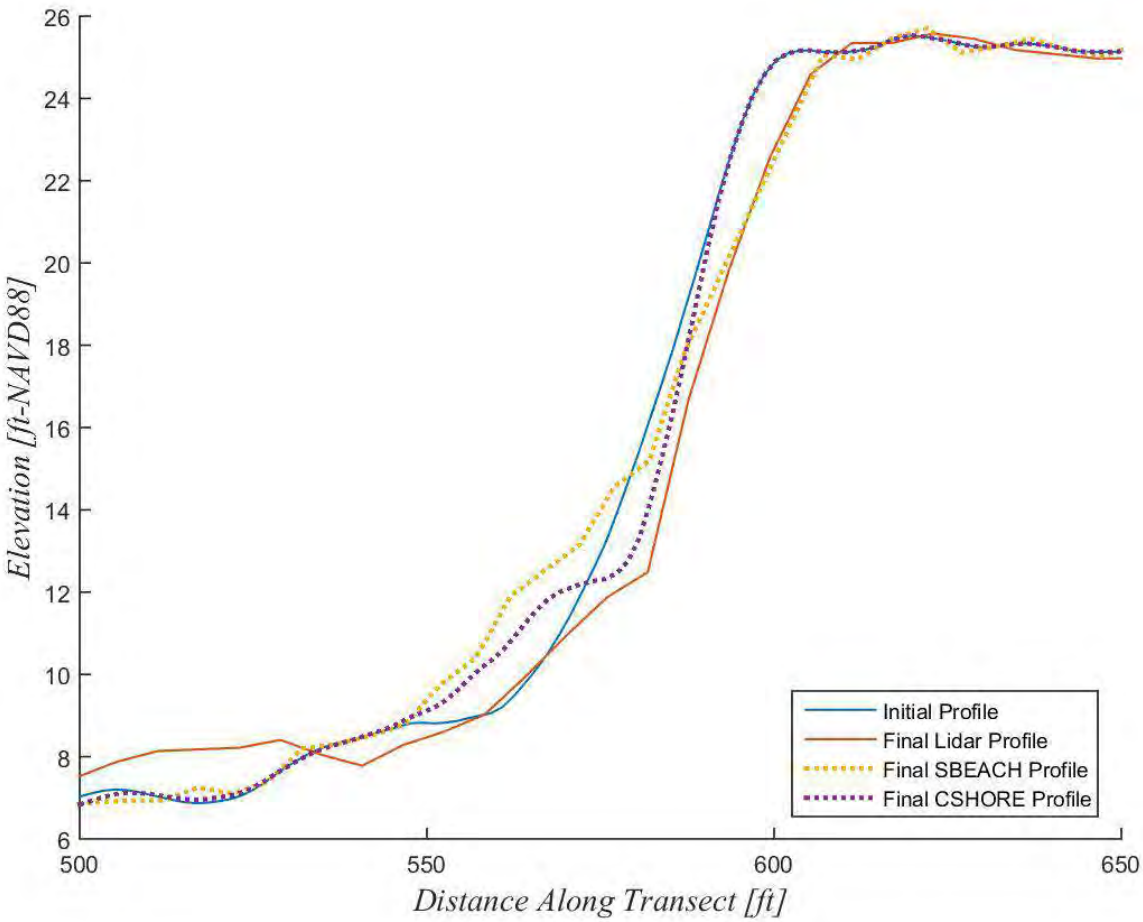


Figure 12. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 2.

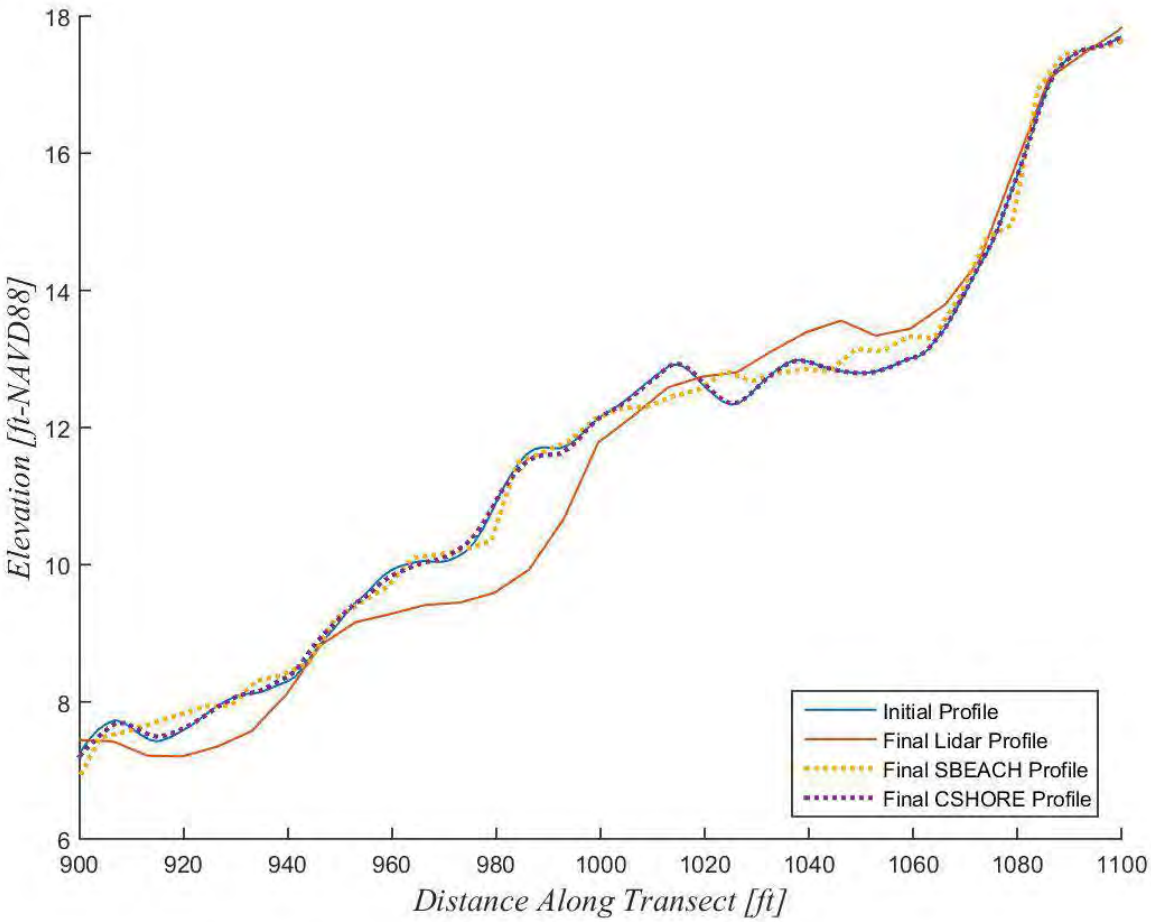


Figure 13. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 3.

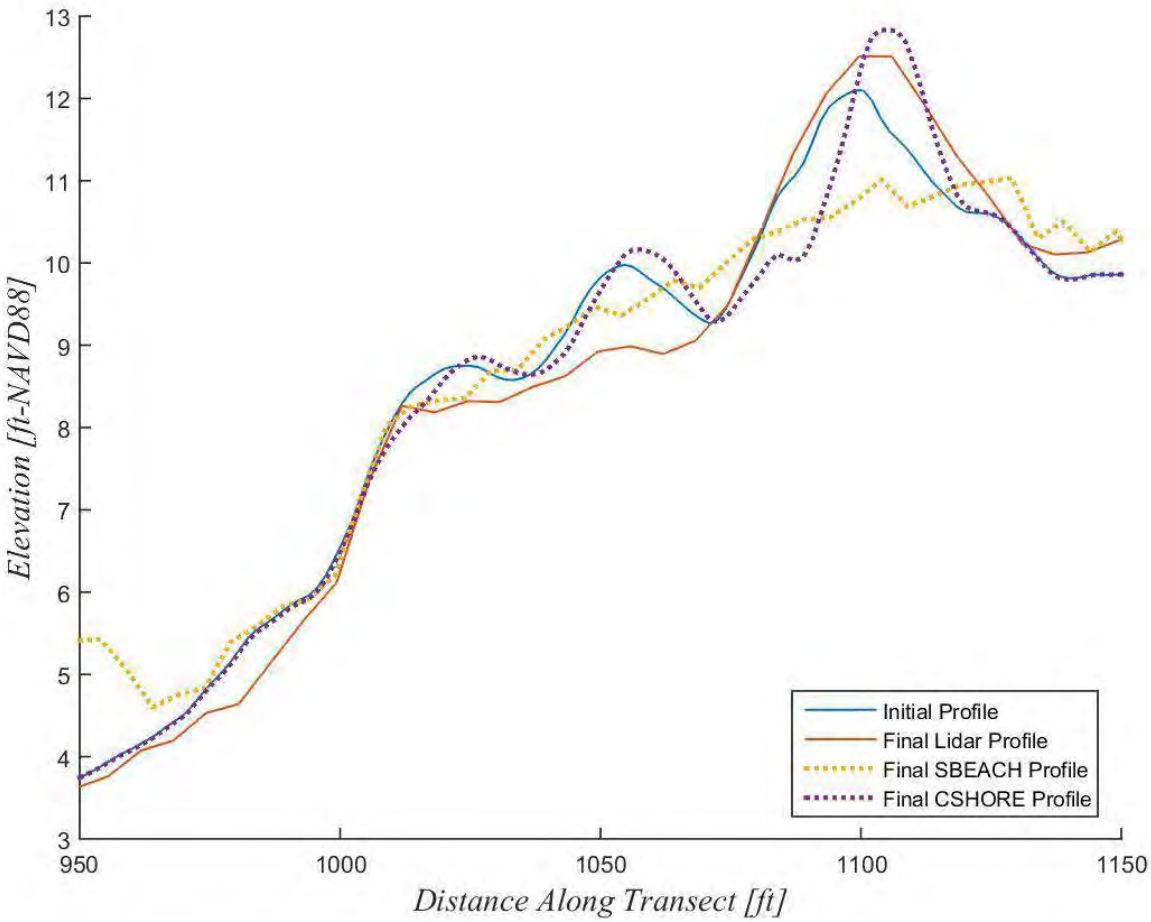


Figure 14. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 4.

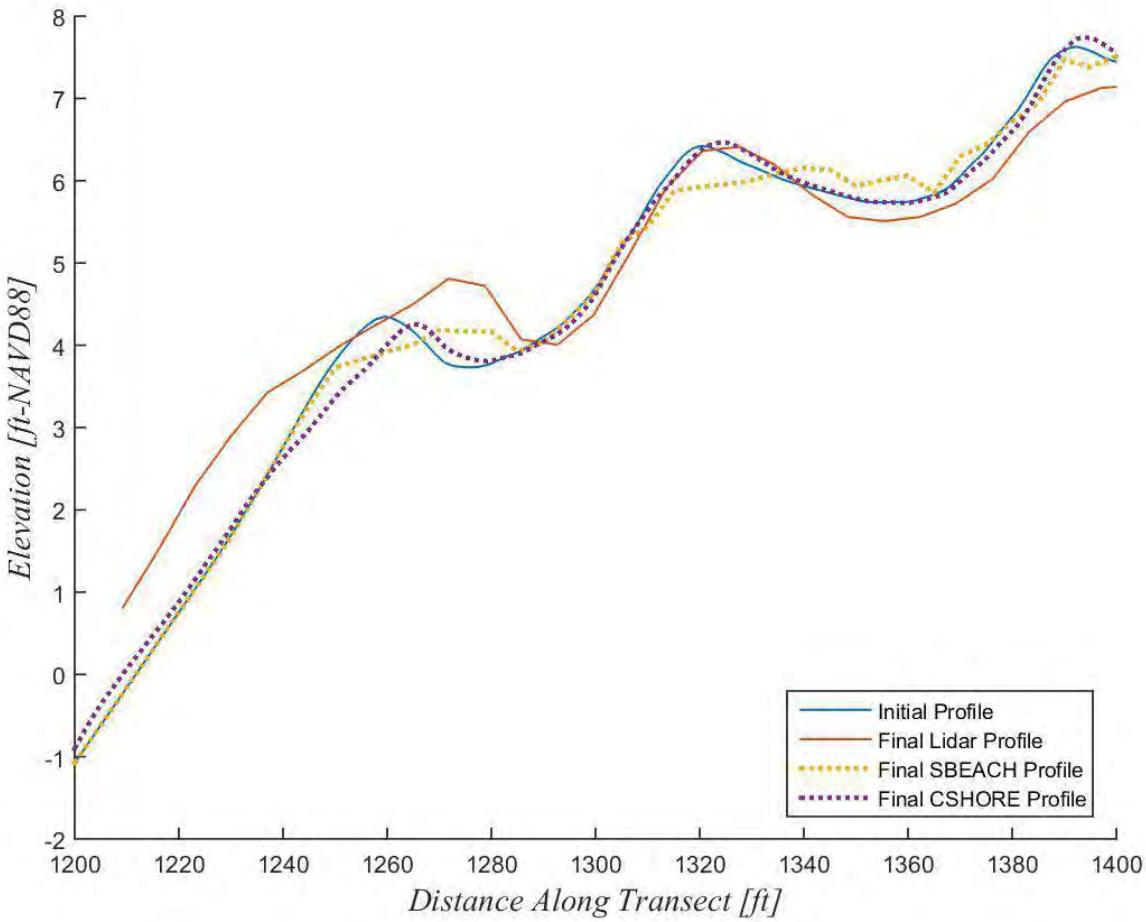


Figure 15. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 5.

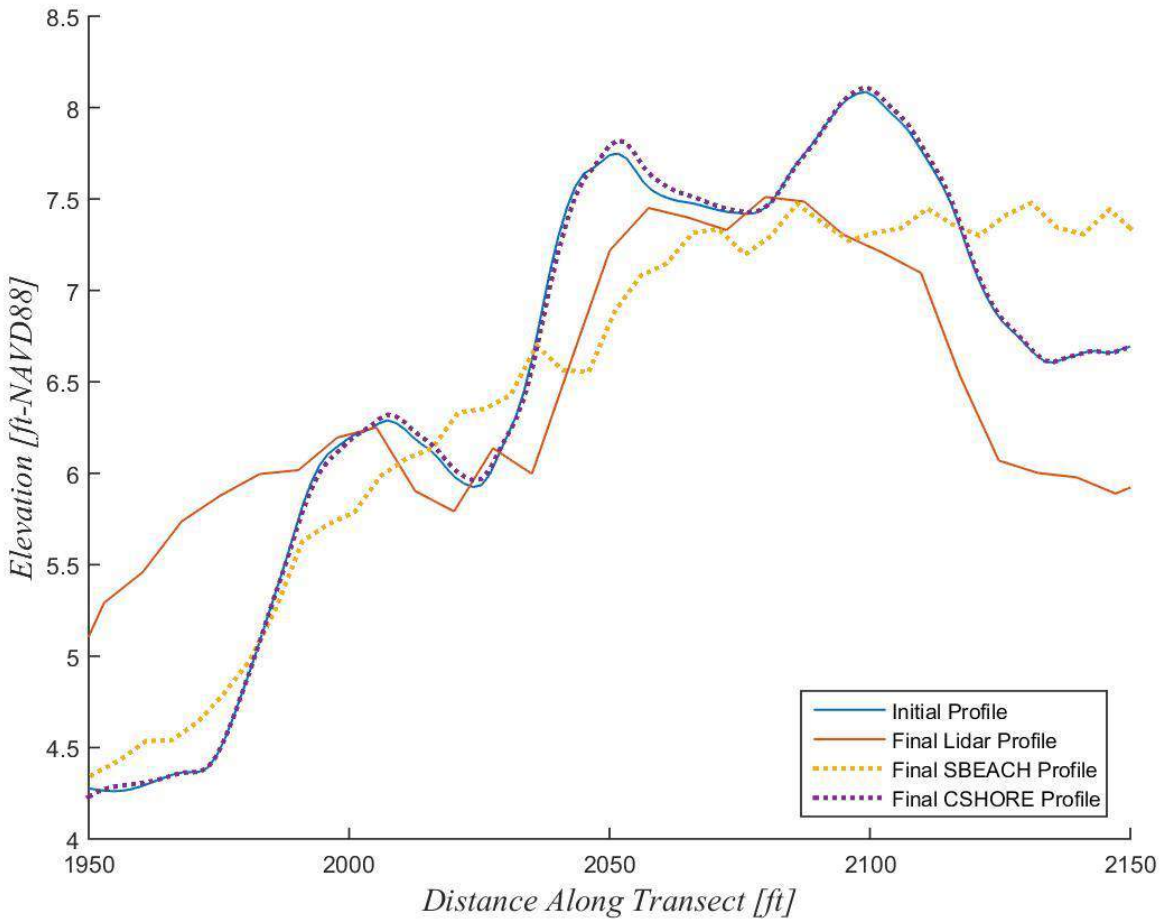


Figure 16. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 6.

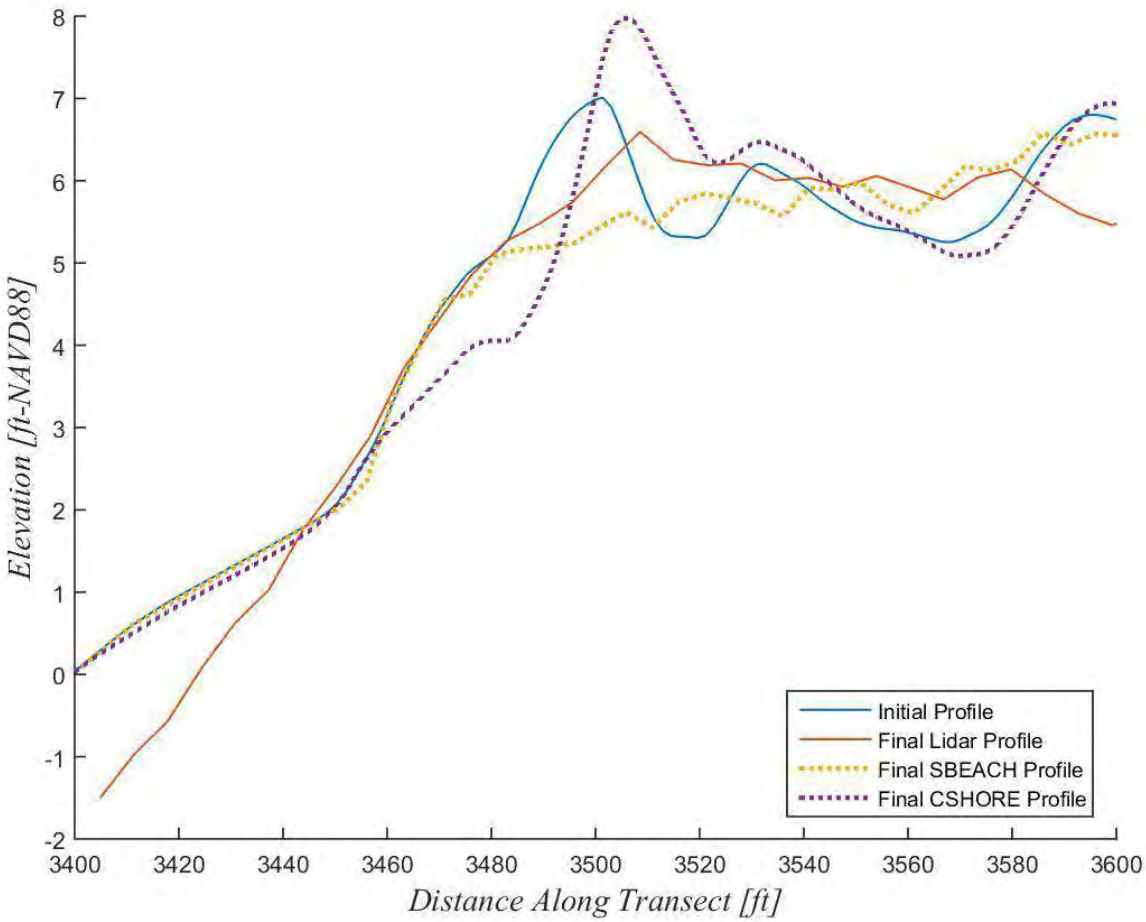


Figure 17. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 7.

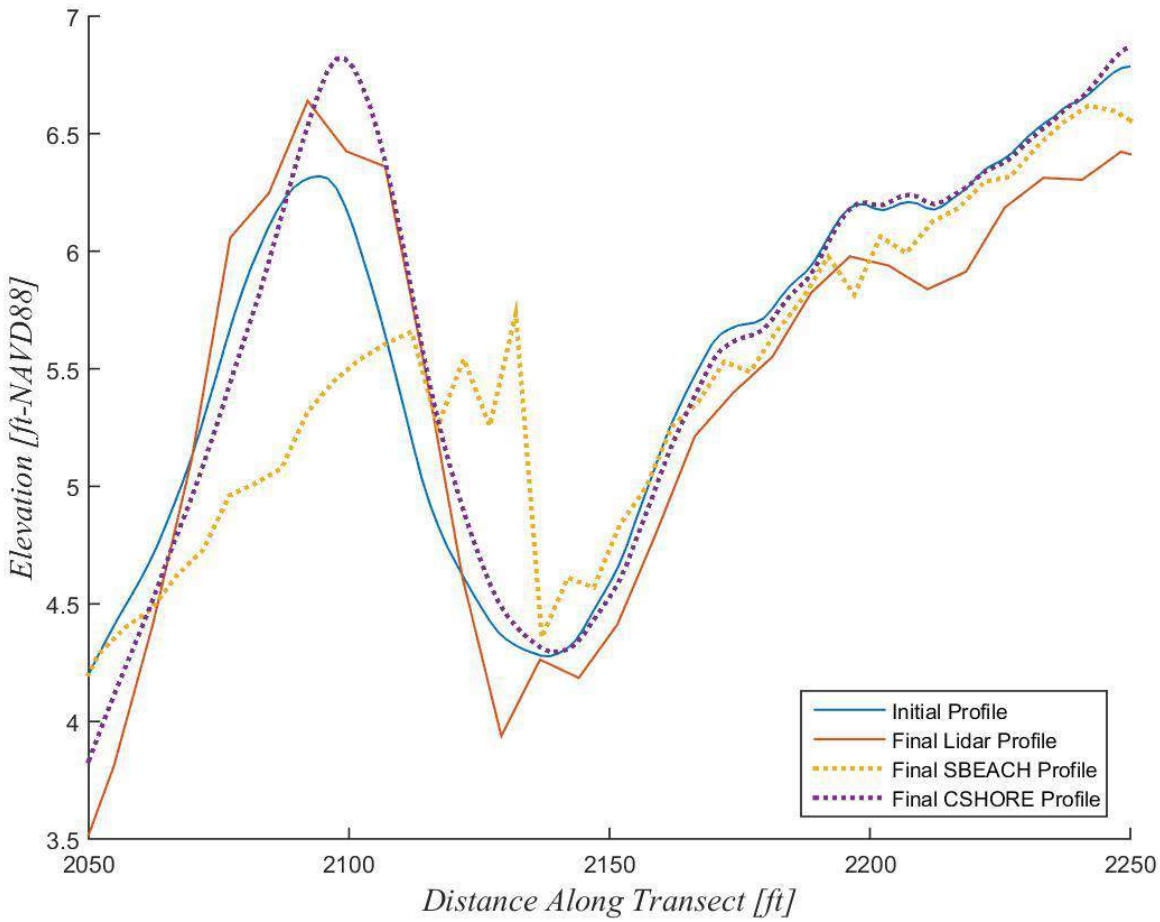


Figure 18. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 21.

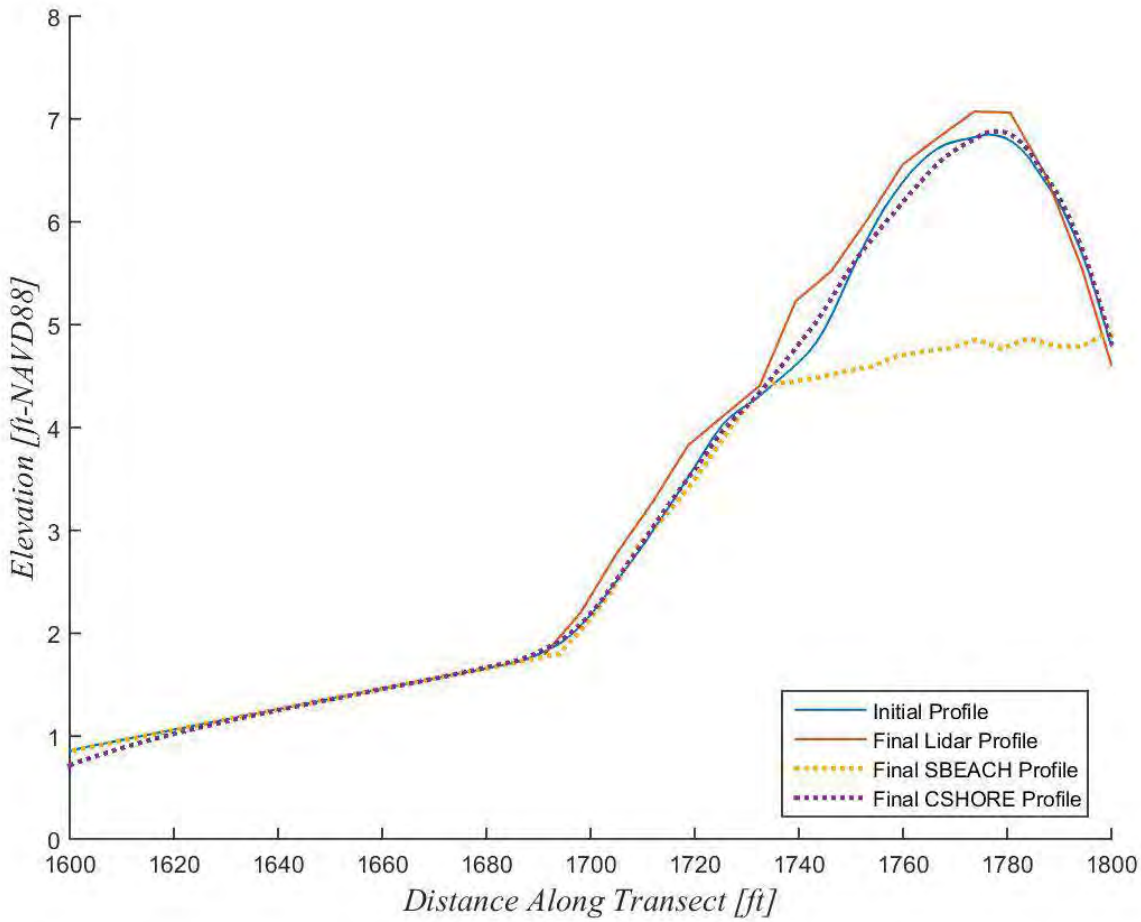


Figure 19. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 22.

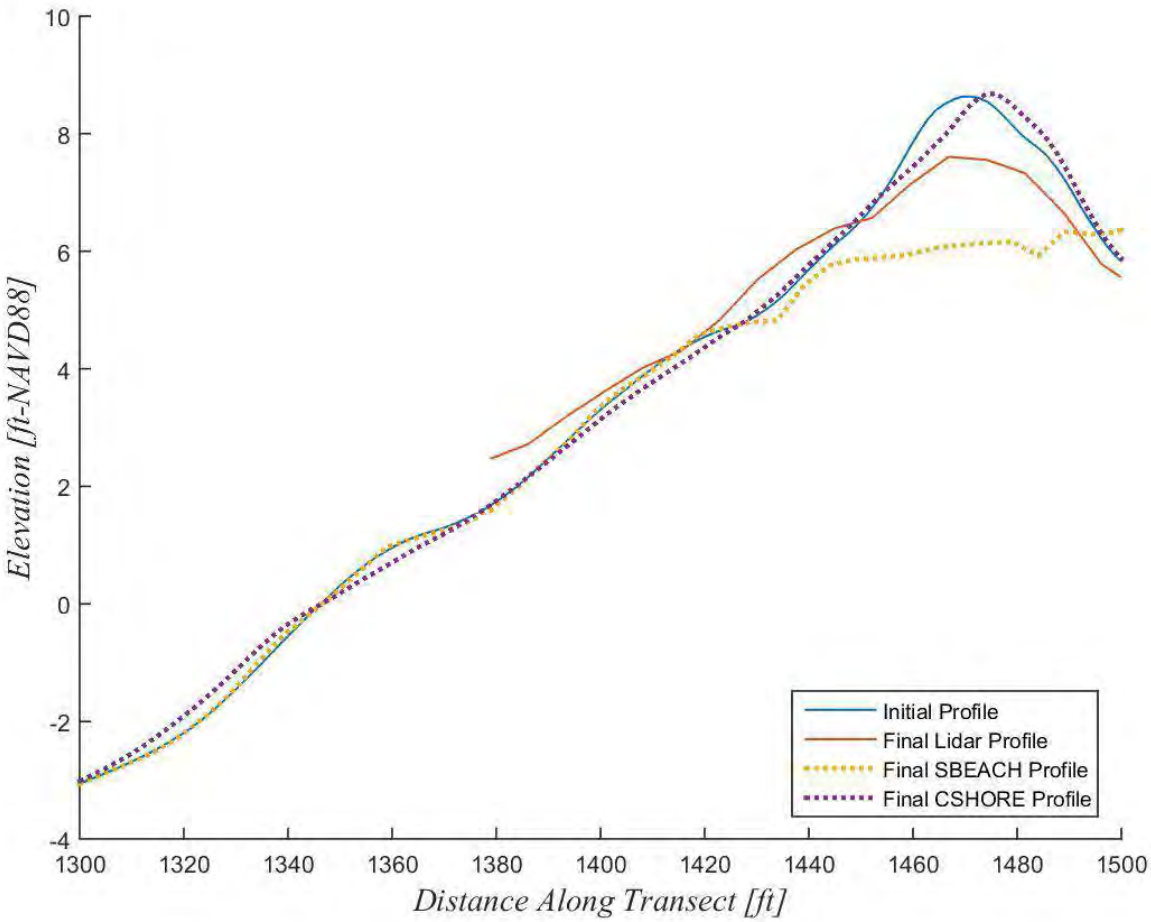


Figure 20. Comparison of CSHORE and SBEACH model results for Hurricane Sandy at transect 23.

CSHORE SIMULATIONS WITH FEMA PFIRM STORMS

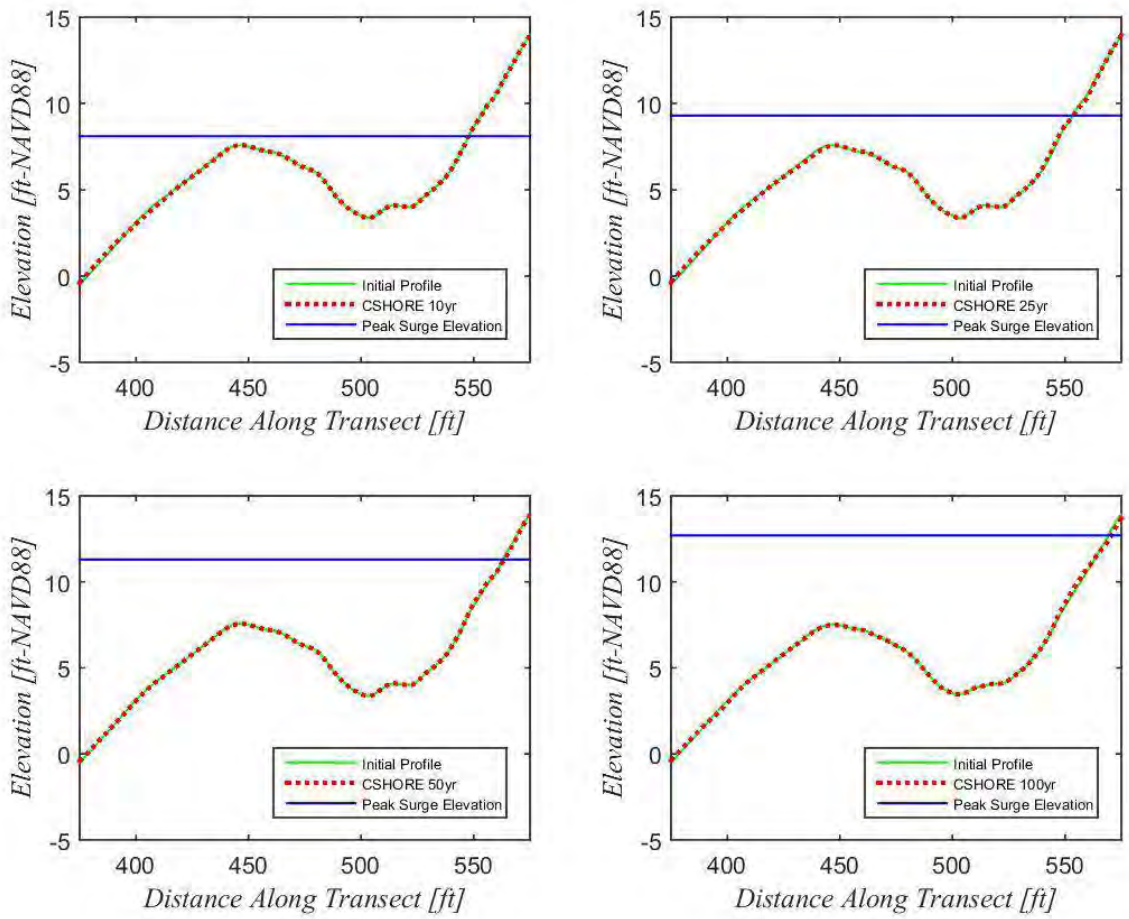


Figure 21. CSHORE results for 10-, 25-, 50-, and 100-year storm events at transect 1.

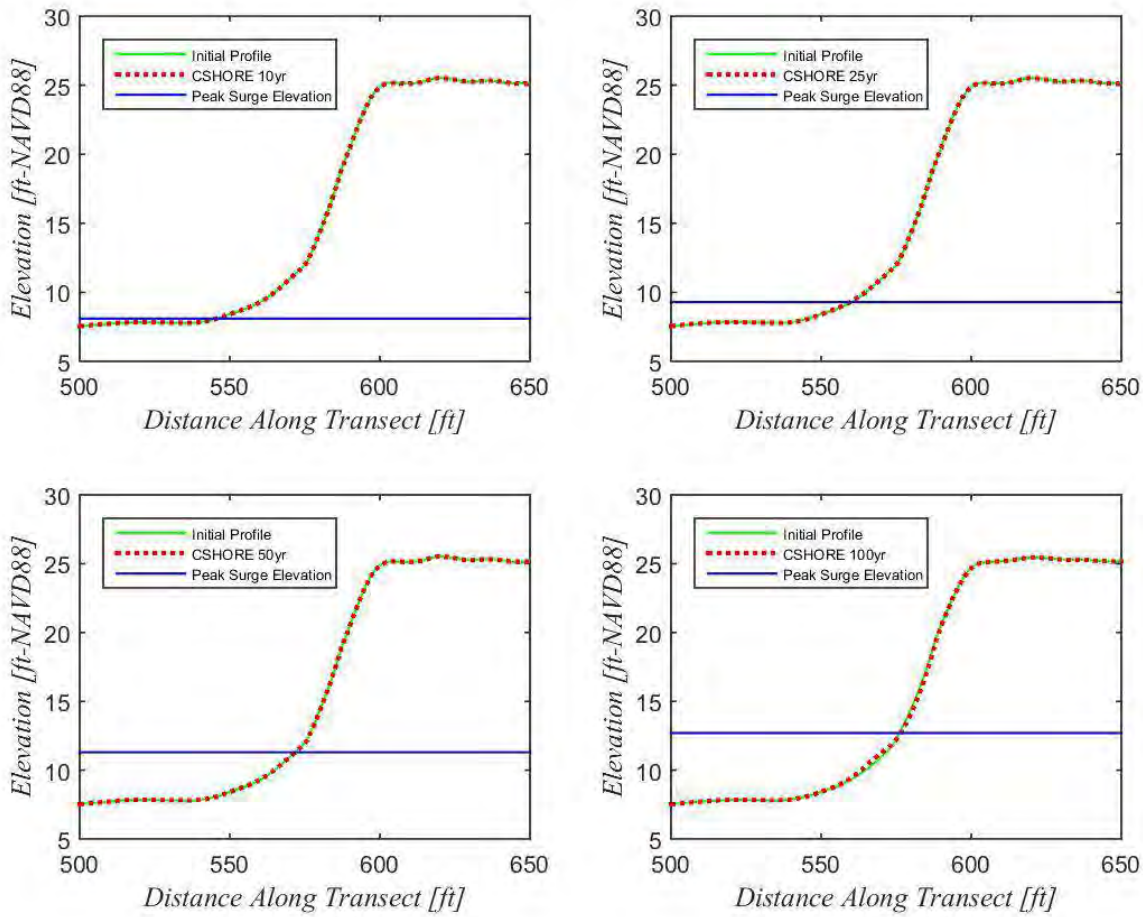


Figure 22. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 2.

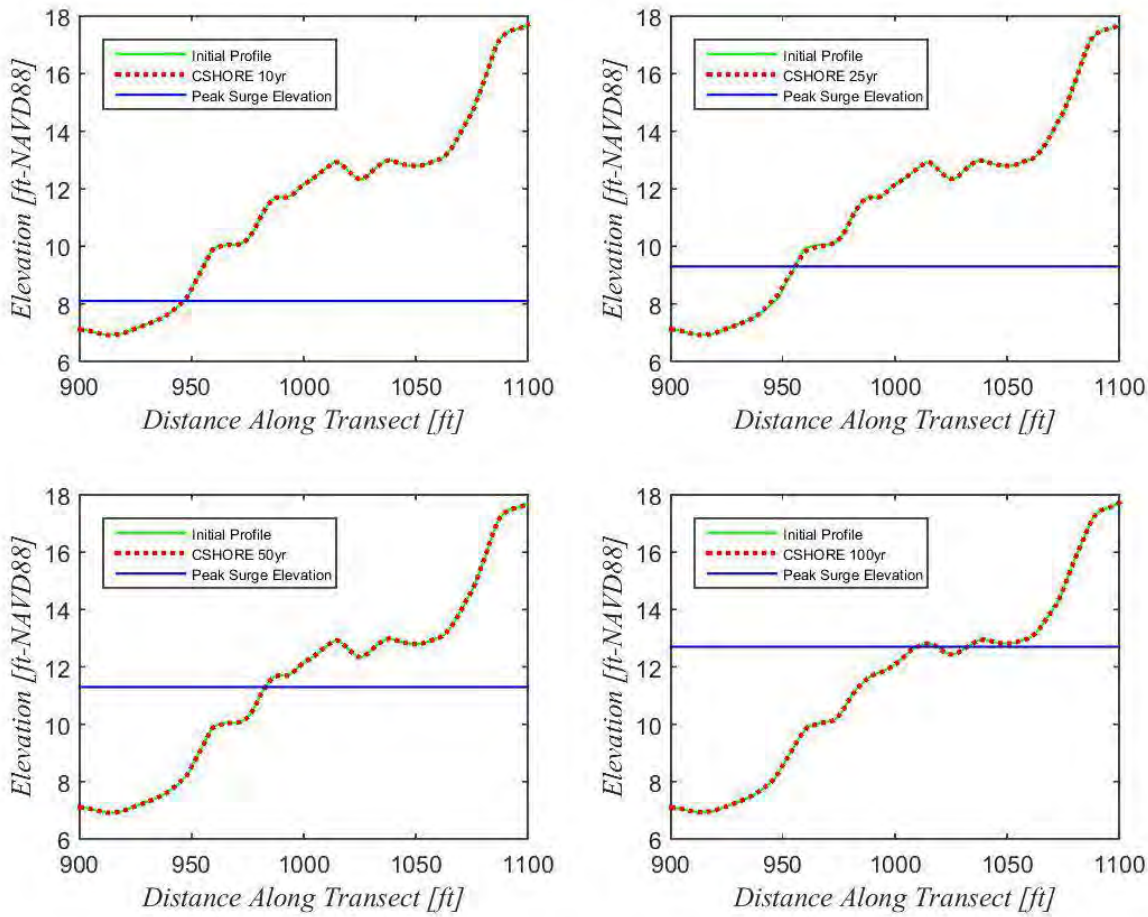


Figure 23. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 3.

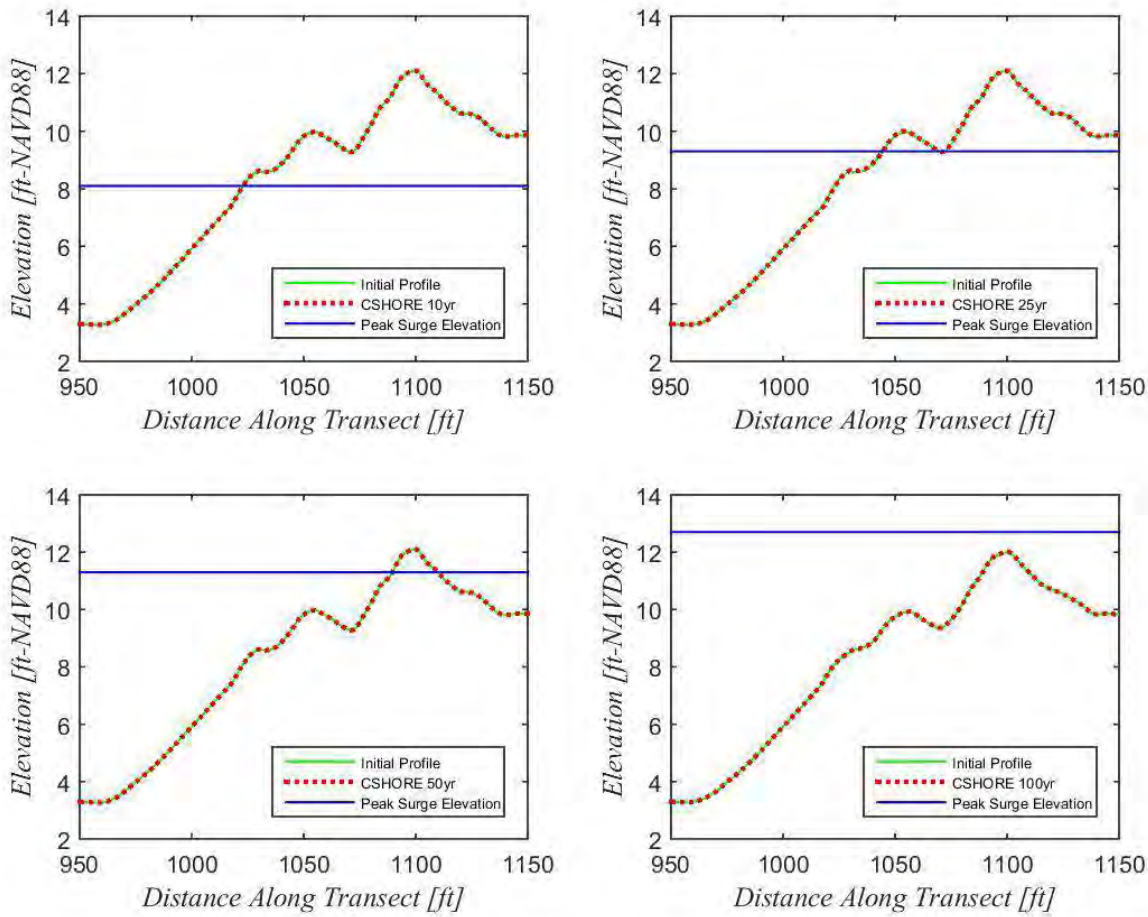


Figure 24. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 4.

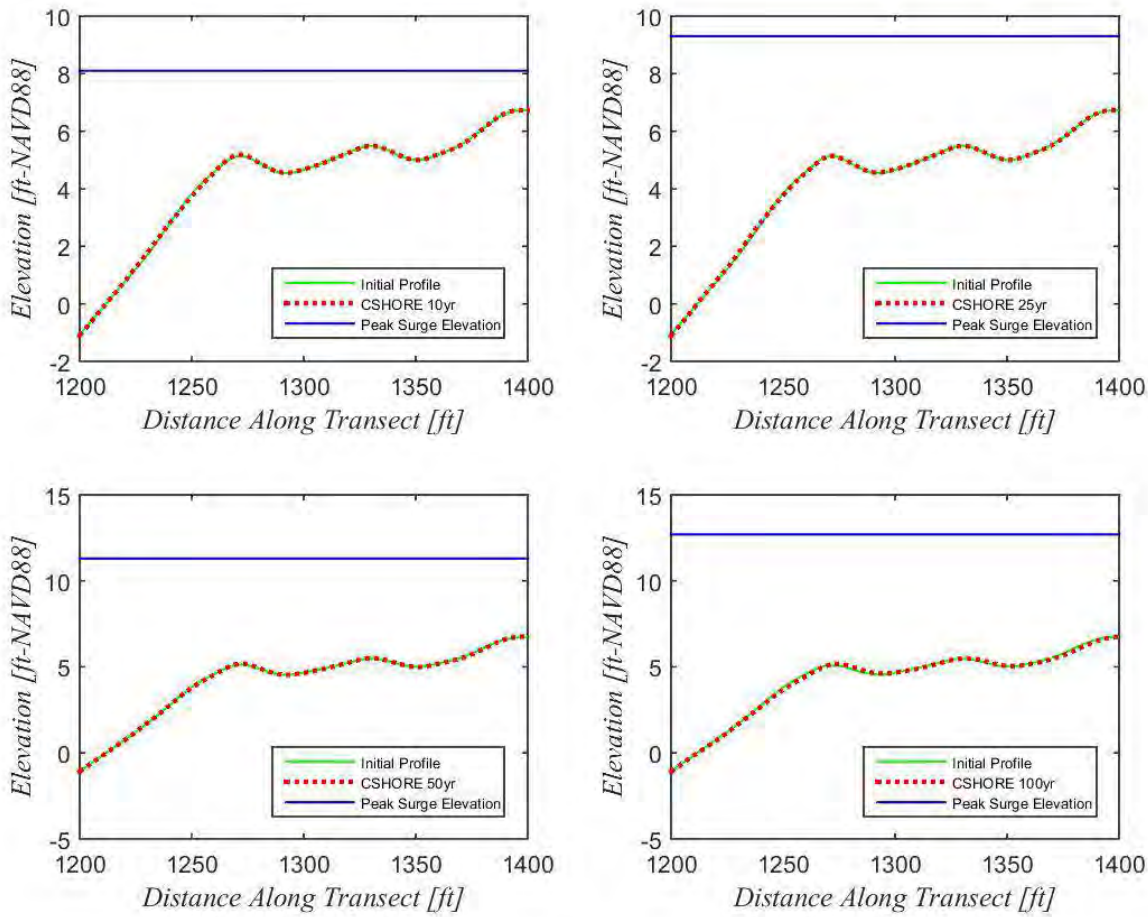


Figure 25. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 5.

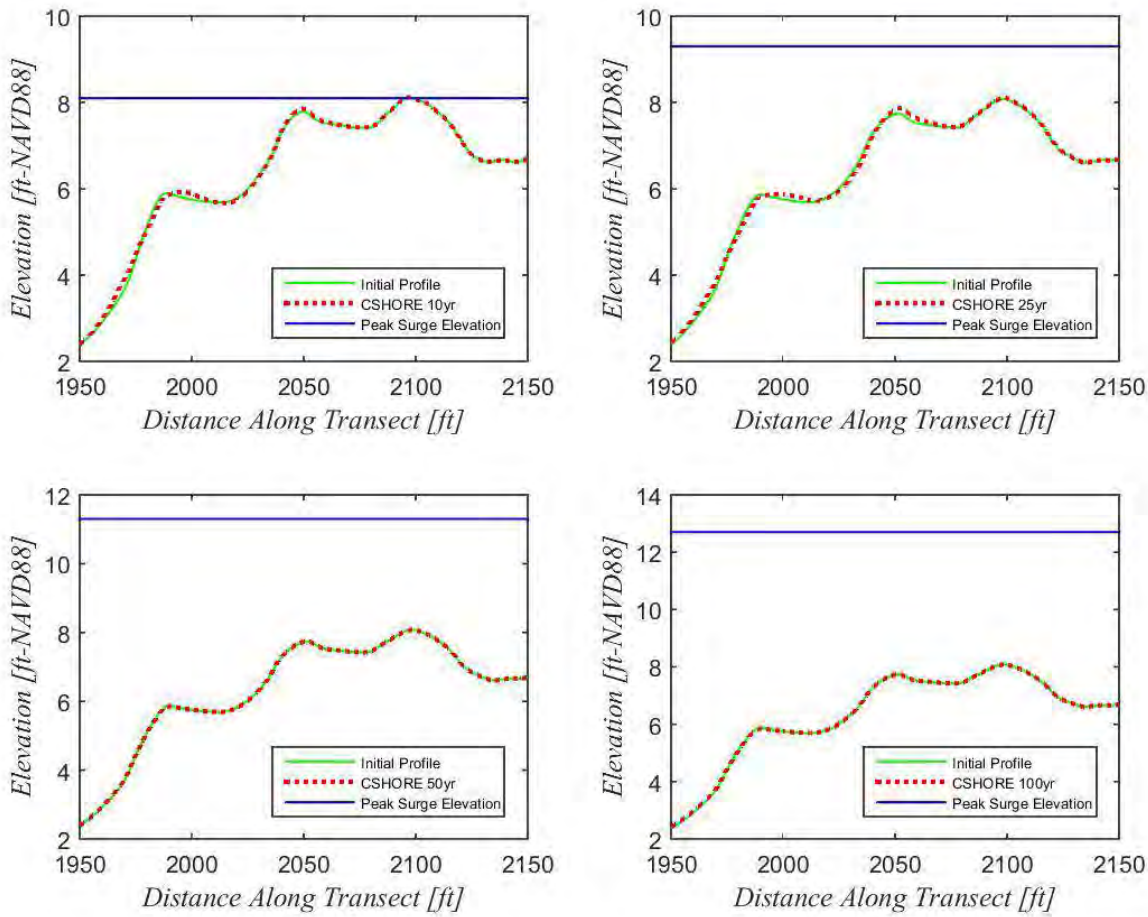


Figure 26. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 6.

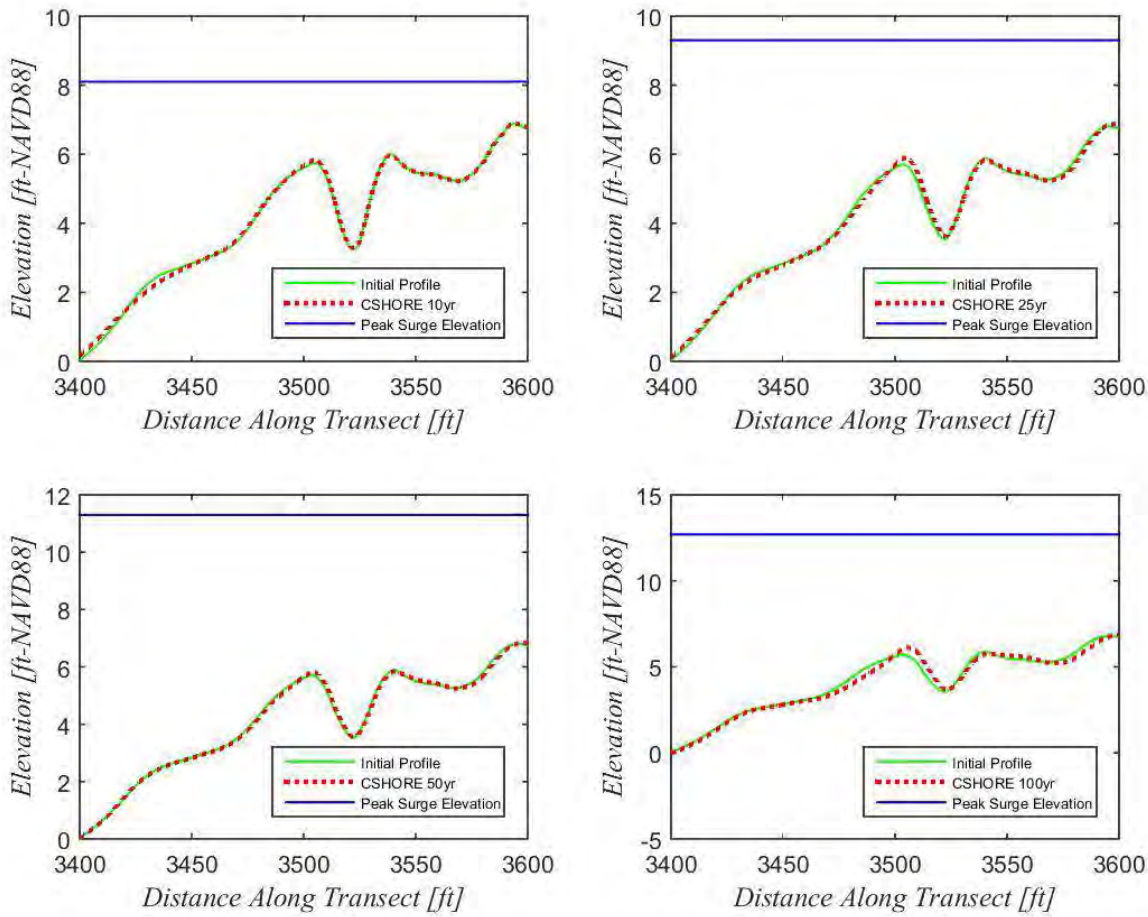


Figure 27. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 7.

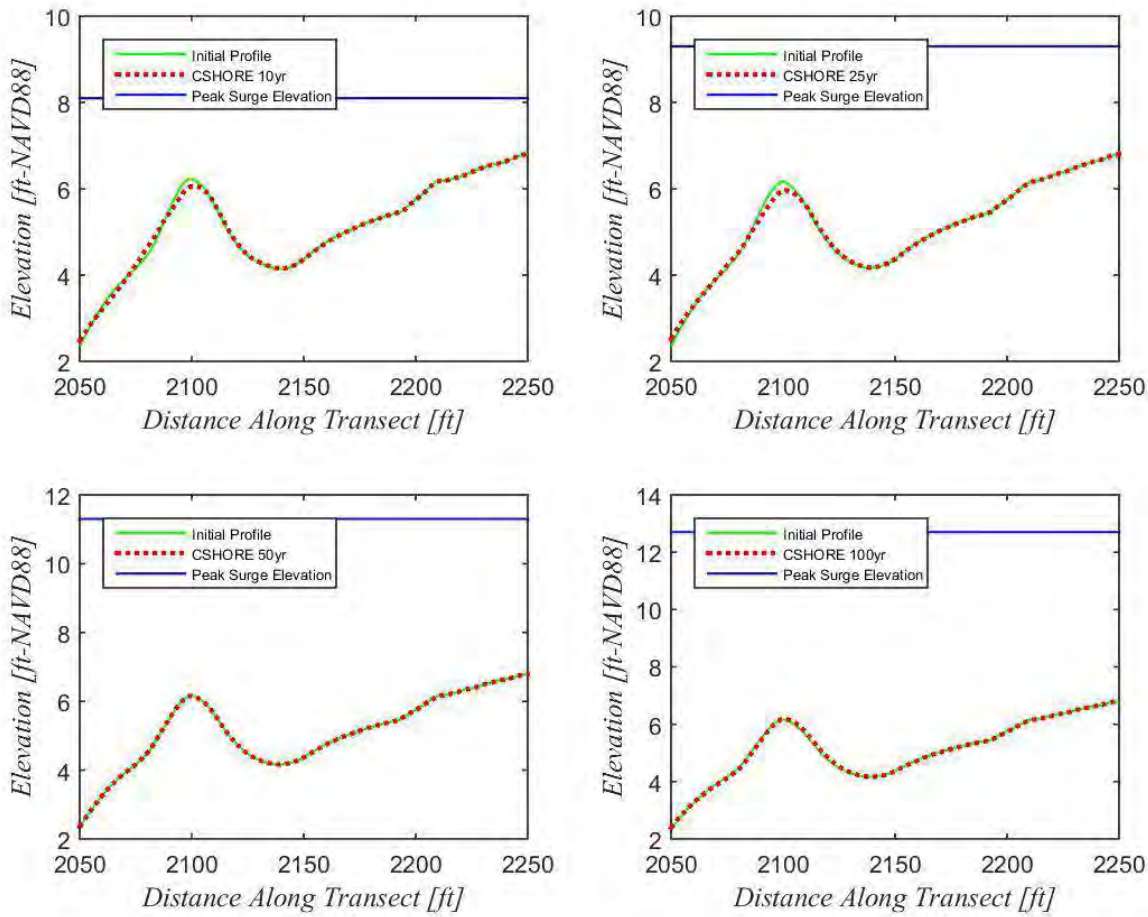


Figure 28. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 21.

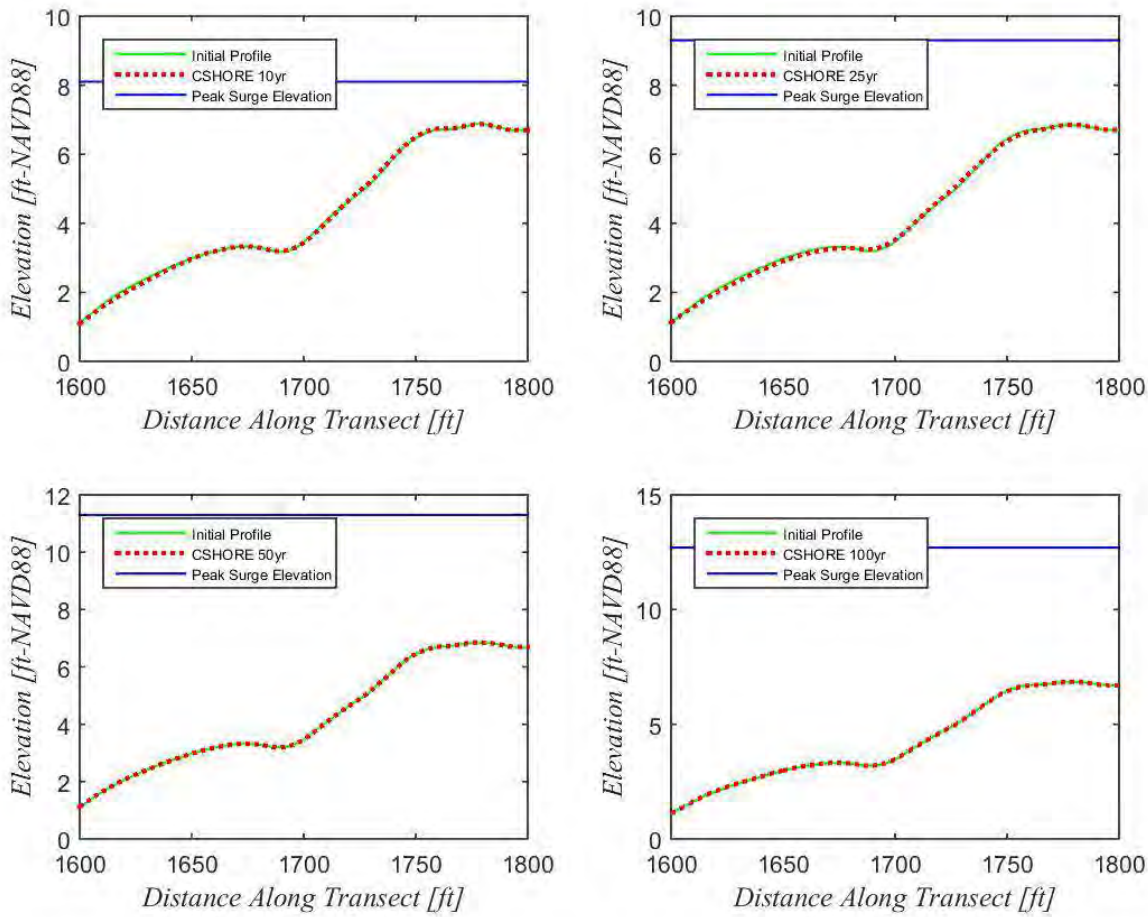


Figure 29. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 22.

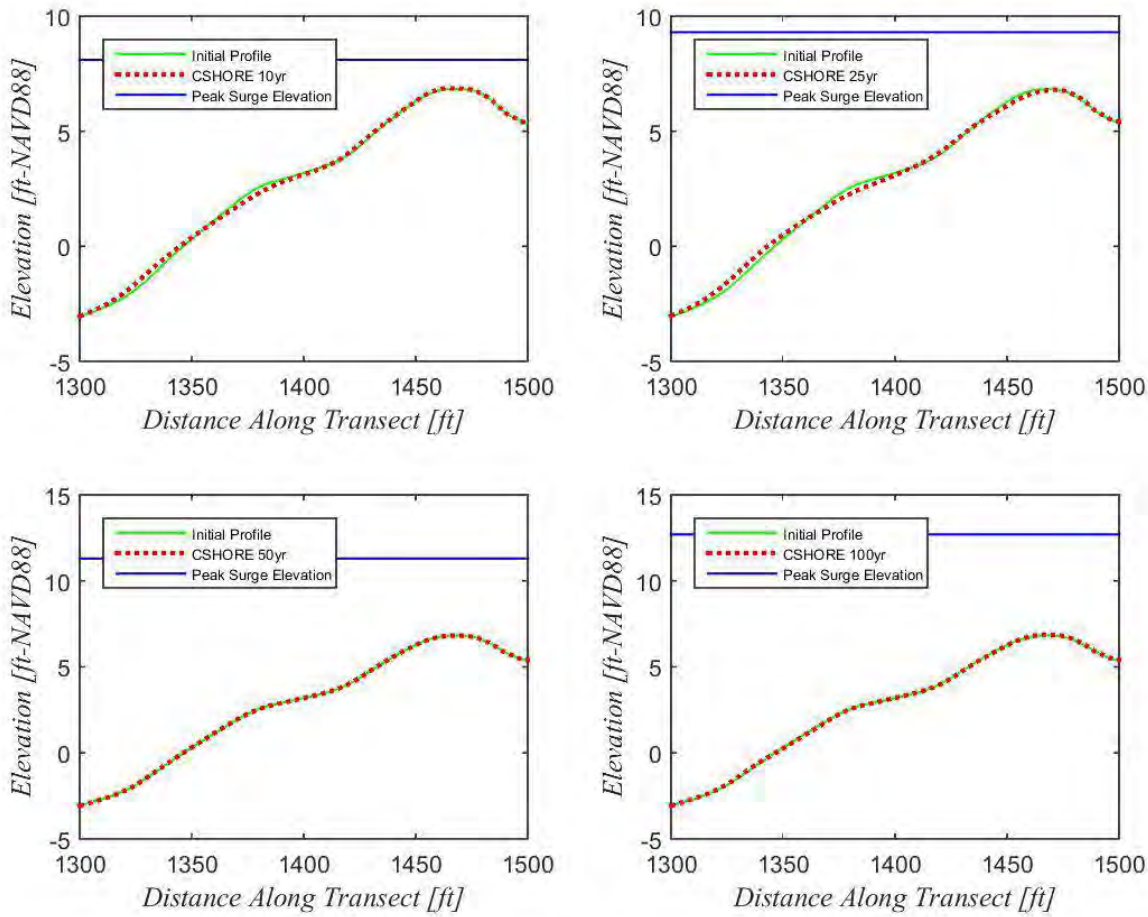


Figure 30. CSHORE results for 10-, 25-, 50-, and 100-year storm events at Transect 23.

LIVING BREAKWATERS

30% DESIGN MODELING RESULTS REPORT

Modeled Scenarios & Results (GENESIS, REFDIF, DELFT3D)

Date: 02/10/2017
Prepared by: ARCADIS
Reviewed by: **SCAPE**

VERSION	DATE	NOTES
1.0	08.01.2016	FIRST VERSION SUBMITTED FOR CLIENT REVIEW. THIS DRAFT ONLY INCLUDES RESULTS COMPLETED THROUGH 07.30.2016
2.0	10.12.2016	VERSION SUBMITTED AS APPENDIX TO 30% DESIGN MODELING REPORT
3.0	02.10.2017	UPDATED VERSION FOR REVISED 30% DESIGN MODELING REPORT

NAME	ORGANIZATION	DATE	COMMENTS PROVIDED?	COMMENTS INCORPORATED?

NY RISING

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SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
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00: Baseline (future without project)

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SCENARIO 01: “HOLD THE SHORELINE”

SCENARIO 02: “STORM WAVE ATTENUATION”

SCENARIO 03: “TESTING FOR A TOMBOLO”

SCENARIO 04: “LEARNING FROM ROUND ONE

SCENARIO 05: “MODIFIED SCENARIO 4”

SCENARIO 06: “MINIMALIST APPROACH”

SCENARIO 07: “MINIMALIST APPROACH WITH SHORELINE RESTORATION”

SCENARIO 09

SCENARIO 10

SCENARIO 11

SCENARIO 12

SCENARIO 13

SCENARIO 14

SCENARIO 15

FINAL 30% DESIGN SCENARIO 66

Final 30% Design Scenario

Overall Take-Aways

INTRODUCTION

OVERVIEW

This document summarizes the numerical modeling performed to date on the Living Breakwaters breakwater design scenarios during 30% Design. The current version of this report and provides a summary of scenarios modeled and model results completed through 30% Design.

Numerical modeling performed to date has been for long-term shoreline change (using the GENESIS model),wave refraction and diffraction (using the REFDIF model), storm-induced profile response (using SBEACH and CSHORE models), and water circulation (using Delft3D model).

SUMMARY OF MODEL RESULTS (AS OF 10.06.2016)

- Modeling efforts have focused on advancing the breakwater layout for the selection of a 30% design preferred scenario. Initial efforts examined scenarios designed to evaluate the impact of breakwater length, spacing, and distance from shore on long-term shore change (erosion and accretion) and the wave climate in the lee of the breakwaters.
- Additional modeling simulations were performed on potential breakwater system configurations to determine system performance and evaluate various layout options at achieving project goals.
- The without project (baseline) and project (30% design) have been simulated with all models. For some models (GENESIS and REFDIF) multiple scenarios were simulated in the screening and development of the preferred scenario.
- The preferred layout is shown to advance and refine beyond 30% design.

MODEL ASSUMPTIONS AND STANDARDS

- Modeling Assumptions and Standards are outlined in the Project Assumptions and Standards Memo (currently being updated in collaboration with Stantec / RACE) and the 30% Design Modeling Report.
- Shoreline change modeling was performed using the GENESIS model and the wave climate assessed in the lee of the breakwaters using the REFDIF model. Storm induced beach profile change for the shoreline areas outside of the Tottenville Shoreline Protection Project area were assessed using the SBEACH and CSHORE models and water circulation/preliminary water quality were evaluated using the Delft3D model.

Living Breakwaters 30% Design
Summary scenarios modeled

Scenrio

Sc. #	Scenario name (if provided)	GENESIS	REFDIF MHW	REFDIF MHW +30" SLR	REFDIF 100yr	REFDIF 100yr + 30" SLR	Delft 3D	SBEACH	CSHORE
00	No Action	X	X		X		1	1	1
01	Hold the Shoreline	X	X		X				
02	Storm Wave Reduction	X	X		X				
03	Test for Tombolo	X	X		X				
04	"Dream Scenario"	X	X		X				
05	sc05	X							
06	sc06	X							
07	sc07	X							
08	"Permitting" Scenario								
09	sc09	X							
10	sc10	X							
11	sc11	X							
12	sc12	X							
13	sc13	X							
14	Preliminary Preferred Scenario	X	X		X				
15	Revised 30% Design Scenario	X	X		X				
-	30% Design Scenario (including shoreline restoration)	X	X	X	X	X	1		1

Notes & assumptions

water level used for all GENESIS Runs @ MHW was	2.08
water level used for all GENESIS Runs w/ SLRwas	4.58
MHW used for typical tides RefDif runs	2.10
Incident wave height for typical tides RefDif runs	3.00
Stillwater elevation for 100yr storm RefDif runs	12.90
Incident wave height for 100yr storm RefDif runs	5.30

RefDIF runs model only single wave directions at a time, the following wave directions (degrees from N) were modeled: E (90); Perpendicular to Shore (150); SW (225)
SBEACH / CSHORE were performed for 5 storm series (10, 25, 50, 100, Sandy); hydrographs were selected by ARCADIS based on FEMA storms and share with TSPP team
SBEACH / CSHORE are used to model event-based change at the shoreline and so only locations outside the TSPP project area were modeled; 7 transects:

HISTORIC ANALYSIS AND EXISTING INFORMATION

SCAPE TEAM

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MFS CONSULTING ENGINEERS
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MHW SPRING 2012

MHW 1978

OBSERVED BEACH GROWTH

OBSERVED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

OBSERVED HISTORIC SHORELINE CHANGE

1978 - SPRING 2012 (PRE-SANDY)

NY RISING

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SPRING 2012 MHW (PRE-SANDY)

FALL 2012 MHW (POST-SANDY)

OBSERVED BEACH GROWTH

OBSERVED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
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CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

OBSERVED EVENT BASED SHORELINE CHANGE

SPRING 2012 (PRE-SANDY) - FALL 2012 (POST SANDY)

NY RISING

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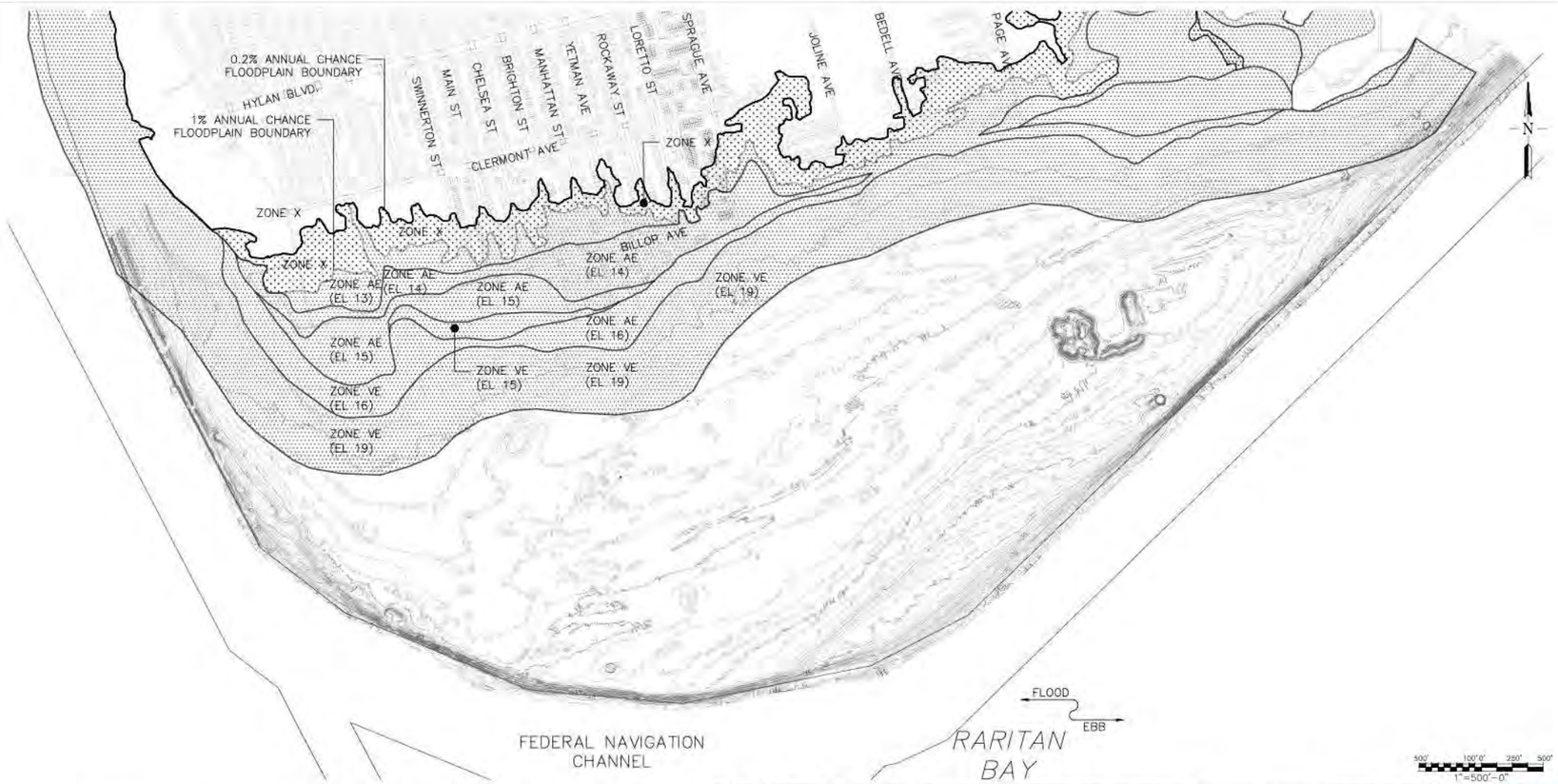

1 G-100 FEMA FLOOD INSURANCE RATE PLAN

LEGEND

SPECIAL FLOOD HAZARD AREAS SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS
OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

1% annual chance floodplain boundary
0.2% annual chance floodplain boundary
Floodway boundary
Zone D boundary
CBRS and OPA boundary
Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
Limit of Moderate Wave Action
513 — Base Flood Elevation line and value; elevation in feet*
(EL 987) — Base Flood Elevation value where uniform within zone; elevation in feet*
* Referenced to the North American Vertical Datum of 1988
15 — 15 Cross section line
23 — 23 Transect line
Culvert, Flume, Penstock or Aqueduct
Road or Railroad Bridge
Footbridge
87°07'45", 32°22'30" Geographic coordinates referenced to the North American Datum of 1983 (NAD 83), Western Hemisphere
4076000 N 1000-meter Universal Transverse Mercator grid values, zone 19
600000 FT 5000-foot grid values: New York State Plane coordinate system, Long Island zone (FIPSZONE 3104), Lambert Conformal Conic projection
DX5510 × Bench mark (see explanation in Notes to Users section of this FIRM panel)
● M1.5 River Mile

2 G-100 FIRM LEGEND N.T.S.

3 G-100 PRELIMINARY FLOOD INSURANCE RATE MAP

30% DESIGN SUBMISSION
NOT FOR CONSTRUCTION

FEMA PFIRM MAP

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HISTORIC SHORELINE CHANGE AND FEMA PFIRMS

Historic shoreline change analysis was performed based on orthoimagery available between 1978 and 2012, for a period covering the range of the wave hindcast data (1982 to 2012).

The rates of shoreline change exceed 1 foot per year mostly adjacent to Conference House Park west of Brighton Street, with the greatest shoreline erosion rate at 3.5 feet per year (±0.4 feet per year).

Most of the shoreline change rates moving to the northeast from Brighton Street along the shoreline are less than 1 foot per year. An exception is shown between Manhattan and Rockaway Streets where the rate is estimated at 1.7 feet per year (±0.4 feet per year) and between Page Avenue and Richard Avenue where the long-term erosion rate is estimated at 2.4 feet per year (±0.4 feet per year). This area is downdrift of an L-shaped timber pile groin structure, which may have been a historic pier.

Areas of the most pronounced localized shoreline change are downdrift of existing groin structures.

BASELINE (FUTURE WITHOUT PROJECT)

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MODELED 2035 MHW

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
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CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

BASELINE, FUTURE WITHOUT PROJECT

GENESIS RESULTS

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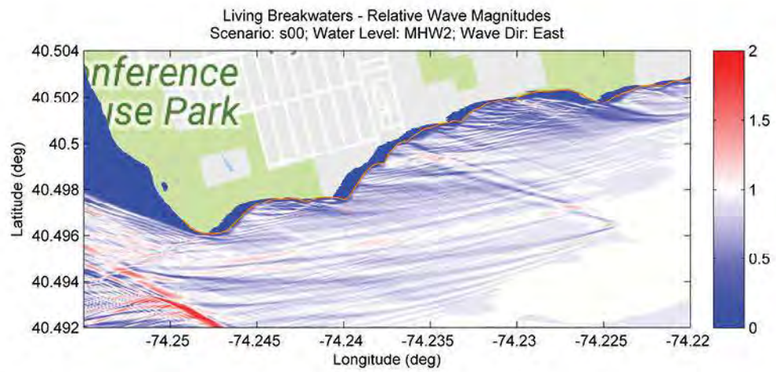
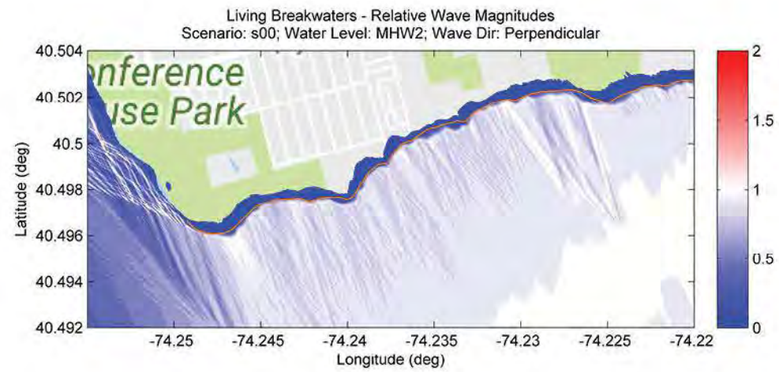
PRUDENT ENGINEERING

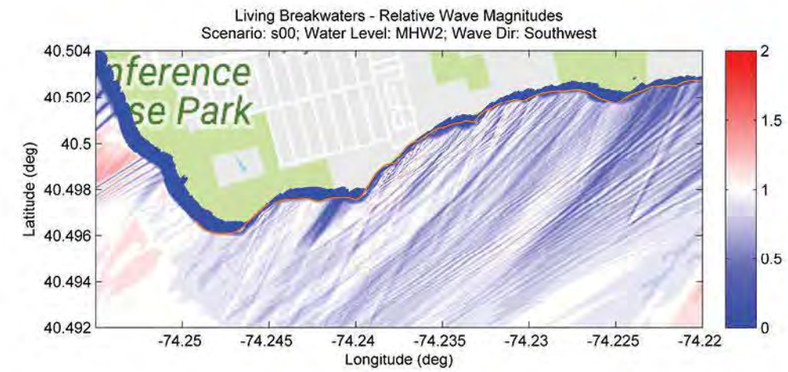
MHW | Input Wave Height of 3 feet | Waves from East



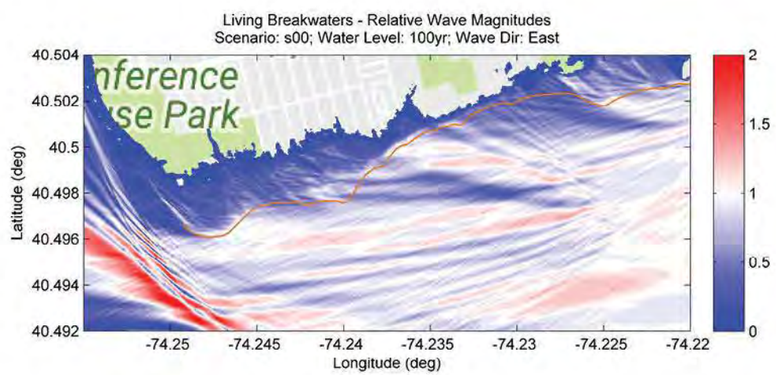
MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore



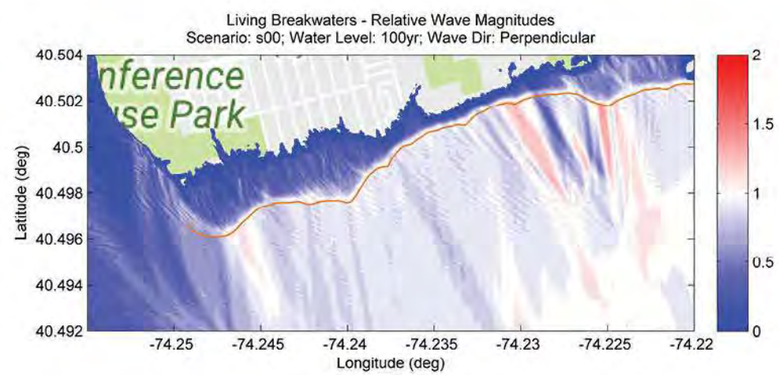
MHW | Input Wave Height of 3 feet | Waves from Southwest



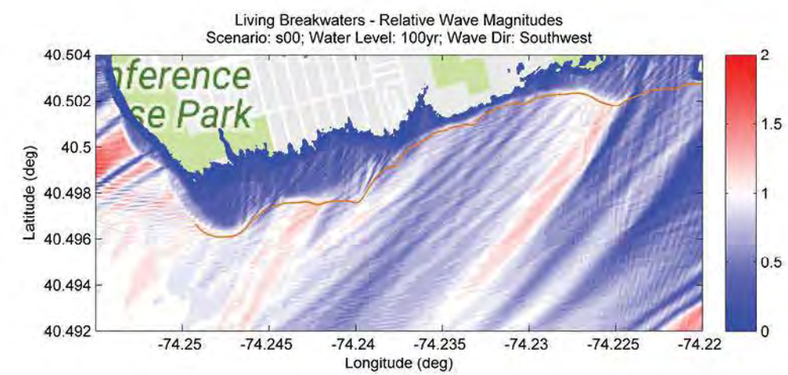
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore

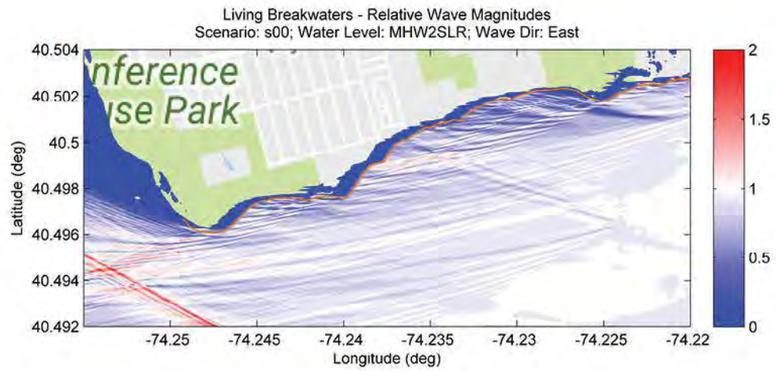


100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



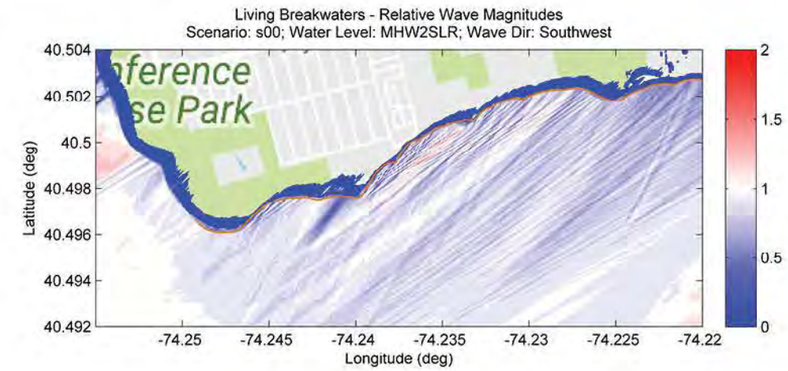
WAVE HEIGHTS SHOWN ARE RELATIVE WAVE HEIGHTS (MODELED WAVE HEIGHT/INCOMING OFFSHORE WAVE HEIGHT).

MHW + 30" SLR | Input Wave Height of 3 feet | Waves from East

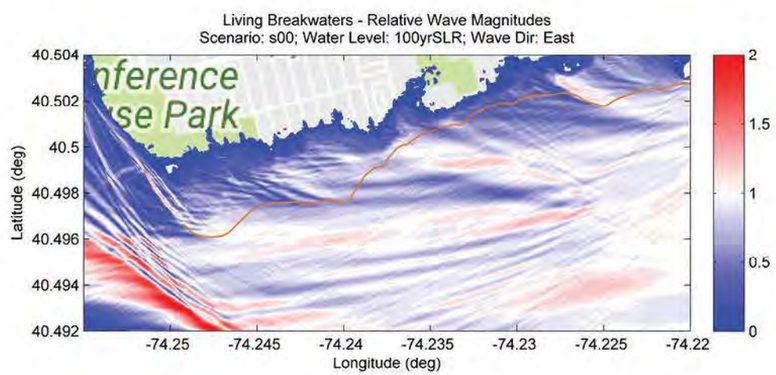


MHW + 30" SLR | Input Wave Height of 3 feet | Waves Perpendicular to Shore

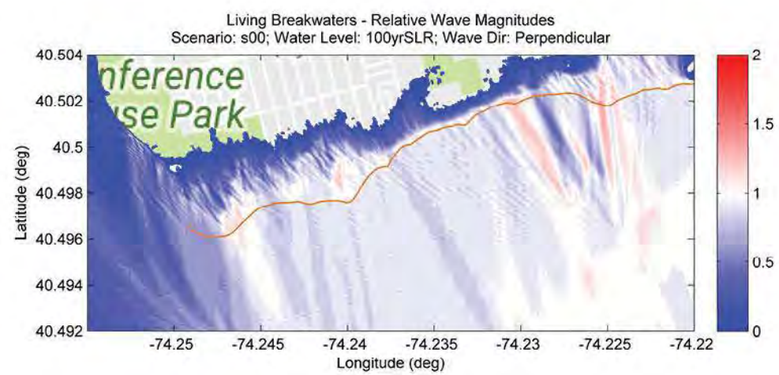
MHW + 30" SLR | Input Wave Height of 3 feet | Waves from Southwest



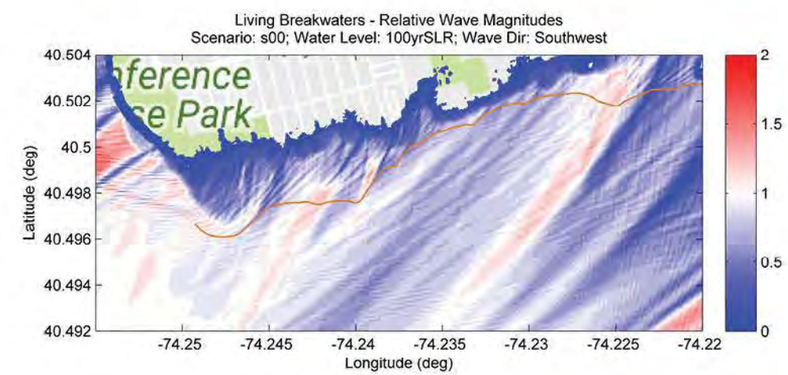
100 Year + 30" SLR | Input Wave Height of 5.3 feet | Waves from East



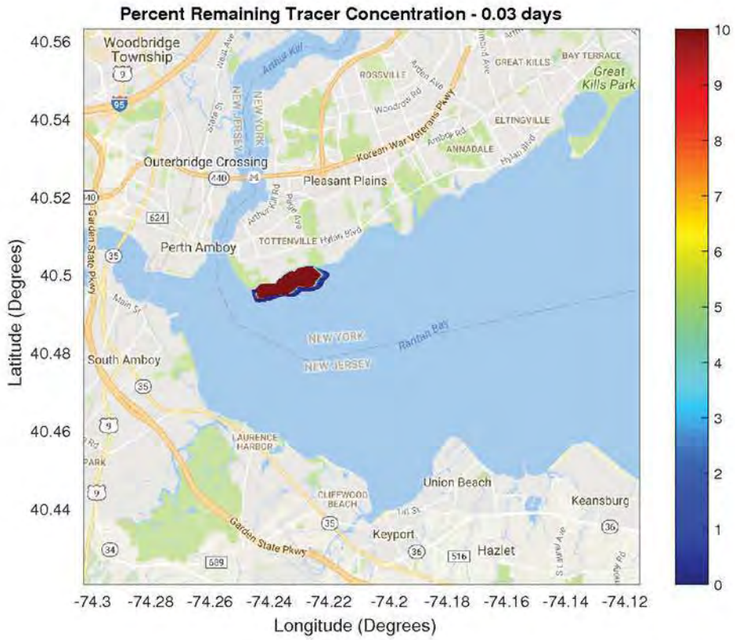
100 Year + 30" SLR | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore

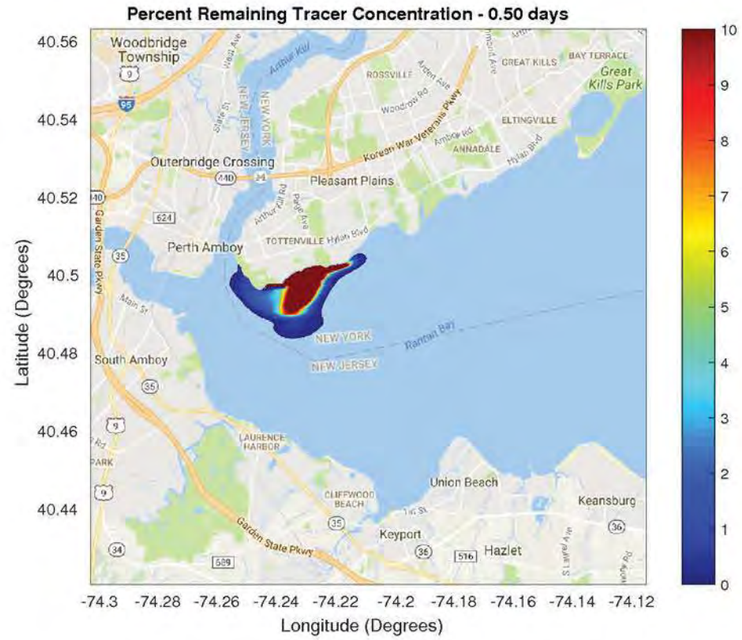


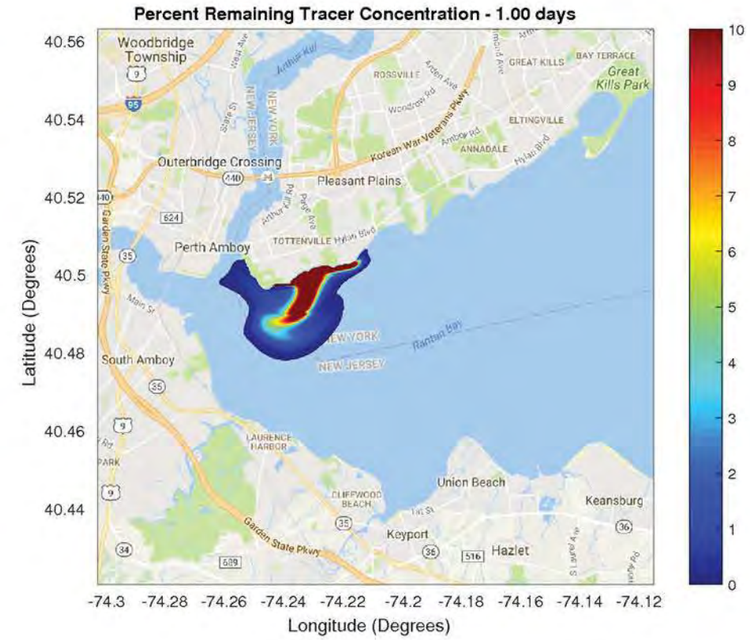
100 Year + 30" SLR| Input Wave Height of 5.3 feet | Waves from Southwest

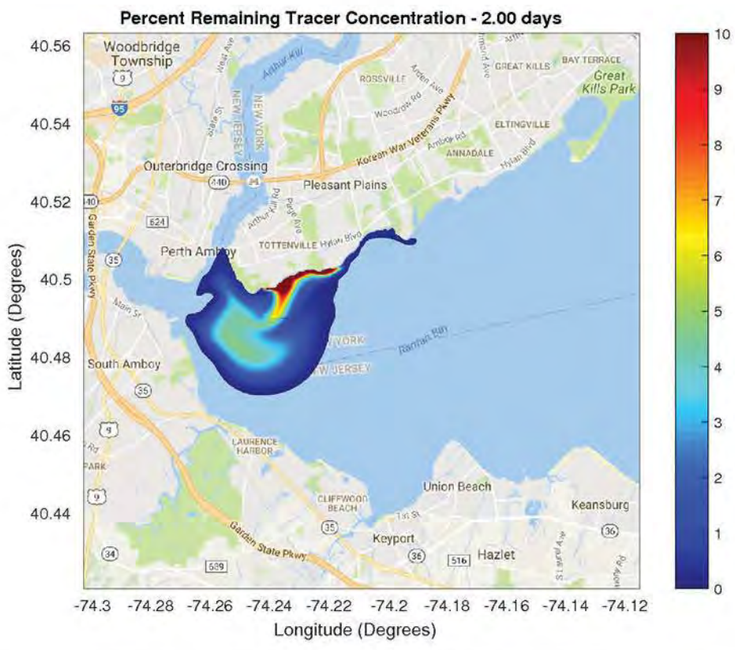


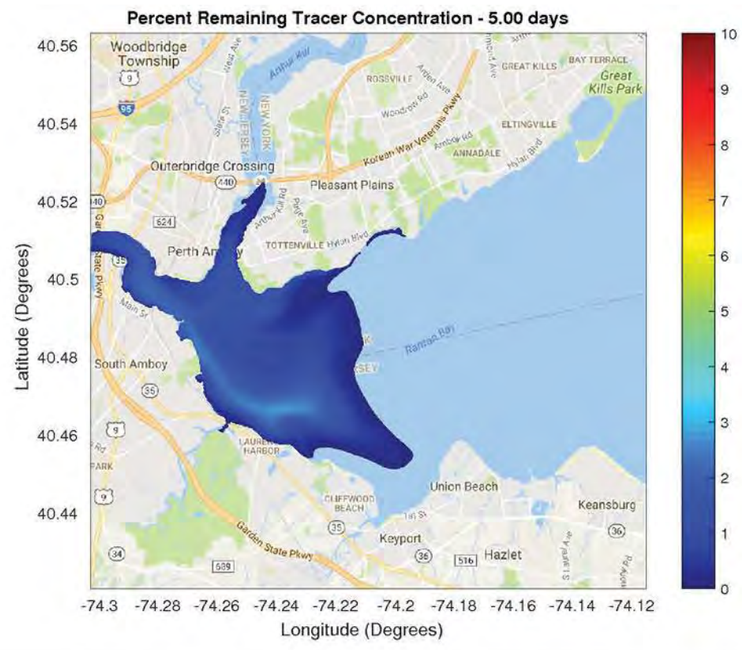
WAVE HEIGHTS SHOWN ARE RELATIVE WAVE HEIGHTS (MODELED WAVE HEIGHT/INCOMING OFFSHORE WAVE HEIGHT).











BASELINE, FUTURE WITHOUT PROJECT

DELFT-3D RESULTS

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

00: BASELINE (FUTURE WITHOUT PROJECT)

ASSUMPTIONS: SHORELINE CONDITIONS

- 2015 shoreline (which was a compilation of the 2015 TSPP survey, 2014 LiDAR in areas outside the survey, and the 2015 structures survey supplemented with aerial information) was used as starting point / baseline for shoreline change of the preferred alternative.
- Initial model simulations used the pre-Sandy 2012 shoreline developed from aerial photography as the initial shoreline based on the shorelines used in the calibration process and the data available at the start of the scenario modeling process (this initial shoreline was used for consistency of comparison until the preferred scenario was selected).
- Shoreline structures / conditions assumed to be as surveyed in fall 2015; baseline model results assume no alteration of existing shoreline structures.
- The shoreline is the surveyed MHW line defined as 2.08 ft. NAVD88 tidal datum at Sandy Hook. Outside the survey limits, MHW was delineated from post-Sandy USGS LiDAR(August 2014).

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- The overall trends in shoreline change remain similar. Southwest of Sprague Avenue, the future without scenario showed shoreline change rates for the next 20 years consistent with the severe (>1') rates seen over the past 30 years. Northeast of Sprague Avenue, the future without scenario showed somewhat reduced rates shoreline change for the next 20 years relative to the rates seen over the past 30 years.
- The complex (wavey) nature of this shoreline and large number of structures on the shoreline likely complicates shoreline change processes, making results more varied
- Changes in sea levels may also play a factor in the response of the shoreline. Currently the model simulation have used current mean sea level. This allowed for comparison between scenarios but the effects of varying sea level will be tested once the preferred scenario is advanced in the next phase of design. Simplified shoreline change models, such as GENESIS, are effective at evaluating trends in shoreline changes and impacts of shoreline and nearshore structures but do not fully represent the cross shore processes that are impacted by sea level rise. Sea level rise influences are further evaluated in this phase of modeling in REFDIF.

WAVE ACTION

- Both the channel and the northern depth anomaly (the hole), impact wave refraction and diffraction and can result in some increased wave heights.
- The beach itself is one of the best attenuators of storm waves (building beach and complimentary on-shore interventions may have best storm wave reduction benefits)

WATER QUALITY

- The tracer plume originating from the project area dissipates to less than a few percent concentration in less than 5 days.

DESIGN SCENARIOS

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 01

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW 2012

OBSERVED BEACH GROWTH

OBSERVED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 01

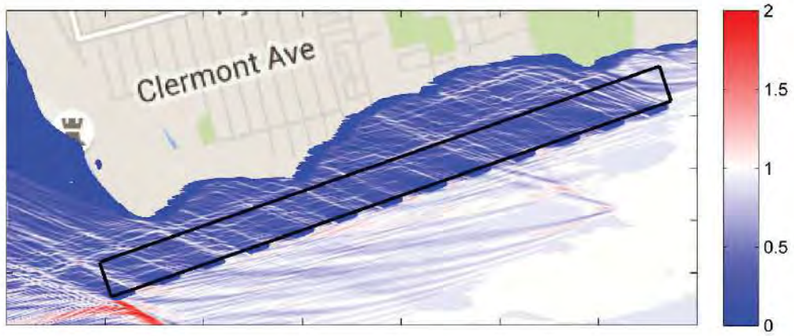
SCENARIO LAYOUT

NY RISING

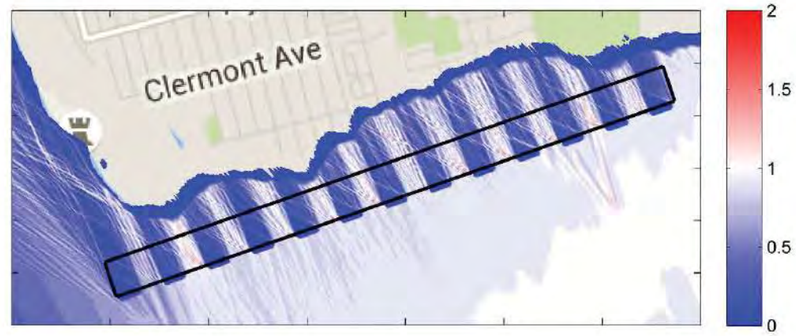
SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

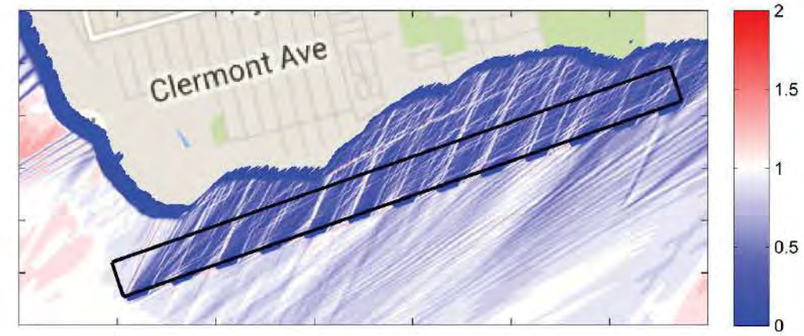
MHW | Input Wave Height of 3 feet | Waves from East



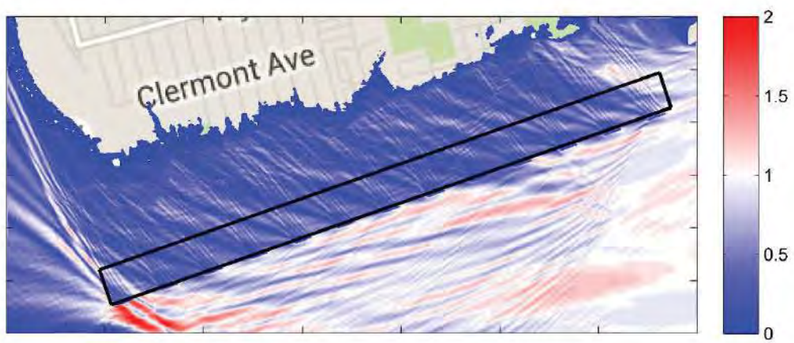
MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore



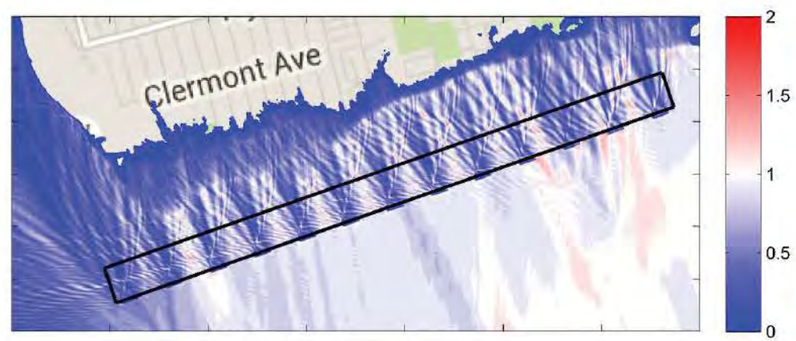
MHW | Input Wave Height of 3 feet | Waves from Southwest



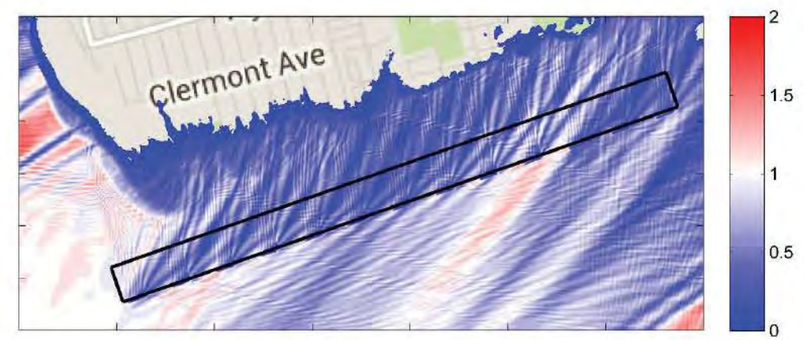
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



Wave heights shown are relative wave heights (modeled wave height/incoming offshore wave height).

SCENARIO 01: “HOLD THE SHORELINE”

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- System provided effective shoreline stabilization in almost all areas.
- Limited effect at furthest distance to shore (x=1,300 feet, L/x=.25, where x is distance from shore and L is breakwater length) Trapping of greater amounts of sediment ‘upstream’ appears to limit potential of sediment capture downstream, suggesting that this is not a high sediment system.
- Salient response at north end was surprisingly strong; may be the salient itself beginning to act to trap sediment behind it. => may not need to extend breakwaters all the way north to get salient effect there.

WAVE ACTION

- The wave shadow zone (area where we see wave height reduction) is larger when waves are oblique rather than head-on in relation to breakwater orientation

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
AREADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
RPS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 02: "STORM WAVE ATTENUATION"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 02: "STORM WAVE ATTENUATION"

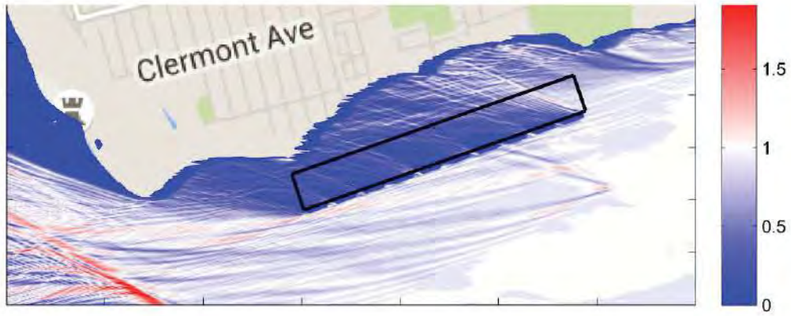
GENESIS RESULTS

NY RISING

SCAPE TEAM

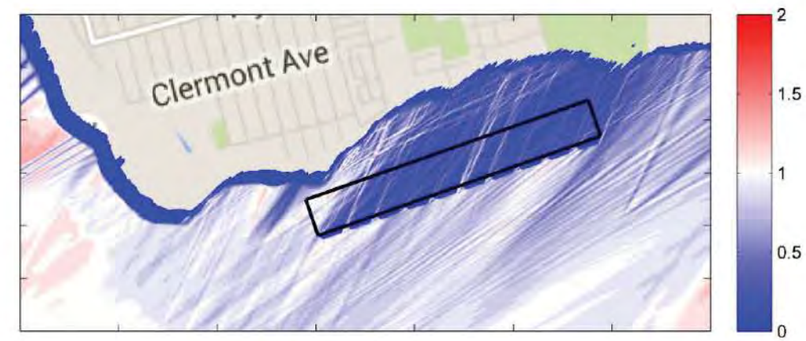
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW | Input Wave Height of 3 feet | Waves from East

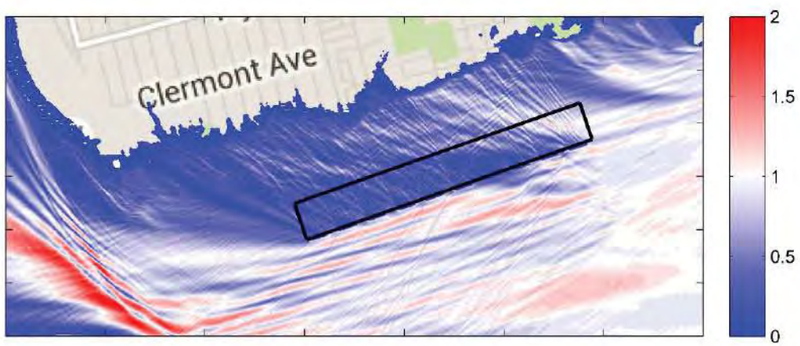


MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore

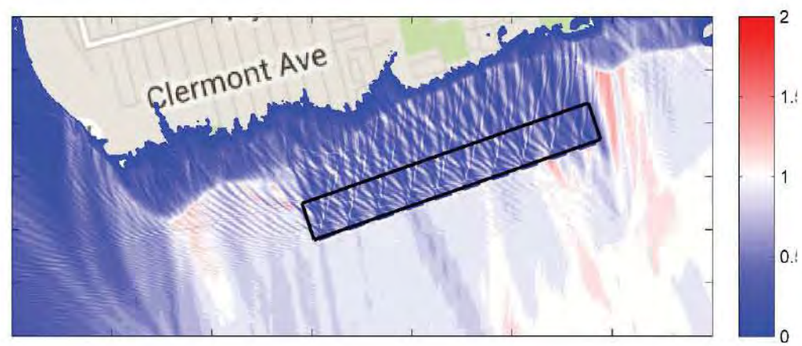
MHW | Input Wave Height of 3 feet | Waves from Southwest



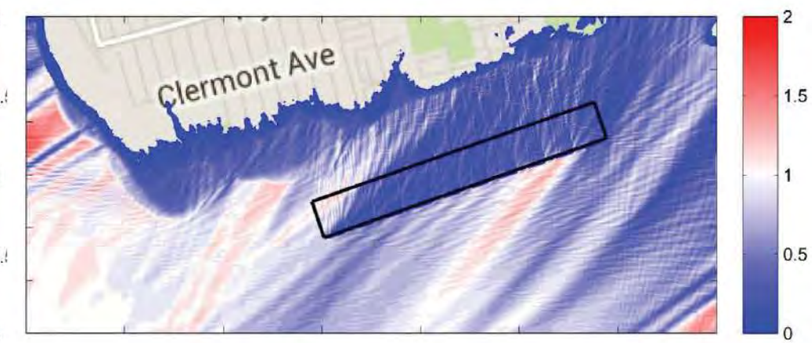
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



SCENARIO 02: "STORM WAVE ATTENUATION"

REF DIF RESULTS

SCENARIO 02: "STORM WAVE ATTENUATION"

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Breakwaters acted as a single unit in how they impacted shoreline change => Breakwaters with small gap width (30') or Wg/(L+Wg) (1/4) act like a single unit in salient formation
- If sediment is trapped 'upstream', but if nothing is done at the southern end, this could exacerbate erosion in Conference House Park => breakwater system will need to extend to the southwestern edge of Zone 2 to avoid further erosion in this zone.

WAVE ACTION

- Smaller gap widths allow fewer / lower waves to pass through.
- Again, the wave shadow zone (area where we see wave height reduction) is larger when waves are oblique rather than head-on in relation to breakwater orientation

SCENARIO 02: "STORM WAVE ATTENUATION"
MODEL TAKE-AWAYS AND LESSONS LEARNED

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUIÑONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 03: "TESTING FOR TOMBOLO"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 03: "TESTING FOR TOMBOLO"

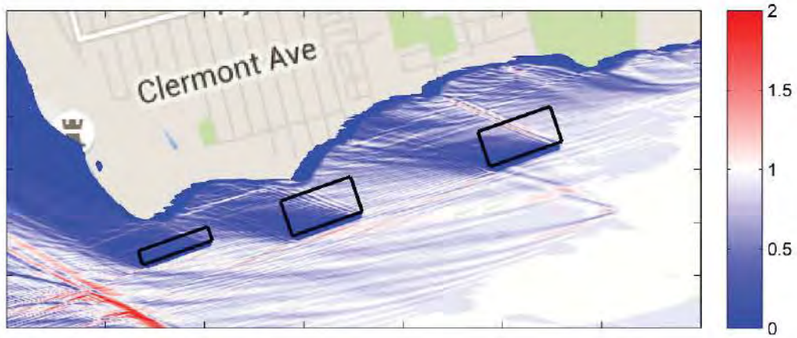
GENESIS RESULTS

NY RISING

SCAPE TEAM

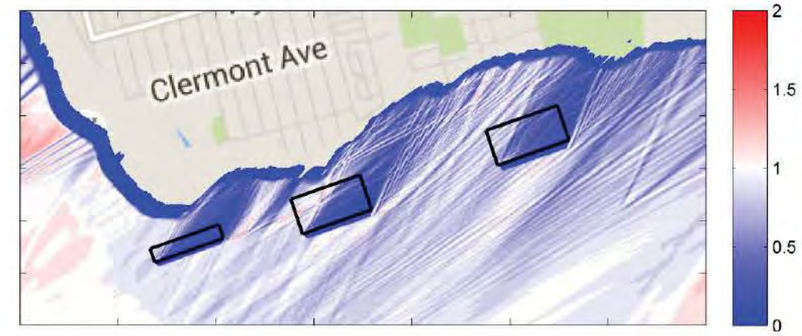
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW | Input Wave Height of 3 feet | Waves from East

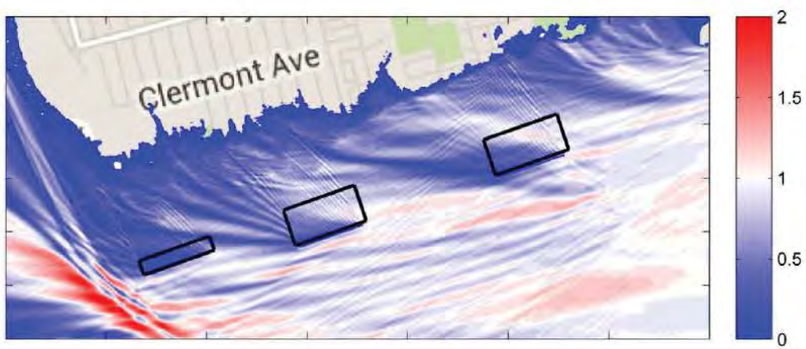


MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore

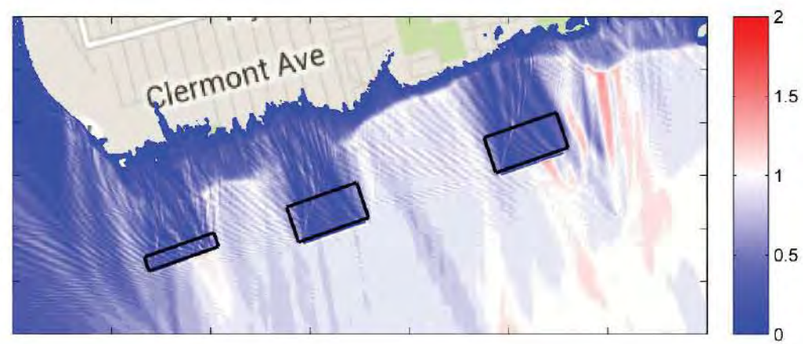
MHW | Input Wave Height of 3 feet | Waves from Southwest



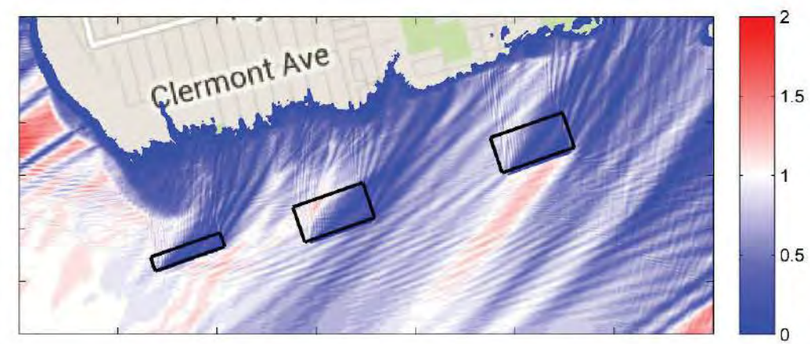
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



SCENARIO 03: "TESTING FOR A TOMBOLO"

REF DIF RESULTS

SCENARIO 03: "TESTING FOR A TOMBOLO"

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- The long breakwaters all show significant salient response.
- Shoreline response is not proportional to distance to shore (X) or the ratio of breakwater segment length to distance to shore (L/X), suggesting that other factors influence the scale of salient formation, including but not limited to amount of sediment in the system, amount of sediment trapped upstream, shape of shoreline, and existing coastal structures.
- It may be possible to create a tombolo, which would act like a terminal groin at the end of the system.

WAVE ACTION

- The wide spacing between breakwater segments means that there is little wave reduction in the gaps between them.
- The breakwaters themselves are effective wave attenuators.

NY RISING
SCAPE TEAM
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
HARSON'S BRANCKEBROOK
AREADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
RPS CONSULTING ENGINEERS
PRUDENT ENGINEERING

2012 MHW

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
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CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 04: "LEARNING FROM ROUND ONE"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
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2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUIÑONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 04: "LEARNING FROM ROUND ONE"

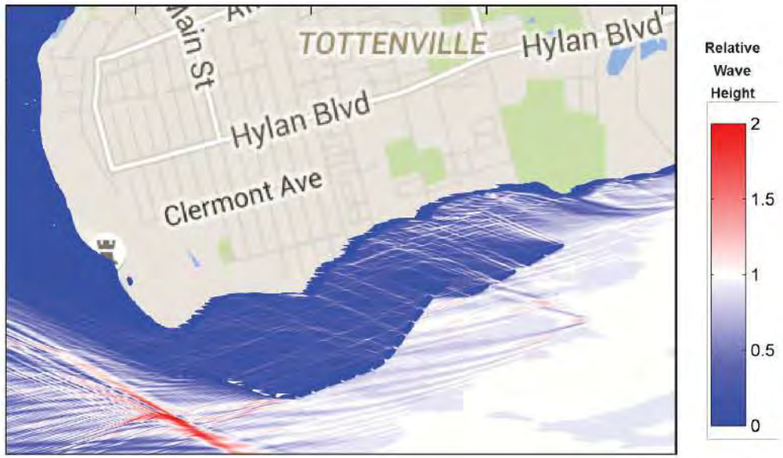
GENESIS RESULTS

NY RISING

SCAPE TEAM

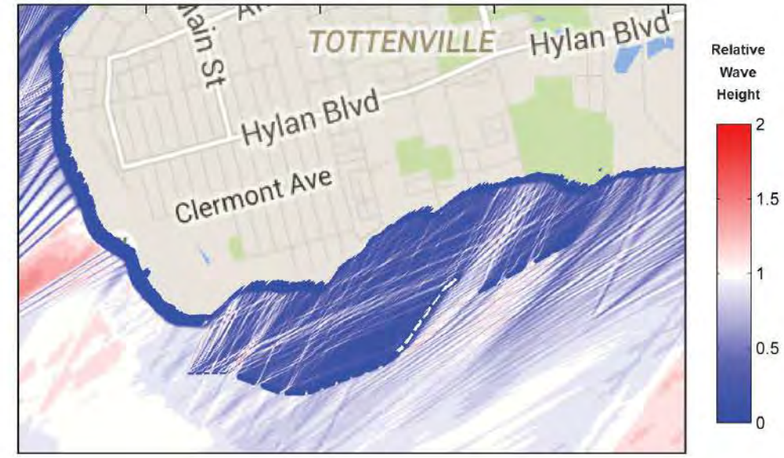
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW | Input Wave Height of 3 feet | Waves from East

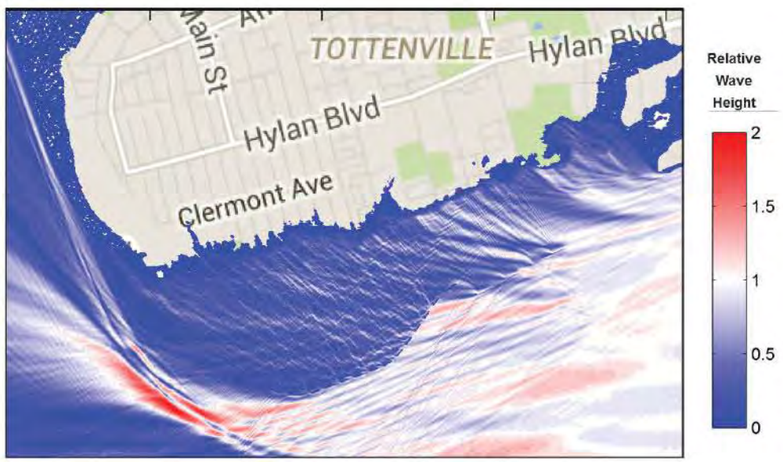


MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore

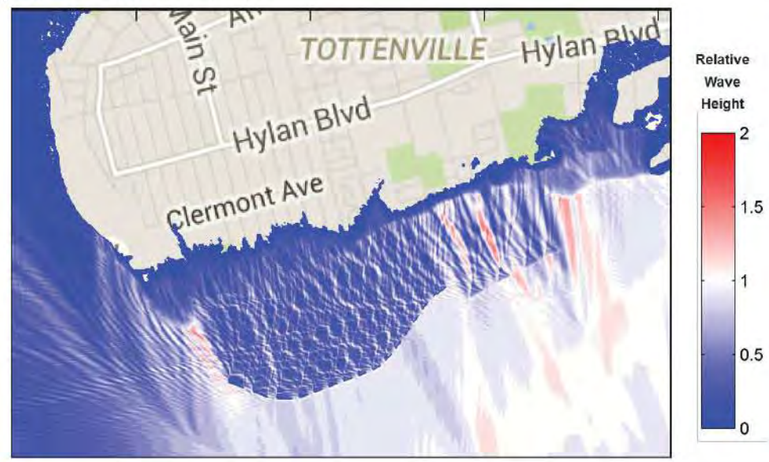
MHW | Input Wave Height of 3 feet | Waves from Southwest



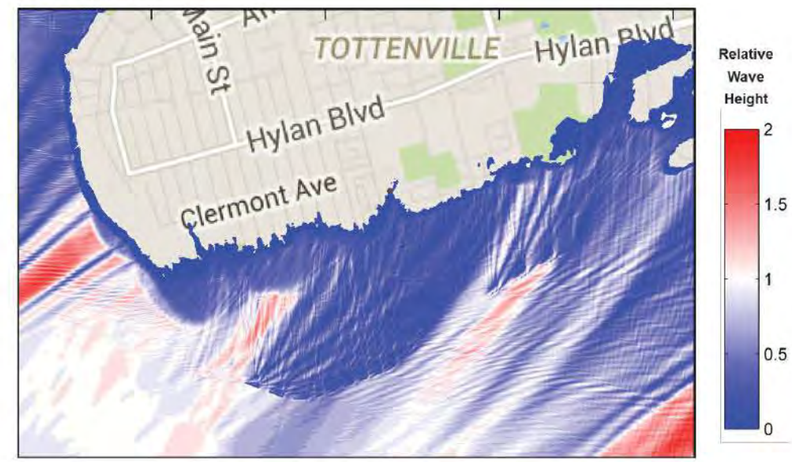
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



SCENARIO 04: "LEARNING FROM ROUND ONE"

REF DIF RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 04: "LEARNING FROM ROUND ONE

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Shoreline is stabilized along length
- Limited longshore sediment supply is trapped along northeast shoreline and does not reach Zones 2 and 3 where accretion is desired
- Varying breakwater layout for desired goals by region appears to have merit

WAVE ACTION

- Effective wave shadow zone throughout most of the project area (area where we see wave height reduction)
- Lower crested breakwaters on western edge show limited effectiveness in attenuating waves under higher water levels

OTHER

- Large footprint = costly, high impact

SCENARIO 04: "LEARNING FROM ROUND ONE"
MODEL TAKE-AWAYS AND LESSONS LEARNED

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED
SHORELINE RESTORATION

DATA SOURCES:
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CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 05: "MODIFIED SCENARIO 04"

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 05: "MODIFIED SCENARIO 04"

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 05: “MODIFIED SCENARIO 4”

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Shoreline is stabilized along much of its length
- Significant accretion between Manhattan St and Page Ave
- Some erosion continued in Zone 2
- Removing northeastern breakwaters allowed more sediment to move farther west along the shoreline
- Bringing breakwaters closer to shore increased shoreline accretion and wave protection

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 06: "MINIMALIST APPROACH"

SCENARIO LAYOUT

NY RISING

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 06: "MINIMALIST APPROACH"

GENESIS RESULTS

NY RISING

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SCENARIO 06: “MINIMALIST APPROACH”

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Northeastern breakwaters were effective in retaining sediment and causing shoreline accretion
- Removal and lowering of southwestern breakwaters resulted in loss of protection and considerable erosion in conjunction with sediment trapping up drift

NY RISING
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MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 07: "MINIMALIST APPROACH WITH SHORELINE RESTORATION"

SCENARIO LAYOUT

NY RISING

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 07: "MINIMALIST APPROACH WITH SHORELINE RESTORATION"

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 07: “MINIMALIST APPROACH WITH SHORELINE RESTORATION”

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Shoreline restoration shifted shoreline outward in region of fill
- Shoreline restoration was relatively well retained
- Erosion of western part of shoreline was slightly reduced but still significant as in previous scenario (same breakwater layout sc06)

SCENARIO 07: “MINIMALIST APPROACH WITH SHORELINE RESTORATION”

MODEL TAKE-AWAYS AND LESSONS LEARNED

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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SCENARIO 09

SCENARIO LAYOUT

NY RISING

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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SCENARIO 09

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 09

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Moving the western and central breakwaters closer to shore enhanced shoreline protection.
- Having a breakwater in the middle of the western bay at the park reduced erosion of that region.
- Removal of southwestern breakwaters resulted in loss of protection and considerable erosion of Ward's Point in conjunction with sediment trapping up drift.

NY RISING

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MHW 2012

ANTICIPATED BEACH GROWTH

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SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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0′ 500′ 1000′ 2000′

SCENARIO 10

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

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SHORELINE STRUCTURES

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PROPOSED SHORELINE RESTORATION

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SCENARIO 10

GENESIS RESULTS

NY RISING

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SCENARIO 10

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Repositioning of the central breakwaters improved shoreline shape and moving farther offshore into deeper water is likely to aid constructability without any noticeable loss in shoreline retention in the simulation.
- Moving of the southwestern breakwater resulted in accretion at the western point (Ward's Point) but significant erosion continued in the adjacent embayment.

SCAPE TEAM

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PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

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SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 11

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
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PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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0' 500' 1000' 2000'

SCENARIO 11

GENESIS RESULTS

NY RISING

SCAPE TEAM

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PRUDENT ENGINEERING

SCENARIO 11

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Reducing the number of breakwaters in the central portion and moving the southwestern breakwater increased erosion especially in the adjacent embayment.
- Significant accretion at Ward's Point and between Manhattan St and Bedell Ave

NY RISING

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MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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0' 500' 1000' 2000'

SCENARIO 12

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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SCENARIO 12

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 12

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Splitting the southwestern breakwater into two to provide protection to the point and embayment reduced erosion in the region, but erosion continued.
- Adding back a breakwater to the central section improved shoreline retention and protection between Bedell St and Page Ave
- Retained accretion between Manhattan St and Bedell St

NY RISING
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PRUDENT ENGINEERING

MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

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SCENARIO 13

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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PRUDENT ENGINEERING

MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

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SCENARIO 13

GENESIS RESULTS

NY RISING

SCAPE TEAM

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SCENARIO 13

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Moving the southwestern breakwaters and lengthening the breakwater at the southwestern point improved the modeled shoreline response shape; almost eliminated erosion in Zone 2
- Consistent beach accretion between Yettman St and Page Ave

NY RISING
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MHW 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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0' 500' 1000' 2000'

SCENARIO 14

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

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MODELED 2032 MHW

MHW SPRING 2012

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

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BREAKWATER FOOTPRINT

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SCENARIO 14

GENESIS RESULTS

NY RISING

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PRUDENT ENGINEERING

MODELED 2035 MHW

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

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CONTOUR BATHYMETRY GENERATED BY HILL

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SCENARIO 14 (2015 MHW)

GENESIS RESULTS

NY RISING

SCAPE TEAM

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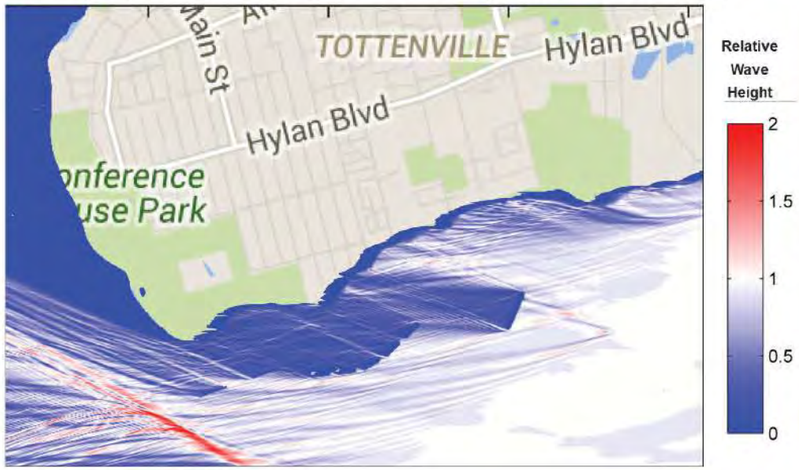
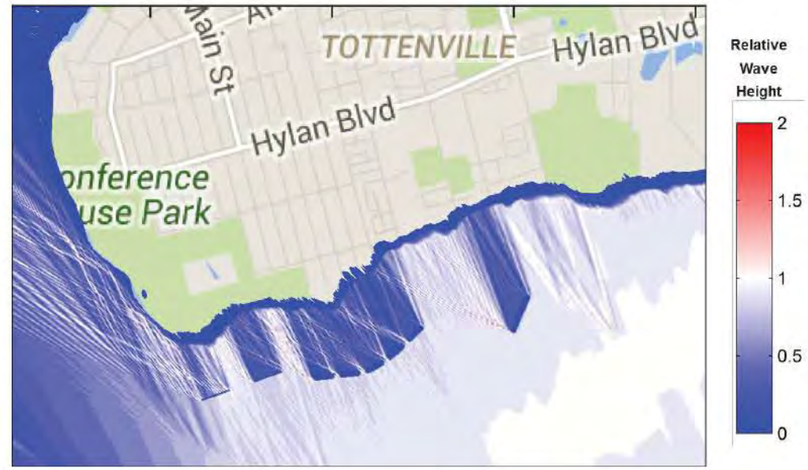
PRUDENT ENGINEERING

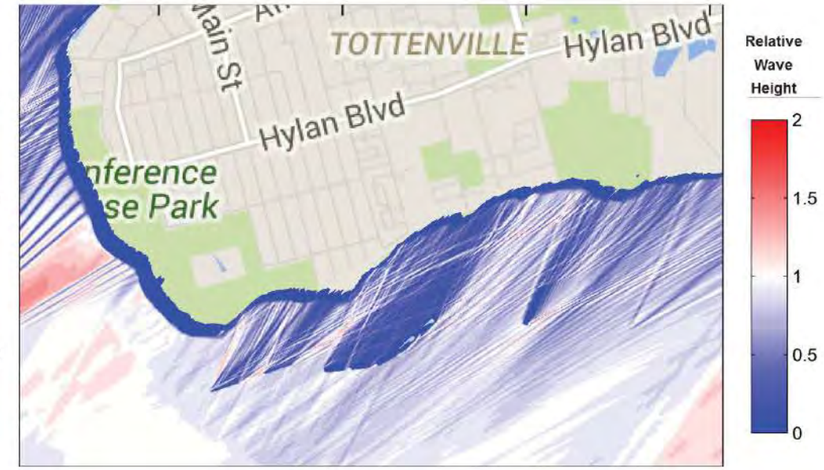
MHW | Input Wave Height of 3 feet | Waves from East



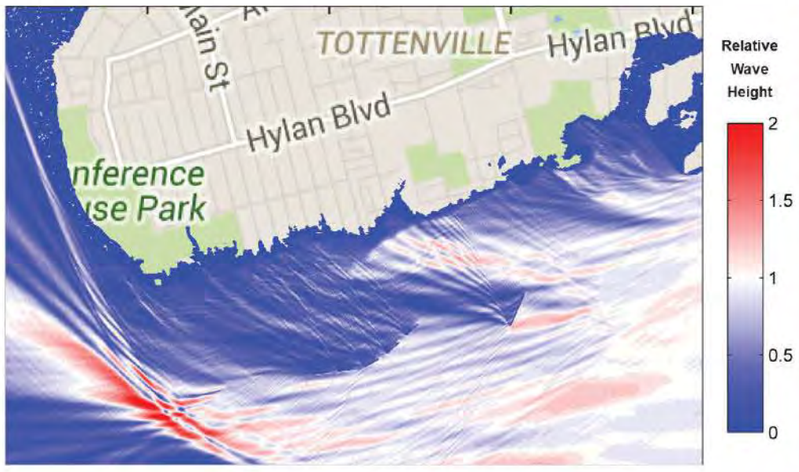
MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore



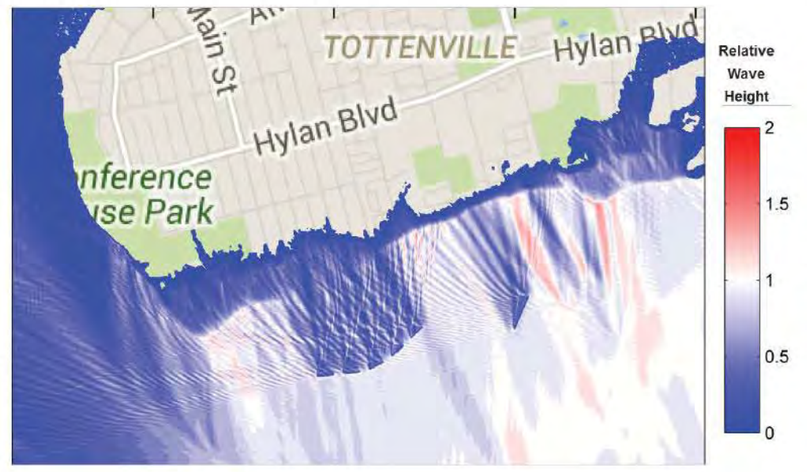
MHW | Input Wave Height of 3 feet | Waves from Southwest



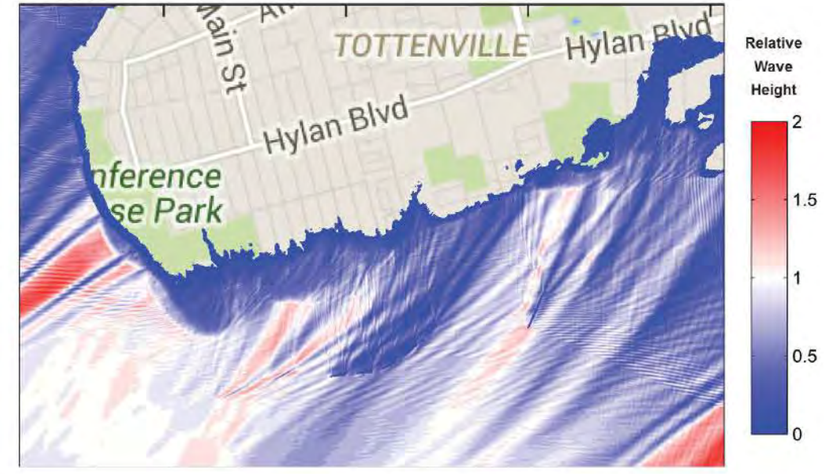
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore



100 Year | Input Wave Height of 5.3 feet | Waves from Southwest



SCENARIO 14

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Similar to Scenario 13, refinement of southwestern breakwater location and lengthening of these breakwater segments improved modeled shoreline response, shoreline shape, sediment accretion, and sediment retention at the southwestern point and adjacent embayment.

WAVE ACTION

- Breakwaters provide effective wave shadow zones in their lee for area between Brighton St. and Sprague Ave. where vulnerable locations / assets are located for most wave directions. Some additional study may be required for waves from the east.
- Lower crested southwestern breakwaters show reduced effectiveness in attenuating waves under higher water levels. Note that storm wave attenuation has not been identified as a priority for this area, as vulnerable assets are not located in this area.
- Increased wave exposure in gap between northeastern and central breakwaters: the increased spacing and reduction of number of northeastern breakwaters was to attempt to balance between wave attenuation and sediment trapping. Further refinement of breakwater alignment may be required if storm wave attenuation for the northeastern area of the project area is a greater priority.

NY RISING
SCAPE TEAM
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
HARSON'S MANCKEBACH
ARCADIS
BEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
RPS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 15

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2035 MHW

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

SCENARIO 15

GENESIS RESULTS

NY RISING

SCAPE TEAM

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LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

SCENARIO 15

MODEL TAKE-AWAYS AND LESSONS LEARNED

SHORELINE CHANGE

- Similar to Scenario 14, addition of one more central breakwater and eastern breakwater to balance shoreline response with improved wave protection.
- Additional accretion to the northern eastern portion of the project shoreline due to the additional breakwaters. Some reduction in sediment available and accretion farther down the shore.

WAVE ACTION

- Breakwaters provide effective wave shadow zones in their lee for area between Brighton St. and Sprague Ave. where vulnerable locations / assets are located for most wave directions. Additional protection from waves from the east afforded by the additional breakwaters.
- Lower crested southwestern breakwaters show reduced effectiveness in attenuating waves under higher water levels. Note that storm wave attenuation has not been identified as a priority for this area, as vulnerable assets are not located in this area.

NY RISING
SCAPE TEAM
SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
HARSON'S MANCKERMAN
AREADIS
BEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
RPS CONSULTING ENGINEERS
PRUDENT ENGINEERING

FINAL 30% DESIGN SCENARIO

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

2015 MHW

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

30% DESIGN SCENARIO

SCENARIO LAYOUT

NY RISING

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

MODELED 2035 MHW

MHW 2015

ANTICIPATED BEACH GROWTH

ANTICIPATED EROSION

SHORELINE STRUCTURES

BREAKWATER FOOTPRINT

PROPOSED SHORELINE RESTORATION

DATA SOURCES:
2035 MHW MODELED BY ARCADIS USING GENESIS
2012 MHW LINES BY ARCADIS USING ORTHOIMAGERY
2015 MHW LINE AND SHORELINE STRUCTURES SURVEYED BY NYACK, SUPPLEMENTED WITH 2014 LIDAR AND HISTORIC AERIAL IMAGERY
CHANNEL EDGE: BASED ON COORDINATES PROVIDED BY USACE (JOHN BELDIN-QUINONES) ON 2/25/2015
CONTOUR BATHYMETRY GENERATED BY HILL

0' 500' 1000' 2000'

30% DESIGN SCENARIO

GENESIS RESULTS

NY RISING

SCAPE TEAM

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OCEAN AND COASTAL CONSULTANTS
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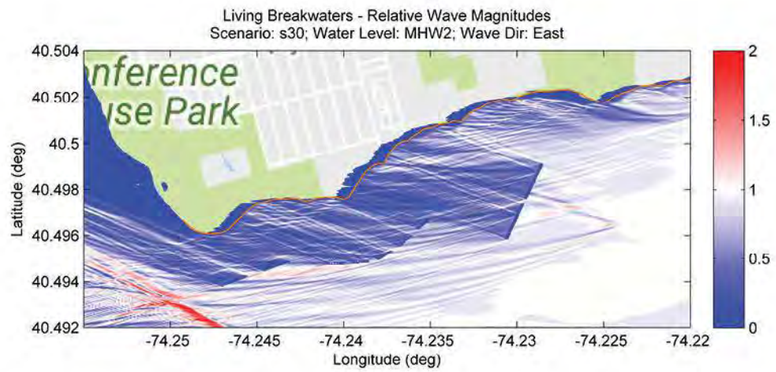
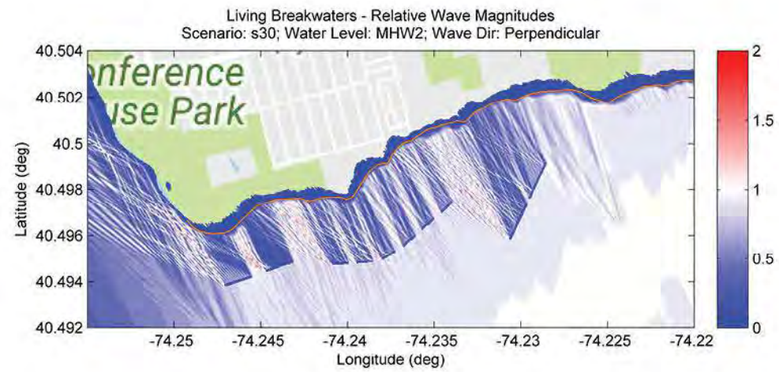
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

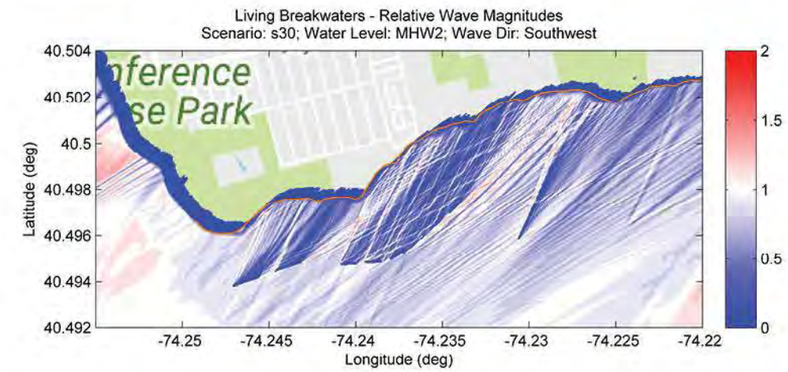
MHW | Input Wave Height of 3 feet | Waves from East



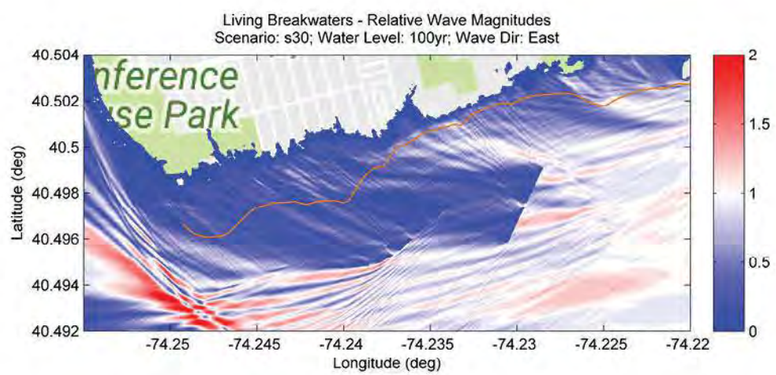
MHW | Input Wave Height of 3 feet | Waves Perpendicular to Shore



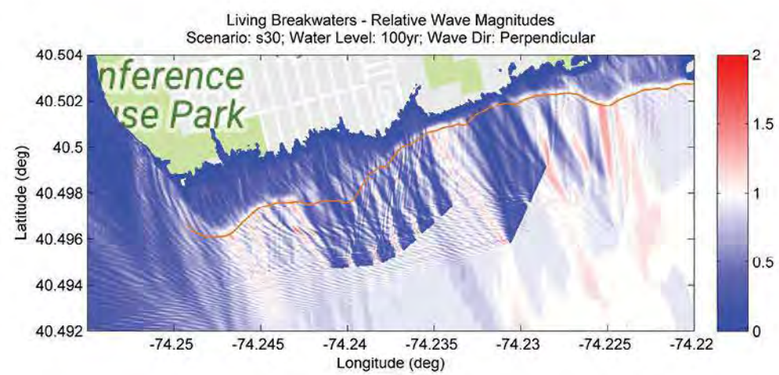
MHW | Input Wave Height of 3 feet | Waves from Southwest



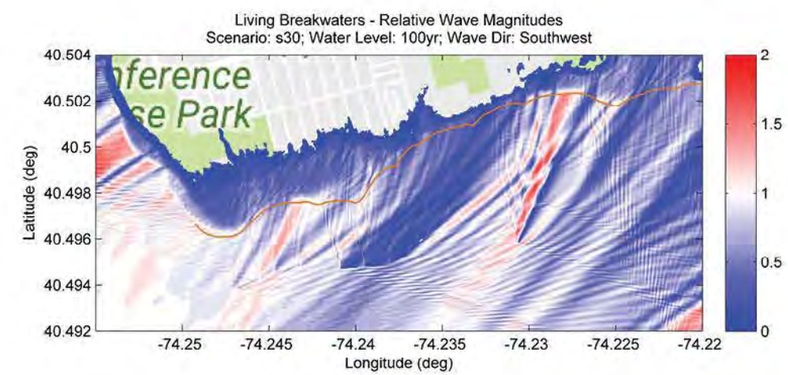
100 Year | Input Wave Height of 5.3 feet | Waves from East



100 Year | Input Wave Height of 5.3 feet | Waves Perpendicular to Shore

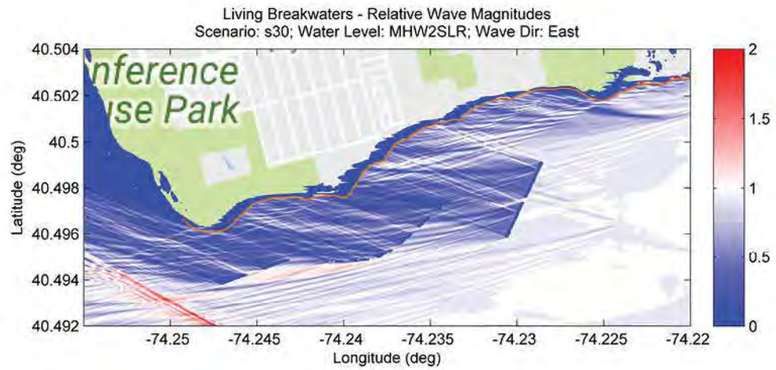


100 Year | Input Wave Height of 5.3 feet | Waves from Southwest

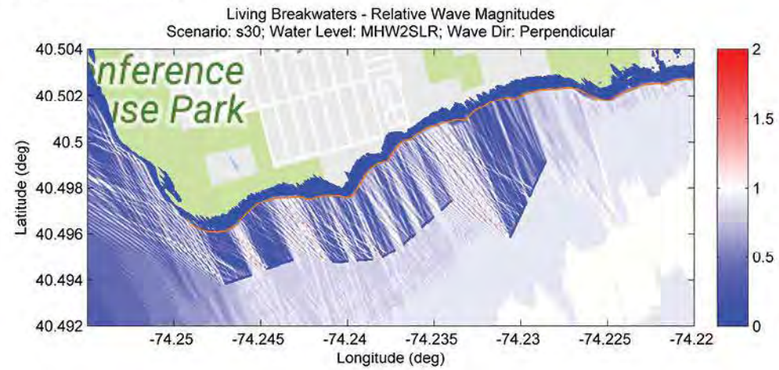


WAVE HEIGHTS SHOWN ARE RELATIVE WAVE HEIGHTS (MODELED WAVE HEIGHT/INCOMING OFFSHORE WAVE HEIGHT).

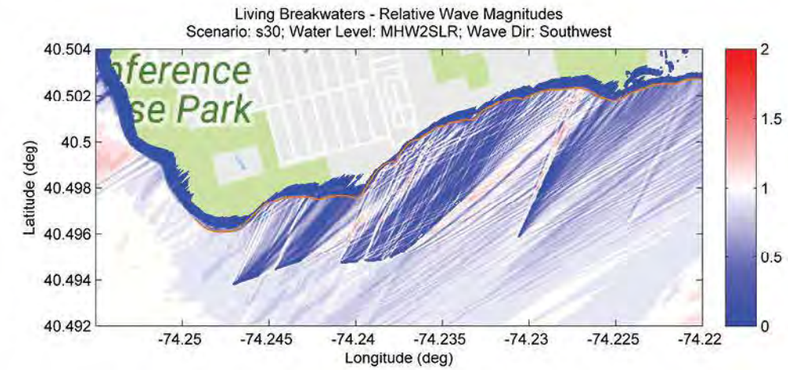
MHW + 30" SLR | Input Wave Height of 3 feet | Waves from East



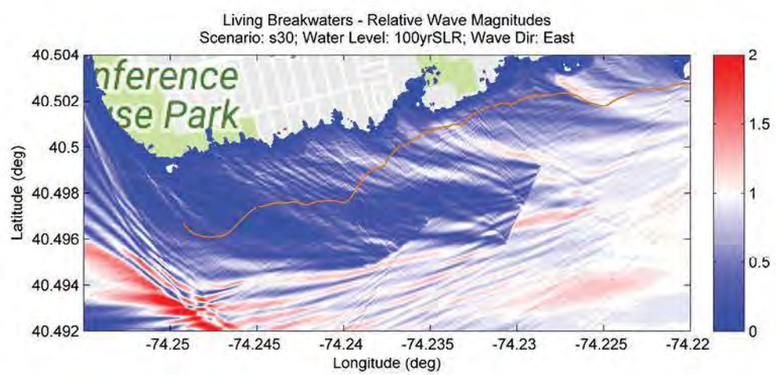
MHW + 30" SLR | Input Wave Height of 3 feet | Waves Perpendicular to Shore



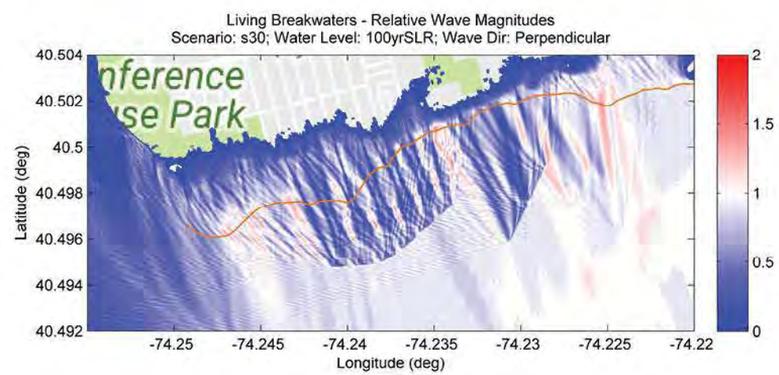
MHW + 30" SLR | Input Wave Height of 3 feet | Waves from Southwest



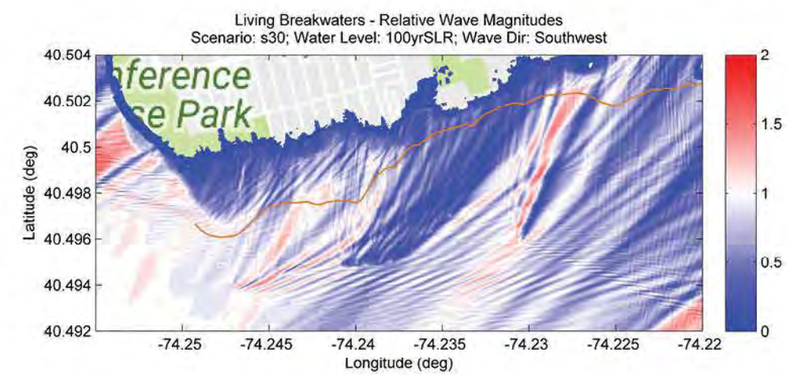
100 Year + 30" SLR | Input Wave Height of 5.3 feet | Waves from East



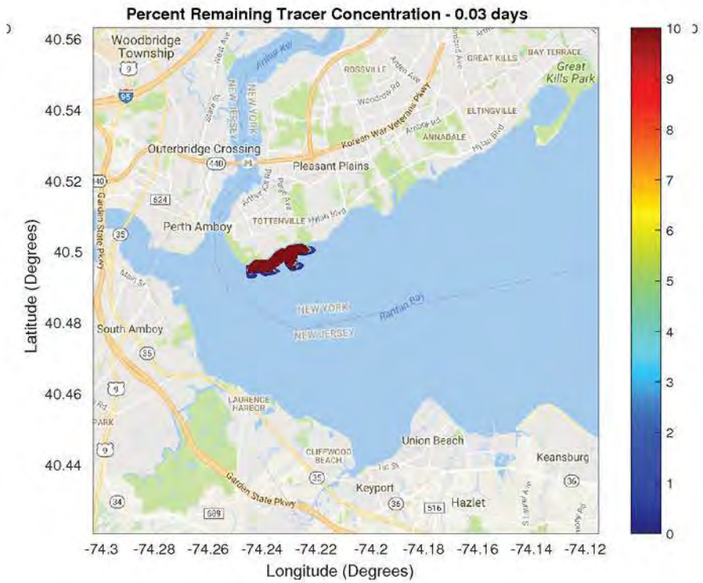
100 Year + 30" SLR| Input Wave Height of 5.3 feet | Waves Perpendicular to Shore

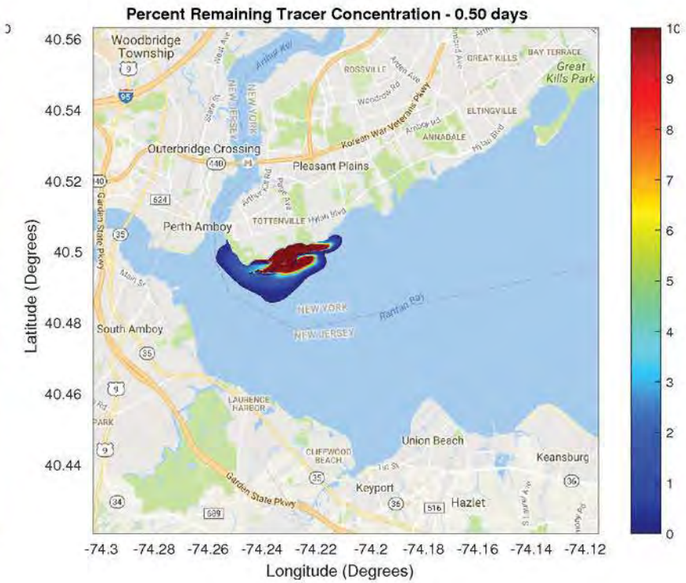


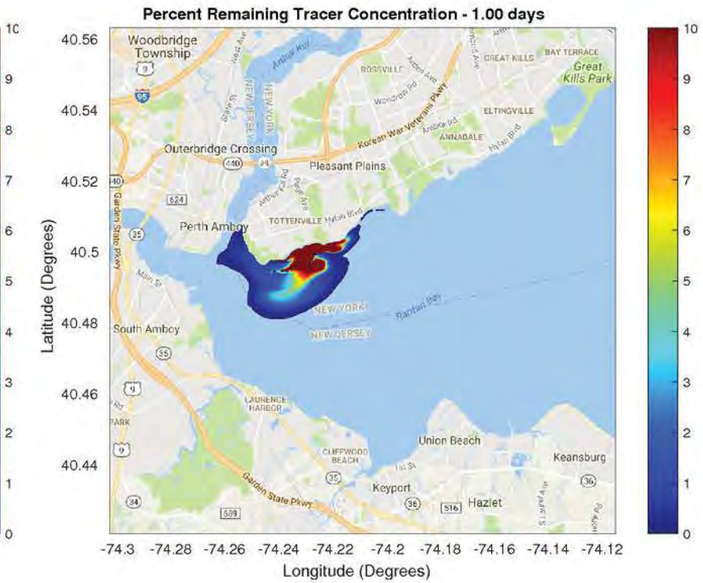
100 Year + 30" SLR| Input Wave Height of 5.3 feet | Waves from Southwest

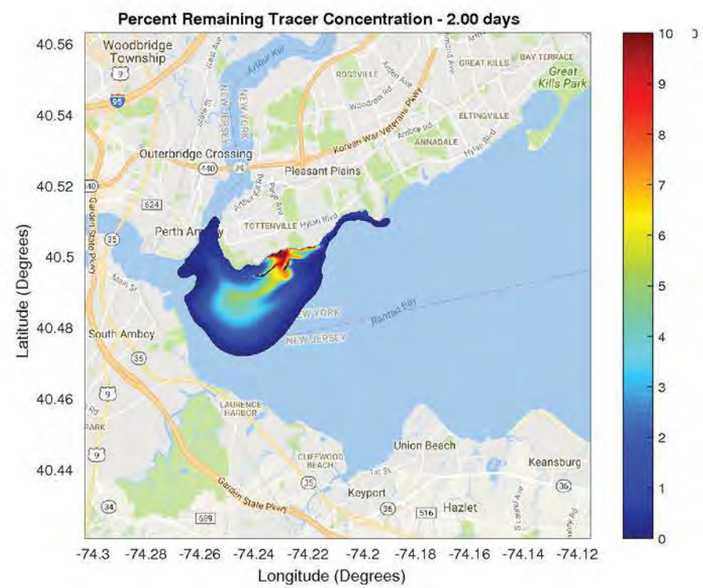


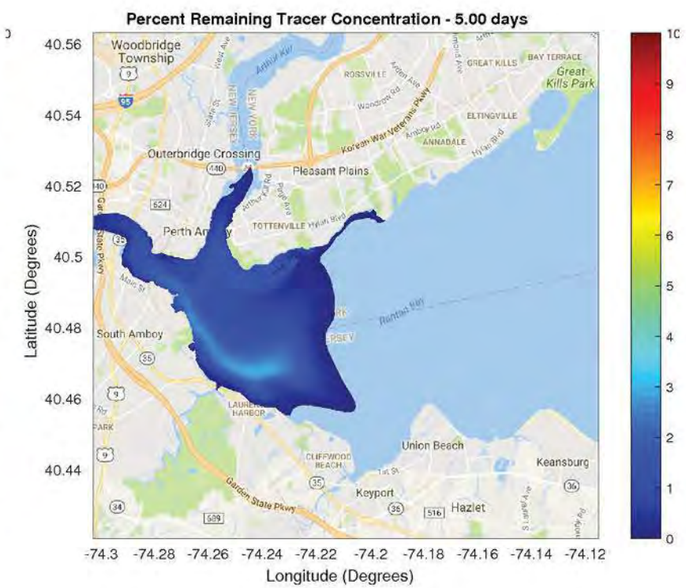
WAVE HEIGHTS SHOWN ARE RELATIVE WAVE HEIGHTS (MODELED WAVE HEIGHT/INCOMING OFFSHORE WAVE HEIGHT).











30% DESIGN SCENARIO

DELFT-3D RESULTS

SCAPE TEAM

SCAPE / LANDSCAPE ARCHITECTURE
OCEAN AND COASTAL CONSULTANTS
PARSONS BRINCKERHOFF
ARCADIS
SEARC ECOLOGICAL MARINE CONSULTING
LOT-EK ARCHITECTURE
MFS CONSULTING ENGINEERS
PRUDENT ENGINEERING

FINAL 30% DESIGN SCENARIO

SUMMARY OF MODEL RESULTS

SHORELINE CHANGE

- Same as Scenario 15 with the addition of some shoreline restoration
- Beach is well retained and provides increased beach width over critical area of the shoreline
- Balance of shoreline response and wave protection

WAVE ACTION

- Same as Scenario 15.

WATER QUALITY

- No significant changes in residence time due to breakwaters

OVERALL TAKE-AWAYS

SHORELINE CHANGE

- Living Breakwaters spacing, gap width, distance to shoreline, and alignment iteratively tested to develop a preferred scenario.
- Living Breakwater System can provide effective shoreline stabilization in almost all areas.
- Breakwater distance from shore, length, gap width, and the relative ratios between them influence the shoreline behavior. Other factors influence the scale of salient formation, including but not limited to amount of sediment in the system, amount of sediment trapped upstream, shape of shoreline, and existing coastal structures.
- Trapping of greater amounts of sediment 'upstream' appears to limit potential of sediment capture downstream.
- "Opening" northeast breakwater area was required to allow updrift sediment to transport to zone 2 / zone 3.
- Southwestern breakwaters are required to stabilize historical erosion at Conference House Park.

WAVE ACTION

- With enough properly spaced breakwaters an effective wave shadow zone (area where we see wave height reduction) throughout most of the project area can be created.
- Smaller gap widths allow fewer / lower waves to pass through.
- Wide spacing between breakwater segments results in little wave reduction in the gaps between them.
- Use of lower crested breakwaters on western edge show limited effectiveness in attenuating waves under higher water levels, so are only being recommended where storm wave attenuation is not a priority (southeastern end of the project area)

WATER QUALITY

- No significant changes in residence time due to breakwaters

SHORELINE RESTORATION

- Shoreline restoration shifted shoreline outward in region of fill.
- Shoreline restoration was relatively well retained.

Appendix E-7
Target Species Rationale

A. INTRODUCTION AND BACKGROUND

The design, construction, and operation of the Breakwaters Project would result in the creation of ecologically enhanced, three-dimensional reef-like habitat that would increase the diversity of the aquatic habitats available for plant and invertebrate species that provide or create habitat (habitat forming plants and invertebrates) found in Raritan Bay (e.g., brown algae and local shellfish like mussels and barnacles). As habitat forming species recruit and mature on the Breakwaters Project structures, the newly enhanced matrix of physical and biogenic structures should facilitate recruitment and retention of resident and transient fishes, crabs, bivalves, small invertebrates, and plankton (e.g., Nestlerode 2004; Burt et al. 2012; Firth et al. 2014; Perkol-Finkel and Sella. 2014, 2015; Sella and Perkol-Finkel 2015). The Breakwaters Project would diversify existing nearshore benthic habitats in Raritan Bay by providing complex structured habitat for a variety of organisms, while achieving its primary ecosystem service of wave-attenuation and shoreline risk reduction that would be achieved in conjunction with the Tottenville Shoreline Protection Project (Shoreline Project). Together, these Proposed Actions aim to provide risk reduction from storm wave action and coastal flooding and erosion along the shoreline in Tottenville, while enhancing ecosystems and shoreline access, use, and stewardship. The creation of reef-like habitat would also contribute to larger-scale efforts in the Hudson-Raritan Estuary to improve water quality and restore ecosystem functions, including historically abundant shellfish communities.

Design considerations for the breakwaters explicitly incorporate materials and methods that would facilitate the attraction of several functional groups and species (i.e., target groups), by using a combination of materials and structures engineered to recruit and retain habitat forming species (e.g., ecological design) of the breakwater structures (e.g., number, slopes, orientation, reef ridges, and reef streets), and placement of ecologically enhanced structural units. The key ecological relationships (e.g., predator-prey, competition, facilitation, recruitment, reproduction) expected from successful reef-like habitats would be more likely to occur as a result of the Breakwaters Project compared to standard breakwaters because the design process considers the specific ecological needs of the local estuarine flora and fauna – particularly those of ecosystem engineers[1] like oysters and other bivalves, polychaetes, and encrusting organisms (Bruno et al. 2003; Browne and Chapman 2011). The total amount of inshore habitat in Raritan Bay and Sandy Hook Bay is approximately 33,500 acres, of which the Breakwaters Project study area would comprise 610 acres. The maximum projected footprint of the breakwater segments would cover approximately 11.4 acres or 2 percent of existing bottom habitat within the study area. The breakwaters would also replace 115,990 cubic yards (CY) of open water habitat below mean high water (MHW) with subtidal, intertidal, and emergent hard/rocky habitat. Within the Hudson

[1] Ecosystem engineer—species that affect the physical space in which other species live and their direct effects can last longer than the lifetime of the organism (Hastings et al. 2007).

Raritan Estuary, the footprint of the breakwater segments represents an even smaller percentage of the available benthic habitat. Thus, while the Breakwaters Project would displace existing sand and gravel benthic habitats and open water habitats below MHW in the study area, it would add structured habitat that has been identified as a restoration priority for the greater Hudson River Estuary, add to the "mosaic" of available habitats, and promote the development of a productive and diverse local ecological community (USACE 2016a).

The unpredictability of fish and invertebrate recruitment and community assembly processes precludes precise prediction of the abundance of a particular species or taxa that would result from habitat modification. Thus, while the potential increase in local productivity associated with the diversity of structured habitats resulting from the Breakwaters Project would provide increased ecological niche space, the success of any particular species at any time or place on the Breakwaters Project structures or in their vicinity is challenging to predict with acceptable confidence. Because the benefits of the new structured habitat are expected to accrue to several species and functional groups of Raritan Bay (e.g., fish, benthic invertebrates, plants, and plankton), metrics of ecosystem functioning on the associated reef-like habitat should consider the broad suite of species groups likely to benefit from the project in terms of their representative ecological functions, as well as their social and economic value. Adopting this perspective lends to a more holistic view that considers restoring ecosystem functions to an ecologically degraded region rather than pinning success on the presence of any single species that, for external factors unrelated to the Breakwaters Project, may not successfully colonize to the study area.

While ecologically enhanced breakwater structures and man-made reefs generally increase productivity, species diversity, or both, and reduce the ratio between invasive to local species compared to areas without structured habitat and low-complexity breakwaters (Burt et al. 2012; Wen et al. 2013; Aguilera et al. 2014; Firth et al. 2014, Sella and Perkol-Finkel, 2015), ecological caveats to consider in the design, construction, and operation of breakwaters include the potential for introducing invasive species (Glasby et al. 2007; Dafforn et al. 2012).

The following sections review the ecological functions of selected targeted functional groups, design considerations relevant to each group, and provide suggested metrics of ecosystem function. Such metrics of enhancement and restoration progress should consider the duration of the enhancement and spatial context that reflect progress on a species group level and across species groups (e.g., how many species groups show progress toward an enhanced or restored state). The sections below provide an overview of target species groups expected to benefit from the installation of the Breakwaters Project off the southeast coast of Staten Island. The groups and the species included in each group are based on historical surveys and the surveys conducted by the project team in 2015 and 2017 to document existing biological and ecological conditions in the study area (Normandeau 2015 a,b,c,d; SeArc 2015).

Historically, Raritan Bay and the larger Hudson-Raritan estuary was an extremely productive estuarine system and supported at least 338 fish species of resident, migratory, and transitory fish species (Berg and Levinton 1985; MacKenzie 1990; Briggs and Waldman 2002). Although the fish diversity remains high in Raritan Bay, the productivity of the system is depleted compared to historical levels (MacKenzie 1990). The reduction in fish productivity has been attributed to overharvesting, loss and degradation of habitat, and pollution (MacKenzie 1990). The recent surveys documenting existing conditions of the study area used beach seines, otter and beam trawls, fish traps, and visual surveys to collect a comprehensive sample of the current fish community in the study area. Atlantic silversides, Atlantic menhaden, striped killifish,

bluefish, and winter flounder were dominant during both survey years and represented the majority of the catch in shore seines. Relatively high abundances of tautog, northern kingfish, bay anchovy, white mullet, mummichog, and American eel were observed during 2015; during 2017, blue crab and northern pipefish were also among the numerically abundant taxa collected in shore seines. Bay anchovy, scup, winter flounder, Say mud crab, and blue crab were the most common species in trawl catches in 2015; during 2017, black sea bass and summer flounder were also among the numerically abundant taxa. In fish traps, the dominant species during both years included portly spider crab and blue crab; tautog and scup were also observed in relatively high abundance.

Over the last half-century, several research surveys documented the evolution of the benthic community composition in Raritan Bay. While the observed benthic community fauna fluctuated over these sampling events, the overall structure of the species composition has been consistent in surveys conducted beginning in the 1950s to recent years with some of the observed variability associated with different sampling protocols (Normandeau 2015a,b,c,d; SeArc 2015). Previous surveys of the New York Harbor estuary's benthic invertebrate fauna have identified 328 total species with the dominant taxonomic groups comprising polychaetes (43 percent), crustaceans (31 percent), and mollusks (17 percent) (Cerrato 2006). More broadly, taxa present in the system include aquatic earthworms (oligochaetes), segmented worms (polychaetes), snails (gastropods), bivalves (e.g., soft shell clam, dwarf surf clam, blue mussel, ribbed mussel and oyster), barnacles, amphipods, isopods, crabs, and shrimp. Surveys conducted to document existing conditions for the Breakwaters Project study area found 184 taxa in benthic grab samples collected from soft bottom habitat (sand, mud, and gravel) with 83 taxa representing 99 percent of all individuals, while concurrent sampling of hard bottom habitat identified 115 epifaunal taxa (Normandeau 2015 a,b,c,d; SeArc 2015). Benthic invertebrate surveys conducted in 2017 within the study area found 193 taxa collected from soft bottom grab samples, with 72 taxa representing 99 percent of all individuals. The six most abundant soft-bottom taxa represented 72 percent of all individuals.

Surveys of the existing conditions in soft sediments (e.g., sand, gravel, mud) identified distinct epibenthic and benthic invertebrate communities (i.e., small animals living in and on the sediment) residing in the different sediment types found in the study area (Normandeau 2015 a,b,c,d). Soft bottom surveys identified distinct but taxonomically similar assemblages between sites with different substrates. Sand and gravel substrates were most common throughout the study area. While both substrate types contained similar taxonomic groups, sample sites with sand and gravel substrates had higher densities compared to those with only sand substrates. The exception to this observation was that sand sites contained higher densities of small gem clams. Hard bottom benthic surveys found that gastropods, amphipods and polychaete worms comprised the majority of the hard-bottom epibenthic assemblage at all five hard-bottom sites, with amphipods as the numerically dominant invertebrate. Nearby artificial structures contained 43 taxa of algae, invertebrates, fish, and birds where the shallower areas were dominated by algae and polychaetes were most common in deeper water sites (SeArc 2015).

Because the Breakwaters Project would add high-quality, spatially complex reef-like habitat to the study area that should attract habitat forming species as well as fish and benthic invertebrate species, the initial benefits to the local ecological community would reflect early-stage colonization processes. Habitat forming benthic invertebrates (e.g., mussels, barnacles, tunicates, and bryozoans) and algae (encrusting algae and macroalgae) found during the survey would be expected to recruit to the breakwaters (Normandeau 2015 a,b,c,d; SeArc 2015; Ferrario et al. 2016; Firth et al. 2016). In addition, structured habitat with viable populations of habitat forming

bivalves and other invertebrates could provide increased feeding opportunities for juvenile and adult fish, potentially attracting juvenile recruits to suitable nursery habitat and contributing to improved productivity in local populations (Mann and Harding 1997, 1998; Coen and Grizzle 2007). Thus, the developing ecological community would be shaped by the larger species pool and the larvae it would supply. Additional ecological interactions such as competition, predation, and facilitation would influence both the development of the local community and the potential for bivalve colonization and persistence in the study area enhancement efforts (details described below) (e.g., Bruno et al. 2001, Mitcheli et al., 2005; Mann and Harding 1997, 1998; Coen and Grizzle 2007).

Fish species would likely derive benefits from the Breakwaters Project depending on their preference (and their prey's preference) for reef-like habitat and adjoining waters at different life stages (Mann and Harding 1997, 1998; Nestlerode 2004). Fish that are strongly linked to structure for shelter and food should be most tightly coupled with development of the breakwaters (e.g., structure-oriented target species groups below), while the increased productivity associated with these structures and the mosaic of transitional habitats created should provide attractive habitat to both pelagic forage species and ecologically and economically important transient species using the newly created habitat (e.g., Jones and Andrews 1992; Coen and Grizzle 2007; Burt et al. 2012).

Expectations regarding the long-term ecological community that would inhabit the Breakwaters Project study area should recognize that it would differ from the current one in terms of the number of species, the relative abundance of those species, the species groups present, and the ecological functions and ecosystem services provided. Not only would the newly created reef-like structures differ from historical conditions, they would differ from expectations for hypothetical "natural" reef community in the same site, partially due to the different substrates, monitoring effects, and the currently reduced abundance of resident species compared to historical levels (Burt et al. 2011, 2012). Because the Breakwaters Project reflects active efforts to incorporate ecological processes that support the recruitment and persistence of structure-oriented and habitat forming organisms, the structure should facilitate recruitment of an ecological community representative of the native diversity of species of the region.

The use of bio-enhancing concrete armor units, in conjunction with careful design of each breakwater segment and the entire system of ecologically enhanced breakwaters, would encourage the recruitment of several different species and life stages from several functional species groups to the study area, while meeting the primary goal of shoreline stabilization. The Breakwaters Project would convert 11.4 acres of bottom habitat from sand/gravel substrate to complex rocky structured habitat and would replace 115,990 CY of open water habitat below MHW, it would be necessary to first demonstrate that impacts of the Breakwaters Project would not result in significant adverse impacts to the existing ecological communities. This could be done by confirming the continued presence of taxa historically present in the study area. Thus, monitoring studies should be designed to document the continued presence of those species groups currently and historically found in the study area, while also tracking trends in the distribution and relative absence of non-native invasive species. Additional ecological enhancements to the community would be demonstrated by evidence of increased species richness (i.e., more species) in the study area, presence of habitat forming groups on and near the breakwaters (e.g., mussels, barnacles, clams, tubeworms, macroalgae), colonization of bio-enhancing concrete structures by target species groups, increased productivity and abundance of species groups, and evidence of new trophic interactions (e.g., predatory fish consuming forage fish associated with the new structures or crabs consuming habitat forming benthic

invertebrates). Considering a range of species groups, rather than focusing on a limited number of species and ecosystem functions, expands the range of possible outcomes that include desirable ecological functions and ecosystem services (e.g., increased species richness, increased community resilience, greater biogenic structure and habitat complexity). This approach accounts for the multiple pathways that colonization of the breakwaters could take in delivering the functions representative of a robust ecological community over time, across the Breakwaters Project system, and among neighboring estuarine habitats (Zedler 2005; Micheli and Halpern 2005).

B. FUNCTIONAL GROUPS

The functional groups described below aggregate species that share similar ecological roles in the Hudson River Estuary to emphasize the importance of a functionally diverse ecosystem rather than the presence of a few particular species. This is particularly important in highly variable environments exemplified by temperate estuaries like Raritan Bay and the larger Hudson-Raritan estuary. In these ecosystems, fluctuations in recruitment or changes in migratory patterns may result in high variability in the abundance of local populations of each species that, alone, do not reflect the state of the ecosystem. Environmental conditions (e.g., salinity, water temperature, sea level) in temperate estuaries vary over ecologically relevant ranges at many temporal and spatial scales. For example, salinity and temperature change with the ebb and flow of the daily tidal cycle, and are further influenced by the freshwater inputs from Hudson River and other tributaries in the watershed. At larger time scales, seasonal variability in temperate estuaries between winter and summer conditions means that for many species the estuary provides suitable habitat for only part of the year; thus, the typical community composition changes throughout the year. In addition, year-to-year variability in the form of dry and wet years or winter and tropical storms impart strong signals that influence both the environmental conditions and the species occupying the estuary. In some cases, species groups also reflect common economic (e.g., commercial or recreational fisheries) or social (e.g., conservation of protected species) values. While this classification scheme is not a perfect system, the proposed groups encompass several desirable ecological characteristics expected of newly created reef-like ecosystems, while considering the effects of the variability of environmental and ecosystem conditions characteristic of the study area. Consideration of the latter point is important. Because the Breakwaters Project would create new structured habitat that would likely be colonized both by species present in the study area before construction, and potentially by those not currently present, it would be important to ensure that species groups present before the project continue to occupy the study area – either on or among the breakwaters or in nearby waters.

The functional roles of species found in the study area encompass habitat creators, structure-oriented fish and invertebrates, and transient species attracted by the new structured habitat. These functional roles can be refined to include groups of species that ensure that different ecological functions (e.g., habitat forming) are spread across these groups. This approach hedges against the potential absence of a function due to the absence of a particular species or species group by spreading ecological functions across species within and across functional groups. Each target species group is described in terms of its representative species, ecological roles in both existing estuarine and the newly created reef-like habitats of the Breakwaters Project, design considerations, and other relevant factors for developing the expected range of possible outcomes from the construction of the Breakwaters Project. Representative taxa comprising each functional group described below were chosen because of their commonness, ecological role (e.g., keystone species, habitat-formers, or filter-feeder), economic importance (i.e., commercial

and recreational fisheries), or conservation status. The taxa listed are examples of common or well-known species that provide the services and roles descriptive of each functional group. The functional groups are defined in terms of representative species and taxa; hence, taxa not included in the functional groups described below are not precluded from any of these groups.

HABITAT FORMING AUTOTROPHS

Habitat forming autotrophs would contribute to the base of the Breakwaters Project food web. This group consists of macroalgae species (i.e., seaweed) found on hard substrates throughout the study area and represents the primary producers most likely to colonize the breakwaters. This distinction between habitat-forming autotrophs and phytoplankton was made to emphasize the breakwaters' importance as substrate for habitat formers. Historically common macroalgae species in the Hudson-Raritan Estuary include brown algae (*Fucus* sp.) and green algae (*Ulva lactua*) (Perlmutter 1971). Recent surveys in the study area found that red branching algae (*Agardhiella* spp.), *U. lactuca*, and red filamentous algae were the most common macroalgae sampled. Green algae, when found in great abundance, may be considered a nuisance species.

Habitat forming macroalgae provide several ecological functions in estuarine systems: primary production/food; nursery, foraging, and spawning habitat for fish and benthic invertebrates; water flow modulation; and nutrient cycling. Macroalgae require suitable hard substrates and tend to stratify by type and species across the rocky coastlines where they are present, with green algae common in along the shorelines, brown algae in the mid-intertidal zone to sub-tidal waters, and red algae occurring in the lower intertidal waters. Habitat complexity (e.g., the presence of tidal pools, crevices, textured bio-enhanced concrete armoring units) also appears to contribute to macroalgae species diversity (and the benthic community as a whole); thus, Breakwaters Project design considerations such as deploying settlement structures (e.g., tidal pools) throughout the water column would encourage their recruitment and retention (Firth et al. 2014; Evans et al. 2016). The habitat provided by macroalgae could also serve as fish habitat for economically important species at different life stages (e.g., black sea bass, red hake, summer flounder, windowpane, winter flounder, clearnose skates, little skate, winter skate, and striped bass) in the study area. Canopy-forming macroalgae on man-made structures may be subjected to increased grazing pressure by herbivores species on one hand, and damaged by handling and clipping interactions from a wide range of species on the other hand. (Ferrario et al. 2016). Another benefit of canopy-forming algae is that it can cool tidal pool temperatures by 25 percent, stabilizing microclimate reducing both weathering and ecological stress (Coombes et al. 2003).

The percent cover, species richness, distribution, and canopy size (e.g., mean stipe length) of macroalgae patches on different components of the breakwaters (waveside and leeside of the core structure, reef streets and fingers, emergent areas, reef ends) and other locations in the study area (neighboring sediments), as well as quantification of the fish and benthic invertebrate community residing in those patches, would provide insight into the ecosystem services provided by habitat forming autotrophs.

BIVALVE HABITAT FORMING SESSILE INVERTEBRATES

The Breakwaters Project would provide structured reef-like habitat designed to attract and retain habitat forming bivalve mollusk species. Each segment of the Breakwaters Project would incorporate features that promote recruitment and retention of bivalves. Ecologically designed reef-like structures generally attract primary habitat forming sessile invertebrates (e.g., barnacles, mussels) and have been shown to support ecological communities that function

similarly to restored oyster reef systems (e.g., Grabowski 2005; Luckenback et al. 2005; Gregalis et al. 2008). Growth of bivalves on the breakwater segments would be encouraged through the combination of site selection, use of bio-enhanced concrete units constructed using special concrete admixtures with textured surfaces, and multiple sizes of primary granite/rock substrate. Several types of bio-enhancing concrete units would be used including fish hubs and tidal pool units. These structures would also promote the attraction and retention of macroalgae and other habitat forming invertebrates, as well as fish and benthic invertebrates benefitting from the expected increases in refuge habitat and foraging opportunities.

Competitive dominant habitat forming species would reduce the space for other primary space holders, but their presence would increase the available niche space for other species including secondary habitat formers (studies cited in Bruno et al. 2003). In other cases, some primary habitat forming species could facilitate the settlement of other primary habitat formers. For example, the presence of mussel beds and barnacles has been shown to promote settlement of oyster larvae (Osman 1989). However, other sessile invertebrates, such as bryozoans, ascidians, and boring sponges, negatively impacted oyster larvae settlement (Osman 1989; Barnes 2008).

Beneficial ecosystem functions associated with the establishment of primary habitat forming invertebrates augment many of those associated with creating reef-like habitat. These functions include stabilization of benthic or intertidal habitat, nursery and spawning habitat for fishes, predator refuges for forage fish and juvenile fish and shellfish, and the modification of local currents that may enhance delivery of planktonic food particles to filter-feeding species (Grabowski et al. 2007). In addition, the presence of a healthy population of habitat forming shellfish provide increased forage for fish and other shellfish (e.g., oyster drills and blue crabs), increased opportunities for secondary habitat formers (as reviewed in Bruno et al. 2003), increased benthic-pelagic coupling (filter-feeding and subsequent excretion that transfers energy and biomass from the water column to the neighboring sediments) (e.g., Mann and Harding 1997, 1998; Coen et al. 2007). Studies have also shown that unstructured habitat areas adjoining reefs are associated with increased abundance and species diversity over more isolated unstructured habitat (edge-effects) (Scyphers et al. 2011, 2015).

Several of the considerations for designing a reef-like system amenable to colonization and establishment of populations of habitat forming bivalves were discussed above. The construction of the Breakwaters Project, however, must avoid adverse impacts to the existing functioning of the local community, including no adverse impacts to protected species and critical habitat, as well as avoid significant adverse impact to areas of essential fish habitat. Monitoring efforts, therefore, would need to assess that community composition has not notably lost representative taxa or species groups as a result of the construction of the Breakwaters Project (i.e., continued occurrence of species groups observed in existing conditions surveys). The materials used to construct the breakwaters structures and the rugosity, height, length, width, and slope of the structures all influence the settlement of primary habitat forming bivalves. Competition among primary habitat formers might be expected, but presence of one species could facilitate settlement of another (Barnes 2008). Finally, the local abundance of predators and competitors (e.g., boring sponges, *Cliona* sp.) may preclude veliger settlement or facilitate predation by other species (Barnes 2008).

Monitoring studies should characterize the number of different species present and their relative performance. Other useful metrics include density, spatial coverage, growth, and survival of key species (e.g., mussels and barnacles) on each breakwater and the different habitat types on each breakwater (e.g., lee vs wave sides). The Breakwaters Project also provides an opportunity to

evaluate how colonization by barnacles, mussels, and other bivalves could facilitate recruitment of other species to the breakwaters and how those relationships vary at different depths and locations along the structures. Measuring water clarity would provide insight into potential improvements to local water quality attributable to local filter feeding organisms. These data would quantify key interactions that influence the local ecology and water quality.

NON-BIVALVE HABITAT FORMING SESSILE INVERTEBRATES

Biogenic habitat created by other benthic invertebrates provides additional structural complexity to that associated with the breakwaters structures themselves, while concomitantly increasing the potential for ecosystem functions including filter-feeding, providing food for local grazers and predators, creating additional habitat and increasing habitat complexity for fish and other benthic invertebrates, sequestering carbon, bioprotection, and contributing to local biodiversity (Ostroumov 2005; Coen et al. 2007; Aguilera 2014). Bioprotection describes processes by which organisms protect the surfaces they colonize from weathering and erosion. Here the build-up of a biogenic calcium carbonate layer over the breakwaters would increase both the availability of heterogeneous habitat while contributing to the stability and longevity (Risinger 2012, Coombes et al. 2013). The concepts and approaches used to monitor bivalve habitat formers could be used for this group as well.

Members of this diverse group found in the study area during surveys documenting existing conditions included barnacles, bryozoans, hydroids, tunicates, encrusting sponges, sea anemones, and tube worms (Normandeau 2015 a,b,c,d; SeArc 2015). Species in this group are primarily filter-feeders, but also include predatory sea anemones. Similar to primary habitat-formers, many members of this species group function as ecosystem engineers that transform their physical environment by accreting biogenic structures that typically outlast the lifespans of the individual organisms, but these structures typically have a smaller spatial scale than, for example, the hard structures associated with oyster reefs or mussel beds (Gutierrez and Jones 2003; Hastings et al. 2007). Note that anemones, tunicates, and sponges do not accrete calcium carbonate and, therefore, do not leave behind the long-lasting structures associated with oysters, mussels, barnacles, or tubeworms. The additional fine-scale habitat complexity created by these habitat formers provides alternative predator refuges and foraging opportunities available to small, mobile invertebrates (Sella and Perkol-Finkel 2015).

While taxa in this group provide similar services, each taxon would occupy different regions of the Breakwaters Project and make distinct contributions to habitat creation, filter-feeding, and other ecosystem services provided by this group. Barnacles inhabit the intertidal zone, but species differ in their preferred elevation band along the intertidal region. These filter-feeders consume plankton and detritus, and produce shells composed of calcium carbonate. Barnacles are prey for fish, larger crustaceans, and worms. Bryozoans are colonial organisms that form three dimensional aggregations that often encrust hard substrates and algae. These “moss animals” are suspension feeders that consume plankton and detritus. Encrusting bryozoans secrete calcium carbonate and chitin (a polysaccharide that also forms the shells of insects, crabs, and other arthropods) sheets over hard substrate that adds additional relief to hard substrates (i.e., eco-enhancing concrete units and tide pools and standard armor units). Bryozoans and their pelagic larvae are prey for nudibranchs, fish, crustaceans, and echinoderms (Lidgard 2008). Taxa found in the existing conditions surveys included *Schizoporella*, *Watersipora* sp., and *Membranipora* (Normandeau 2015 a,b,c,d; SeArc 2015**).** Tunicates are filter feeders that live as solitary individuals or as colonies, and may be sessile or planktonic. Because tunicates do not produce a durable calcium carbonate skeletal structure that would

persist long after the death of a tunicate, they are not considered ecosystem engineers; however, they do add habitat complexity at finer spatial scales and are prodigious filter-feeders. Polychaetes are another important member of the benthic invertebrate community in the Hudson-Raritan Estuary system; they secrete calcium carbonate tubes around their bodies, which provides both protection to these filter-feeding tubeworms and habitat to small fish and benthic invertebrates. Sponges, the simplest of multi-cellular animals, are sessile organisms and efficient filter feeders, capturing particles as small as bacteria. Sponges have different forms, which influence their role as habitat forming species. Encrusting sponges cover the surface of hard substrates, with some local taxa of boring sponge (e.g., *Cliona* sp.) able to influence the local benthic invertebrate community by drilling into accreted calcium carbonate substrate and shells (Barnes 2008). Like tunicates, sponges are neither important prey items nor do they deposit calcium carbonate structures that create and augment local biogenic habitat. Thus, sponges are not considered ecosystem engineers. These habitat forming filter feeders contribute to local habitat complexity on the scale of centimeters to meters and provide additional benthic pelagic coupling. Sponges found in the existing conditions surveys included *Microciona prolifera* and *Halichondria bowerbanki* and the boring sponge (*Cliona* sp.).

The existing conditions surveys found several members of this group in the study area and on nearby artificial habitat structures, including: barnacles (e.g., *Amphibalanus* sp., *Chthamalus fragilis*), tube-forming polychaete worms (e.g., *Sabellaria vulgaris*, Serpulidea), sponges (e.g., *Microciona prolifera*, *Halichondria bowerbanki*), anemones (e.g., *Diadumene leucolena*, *D. lineata*, *Metridium senile*), and tunicates (e.g., *Molgula manhattansis*) (Normandeau 2015 a,b,c,d; SeArc 2015).

CRYPTIC FISH

The rocky, reef-like habitat formed by the breakwaters would create habitat not currently present in the study area that is suitable for small, structure-oriented, benthic fish species (Normandeau 2015 a,b,c,d; SeArc 2015). Examples of these "cryptic" fish species found in coastal and estuarine waters of New York include gobies (naked, seaboard, and highfin), blennies (feather and freckled), rock gunnel, skilletfish, and oyster toadfish.[1] Recruitment of cryptic fish to the breakwaters would indicate added complexity to the existing food web because these fish are prey for several fish species, blue crabs, and other invertebrates (e.g., Mann and Harding 1997, 1998). In addition, this target species group feeds on small benthic invertebrates (e.g., tube worms, amphipods, isopods) (D'Aguillo et al. 2014). Of the species in this group, only oyster toadfish and naked goby were collected in the study area during seine, trawl, and trap surveys conducted in 2015 and 2017 to characterize existing biological conditions (Normandeau 2015 a,b,c,d; SeArc 2015). The relative absence of this group in the existing conditions surveys is consistent with the lack of abundant structured habitat. This group should benefit from the ecological design considerations discussed above, because these fish would be attracted to productive reef-like structures and the protection they offer from predators and foraging opportunities. Thus, features designed to attract habitat forming invertebrates and the resultant community of benthic and epibenthic invertebrates would ultimately attract these cryptic fish species. Specifically, cryptic fish (blennies and gobies) attracted to eco-enhanced concrete that were not found in non-ecologically designed structural armoring units (Sella and Perkol-Finkel

[1] Note that while oyster toadfish are included in this group because they use rocky habitats, they are primarily piscivores with few natural predators.

2015). These fish would use the breakwater structures for refuge and breeding and rarely occur more than a few feet from structured habitat.

Efforts to monitor relative abundance and distribution of cryptic fish on the breakwater structures would entail either dive or fish trap studies. These studies would enable the characterization of number of species present and their density, spatial coverage, and preferred habitats. The Breakwaters Project would provide an opportunity to measure the colonization rate of these species and to assess their role as forage in higher trophic level organisms. Providing a key link in the trophic system is important because the presence of prey for game fish should attract predators like weakfish and striped bass. Long-term diet studies of these species and their predators would provide important insights into the energetic transfers on the breakwaters and organisms occupying neighboring habitats.

STRUCTURE-ORIENTED FISH

Natural and man-made reefs and reef-like structures provide the primary habitat for many economically and ecologically important structure-oriented fish species. The use of structured habitat for each of these species varies by life stage and season, but species in this group use structured habitat and its surroundings for refuge and feeding at different life stages. The body shape and jaw structure of these species (e.g., tautog, black sea bass, and cunner) are well-suited for capturing motile prey or navigating highly structured habitat to consume sessile benthic invertebrates. Both tautog and black sea bass are managed within their range along the U.S. mid-Atlantic coast, and their structure-oriented, non-migratory behavior has led to population assessments and management efforts at regional to state-by-state scales. Black sea bass, tautog, and cunner have active recreational and commercial fisheries in New York, with an average total catch of 2,513,318 black sea bass, 1,178,639 tautog, and 36,244 cunner from 2014 to 2015.[1] Commercial landings of black sea bass in New York averaged 187,085 pounds from 2014 to 2015; over the same period commercial landings of tautog and cunner averaged 116,521 pounds and 3,485 pounds, respectively.[2] The most recent stock assessment available for black sea bass reports that the stock is neither overfished nor is it experiencing overfishing (NEFSC 2016). The most recent tautog stock assessment employed regional approach to defining management units rather than assessing the status coast wide and found that the tautog population in New York-New Jersey is currently overfished (ASMFC 2015c).

Because these fish are strongly associated with structure, monitoring their distribution and relative abundance would likely require dive-based surveys (juveniles and adults) and/or trap surveys (adults – depending on trap size) similar to those employed to monitor the development on the cryptic fish target species group. Because species in this group prey on organisms found both on the breakwater structures and in surrounding waters, diet studies would provide information on trophic linkages and energy transfers between the Breakwaters and neighboring habitats.

[1] Marine Recreational Information Program online query, November 20, 2016; http://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/queries/index

[2] Commercial Fisheries Statistics online query, November 20, 2016. https://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/annual-landings/index

TRANSIENT/PELAGIC FORAGE FISH

While cryptic fish are important prey for fish feeding on and around structured habitat, pelagic forage fish like anchovies, silversides, and herring are among the most abundant fish in the coastal ocean and are consumed by just about every piscivorous species where they are found. Recent actions of U.S. Atlantic Coast fisheries management regulators reflect the ecological role of forage fish in supporting higher trophic level fish species in the ecosystem. In August 2016, the Mid-Atlantic Fishery Management Council approved its Ecosystem Approach to Fisheries Management and passed an amendment to protect forage fish species in Mid-Atlantic that do not have fishery management plans (http://www.mafmc.org/actions/unmanaged-forage). In addition, ecosystem considerations (e.g., trophic interactions) are also a common, if not required component, in federal and interstate fishery management plans and stock assessments (e.g., Magnuson-Stevens Fishery Conservation and Management Act, 16 U.S.C. §§1801 *et seq.*; ASMFC 2016a).

Several species of forage fish can be found in Raritan Bay and neighboring waters, including, but not limited to, American shad, Atlantic menhaden, Atlantic herring, killifish, mummichog, river herring (alewife and blueback herring), silversides (Atlantic, inland, rough, and brook), spot, butterfish, stickleback, sand lance, and white mullet. With the exception of sand lance, all of these species comprised the forage fish found in the study area during existing conditions surveys conducted in June, July, and September of 2015 and 2017. Some of these forage fish support noteworthy fisheries, with Atlantic menhaden supporting the second largest commercial fishery in the U.S. by landings (1,256,192, 000 lbs. in 2014, SEDAR 2015). The numerical dominance of bay anchovy and silversides in research survey catches, as well as their common occurrence in predatory fish (e.g., striped bass, weakfish, bluefish, and summer flounder) stomach contents, supports their key role in the coastal food web dynamics (Houde and Zastrow 1991; Steimle et al. 2000; Bonzek el al. 2014). Many of these forage species are filter feeders, a mechanism often associated with the potential for improving water quality via the net uptake of excess nutrients. A study investigating the potential for improving water quality through filter-feeding by Atlantic menhaden in the Chesapeake Bay suggested that this mechanism had little effect, in part because the uptake of phytoplankton by menhaden was size-limited, and only young-of-the-year (YOY) fish effectively grazed particles the size of phytoplankton (Lynch et al. 2010). Species in this target group generally consume phytoplankton, zooplankton, and small benthic invertebrates. While all use the Hudson-Raritan Estuary, the presence of a particular taxon primarily depends on season and life stage. For example, Atlantic menhaden occur in estuaries during warmer months, but are found offshore during the winter when spawning occurs (SEDAR 2015).

Many of these fish occur in nearshore waters sufficiently removed from structured habitat, so beach seines are effective tools for sampling the relative abundance of these species in the study area. For fish more distant from the shoreline, small otter trawls could be used as well (note that beam trawls used during the existing conditions survey in 2015 were largely ineffective at sampling fish and macroinvertebrate species; otter trawls were used in 2017). If dive surveys are used to enumerate benthic invertebrates, structure-oriented fish, and cryptic forage fish, then these surveys could also include counts of this target species group and make notes on their use of structured habitat and interactions with other target species groups. Diet studies of higher trophic level structure-oriented fish and upper trophic level transient fish would provide insight into patterns of prey consumption by higher trophic level fish (e.g., do these transient species tend to eat pelagic forage fish or cryptic forage fish associated with the breakwaters structures?).

UPPER TROPHIC LEVEL TRANSIENT FISH

This group consists of pelagic species that may occasionally forage near structured habitats to feed on locally abundant forage fish or benthic invertebrates (Mann and Harding 1997, 1998, Scyphers et al. 2011, 2015). These species include popular recreational and commercial fish such as striped bass (*Morone saxitilis*), white perch (*M. americana*), bluefish (*Pomatomus saltatrix*), weakfish (*Cynoscion regalis*), black drum (*Pogonias cromis*), red hake (*Urophycis chuss*), summer flounder (*Paralythis dentatus*), windowpane flounder (*Scopthalmus aquosus*), and winter flounder (*Pseudopleuronectes americanus*) that are likely to forage at the Breakwaters Project location or in nearby waters. While Atlantic sturgeon (*Acipenser oxyrhynchus*) are a protected species, they are included in this group because they could occur in the study area during migrations and different life stages.

The species in this target group represent some of the most popular recreational and commercial fisheries in New York and along the U.S. mid-Atlantic coast. In New York, the average commercial landing of summer flounder for 2014 and 2015 was 830,881 pounds, while recreational anglers caught 4,484,971 fish on average during the same period. The current stock assessment update found that while the stock currently experiences overfishing, it is not currently overfished; the spawning population abundance is well below the target and has declined in recent years to the lowest levels since the late 1990s (Tercerio 2015). Bluefish commercial landings averaged 949,979 pounds from 2014 to 2015 in New York, while a total of 2,264,921 bluefish were caught recreationally during the same period. While the bluefish stock is not currently overfished and is not experiencing overfishing, its estimated abundance has consistently been below the target biomass reference since the early 1990s (NEFSC 2015). In fisheries management, target biomass levels denote the abundance should, on average, be equally likely to be above or below that abundance level; thus, while bluefish are not overfished their abundance levels have consistently fallen below management goals. New York's striped bass commercial landings averaged 510,189 pounds from 2014 to 2015, while the state's recreational fishery caught an average of 920,513 fish each year over the same period. Currently, the coast-wide striped bass stock is neither overfished nor is overfishing occurring. Recruitment in the Hudson River declined from 2007 to 2011; however, the 2014 cohort appears strong (ASMFC 2015a). The coast wide weakfish stock abundance is considered low relative to recent decades and the population has experienced high levels of mortality for much of the last 15 years (i.e., total mortality rates exceeding the threshold level) (ASMFC 2016b). In 2014 and 2015, annual commercial landings averaged 28,868 pounds in New York while recreation catch averaged 2,698 fish each year.

The New York State Department of State has declared portions of the Hudson River as "significant coastal fish and wildlife habitat" for striped bass as a protective measure against the year-to-year variability in environmental conditions and harvest levels. In addition, the elasmobranchs clearnose skate, little skate, and winter skate also may forage for benthic fish and invertebrates attracted to the Breakwaters Project. Because many of these fish are managed and have a long history of harvest, estimates of population health are available for several of these species, and essential fish habitat has been designated for some fish falling under the purview of the federal government. While the construction of the Breakwaters Project would transform some existing soft bottom sediments and open water into ecologically designed reef-like habitat, the area lost would be minimal compared to the amount of similar habitat available in the study area and would not be lost all at once but sequentially as each breakwater segment is constructed. Additional foraging opportunities are expected from the construction of the Breakwaters Project, so an increased supply of forage fish and benthic invertebrates would help

ensure presence of this group. It is likely that juveniles of some of these species may also use the Breakwaters Project as predatory refugia during their early life stages. Existing conditions beach seine, trawl, and pot surveys collected bluefish, winter flounder, American eel, weakfish, silver hake, and scup in the study area.

Juveniles of some species in this target group occur in nearshore waters that are best sampled using beach seines, while otter trawls are better sampling tools for larger fish in the study area. Dive surveys used to enumerate benthic invertebrates, structure-oriented fish, and cryptic forage fish could also include counts of this target species group and make notes on their use of structured habitat and interactions with other target species groups. Diet studies of this higher trophic level group provide insight into patterns of prey consumption at the breakwaters.

BENTHIC MACROINVERTEBRATES

This group spans a diverse group of taxa including crustaceans (e.g., crabs, hermit crabs, lobster), mollusks (e.g., snails, whelks, limpets), and horseshoe crabs. Collectively, these species contribute to a broad range of ecological services in the form of predator-prey interactions (e.g., food for protected shorebirds, detritus consumers) and also support diverse commercial, recreational, and, for horseshoe crabs, biomedical fisheries. Because the ecologically designed and fully constructed Breakwaters Project would provide both refuge and foraging habitat for the members of this assemblage, benthic macroinvertebrates would likely constitute an important species group on the structure and the surrounding waters (Coen et al. 2007). Many of the species in this group, such as economically important blue crabs, American lobsters, knobbed whelks, and horseshoe crabs, are well-known. Other members of the Raritan Bay benthic invertebrate community (e.g., rock crabs, lady crabs, and oyster drills) are less well-known and do not support large fisheries or venture onto shorelines to spawn (USACE 2016a; Normandeau 2015 a,b,c,d; SeArc 2015). The benthic habitat and fish surveys conducted in the summer and fall of 2015 and 2017 collected Say mud crabs, blue crabs, lady crabs, portly spider crabs, longwrist hermit crabs, horseshoe crabs, oyster drills, and other species.

Although many of the large crustaceans in this group are opportunistic scavengers or predators, these taxa are preyed upon by other invertebrates, as well as fish (e.g., red drum, croaker) and bird species. The shellfish species also comprise part of the diet of the three sea turtle species that could occur in the study area (Kemp's Ridley, loggerhead, and green). One highly visible ecosystem service provided by this group is that horseshoe crab eggs deposited on sandy beaches are an important food source for migratory shorebirds including the threatened red knot (*rufa* subspecies). While horseshoe crabs would likely benefit from increased foraging opportunities afforded by the breakwaters, they could also benefit from improved shorelines that would serve as spawning habitat. They require access to open, undisturbed sand/pebble beaches in calmer waters, where a portion of the beach is at or above MHW level for egg laying and larval development. Because such habitat is a bottleneck (i.e., a habitat limitation) for this species, it is important to ensure adequate shoreline habitat for nesting and egg/larvae development (ASMFC 2015b). In addition, horseshoe crabs support two commercial fisheries, a bait fishery and a biomedical fishery that harvests horseshoe crab blood to produce Limulus amoebocyte lysate (LAL) – the most sensitive test available to detect human pathogens in hospitals. Thus, horseshoe crabs are an ecologically and economically important species in the Hudson-Raritan Estuary.

The use of eco-enhancing concrete armor units and the bio-active tide pool units should help to attract and retain habitat forming species. These habitat forming species would then serve as refuge for either benthic macroinvertebrates or their prey, as would the wide range of rock sizes

and different habitats found on the breakwaters (waveside and leeside breakwater cores, reef streets and ridges, emergent areas, reef ends, and adjoining sediments). Macroinvertebrate monitoring programs tracking their spatial and temporal distribution and relative abundance should use multiple methods (e.g., trap, visual, and destructive surveys) to help reduce potential impacts from selectivity and avoidance behaviors. Horseshoe crab spawning surveys can identify areas of beach used and provide insight into areas preferred by spawning adults (i.e., do horseshoe crabs use the restored areas of the beach?).

PROTECTED SPECIES

A final target species group to consider includes protected species that could occur in the study area and are known to use the Hudson-Raritan Estuary and neighboring coastal waters. This group includes federally-listed species that have the potential to occur in Raritan Bay near the project site (NMFS 2015). While Atlantic sturgeon (*Acipenser oxyrhynchus*; New York Bight Distinct Population Segment and others, endangered) occur in the Hudson-Raritan Estuary, they are included in the *Upper trophic level transient fish* functional group and discussed there. Hence, species in this target group include sea turtle species that may occur in the study area: loggerhead sea turtle (*Caretta caretta*; threatened), green sea turtle (*Chelonia mydas*; threatened), and Kemp's ridley sea turtle (*Lepidochelys kempi*; endangered) (NMFS 2015). Monitoring efforts for other species, such as the harbor seal (*Phoca vitulina*) should note the presence and estimated number of any protected species observed in the study area and cooperate with ongoing regional efforts to monitor these species.

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Appendix E-8
Tottenville Shoreline Protection Project
Wetland Delineation

AKRF

Environmental and Planning Consultants

440 Park Avenue South
7th Floor
New York, NY 10016
tel: 212 696-0670
fax: 212 213-3191
www.akrf.com

Memorandum

To: Governor's Office of Storm Recovery (GOSR)

From: Jesse Moore, AKRF

Date: December 15, 2016

Re: Tottenville Shoreline Protection Project – Wetland Delineation

cc: Sandy Collins, AKRF

INTRODUCTION

The Governor's Office of Storm Recovery (GOSR) is proposing the Tottenville Shoreline Protection project (Shoreline Project), a series of shoreline protection measures, including an earthen berm, eco-revetment, hybrid dune system, and raised edge (revetment with trail) with revetment, along with wetland enhancements, and landscaping with native coastal plant species, from approximately west of the intersection of Swinnerton Street and Billop Avenue to Page Avenue (**Figure 1**).

In August 2016, AKRF delineated one wetland (Wetland F) in the Study Area and two wetlands (Wetlands AB and G) off site for purposes of identifying any freshwater wetland buffer areas. This memorandum outlines the details of the wetland delineation.

METHODOLOGY

Prior to the wetland delineation, United States Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) (see **Figure 2**) and New York State Department of Environmental Conservation (NYSDEC) (see **Figure 3**) maps were reviewed to determine locations of state-mapped and/or NWI-mapped wetlands on and in the vicinity of the Study Area. The Natural Resources Conservation Service (NRCS) soils maps (see **Figure 4**) were also reviewed to determine soil types within the Study Area, particularly with respect to soil series identified as hydric. AKRF wetland scientists conducted a wetland delineation of the Study Area on August 8, 2016 and August 10, 2016, using the United States Army Corps of Engineers (USACE) wetland delineation methodology.[1] Methodology pertaining to the three USACE wetland indicators (i.e., hydrology, soils, and hydrophytic vegetation) is described below. The

[1] Environmental Laboratory. 1987. "Corps of Engineers Wetlands Delineation Manual," Technical Report Y-87-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss; U.S. Army Corps of Engineers. 2011. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Northcentral and Northeast Region (version 2.0), ed. J.S. Wakeley, R.W. Lichvar, C.V. Noble, and J.F. Berkowitz. ERDC/EL TR-12-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

USACE *Wetland Determination Data Form – Northcentral and Northeast Region* (2012) was used to document the wetlands observed on the Study Area. Photographs were also taken of the delineated wetlands (see **Figures 5** and **6**).

HYDROLOGY AND SOILS

The hydrology of the Study Area was characterized using aerial photographs, site observations, and an auger to determine soil saturation and/or a high water table. Soils were characterized with the use of an auger and a Munsell Soil Color Chart. During the wetland delineation, both hydrology and soils observations were made during a period of dry weather.

VEGETATION

The USACE *Northcentral and Northeast 2014 Regional Wetland Plant List* was used to determine the wetland/upland status[2] of the plant species identified on the Study Area. Percent cover was documented in the tree, woody vine, sapling/shrub, and herbaceous strata. In most instances, a 30-foot (ft) radius plot was established to document plant species percent cover in the tree and vine strata. Within this 30-ft plot, a 15-ft radius plot was established for the measurement of percent cover of shrubs and saplings. For species in the herbaceous stratum, a 5-ft radius plot was established within the 30-ft radius plot.

EXISTING CONDITIONS

MAPPING

National Wetlands Inventory-Mapped Wetlands

NWI wetland maps indicate that one freshwater wetland and six tidal wetlands occur within the vicinity of the Study Area, and two freshwater wetlands occur offsite and were delineated for purposes of assessing whether the New York State Department of Environmental Conservation (NYSDEC) freshwater wetland buffer was within the Study Area (see **Figure 2**). The NWI-mapped freshwater wetland within the vicinity of the Study Area is a palustrine unconsolidated bottom/scrub-shrub wetland with broad-leaved deciduous vegetation that is semi-permanent-tidal (PUB/SS1T). The NWI-mapped tidal wetlands include: an estuarine intertidal wetland dominated by emergent persistent vegetation that is irregularly flooded (E2EM1P), an estuarine intertidal wetland with an unconsolidated sand shore that is irregularly flooded (E2US2P), an estuarine intertidal wetland with an unconsolidated sand shore that is regularly flooded (E2US2N), an estuarine subtidal wetland with an unconsolidated bottom that is permanently flooded and oligohaline (E1UBL6), an estuarine intertidal wetland with emergent persistent vegetation that is irregularly flooded and oligohaline (E2EM1P6), and an estuarine intertidal wetland with emergent *Phragmites australis* dominated vegetation that is irregularly flooded and oligohaline (E2EM5P6). The two offsite NWI-mapped freshwater wetlands include: a palustrine forested wetland with broad-leaved deciduous vegetation that is seasonally flooded and/or saturated (PFO1E) and a palustrine wetland with emergent *Phragmites australis* dominated vegetation that is seasonally flooded and/or saturated (PEM5E). Site inspection confirms wetland type and approximate locations of the E2US2P, E2US2N, E2EM5P6, E2EM1P6, E1UBL6, PFO1E, and PEM5E wetlands. However, site inspection does not confirm the presence of the E2EM1P and PUB/SS1T wetlands.

New York State Department of Environmental Conservation-Mapped Wetlands

NYSDEC tidal wetland maps indicate littoral zone tidal wetlands (LZ) occur within the vicinity of the Study Area (see **Figure 3**). LZ wetlands are the tidal wetland zone that is permanently flooded by no

[2] Wetland/upland statuses for plant species include Obligate (OBL; occurring in wetlands greater than or equal to 99 percent of the time), Facultative Wetland (FACW; occurring in wetlands between 67 and 99 percent of the time), Facultative (FAC; occurring in wetlands between 34 and 66 percent of the time), Facultative Upland (FACU; occurring in wetlands between 1 and 33 percent of the time), and Upland (UPL; occurring in wetlands less than or equal to 1 percent of the time). Dominant species indicative of wetlands include species rated as OBL, FACW, and FAC.

more than 6 feet of water at mean low water (MLW) and is not included in any other wetland category. Site inspection confirms these mapped wetland types and approximate locations. There are two NYSDEC-mapped freshwater wetlands within the vicinity of the Study Area, AR-22 to the west of the Study Area and AR-15 to the east of the Study Area (see **Figure 3**). The two NYSDEC-mapped freshwater wetlands are located more than 100 feet from the Study Area, thus the Study Area is not within the NYSDEC-regulated freshwater wetland adjacent area for AR-15 or AR-22.

Natural Resources Conservation Service -Mapped Soils

Within the Study Area soils are mapped as "Be – Beaches," "BtA – Boonton loam, 0 to 3 percent slopes," "CaA – Catden muck, 0 to 2 percent slopes," "FrA – Fortress fine sandy loam, 0 to 3 percent slopes," "GUA – Greenbelt-Urban land complex, 3 to 8 percent slopes," "GUB – Greenbelt-Uban land complex, 3 to 8 percent slopes," "HHA – Haledon-Hasbrouck complex, 0 to 3 percent slopes, frequently ponded," "NoA – North Meadow sandy loam, 0 to 3 percent slopes," "PkA – Preakness mucky silt loam, 0 to 3 percent slopes," "PvA – Preakness silt loam, 0 to 3 percent slopes, frequently ponded," "UGA – Urban land-Greenbelt complex, 0 to 3 percent slopes," "ULA – Urban land-Laguardia complex, 0 to 3 percent slopes," and "WbA – Westbrook mucky peat, sandy substratum, 0 to 1 percent slopes, very frequently flooded" by NRCS (see **Figure 4**). The NRCS lists five of the series mapped for the Study Area as hydric: CaA, HHA, PkA, PvA, and WbA. Hydric soil is one of the three parameters that define a wetland according to the USACE methodology.

ONSITE DELINEATION

One wetland (Wetland F) was delineated within the Study Area and two wetlands (Wetlands AB and G) were delineated in the vicinity of the Study Area in August 2016 (see **Surveyed Wetland Drawings**). These wetlands were flagged as follows:

- Wetland AB: A-1 to A-9, B-1 to B-19;
- Wetland F: F-1 to F-37; and
- Wetland G: G-1 to G-19.

Wetland AB

Wetland AB is a freshwater emergent wetland located in the vicinity of the eastern portion of the Study Area, east of Page Avenue in Butler Manor Woods (see **Figure 6a, Photographs 1 and 2**). The soils, hydrology, and hydrophytic vegetation of Wetland AB are described below.

The Data Form for Wetland AB depicts the dominant species associated with this wetland. These species include pin oak (*Quercus palustris*) (FACW) and red maple (*Acer rubrum*) (FAC) in the tree layer, common reed (*Phragmites australis*) (FACW) for the herbaceous layer and poison ivy (*Toxicodendron radicans*) (FAC) for the woody vine layer.

Soils of this wetland meet the criteria of "F6 Redox Dark Surface." The primary hydrology indicators are "B7 Inundation Visible on Aerial Imagery," "B8 Sparsely Vegetated Concave Surface," and "B9 Water-stained Leaves." The secondary hydrology indicator is "B16 Moss Trim Lines" (see Data Form Wetland AB).

Upland AB

This upland area is located between to Wetland AB and a walking trail to the west. The dominant species associated with the upland area are sweetgum (*Liquidambar styraciflua*) (FAC) and pin oak (FACW) in the tree layer, hackberry (*Celtis occidentalis*) (FAC) in the sapling/shrub layer, common mugwort (*Artemisia vulgaris*) (UPL) in the herb layer, and poison ivy (FAC) in the woody vine layer. The soils and hydrology of this area do not meet the USACE criteria for a wetland. For these reasons, this area was documented as upland (see Data Form for Upland AB).

Wetland F

Wetland F is a tidal emergent wetland located in the western portion of the Study Area, south of Billop Avenue and west of Manhattan Street (see **Figure 6b, Photographs 3 and 4**). The soils, hydrology, and hydrophytic vegetation of Wetland F are described below.

The Data Form for Wetland F depicts the dominant species associated with this wetland. These species include common reed (FACW) in the herbaceous layer.

Soils of this wetland meet the criteria of "S1 Sandy Mucky Mineral." The primary hydrology indicators are "A2 High Water Table" at 7 inches depth, "A3 Saturation" at the surface, and "B1 Water Marks." The secondary hydrology indicators are "B10 Drainage Patterns" and "D2 Geomorphic Position" due to its location in a depression adjacent to tidal waters with a connection to these tidal waters via a culvert (see Data Form Wetland F).

Upland F

This upland area is located south of Wetland F along the maritime dune. The maritime dune is unvegetated. The vegetation, soils, and hydrology of this area do not meet the USACE criteria for a wetland. For these reasons, this area was documented as upland (see Data Form for Upland F).

Wetland G

Wetland G is a freshwater/tidal emergent wetland complex located in the vicinity of the western portion of the Study Area, in Conference House Park (see **Figure 6c, Photographs 5 and 6**). The soils, hydrology, and hydrophytic vegetation of Wetland G are described below.

The Data Form for Wetland G lists the dominant species associated with this wetland. These species include buttonbush (*Cephalanthus occidentalis*) (OBL) in the sapling/shrub layer and arrow arum (*Peltandra virginica*) (OBL) in the herbaceous layer.

Soils of this wetland meet the criteria of "S1 Sandy Mucky Mineral." The primary hydrology indicators are "A1 Surface Water" at over 6 inches deep, "A2 High Water Table" at 9 inches below surface, "A3 Saturation" observed at the surface, "B7 Inundation Visible on Aerial Imagery," "B13 Aquatic Fauna," and "B9 Water-stained Leaves." (see Data Form Wetland G).

Upland G

This upland area is located east of Wetland G. The dominant species associated with the upland area are pin oak (FACW) in the tree layer, pokeweed (*Phytolacca americana*) (FACU) and wineberry (*Rubus phoenicolasius*) (FACU) in the herbaceous layer. The vegetation, soils, and hydrology of this area do not meet the USACE criteria for a wetland. For these reasons, this area was documented as upland (see Data Form for Upland G).

CONCLUSIONS AND RECOMMENDATIONS

As described above, one vegetated freshwater emergent wetland (Wetlands AB) within the Study Area one wetland containing both freshwater and tidal emergent areas (Wetland G) within the vicinity of the Study Area, and one vegetated tidal emergent wetland (Wetlands F) within the Study Area were delineated, as per the USACE wetland delineation methodology. Any impacts to federally- or state-mapped wetlands are subject to Section 401 and 404 permits under the Clean Water Act and Tidal Wetland permits under Article 25 and Freshwater Wetland permits under Article 24 of the Environmental Conservation Law.

Figures:

1. USGS Topographic Map
2. NWI Wetlands
3. NYSDEC Tidal Wetlands
4. NRCS Soils

5. Photograph Key
6. Representative Site Photographs

Attachments:

Surveyed Wetland Drawings

USACE Wetland Determination Forms

2/10/2017

Source: USGS Topo base map service from The National Map

Proposed Breakwater Features

Proposed Shoreline Restoration Area

Approximate Location of Proposed Water Hub and Accessory Seasonal Boat Launch (exact location to be determined)

Proposed Shoreline Project Elements

Proposed Floating Dock and Oyster Nursery

0 1,000 FEET

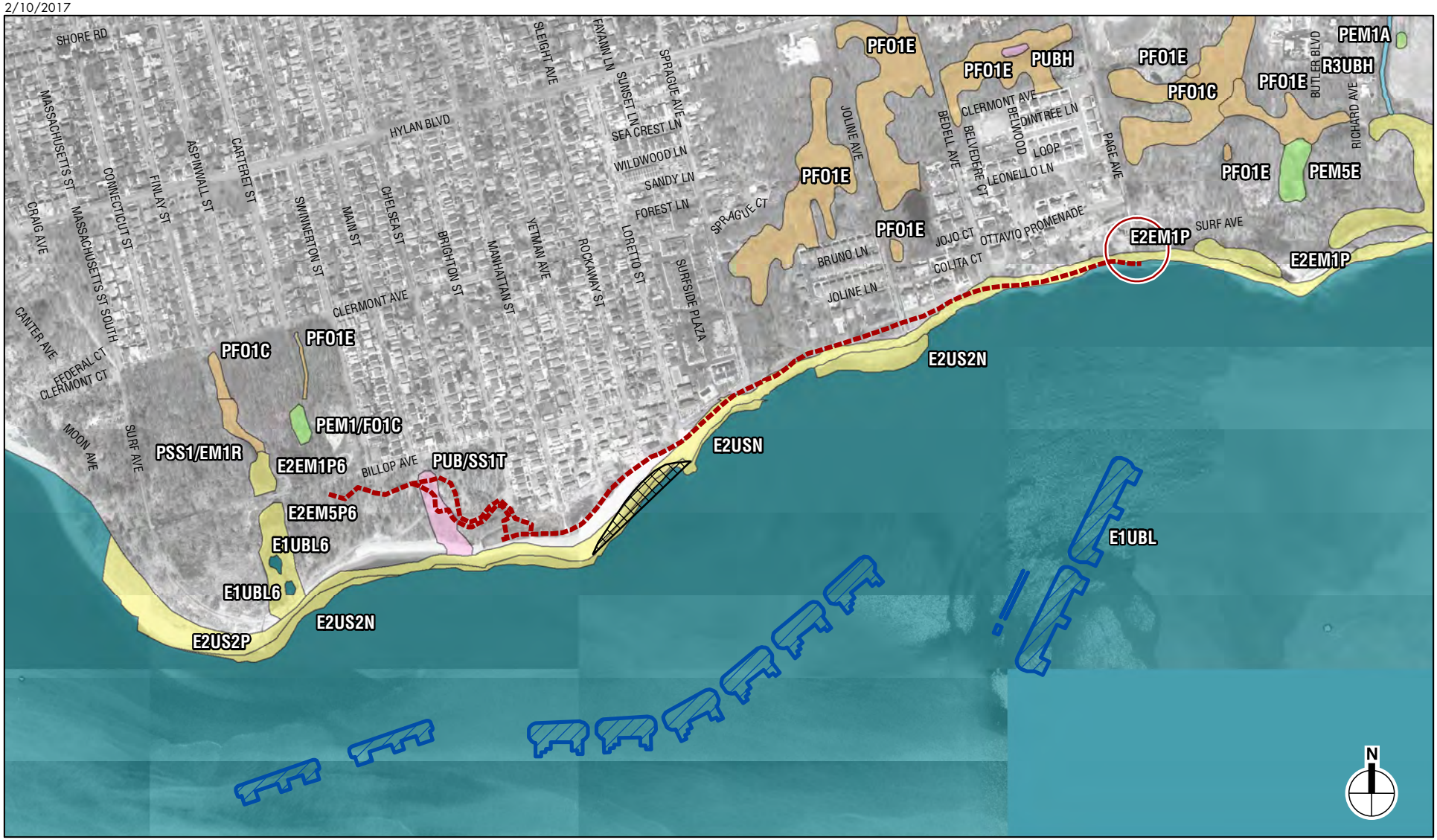
Approximate coordinates of Project Site:
74°14'13"W 40°29'59"N

USGS 7.5 Minute Topographic Map
Arthur Kill Quad

Coastal and Social Resiliency Initiatives for Tottenville Shoreline

Figure 1

2/10/2017



Proposed Breakwater Features

Proposed Shoreline Restoration Area

Proposed Floating Dock and Oyster Nursery

Proposed Shoreline Project Elements

Approximate Location of Proposed Water Hub and Accessory Seasonal Boat Launch (exact location to be determined)

Freshwater Forested/Shrub Wetland (PFO, PSS)

Freshwater Emergent Wetland (PEM)

Freshwater Pond (PUB, PAB)

Estuarine and Marine Wetland (E2, M2)

Riverine (R)

Estuarine and Marine Deepwater (E1, M1)

0 1,000 FEET

U.S. Fish and Wildlife Service
National Wetlands Inventory

Coastal and Social Resiliency Initiatives for Tottenville Shoreline

Figure 2

2/10/2017

Proposed Breakwater Features

Proposed Shoreline Restoration Area

Proposed Floating Dock and Oyster Nursery

Proposed Shoreline Project Elements

Approximate Location of Proposed Water Hub and Accessory Seasonal Boat Launch (exact location to be determined)

NYSDEC Tidal Wetlands (1974)

Littoral Zone (LZ)

State-regulated freshwater wetlands

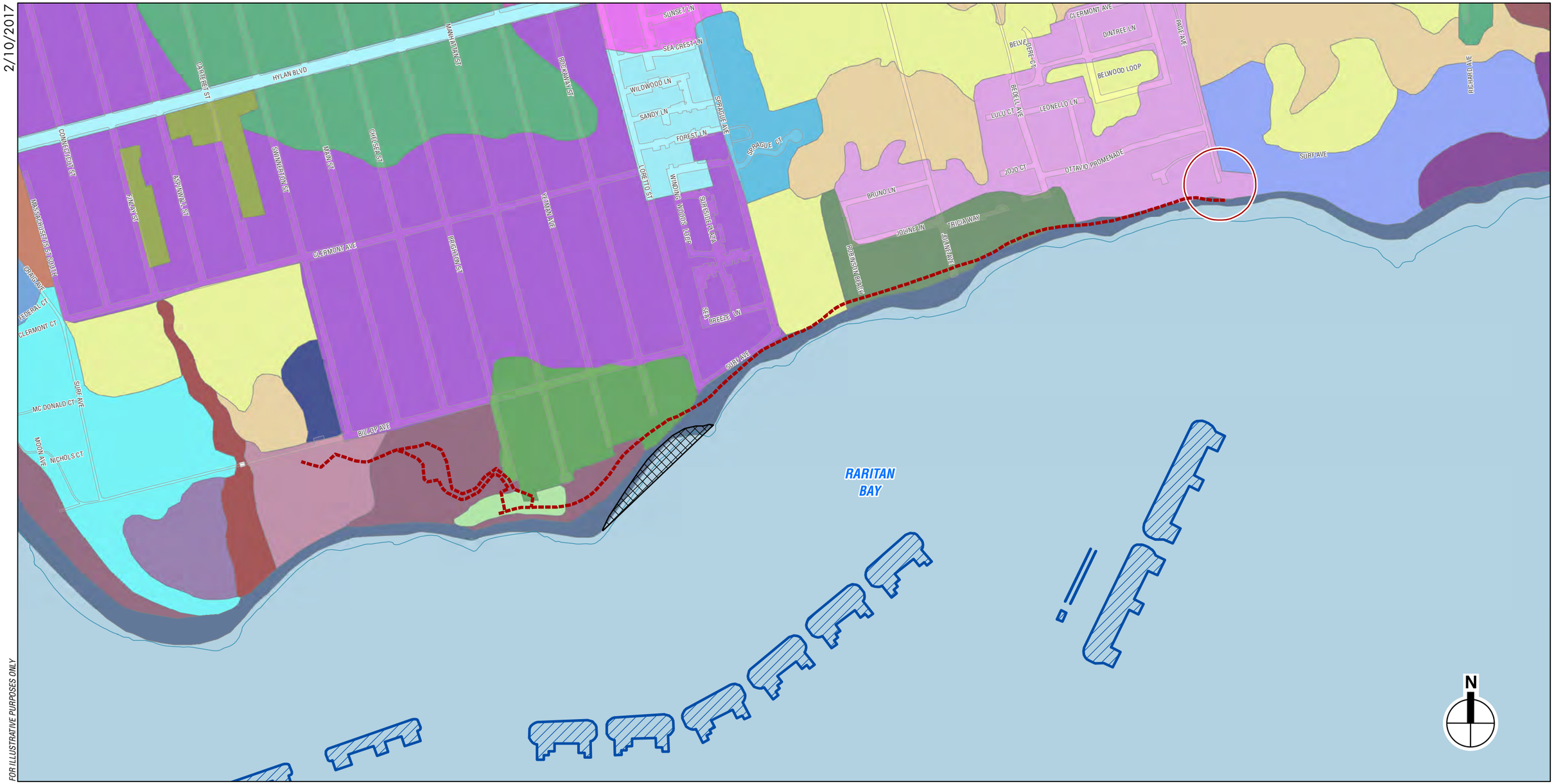
0 2,000 FEET

NYSDEC Freshwater Wetlands

Coastal and Social Resiliency Initiatives for Tottenville Shoreline

Figure 3

2/10/2017



FOR ILLUSTRATIVE PURPOSES ONLY

- Proposed Breakwater Features
- Proposed Shoreline Restoration Area
- Proposed Shoreline Project Elements
- Approximate Location of Proposed Water Hub and Accessory Seasonal Boat Launch (exact location to be determined)
- Proposed Floating Dock and Oyster Nursery

BHBu	ELUA	HHA	PvA	UVBl
Be	FrA	HaA	UGA	UsA
BtA	GUA	IwA	UGAl	UtA
BtB	GUB	NoA	UGB	WbA
CaA	GbA	PkA	ULA	WiC

0 — 1,000 FEET

Coastal and Social Resiliency Initiatives for Tottenville Shoreline

Soils Map
Figure 4

2/10/2017

FOR ILLUSTRATIVE PURPOSES ONLY

Proposed Breakwater Features

Proposed Shoreline Restoration Area

Proposed Shoreline Project Elements

Approximate Location of Proposed Water Hub and Accessory Seasonal Boat Launch (exact location to be determined)

Proposed Floating Dock and Oyster Nursery

Photograph View Direction and Reference Number

0 1,000 FEET

Natural Resources
Key to Photographs
Figure 5

Coastal and Social Resiliency Initiatives for Tottenville Shoreline

View of Wetland AB, facing southeast **1**

View of Wetland AB, facing west **2**

Natural Resources
Photographs
Figure 6a

View of Wetland F, facing east **3**

View of Wetland F, facing north **4**

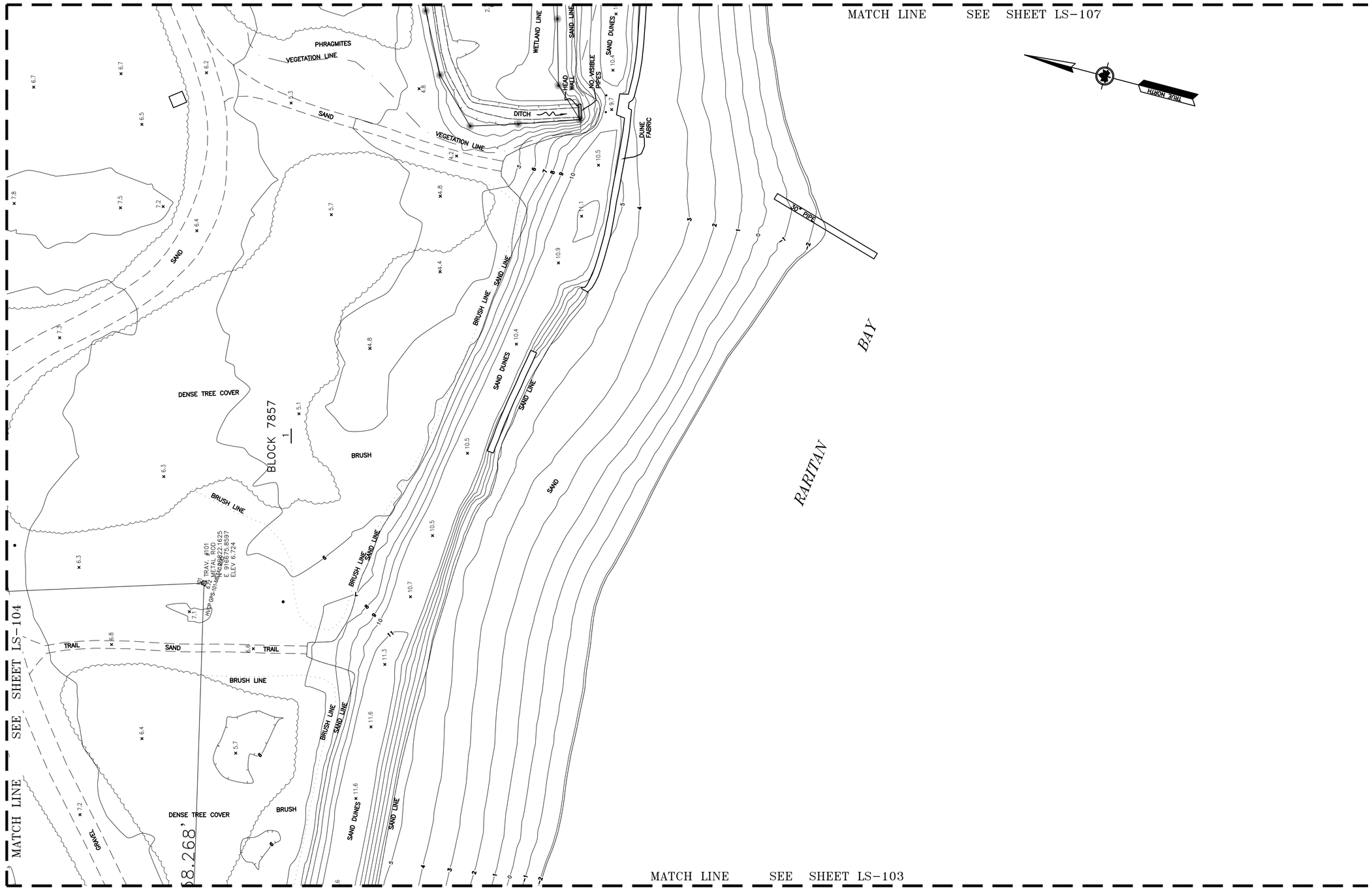
Natural Resources
Photographs
Figure 6b

View of Wetland G, facing north **5**

View of Wetland G, facing south **6**

Natural Resources
Photographs

MATCH LINE SEE SHEET LS-107

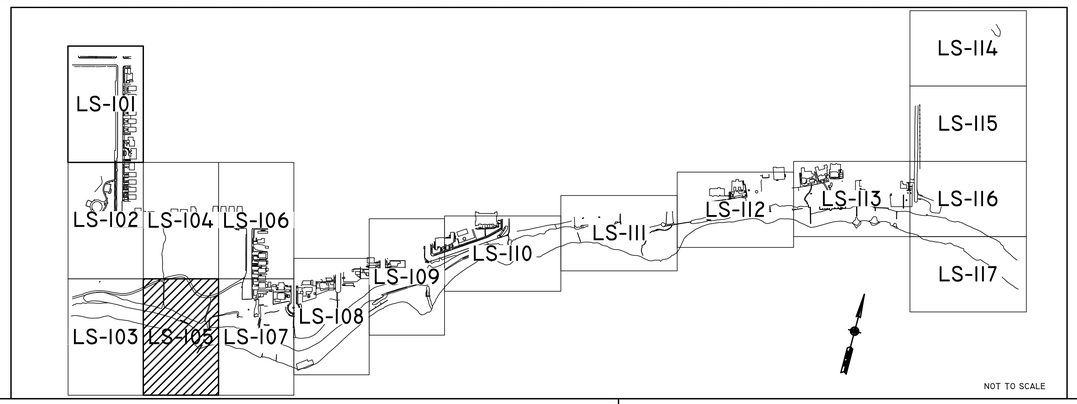


MATCH LINE SEE SHEET LS-104

MATCH LINE SEE SHEET LS-103

20' 0 10' 20' 40' 80'

GRAPHIC SCALE



30% DESIGN DEVELOPMENT
NOT FOR CONSTRUCTION

CITY OF NEW YORK
PARKS & RECREATION
OLMSTED CENTER
FLUSHING MEADOWS CORONA PARK
FLUSHING, NEW YORK 11368

PROJECT TITLE
TOTTENVILLE SHORELINE PROTECTION PROJECT

DRAWING TITLE
TOPOGRAPHIC SURVEY - SHEET 5 OF 17

DESIGNED BY X. XXXX	DRAWN BY P.POZNANSKI	CHECKED BY C.MEE
REVIEWED-TEAM LEADER X. XXXX	FORESTRY X. XXXX	APPROVED-DIRECTOR X. XXXX
APPROVED DEPUTY CHIEF OF DESIGN X. XXXX	APPROVED-CHIEF ENGINEER X. XXXX	CONTRACT NO. XXXXXXX
DATE: MONTH DD, YYYY	B-SCAN	SCALE 1" = 20'-0"
BLOCK NNNN		DRAWING NO. LS-105
LOT LLL		DATE 06/15/2016

Naik GROUP
253 WEST 30TH STREET NEW YORK, NY 10001
Ph: 212.575.2701

SHEET No. 13 OF 114 SHEETS

MATCH LINE SEE SHEET LS-106

MATCH LINE SEE SHEET LS-108

MATCH LINE SEE SHEET LS-105

MANHATTAN STREET

BLOCK 7881

BLOCK 7857

#460 3 STY. BRICK & FRAME 16

#464 3 STY. BRICK & FRAME 18

#463 2 STY. BRICK & FRAME 46

#469 3 ½ STY. FRAME 43

POOL

DECK

STEPS

PAVED DRIVE

CONC.

GRASS

1'BR.WALL

LANDSC.

3'H STONE WALL

PLANTERS

STONE C.

PRIVATE PROPERTY

ELEVATED WOODEN DECK

CONC. WALK (G)

ASPHALT PVMT. (G)

GRAVEL

DENSE TREE COVER

DENSE BRUSH COVER

PHRAGMITES

VEGETATION LINE

SAND LINE

SAND DUNES

DUNE FABRIC

DITCH

DITCH BOTTOM LINE

WETLAND AREA

WETLAND LINE

SWAMP

WOODEN DOCK RUINS

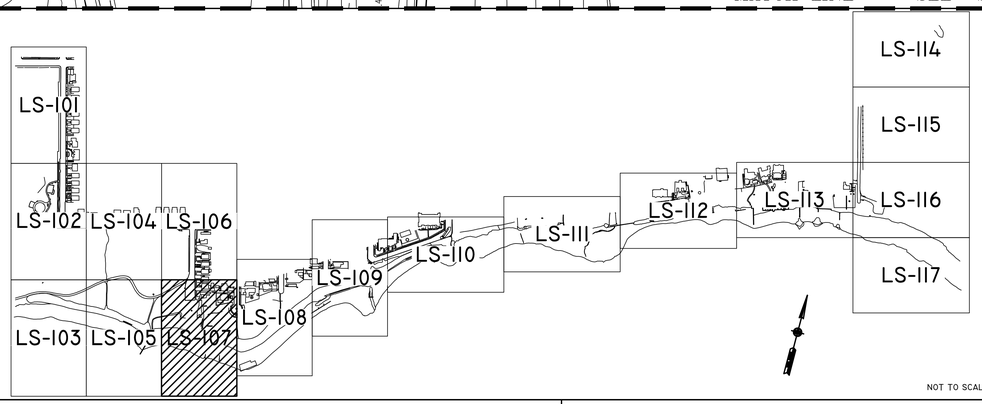
SAND

RARITAN BAY

TIDE NORTH

20' 0 10' 20' 40' 80'

GRAPHIC SCALE



NOT TO SCALE

30% DESIGN DEVELOPMENT
NOT FOR CONSTRUCTION

CITY OF NEW YORK
PARKS & RECREATION
OLMSTED CENTER
FLUSHING MEADOWS CORONA PARK
FLUSHING, NEW YORK 11368

PROJECT TITLE
TOTTENVILLE SHORELINE PROTECTION PROJECT

DRAWING TITLE
TOPOGRAPHIC SURVEY - SHEET 7 OF 17

DESIGNED BY X. XXXX	DRAWN BY P.POZNANSKI	CHECKED BY C.MEE
REVIEWED-TEAM LEADER X. XXXX	FORESTRY X. XXXX	APPROVED-DIRECTOR X. XXXX
APPROVED DEPUTY CHIEF OF DESIGN X. XXXX	APPROVED-CHIEF ENGINEER X. XXXX	CONTRACT NO. XXXXXXX
B-SCAN	SCALE 1" = 20'-0"	DRAWING NO. LS-107
	DATE 06/15/2016	SHEET No. 15 OF 114 SHEETS

DATE: MONTH DD, YYYY

BLOCK NNNN

LOT LLL

Naik GROUP
253 WEST 35TH STREET NEW YORK, NY 10001
Ph: 212.575.2701

WETLAND DETERMINATION DATA FORM – Northcentral and Northeast Region

Project/Site: Living Breakwaters City/County: Richmond County Sampling Date: 08/08/2016

Applicant/Owner: Governor's Office of Storm Recovery (GOSR) State: NY Sampling Point: Wetland AB

Investigator(s): Jesse Moore, Teresa Cannone, AKRF, Inc. Section, Township, Range: Tottenville

Landform (hillslope, terrace, etc.): Depression Local relief (concave, convex, none): Concave Slope (%): ____

Subregion (LRR or MLRA): MLRA 149B of LRR S Lat: 40.503870 Long: -74.224968 Datum: ____

Soil Map Unit Name: PkA – Preakness mucky silt loam 0 to 3 percent slopes NWI classification: PEM5E

Are climatic/hydrologic conditions on the site typical for this time of year? Yes X No ____ (If no, explain in Remarks.)

Are Vegetation N, Soil N, or Hydrology N significantly disturbed? Are "Normal Circumstances" present? Yes X No ____

Are Vegetation N, Soil N, or Hydrology N naturally problematic? (If needed, explain any answers in Remarks.)

SUMMARY OF FINDINGS – Attach site map showing sampling point locations, transects, important features, etc.

Hydrophytic Vegetation Present?	Yes X No ____	**Is the Sampled Area within a Wetland?**	**Yes** X **No** ____
Hydric Soil Present?	Yes X No ____	If yes, optional Wetland Site ID:	
Wetland Hydrology Present?	Yes X No ____		

Remarks: (Explain alternative procedures here or in a separate report.)

HYDROLOGY

Wetland Hydrology Indicators:

Primary Indicators (minimum of one is required; check all that apply)

- ____ Surface Water (A1)
- ____ High Water Table (A2)
- ____ Saturation (A3)
- ____ Water Marks (B1)
- ____ Sediment Deposits (B2)
- ____ Drift Deposits (B3)
- ____ Algal Mat or Crust (B4)
- ____ Iron Deposits (B5)
- X Inundation Visible on Aerial Imagery (B7)
- X Sparsely Vegetated Concave Surface (B8)
- X Water-Stained Leaves (B9)
- ____ Aquatic Fauna (B13)
- ____ Marl Deposits (B15)
- ____ Hydrogen Sulfide Odor (C1)
- ____ Oxidized Rhizospheres on Living Roots (C3)
- ____ Presence of Reduced Iron (C4)
- ____ Recent Iron Reduction in Tilled Soils (C6)
- ____ Thin Muck Surface (C7)
- ____ Other (Explain in Remarks)

Secondary Indicators (minimum of two required)

- ____ Surface Soil Cracks (B6)
- ____ Drainage Patterns (B10)
- X Moss Trim Lines (B16)
- ____ Dry-Season Water Table (C2)
- ____ Crayfish Burrows (C8)
- ____ Saturation Visible on Aerial Imagery (C9)
- ____ Stunted or Stressed Plants (D1)
- ____ Geomorphic Position (D2)
- ____ Shallow Aquitard (D3)
- ____ Microtopographic Relief (D4)
- ____ FAC-Neutral Test (D5)

Field Observations:

Surface Water Present?	Yes ____	No X	Depth (inches): ____
Water Table Present?	Yes ____	No X	Depth (inches): ____
Saturation Present?	Yes ____	No X	Depth (inches): ____

Wetland Hydrology Present? **Yes** X **No**

Describe Recorded Data (stream gauge, monitoring well, aerial photos, previous inspections), if available:

Remarks:

VEGETATION – Use scientific names of plants. Sampling Point: Wetland AB

Tree Stratum (Plot size: 30' radius)	Absolute % Cover	Dominant Species?	Indicator Status
1. *Quercus palustris*	20	Y	FACW
2. *Acer rubrum*	15	Y	FAC
3. *Liquidambar styraciflua*	7	N	FAC
4.			
5.			
6.			
7.			
	42	=Total Cover	
Sapling/Shrub Stratum (Plot size: 15' radius)			
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	0	=Total Cover	
Herb Stratum (Plot Size: 5' radius)			
1. *Phragmites australis*	85	Y	FACW
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9..			
10.			
11.			
12.			
	85	=Total Cover	
Woody Vine Stratum (Plot size: 30' radius)			
1. *Toxicodendron radicans*	5	Y	FAC
2.			
3.			
4.			
	5	=Total Cover	

Dominance Test worksheet:

Number of Dominant Species That Are OBL, FACW, or FAC: 4 (A)

Total Number of Dominant Species Across All Strata: 4 (B)

Percent of Dominant Species That Are OBL, FACW, or FAC: 100 (A/B)

Prevalence Index Worksheet:

Total % Cover of:		Multiply by	
OBL species		x1=	
FACW species		x2=	
FAC species		x3=	
FACU species		x4=	
UPL species		x5=	
Column Totals:	(A)		(B)

Prevalence Index = B/A =

Hydrophytic Vegetation Indicators:

- ___ 1 – Rapid Test for Hydrophytic Vegetation
- X 2 – Dominance Test is >50%
- ___ 3 – Prevalence Index is #3.0[1]
- ___ 4 – Morphological Adaptations[1] (Provide supporting data in Remarks or on a separate sheet)
- ___ Problematic Hydrophytic Vegetation[1] (Explain)

[1] Indicators of hydric soil and wetland hydrology must be present, unless disturbed or problematic.

Definitions of Vegetation Strata:

Tree – Woody plants 3 in. (7.6 cm) or more in diameter at breast height (DBH), regardless of height.

Sapling/shrub – Woody plants less than 3 in. DBH and creater than or equal to 3.28 ft (1 m) tall.

Herb – All herbaceous (non-woody) plants, regardless of size, and woody plants less than 3.28 ft tall.

Woody vines – All woody vines greater than 3.28 ft in height.

Hydrophytic Vegetation Present? **Yes** X **No** ___

Remarks: (Include photo numbers here or on a separate sheet.)

SOIL Sampling Point: Wetland AB

Profile Description: (Describe to the depth needed to document the indicator or confirm the absence of indicators.)

Depth (inches)	Matrix Color (moist)	Matrix %	Redox Features Color (moist)	Redox Features %	Redox Features Type[1]	Redox Features Loc[2]	Texture	Remarks
0-2	7.5YR 3/2	100					Organic matter	
2-11	10YR 3/2	75	5YR 3/4	5	C	M	Silty clay	
	10YR 8/6	10						
	10YR 2/1	10						
11-24	10YR 3/2	85	7.5YR 5/8	15	C	M	Silty clay	

[1]Type: C=Concentration, D=Depletion, RM=Reduced Matrix, MS=Masked Sand Grains. [2]Location: PL=Pore Lining, M=Matrix

Hydric Soil Indicators:

- ____ Histosol (A1)
- ____ Histic Epipedon (A2)
- ____ Black Histic (A3)
- ____ Hydrogen Sulfide (A4)
- ____ Stratified Layers (A5)
- ____ Depleted Below Dark Surface (A11)
- ____ Thick Dark Surface (A12)
- ____ Sandy Mucky Mineral (S1)
- ____ Sandy Gleyed Matrix (S4)
- ____ Sandy Redox (S5)
- ____ Stripped Matrix (S6)
- ____ Dark Surface (s7) (**LRR, MLRA, 149B**)
- ____ Polyvalue Below Surface (S8) (**LRR R, MLRA 149B**)
- ____ Thin Dark Surface (S9) (**LRR R, MLRA 149B**)
- ____ Loamy Mucky Mineral (F1) (**LRR K, L**)
- ____ Loamy Gleyed Matrix (F2)
- ____ Depleted Matrix (F3)
- X Redox Dark Surface (F6)
- ____ Depleted Dark Surface (F7)
- ____ Redox Depressions (F8)

Indicators for Problematic Hydric Soils[3]:

- ____ 2 cm Muck (A10) (**LRR K, L, MLRA 149B**)
- ____ Coast Prairie Redox (A16) (**LRR K, L, R**)
- ____ 5 cm Mucky Peat or Peat (S3) (**LRR K, L, R**)
- ____ Dark Surface (S7) (**LRR, K, L**)
- ____ Polyvalue Below Surface (S8) (**LRR K, L**)
- ____ Thin Dark Surface (S9) (**LRR K, L**)
- ____ Iron-Manganese Masses (F12) (**LRR K, L, R**)
- ____ Piedmont Floodplain Soils (F19) (**MLRA 149B**)
- ____ Mesic Spodic (TA6) (**MLRA 144A, 145, 149B**)
- Red Parent Material (F21)
- ____ Very Shallow Dark Surface (TF12)
- ____ Other (explain in Remarks)

[3]Indicators of hydrophytic vegetation and wetland hydrology must be present, unless disturbed or problematic.

Field Observations:
Type: _____
Depth (inches): _____

Hydric Soil Present? **Yes** X **No**

Remarks:

WETLAND DETERMINATION DATA FORM – Northcentral and Northeast Region

Project/Site: Living Breakwaters City/County: Richmond County Sampling Date: 08/10/2016

Applicant/Owner: GOSR State: NY Sampling Point: Wetland F

Investigator(s): Jesse Moore, Teresa Cannone, AKRF, Inc. Section, Township, Range: Tottenville

Landform (hillslope, terrace, etc.): Depression Local relief (concave, convex, none): Concave Slope (%): ____

Subregion (LRR or MLRA): MLRA 149B of LRR S Lat: 40.498005 Long: -74.240877 Datum: ____

Soil Map Unit Name: ULA NWI classification: None

Are climatic/hydrologic conditions on the site typical for this time of year? Yes X No ____ (If no, explain in Remarks.)

Are Vegetation N, Soil N, or Hydrology N significantly disturbed? Are "Normal Circumstances" present? Yes X No ____

Are Vegetation N, Soil N, or Hydrology N naturally problematic? (If needed, explain any answers in Remarks.)

SUMMARY OF FINDINGS – Attach site map showing sampling point locations, transects, important features, etc.

Hydrophytic Vegetation Present?	Yes X No ____	**Is the Sampled Area within a Wetland?**	**Yes** X **No** ____
Hydric Soil Present?	Yes X No ____	If yes, optional Wetland Site ID:	
Wetland Hydrology Present?	Yes X No ____		

Remarks: (Explain alternative procedures here or in a separate report.)

A berm separates wetland F into two sections which are connected by a culvert.

HYDROLOGY

Wetland Hydrology Indicators:

Primary Indicators (minimum of one is required; check all that apply)

- ____ Surface Water (A1)
- X High Water Table (A2)
- X Saturation (A3)
- X Water Marks (B1)
- ____ Sediment Deposits (B2)
- ____ Drift Deposits (B3)
- ____ Algal Mat or Crust (B4)
- ____ Iron Deposits (B5)
- ____ Inundation Visible on Aerial Imagery (B7)
- ____ Sparsely Vegetated Concave Surface (B8)
- ____ Water-Stained Leaves (B9)
- ____ Aquatic Fauna (B13)
- ____ Marl Deposits (B15)
- ____ Hydrogen Sulfide Odor (C1)
- ____ Oxidized Rhizospheres on Living Roots (C3)
- X Presence of Reduced Iron (C4)
- ____ Recent Iron Reduction in Tilled Soils (C6)
- ____ Thin Muck Surface (C7)
- ____ Other (Explain in Remarks)

Secondary Indicators (minimum of two required)

- ____ Surface Soil Cracks (B6)
- X Drainage Patterns (B10)
- ____ Moss Trim Lines (B16)
- ____ Dry-Season Water Table (C2)
- ____ Crayfish Burrows (C8)
- ____ Saturation Visible on Aerial Imagery (C9)
- ____ Stunted or Stressed Plants (D1)
- X Geomorphic Position (D2)
- ____ Shallow Aquitard (D3)
- ____ Microtopographic Relief (D4)
- ____ FAC-Neutral Test (D5)

Field Observations:

Surface Water Present?	Yes ____	No X	Depth (inches): ____
Water Table Present?	Yes X	No ____	Depth (inches): 7"
Saturation Present?	Yes X	No ____	Depth (inches): Surface

Wetland Hydrology Present? **Yes** X **No**

Describe Recorded Data (stream gauge, monitoring well, aerial photos, previous inspections), if available:

Remarks:

VEGETATION – Use scientific names of plants.

Sampling Point: Wetland F

Tree Stratum (Plot size: 30' radius)	Absolute % Cover	Dominant Species?	Indicator Status
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	0	=Total Cover	

Sapling/Shrub Stratum (Plot size: 15' radius)			
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	0	=Total Cover	

Herb Stratum (Plot Size: 5' radius)			
1. *Phragmites australis*	85	Y	FACW
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9..			
10.			
11.			
12.			
	85	=Total Cover	

Woody Vine Stratum (Plot size: 30' radius)			
1.			
2.			
3.			
4.			
	0	=Total Cover	

Dominance Test worksheet:

Number of Dominant Species That Are OBL, FACW, or FAC: 1 (A)

Total Number of Dominant Species Across All Strata: 1 (B)

Percent of Dominant Species That Are OBL, FACW, or FAC: 100 (A/B)

Prevalence Index Worksheet:

Total % Cover of:		Multiply by	
OBL species		x1=	
FACW species		x2=	
FAC species		x3=	
FACU species		x4=	
UPL species		x5=	
Column Totals:	(A)		(B)

Prevalence Index = B/A =

Hydrophytic Vegetation Indicators:

- ___ 1 – Rapid Test for Hydrophytic Vegetation
- X 2 – Dominance Test is >50%
- ___ 3 – Prevalence Index is #3.0[1]
- ___ 4 – Morphological Adaptations[1] (Provide supporting data in Remarks or on a separate sheet)
- ___ Problematic Hydrophytic Vegetation[1] (Explain)

[1] Indicators of hydric soil and wetland hydrology must be present, unless disturbed or problematic.

Definitions of Vegetation Strata:

Tree – Woody plants 3 in. (7.6 cm) or more in diameter at breast height (DBH), regardless of height.

Sapling/shrub – Woody plants less than 3 in. DBH and creater than or equal to 3.28 ft (1 m) tall.

Herb – All herbaceous (non-woody) plants, regardless of size, and woody plants less than 3.28 ft tall.

Woody vines – All woody vines greater than 3.28 ft in height.

Hydrophytic Vegetation Present? **Yes** X **No** ___

Remarks: (Include photo numbers here or on a separate sheet.)

SOIL Sampling Point: Wetland F

Profile Description: (Describe to the depth needed to document the indicator or confirm the absence of indicators.)

Depth (inches)	Matrix Color (moist)	Matrix %	Redox Features Color (moist)	Redox %	Type[1]	Loc[2]	Texture	Remarks
0-7	5Y 2.5/1	10	10YR 5/6	5	C	M	Mucky sandy silt	
	2.5Y 3/2	85						
7-19	10YR 3/2	100					Silty clay	

[1]Type: C=Concentration, D=Depletion, RM=Reduced Matrix, MS=Masked Sand Grains. [2]Location: PL=Pore Lining, M=Matrix

Hydric Soil Indicators:

- ____ Histosol (A1)
- ____ Histic Epipedon (A2)
- ____ Black Histic (A3)
- ____ Hydrogen Sulfide (A4)
- ____ Stratified Layers (A5)
- ____ Depleted Below Dark Surface (A11)
- ____ Thick Dark Surface (A12)
- X Sandy Mucky Mineral (S1)
- ____ Sandy Gleyed Matrix (S4)
- ____ Sandy Redox (S5)
- ____ Stripped Matrix (S6)
- ____ Dark Surface (s7) (**LRR, MLRA, 149B**)
- ____ Polyvalue Below Surface (S8) (**LRR R, MLRA 149B**)
- ____ Thin Dark Surface (S9) (**LRR R, MLRA 149B**)
- ____ Loamy Mucky Mineral (F1) (**LRR K, L**)
- ____ Loamy Gleyed Matrix (F2)
- ____ Depleted Matrix (F3)
- ____ Redox Dark Surface (F6)
- ____ Depleted Dark Surface (F7)
- ____ Redox Depressions (F8)

Indicators for Problematic Hydric Soils[3]:

- ____ 2 cm Muck (A10) (**LRR K, L, MLRA 149B**)
- ____ Coast Prairie Redox (A16) (**LRR K, L, R**)
- ____ 5 cm Mucky Peat or Peat (S3) (**LRR K, L, R**)
- ____ Dark Surface (S7) (**LRR, K, L**)
- ____ Polyvalue Below Surface (S8) (**LRR K, L**)
- ____ Thin Dark Surface (S9) (**LRR K, L**)
- ____ Iron-Manganese Masses (F12) (**LRR K, L, R**)
- ____ Piedmont Floodplain Soils (F19) (**MLRA 149B**)
- ____ Mesic Spodic (TA6) (**MLRA 144A, 145, 149B**)
- Red Parent Material (F21)
- ____ Very Shallow Dark Surface (TF12)
- ____ Other (explain in Remarks)

[3]Indicators of hydrophytic vegetation and wetland hydrology must be present, unless disturbed or problematic.

Field Observations:
Type: _____
Depth (inches): _____

Hydric Soil Present? **Yes** X **No**

Remarks:

WETLAND DETERMINATION DATA FORM – Northcentral and Northeast Region

Project/Site: Living Breakwaters City/County: Richmond County Sampling Date: 08/10/2016

Applicant/Owner: GOSR State: NY Sampling Point: Wetland G

Investigator(s): Jesse Moore, Teresa Cannone, AKRF, Inc. Section, Township, Range: Tottenville

Landform (hillslope, terrace, etc.): None Local relief (concave, convex, none): None Slope (%): ____

Subregion (LRR or MLRA): MLRA 149B of LRR S Lat: 40.498934 Long: -74.246452 Datum: ____

Soil Map Unit Name: CaA, HaA NWI classification: None

Are climatic/hydrologic conditions on the site typical for this time of year? Yes X No ____ (If no, explain in Remarks.)

Are Vegetation N, Soil N, or Hydrology N significantly disturbed? Are "Normal Circumstances" present? Yes X No ____

Are Vegetation N, Soil N, or Hydrology N naturally problematic? (If needed, explain any answers in Remarks.)

SUMMARY OF FINDINGS – Attach site map showing sampling point locations, transects, important features, etc.

Hydrophytic Vegetation Present?	Yes X No ____	**Is the Sampled Area within a Wetland?**	**Yes** X **No** ____
Hydric Soil Present?	Yes X No ____	If yes, optional Wetland Site ID:	
Wetland Hydrology Present?	Yes X No ____		

Remarks: (Explain alternative procedures here or in a separate report.)

Sampling point near wetland flag G19.

HYDROLOGY

Wetland Hydrology Indicators:

Primary Indicators (minimum of one is required; check all that apply)

- X Surface Water (A1)
- X High Water Table (A2)
- X Saturation (A3)
- ____ Water Marks (B1)
- ____ Sediment Deposits (B2)
- ____ Drift Deposits (B3)
- ____ Algal Mat or Crust (B4)
- ____ Iron Deposits (B5)
- X Inundation Visible on Aerial Imagery (B7)
- ____ Sparsely Vegetated Concave Surface (B8)
- X Water-Stained Leaves (B9)
- X Aquatic Fauna (B13)
- ____ Marl Deposits (B15)
- ____ Hydrogen Sulfide Odor (C1)
- ____ Oxidized Rhizospheres on Living Roots (C3)
- ____ Presence of Reduced Iron (C4)
- ____ Recent Iron Reduction in Tilled Soils (C6)
- ____ Thin Muck Surface (C7)
- ____ Other (Explain in Remarks)

Secondary Indicators (minimum of two required)

- ____ Surface Soil Cracks (B6)
- ____ Drainage Patterns (B10)
- ____ Moss Trim Lines (B16)
- ____ Dry-Season Water Table (C2)
- ____ Crayfish Burrows (C8)
- ____ Saturation Visible on Aerial Imagery (C9)
- ____ Stunted or Stressed Plants (D1)
- ____ Geomorphic Position (D2)
- ____ Shallow Aquitard (D3)
- ____ Microtopographic Relief (D4)
- ____ FAC-Neutral Test (D5)

Field Observations:

Surface Water Present?	Yes X	No ____	Depth (inches):	6+"
Water Table Present?	Yes X	No ____	Depth (inches):	9"
Saturation Present?	Yes X	No ____	Depth (inches):	Surface

Wetland Hydrology Present? **Yes** X **No**

Describe Recorded Data (stream gauge, monitoring well, aerial photos, previous inspections), if available:

Remarks:

Aquatic fauna is small fish species

VEGETATION – Use scientific names of plants.

Sampling Point: Wetland G

Tree Stratum (Plot size: 30' Radius)	Absolute % Cover	Dominant Species?	Indicator Status
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	0	=Total Cover	
Sapling/Shrub Stratum (Plot size: 15' Radius)			
1. *Cephalanthus occidentalis*	10	Y	OBL
2.			
3.			
4.			
5.			
6.			
7.			
	10	=Total Cover	
Herb Stratum (Plot Size: 5' Radius)			
1. *Peltandra virginica*	15	Y	OBL
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9..			
10.			
11.			
12.			
	15	=Total Cover	
Woody Vine Stratum (Plot size: 30' Radius)			
1.			
2.			
3.			
4.			
	0	=Total Cover	

Dominance Test worksheet:

Number of Dominant Species That Are OBL, FACW, or FAC: 2 (A)

Total Number of Dominant Species Across All Strata: 2 (B)

Percent of Dominant Species That Are OBL, FACW, or FAC: 100 (A/B)

Prevalence Index Worksheet:

Total % Cover of:		Multiply by
OBL species		x1=
FACW species		x2=
FAC species		x3=
FACU species		x4=
UPL species		x5=
Column Totals:	(A)	(B)

Prevalence Index = B/A =

Hydrophytic Vegetation Indicators:

- ___ 1 – Rapid Test for Hydrophytic Vegetation
- X 2 – Dominance Test is >50%
- ___ 3 – Prevalence Index is #3.0[1]
- ___ 4 – Morphological Adaptations[1] (Provide supporting data in Remarks or on a separate sheet)
- ___ Problematic Hydrophytic Vegetation[1] (Explain)

[1] Indicators of hydric soil and wetland hydrology must be present, unless disturbed or problematic.

Definitions of Vegetation Strata:

Tree – Woody plants 3 in. (7.6 cm) or more in diameter at breast height (DBH), regardless of height.

Sapling/shrub – Woody plants less than 3 in. DBH and creater than or equal to 3.28 ft (1 m) tall.

Herb – All herbaceous (non-woody) plants, regardless of size, and woody plants less than 3.28 ft tall.

Woody vines – All woody vines greater than 3.28 ft in height.

Hydrophytic Vegetation Present? **Yes** X **No** ___

Remarks: (Include photo numbers here or on a separate sheet.)

SOIL Sampling Point: Wetland G

Profile Description: (Describe to the depth needed to document the indicator or confirm the absence of indicators.)

Depth (inches)	Matrix Color (moist)	Matrix %	Redox Features Color (moist)	Redox %	Type[1]	Loc[2]	Texture	Remarks
0-7	10 YR 2/1	100					Mucky silt	Organic matter
7-12	7.5 YR 4/2	100					Sandy clay	Gravel
12-20	7.5 YR 4/2	100					Silty clay	

[1]Type: C=Concentration, D=Depletion, RM=Reduced Matrix, MS=Masked Sand Grains. [2]Location: PL=Pore Lining, M=Matrix

Hydric Soil Indicators:

- ___ Histosol (A1)
- ___ Histic Epipedon (A2)
- ___ Black Histic (A3)
- ___ Hydrogen Sulfide (A4)
- ___ Stratified Layers (A5)
- ___ Depleted Below Dark Surface (A11)
- ___ Thick Dark Surface (A12)
- X Sandy Mucky Mineral (S1)
- ___ Sandy Gleyed Matrix (S4)
- ___ Sandy Redox (S5)
- ___ Stripped Matrix (S6)
- ___ Dark Surface (s7) (**LRR, MLRA, 149B**)
- ___ Polyvalue Below Surface (S8) (**LRR R, MLRA 149B**)
- ___ Thin Dark Surface (S9) (**LRR R, MLRA 149B**)
- ___ Loamy Mucky Mineral (F1) (**LRR K, L**)
- ___ Loamy Gleyed Matrix (F2)
- ___ Depleted Matrix (F3)
- ___ Redox Dark Surface (F6)
- ___ Depleted Dark Surface (F7)
- ___ Redox Depressions (F8)

Indicators for Problematic Hydric Soils[3]:

- ___ 2 cm Muck (A10) (**LRR K, L, MLRA 149B**)
- ___ Coast Prairie Redox (A16) (**LRR K, L, R**)
- ___ 5 cm Mucky Peat or Peat (S3) (**LRR K, L, R**)
- ___ Dark Surface (S7) (**LRR, K, L**)
- ___ Polyvalue Below Surface (S8) (**LRR K, L**)
- ___ Thin Dark Surface (S9) (**LRR K, L**)
- ___ Iron-Manganese Masses (F12) (**LRR K, L, R**)
- ___ Piedmont Floodplain Soils (F19) (**MLRA 149B**)
- ___ Mesic Spodic (TA6) (**MLRA 144A, 145, 149B**)
- Red Parent Material (F21)
- ___ Very Shallow Dark Surface (TF12)
- ___ Other (explain in Remarks)

[3]Indicators of hydrophytic vegetation and wetland hydrology must be present, unless disturbed or problematic.

Field Observations:
Type: _____
Depth (inches): _____

Hydric Soil Present? **Yes** X **No**

Remarks:

WETLAND DETERMINATION DATA FORM – Northcentral and Northeast Region

Project/Site: Living Breakwaters City/County: Richmond County Sampling Date: 08/08/2016

Applicant/Owner: GOSR State: NY Sampling Point: Upland AB

Investigator(s): Jesse Moore, Teresa Cannone, AKRF, Inc. Section, Township, Range: Tottenville

Landform (hillslope, terrace, etc.): Terrace Local relief (concave, convex, none): None Slope (%): 0

Subregion (LRR or MLRA): MLRA 149B of LRR S Lat: 40.502875 Long: -74.225109 Datum: ____

Soil Map Unit Name: PkA NWI classification: None

Are climatic/hydrologic conditions on the site typical for this time of year? Yes X No ____ (If no, explain in Remarks.)

Are Vegetation N, Soil N, or Hydrology N significantly disturbed? Are "Normal Circumstances" present? Yes X No ____

Are Vegetation N, Soil N, or Hydrology N naturally problematic? (If needed, explain any answers in Remarks.)

SUMMARY OF FINDINGS – Attach site map showing sampling point locations, transects, important features, etc.

Hydrophytic Vegetation Present?	Yes X	No ____	**Is the Sampled Area within a Wetland?** **Yes** ____ **No** X
Hydric Soil Present?	Yes ____	No X	If yes, optional Wetland Site ID:
Wetland Hydrology Present?	Yes ____	No X	

Remarks: (Explain alternative procedures here or in a separate report.)

Sampling point is located on the trail traversing Wetland AB

HYDROLOGY

Wetland Hydrology Indicators:

Primary Indicators (minimum of one is required; check all that apply)

- ____ Surface Water (A1)
- ____ High Water Table (A2)
- ____ Saturation (A3)
- ____ Water Marks (B1)
- ____ Sediment Deposits (B2)
- ____ Drift Deposits (B3)
- ____ Algal Mat or Crust (B4)
- ____ Iron Deposits (B5)
- ____ Inundation Visible on Aerial Imagery (B7)
- ____ Sparsely Vegetated Concave Surface (B8)
- ____ Water-Stained Leaves (B9)
- ____ Aquatic Fauna (B13)
- ____ Marl Deposits (B15)
- ____ Hydrogen Sulfide Odor (C1)
- ____ Oxidized Rhizospheres on Living Roots (C3)
- ____ Presence of Reduced Iron (C4)
- ____ Recent Iron Reduction in Tilled Soils (C6)
- ____ Thin Muck Surface (C7)
- ____ Other (Explain in Remarks)

Secondary Indicators (minimum of two required)

- ____ Surface Soil Cracks (B6)
- ____ Drainage Patterns (B10)
- ____ Moss Trim Lines (B16)
- ____ Dry-Season Water Table (C2)
- ____ Crayfish Burrows (C8)
- ____ Saturation Visible on Aerial Imagery (C9)
- ____ Stunted or Stressed Plants (D1)
- ____ Geomorphic Position (D2)
- ____ Shallow Aquitard (D3)
- ____ Microtopographic Relief (D4)
- ____ FAC-Neutral Test (D5)

Field Observations:

Surface Water Present?	Yes ____	No X	Depth (inches): ____
Water Table Present?	Yes ____	No X	Depth (inches): ____
Saturation Present?	Yes ____	No X	Depth (inches): ____

Wetland Hydrology Present? **Yes** ____ **No** X

Describe Recorded Data (stream gauge, monitoring well, aerial photos, previous inspections), if available:

Remarks:

VEGETATION – Use scientific names of plants.

Sampling Point: Upland AB

Tree Stratum (Plot size: 30' radius)	Absolute % Cover	Dominant Species?	Indicator Status
1. *Liquidambar styraciflua*	70	Y	FAC
2. *Quercus palustris*	40	Y	FACW
3.			
4.			
5.			
6.			
7.			
	110	=Total Cover	
Sapling/Shrub Stratum (Plot size: 15' radius)			
1. *Celtis occidentalis*	30	Y	FAC
2. *Liquidambar styraciflua*	7	N	FAC
3. *Rosa multiflora*	3	N	FACU
4.			
5.			
6.			
7.			
	0	=Total Cover	
Herb Stratum (Plot Size: 5' radius)			
1. *Artemisia vulgaris*	95	Y	UPL
2. *Lonicera japonica*	15	N	FACU
3. *Parthenocissus quinquefolia*	5	N	FACU
4. *Smilax rotundifolia*	3	N	FAC
5.			
6.			
7.			
8.			
9..			
10.			
11.			
12.			
	118	=Total Cover	
Woody Vine Stratum (Plot size: 30' radius)			
1. *Toxicodendron radicans*	30	Y	FAC
2.			
3.			
4.			
	30	=Total Cover	

Dominance Test worksheet:

Number of Dominant Species That Are OBL, FACW, or FAC: 4 (A)

Total Number of Dominant Species Across All Strata: 5 (B)

Percent of Dominant Species That Are OBL, FACW, or FAC: 80 (A/B)

Prevalence Index Worksheet:

Total % Cover of:		Multiply by
OBL species		x1=
FACW species		x2=
FAC species		x3=
FACU species		x4=
UPL species		x5=
Column Totals:	(A)	(B)

Prevalence Index = B/A =

Hydrophytic Vegetation Indicators:

- ___ 1 – Rapid Test for Hydrophytic Vegetation
- X 2 – Dominance Test is >50%
- ___ 3 – Prevalence Index is #3.0[1]
- ___ 4 – Morphological Adaptations[1] (Provide supporting data in Remarks or on a separate sheet)
- ___ Problematic Hydrophytic Vegetation[1] (Explain)

[1] Indicators of hydric soil and wetland hydrology must be present, unless disturbed or problematic.

Definitions of Vegetation Strata:

Tree – Woody plants 3 in. (7.6 cm) or more in diameter at breast height (DBH), regardless of height.

Sapling/shrub – Woody plants less than 3 in. DBH and creater than or equal to 3.28 ft (1 m) tall.

Herb – All herbaceous (non-woody) plants, regardless of size, and woody plants less than 3.28 ft tall.

Woody vines – All woody vines greater than 3.28 ft in height.

Hydrophytic Vegetation Present? **Yes** X **No** ___

Remarks: (Include photo numbers here or on a separate sheet.)

SOIL Sampling Point: Upland AB

Profile Description: (Describe to the depth needed to document the indicator or confirm the absence of indicators.)

Depth (inches)	Matrix Color (moist)	Matrix %	Redox Features Color (moist)	Redox Features %	Redox Features Type[1]	Redox Features Loc[2]	Texture	Remarks
0-20	10 YR 4/4	100					Loam	

[1]Type: C=Concentration, D=Depletion, RM=Reduced Matrix, MS=Masked Sand Grains. [2]Location: PL=Pore Lining, M=Matrix

Hydric Soil Indicators:

____ Histosol (A1)
____ Histic Epipedon (A2)
____ Black Histic (A3)
____ Hydrogen Sulfide (A4)
____ Stratified Layers (A5)
____ Depleted Below Dark Surface (A11)
____ Thick Dark Surface (A12)
____ Sandy Mucky Mineral (S1)
____ Sandy Gleyed Matrix (S4)
____ Sandy Redox (S5)
____ Stripped Matrix (S6)
____ Dark Surface (s7) (**LRR, MLRA, 149B**)

____ Polyvalue Below Surface (S8) (**LRR R, MLRA 149B**)
____ Thin Dark Surface (S9) (**LRR R, MLRA 149B**)
____ Loamy Mucky Mineral (F1) (**LRR K, L**)
____ Loamy Gleyed Matrix (F2)
____ Depleted Matrix (F3)
____ Redox Dark Surface (F6)
____ Depleted Dark Surface (F7)
____ Redox Depressions (F8)

Indicators for Problematic Hydric Soils[3]:

____ 2 cm Muck (A10) (**LRR K, L, MLRA 149B**)
____ Coast Prairie Redox (A16) (**LRR K, L, R**)
____ 5 cm Mucky Peat or Peat (S3) (**LRR K, L, R**)
____ Dark Surface (S7) (**LRR, K, L**)
____ Polyvalue Below Surface (S8) (**LRR K, L**)
____ Thin Dark Surface (S9) (**LRR K, L**)
____ Iron-Manganese Masses (F12) (**LRR K, L, R**)
____ Piedmont Floodplain Soils (F19) (**MLRA 149B**)
____ Mesic Spodic (TA6) (**MLRA 144A, 145, 149B**)
Red Parent Material (F21)
____ Very Shallow Dark Surface (TF12)
____ Other (explain in Remarks)

[3]Indicators of hydrophytic vegetation and wetland hydrology must be present, unless disturbed or problematic.

Field Observations:
Type: _____
Depth (inches): _____

Hydric Soil Present? **Yes** **No** X

Remarks:

WETLAND DETERMINATION DATA FORM – Northcentral and Northeast Region

Project/Site: Living Breakwaters City/County: Richmond County Sampling Date: 08/10/2016

Applicant/Owner: GOSR State: NY Sampling Point: Upland F

Investigator(s): Jesse Moore, Teresa Cannone, AKRF, Inc. Section, Township, Range: Tottenville

Landform (hillslope, terrace, etc.): Dune Local relief (concave, convex, none): None Slope (%): 0

Subregion (LRR or MLRA): MLRA 149B of LRR S Lat: 40.497798 Long: -74.241416 Datum: ____

Soil Map Unit Name: FrA NWI classification: None

Are climatic/hydrologic conditions on the site typical for this time of year? Yes X No ____ (If no, explain in Remarks.)

Are Vegetation N, Soil N, or Hydrology N significantly disturbed? Are "Normal Circumstances" present? Yes X No ____

Are Vegetation N, Soil N, or Hydrology N naturally problematic? (If needed, explain any answers in Remarks.)

SUMMARY OF FINDINGS – Attach site map showing sampling point locations, transects, important features, etc.

Hydrophytic Vegetation Present?	Yes ____	No X	**Is the Sampled Area within a Wetland?**	**Yes** ____ **No** X
Hydric Soil Present?	Yes ____	No X	If yes, optional Wetland Site ID:	
Wetland Hydrology Present?	Yes ____	No X		

Remarks: (Explain alternative procedures here or in a separate report.)

HYDROLOGY

Wetland Hydrology Indicators:

Primary Indicators (minimum of one is required; check all that apply)

- ____ Surface Water (A1)
- ____ High Water Table (A2)
- ____ Saturation (A3)
- ____ Water Marks (B1)
- ____ Sediment Deposits (B2)
- ____ Drift Deposits (B3)
- ____ Algal Mat or Crust (B4)
- ____ Iron Deposits (B5)
- ____ Inundation Visible on Aerial Imagery (B7)
- ____ Sparsely Vegetated Concave Surface (B8)
- ____ Water-Stained Leaves (B9)
- ____ Aquatic Fauna (B13)
- ____ Marl Deposits (B15)
- ____ Hydrogen Sulfide Odor (C1)
- ____ Oxidized Rhizospheres on Living Roots (C3)
- ____ Presence of Reduced Iron (C4)
- ____ Recent Iron Reduction in Tilled Soils (C6)
- ____ Thin Muck Surface (C7)
- ____ Other (Explain in Remarks)

Secondary Indicators (minimum of two required)

- ____ Surface Soil Cracks (B6)
- ____ Drainage Patterns (B10)
- ____ Moss Trim Lines (B16)
- ____ Dry-Season Water Table (C2)
- ____ Crayfish Burrows (C8)
- ____ Saturation Visible on Aerial Imagery (C9)
- ____ Stunted or Stressed Plants (D1)
- ____ Geomorphic Position (D2)
- ____ Shallow Aquitard (D3)
- ____ Microtopographic Relief (D4)
- ____ FAC-Neutral Test (D5)

Field Observations:

Surface Water Present?	Yes ____	No X	Depth (inches): ____
Water Table Present?	Yes ____	No X	Depth (inches): ____
Saturation Present?	Yes ____	No X	Depth (inches): ____

Wetland Hydrology Present? **Yes** ____ **No** X

Describe Recorded Data (stream gauge, monitoring well, aerial photos, previous inspections), if available:

Remarks:

VEGETATION – Use scientific names of plants.

Sampling Point: Upland F

Tree Stratum (Plot size: 30' radius)	Absolute % Cover	Dominant Species?	Indicator Status
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	0	=Total Cover	

Sapling/Shrub Stratum (Plot size: 15' radius)			
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	0	=Total Cover	

Herb Stratum (Plot Size: 5' radius)			
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9..			
10.			
11.			
12.			
	0	=Total Cover	

Woody Vine Stratum (Plot size: 30' radius)			
1.			
2.			
3.			
4.			
	0	=Total Cover	

Dominance Test worksheet:

Number of Dominant Species That Are OBL, FACW, or FAC: 0 (A)

Total Number of Dominant Species Across All Strata: 0 (B)

Percent of Dominant Species That Are OBL, FACW, or FAC: 0 (A/B)

Prevalence Index Worksheet:

Total % Cover of:		Multiply by	
OBL species		x1=	
FACW species		x2=	
FAC species		x3=	
FACU species		x4=	
UPL species		x5=	
Column Totals:	(A)		(B)

Prevalence Index = B/A =

Hydrophytic Vegetation Indicators:

- ____ 1 – Rapid Test for Hydrophytic Vegetation
- ____ 2 – Dominance Test is >50%
- ____ 3 – Prevalence Index is #3.0[1]
- ____ 4 – Morphological Adaptations[1] (Provide supporting data in Remarks or on a separate sheet)
- ____ Problematic Hydrophytic Vegetation[1] (Explain)

[1] Indicators of hydric soil and wetland hydrology must be present, unless disturbed or problematic.

Definitions of Vegetation Strata:

Tree – Woody plants 3 in. (7.6 cm) or more in diameter at breast height (DBH), regardless of height.

Sapling/shrub – Woody plants less than 3 in. DBH and creater than or equal to 3.28 ft (1 m) tall.

Herb – All herbaceous (non-woody) plants, regardless of size, and woody plants less than 3.28 ft tall.

Woody vines – All woody vines greater than 3.28 ft in height.

Hydrophytic Vegetation Present? **Yes** ____ **No** X

Remarks: (Include photo numbers here or on a separate sheet.)

SOIL Sampling Point: Upland F

Profile Description: (Describe to the depth needed to document the indicator or confirm the absence of indicators.)

Depth (inches)	Matrix Color (moist)	Matrix %	Redox Features Color (moist)	Redox Features %	Redox Features Type[1]	Redox Features Loc[2]	Texture	Remarks
0-21	10 YR 6/4	100					Sand	

[1]Type: C=Concentration, D=Depletion, RM=Reduced Matrix, MS=Masked Sand Grains. [2]Location: PL=Pore Lining, M=Matrix

Hydric Soil Indicators:

- ____ Histosol (A1)
- ____ Histic Epipedon (A2)
- ____ Black Histic (A3)
- ____ Hydrogen Sulfide (A4)
- ____ Stratified Layers (A5)
- ____ Depleted Below Dark Surface (A11)
- ____ Thick Dark Surface (A12)
- ____ Sandy Mucky Mineral (S1)
- ____ Sandy Gleyed Matrix (S4)
- ____ Sandy Redox (S5)
- ____ Stripped Matrix (S6)
- ____ Dark Surface (s7) (**LRR, MLRA, 149B**)
- ____ Polyvalue Below Surface (S8) (**LRR R, MLRA 149B**)
- ____ Thin Dark Surface (S9) (**LRR R, MLRA 149B**)
- ____ Loamy Mucky Mineral (F1) (**LRR K, L**)
- ____ Loamy Gleyed Matrix (F2)
- ____ Depleted Matrix (F3)
- ____ Redox Dark Surface (F6)
- ____ Depleted Dark Surface (F7)
- ____ Redox Depressions (F8)

Indicators for Problematic Hydric Soils[3]:

- ____ 2 cm Muck (A10) (**LRR K, L, MLRA 149B**)
- ____ Coast Prairie Redox (A16) (**LRR K, L, R**)
- ____ 5 cm Mucky Peat or Peat (S3) (**LRR K, L, R**)
- ____ Dark Surface (S7) (**LRR, K, L**)
- ____ Polyvalue Below Surface (S8) (**LRR K, L**)
- ____ Thin Dark Surface (S9) (**LRR K, L**)
- ____ Iron-Manganese Masses (F12) (**LRR K, L, R**)
- ____ Piedmont Floodplain Soils (F19) (**MLRA 149B**)
- ____ Mesic Spodic (TA6) (**MLRA 144A, 145, 149B**)
- Red Parent Material (F21)
- ____ Very Shallow Dark Surface (TF12)
- ____ Other (explain in Remarks)

[3]Indicators of hydrophytic vegetation and wetland hydrology must be present, unless disturbed or problematic.

Field Observations:
Type: _____
Depth (inches): _____

Hydric Soil Present? **Yes** **No** X

Remarks:

WETLAND DETERMINATION DATA FORM – Northcentral and Northeast Region

Project/Site: Living Breakwaters City/County: Richmond County Sampling Date: 08/10/2016

Applicant/Owner: GOSR State: NY Sampling Point: Upland G

Investigator(s): Jesse Moore, Teresa Cannone, AKRF, Inc. Section, Township, Range: Tottenville

Landform (hillslope, terrace, etc.): None Local relief (concave, convex, none): None Slope (%): 0

Subregion (LRR or MLRA): MLRA 149B of LRR S Lat: 40.498413 Long: -74.245876 Datum: ____

Soil Map Unit Name: BtA NWI classification: None

Are climatic/hydrologic conditions on the site typical for this time of year? Yes X No ____ (If no, explain in Remarks.)

Are Vegetation N, Soil N, or Hydrology N significantly disturbed? Are "Normal Circumstances" present? Yes X No ____

Are Vegetation N, Soil N, or Hydrology N naturally problematic? (If needed, explain any answers in Remarks.)

SUMMARY OF FINDINGS – Attach site map showing sampling point locations, transects, important features, etc.

Hydrophytic Vegetation Present?	Yes ____	No X	**Is the Sampled Area within a Wetland?**	**Yes** ____ **No** X
Hydric Soil Present?	Yes ____	No X	If yes, optional Wetland Site ID:	
Wetland Hydrology Present?	Yes ____	No X		

Remarks: (Explain alternative procedures here or in a separate report.)

HYDROLOGY

Wetland Hydrology Indicators:

Primary Indicators (minimum of one is required; check all that apply)

- ____ Surface Water (A1)
- ____ High Water Table (A2)
- ____ Saturation (A3)
- ____ Water Marks (B1)
- ____ Sediment Deposits (B2)
- ____ Drift Deposits (B3)
- ____ Algal Mat or Crust (B4)
- ____ Iron Deposits (B5)
- ____ Inundation Visible on Aerial Imagery (B7)
- ____ Sparsely Vegetated Concave Surface (B8)
- ____ Water-Stained Leaves (B9)
- ____ Aquatic Fauna (B13)
- ____ Marl Deposits (B15)
- ____ Hydrogen Sulfide Odor (C1)
- ____ Oxidized Rhizospheres on Living Roots (C3)
- ____ Presence of Reduced Iron (C4)
- ____ Recent Iron Reduction in Tilled Soils (C6)
- ____ Thin Muck Surface (C7)
- ____ Other (Explain in Remarks)

Secondary Indicators (minimum of two required)

- ____ Surface Soil Cracks (B6)
- ____ Drainage Patterns (B10)
- ____ Moss Trim Lines (B16)
- ____ Dry-Season Water Table (C2)
- ____ Crayfish Burrows (C8)
- ____ Saturation Visible on Aerial Imagery (C9)
- ____ Stunted or Stressed Plants (D1)
- ____ Geomorphic Position (D2)
- ____ Shallow Aquitard (D3)
- ____ Microtopographic Relief (D4)
- ____ FAC-Neutral Test (D5)

Field Observations:

Surface Water Present?	Yes ____	No X	Depth (inches): ____
Water Table Present?	Yes ____	No X	Depth (inches): ____
Saturation Present?	Yes ____	No X	Depth (inches): ____

Wetland Hydrology Present? **Yes** ____ **No** X

Describe Recorded Data (stream gauge, monitoring well, aerial photos, previous inspections), if available:

Remarks:

VEGETATION – Use scientific names of plants. Sampling Point: Upland G

Tree Stratum (Plot size: 30' radius)	Absolute % Cover	Dominant Species?	Indicator Status
1. *Quercus palustris*	85	Y	FACW
2. *Sassafras albidum*	10	N	FACU
3.			
4.			
5.			
6.			
7.			
	95	=Total Cover	
Sapling/Shrub Stratum (Plot size: 15' radius)			
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	0	=Total Cover	
Herb Stratum (Plot Size: 5' radius)			
1. *Phytolacca americana*	15	Y	FACU
2. *Rubus phoenicolasius*	10	Y	FACU
3. *Toxicodendron radicans*	5	N	FAC
4.			
5.			
6.			
7.			
8.			
9..			
10.			
11.			
12.			
	30	=Total Cover	
Woody Vine Stratum (Plot size: 30' radius)			
1.			
2.			
3.			
4.			
	0	=Total Cover	

Dominance Test worksheet:

Number of Dominant Species That Are OBL, FACW, or FAC: 1 (A)

Total Number of Dominant Species Across All Strata: 3 (B)

Percent of Dominant Species That Are OBL, FACW, or FAC: 33 (A/B)

Prevalence Index Worksheet:

Total % Cover of:		Multiply by	
OBL species		x1=	
FACW species		x2=	
FAC species		x3=	
FACU species		x4=	
UPL species		x5=	
Column Totals:	(A)		(B)

Prevalence Index = B/A =

Hydrophytic Vegetation Indicators:

- ____ 1 – Rapid Test for Hydrophytic Vegetation
- ____ 2 – Dominance Test is >50%
- ____ 3 – Prevalence Index is #3.0[1]
- ____ 4 – Morphological Adaptations[1] (Provide supporting data in Remarks or on a separate sheet)
- ____ Problematic Hydrophytic Vegetation[1] (Explain)

[1] Indicators of hydric soil and wetland hydrology must be present, unless disturbed or problematic.

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Herb – All herbaceous (non-woody) plants, regardless of size, and woody plants less than 3.28 ft tall.

Woody vines – All woody vines greater than 3.28 ft in height.

Hydrophytic Vegetation Present? **Yes** ____ **No** X

Remarks: (Include photo numbers here or on a separate sheet.)

SOIL Sampling Point: Upland G

Profile Description: (Describe to the depth needed to document the indicator or confirm the absence of indicators.)

Depth (inches)	Matrix Color (moist)	Matrix %	Redox Features Color (moist)	Redox Features %	Redox Features Type[1]	Redox Features Loc[2]	Texture	Remarks
0-6	10 YR 2/1	50					Loam	
	10 YR 3/3	50					Loam	
6-24	10 YR 5/4	100					Loam	

[1]Type: C=Concentration, D=Depletion, RM=Reduced Matrix, MS=Masked Sand Grains. [2]Location: PL=Pore Lining, M=Matrix

Hydric Soil Indicators:

____ Histosol (A1)
____ Histic Epipedon (A2)
____ Black Histic (A3)
____ Hydrogen Sulfide (A4)
____ Stratified Layers (A5)
____ Depleted Below Dark Surface (A11)
____ Thick Dark Surface (A12)
____ Sandy Mucky Mineral (S1)
____ Sandy Gleyed Matrix (S4)
____ Sandy Redox (S5)
____ Stripped Matrix (S6)
____ Dark Surface (s7) (**LRR, MLRA, 149B**)

____ Polyvalue Below Surface (S8) (**LRR R, MLRA 149B**)
____ Thin Dark Surface (S9) (**LRR R, MLRA 149B**)
____ Loamy Mucky Mineral (F1) (**LRR K, L**)
____ Loamy Gleyed Matrix (F2)
____ Depleted Matrix (F3)
____ Redox Dark Surface (F6)
____ Depleted Dark Surface (F7)
____ Redox Depressions (F8)

Indicators for Problematic Hydric Soils[3]:

____ 2 cm Muck (A10) (**LRR K, L, MLRA 149B**)
____ Coast Prairie Redox (A16) (**LRR K, L, R**)
____ 5 cm Mucky Peat or Peat (S3) (**LRR K, L, R**)
____ Dark Surface (S7) (**LRR, K, L**)
____ Polyvalue Below Surface (S8) (**LRR K, L**)
____ Thin Dark Surface (S9) (**LRR K, L**)
____ Iron-Manganese Masses (F12) (**LRR K, L, R**)
____ Piedmont Floodplain Soils (F19) (**MLRA 149B**)
____ Mesic Spodic (TA6) (**MLRA 144A, 145, 149B**)
Red Parent Material (F21)
____ Very Shallow Dark Surface (TF12)
____ Other (explain in Remarks)

[3]Indicators of hydrophytic vegetation and wetland hydrology must be present, unless disturbed or problematic.

Field Observations:
Type: _____
Depth (inches): _____

Hydric Soil Present? **Yes** **No** X

Remarks:

Appendix E-9
Sediment Chemistry Data

Appendix E-9: Sediment Chemistry Data

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		West											
		Class B	Class C	Unrestricted Use	Protection of Groundwater	2012_9		2013_28		2014_19		2071_12		HB06_11		HB06_12	
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/21/2015		9/21/2015		9/21/2015		9/21/2015		9/21/2015		9/21/2015	
1,1,1-Trichloroethane	(mg/kg)			0.68	0.68	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,1-Dichloroethane	(mg/kg)			0.27	0.27	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,1-Dichloroethene	(mg/kg)			0.33	0.33	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,2,4-Trimethylbenzene	(mg/kg)			3.6	3.6	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,2-Dichlorobenzene	(mg/kg)			1.1	1.1	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,2-Dichloroethane	(mg/kg)			0.02	0.02	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,3,5-Trimethylbenzene	(mg/kg)			8.4	8.4	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,3-Dichlorobenzene	(mg/kg)			2.4	2.4	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,4-Dichlorobenzene	(mg/kg)					0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
1,4-Dioxane	(mg/kg)			0.1	0.1	0.0625	U	0.0625	U	0.059	U	0.056	U	0.03675	U	0.055	U
2,4,5-TP	(mg/kg)			0.1	0.1	0.06	U	0.0555	U	0.0545	U	0.056	U	0.054	U	0.054	U
2-Butanone	(mg/kg)					0.00835	U	0.00835	U	0.00785	U	0.00745	U	0.0049	U	0.00735	U
4,4'-DDD	(mg/kg)			0.0033	17	**0.01385**	U	**0.0137**	U	**0.01275**	U	**0.01345**	U	**0.0052**	J	**0.01315**	U
4,4'-DDE	(mg/kg)			0.0033	136	**0.01385**	U	**0.0137**	U	**0.01275**	U	**0.01345**	U	**0.0064**	J	**0.0064**	J
4,4'-DDT	(mg/kg)			0.0033	14	**0.01385**	U	**0.0137**	U	**0.01275**	U	**0.01345**	U	**0.01275**	U	**0.01315**	U
Acenaphthene	(mg/kg)			20	98	0.0875	U	0.082	U	0.0805	U	0.0855	U	0.08	U	0.078	U
Acenaphthylene	(mg/kg)			100	107	0.0529	J	0.045	J	0.0805	U	0.0855	U	0.08	U	0.0683	J
Acetone	(mg/kg)			0.05	0.05	0.0105	J	0.00835	U	0.0119	J	0.0153		0.0083	J	0.00735	U
Aldrin	(mg/kg)			0.005	0.19	**0.00715**	U	**0.00705**	U	**0.00655**	U	**0.00695**	U	**0.00655**	U	**0.0068**	U
alpha-BHC	(mg/kg)			0.02	0.02	0.00715	U	0.00705	U	0.00655	U	0.00695	U	0.00655	U	0.0068	U
alpha-Chlordane	(mg/kg)			0.094	2.9	0.00715	U	0.00705	U	0.00655	U	0.00695	U	0.00655	U	0.0068	U
Anthracene	(mg/kg)			100	1000	0.119	J	0.0847	J	0.0844	J	0.115	J	0.143	J	0.0829	J
Aroclor-1016	(mg/kg)					0.0275	U	0.0275	U	0.0255	U	0.027	U	0.0255	U	0.0265	U
Aroclor-1221	(mg/kg)					0.0275	U	0.0275	U	0.0255	U	0.027	U	0.0255	U	0.0265	U
Aroclor-1232	(mg/kg)					0.0275	U	0.0275	U	0.0255	U	0.027	U	0.0255	U	0.0265	U
Aroclor-1242	(mg/kg)					0.0275	U	0.0275	U	0.0255	U	0.027	U	0.0255	U	0.0265	U
Aroclor-1248	(mg/kg)					0.0275	U	0.0275	U	0.0255	U	0.027	U	0.0255	U	0.0265	U
Aroclor-1254	(mg/kg)					0.029	J	0.024	J	0.024	J	0.021	J	0.037	J	0.039	J
Aroclor-1260	(mg/kg)					0.0275	U	0.0275	U	0.0255	U	0.027	U	0.0255	U	0.0265	U
Arsenic, Total	(mg/kg)	8.2	53	13	16	4.1		4.9		**15.5**		4.2		10.4		8.9	
Barium, Total	(mg/kg)			350	820	14		18.3		20.6		16.6		29.6		23.3	
Benzene	(mg/kg)			0.06	0.06	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Benzo(a)anthracene	(mg/kg)			1	1	0.211		0.316		0.142	J	0.143	J	0.213		0.286	
Benzo(a)pyrene	(mg/kg)			1	22	0.237		0.348		0.177		0.162	J	0.219		0.343	
Benzo(b)fluoranthene	(mg/kg)			1	1.7	0.303		0.454		0.203		0.215		0.274		0.428	
Benzo(g,h,i)perylene	(mg/kg)			100	1000	0.151	J	0.234		0.108	J	0.112	J	0.14	J	0.231	
Benzo(k)fluoranthene	(mg/kg)			0.8	1.7	0.115	J	0.082	U	0.0849	J	0.0855	U	0.104	J	0.156	J

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		West											
		Class B	Class C	Unrestricted Use	Protection of Groundwater	2012_9		2013_28		2014_19		2071_12		HB06_11		HB06_12	
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/21/2015		9/21/2015		9/21/2015		9/21/2015		9/21/2015		9/21/2015	
Beryllium, Total	(mg/kg)			7.2	47	0.4	U	0.3	J	0.38	J	0.27	J	0.45	J	0.42	J
beta-BHC	(mg/kg)			0.036	0.09	0.00715	U	0.00705	U	0.00655	U	0.00695	U	0.00655	U	0.0068	U
Cadmium, Total	(mg/kg)	1.2	9.5	2.5	7.5	0.42	J	0.48	J	1		0.44	J	1		0.99	
Carbon Tetrachloride	(mg/kg)			0.76	0.76	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Chlorobenzene	(mg/kg)			1.1	1.1	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Chloroform	(mg/kg)			0.37	0.37	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Chromium, Total	(mg/kg)			1	19	**15.7**		**18.4**		***28.5***		**16.2**		***33***		***31.1***	
Chrysene	(mg/kg)			1	1	0.218		0.334		0.124	J	0.154	J	0.215		0.296	
cis-1,2-Dichloroethene	(mg/kg)			0.25	0.25	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Copper, Total	(mg/kg)	33	270	50	1720	28.9		32.8		**56.8**		27.6		**63**		**61.4**	
Cyanide, Total	(mg/kg)			27	40	0.215	U	0.215	U	0.2	U	0.215	U	0.195	U	0.205	U
delta-BHC	(mg/kg)			0.04	0.25	0.00715	U	0.00705	U	0.00655	U	0.00695	U	0.00655	U	0.0068	U
Dibenzo(a,h)anthracene	(mg/kg)			0.33	1000	0.0875	U	0.0647	J	0.0805	U	0.0855	U	0.08	U	0.0695	J
Dibenzofuran	(mg/kg)			7	210	0.0875	U	0.082	U	0.0805	U	0.0855	U	0.08	U	0.078	U
Dieldrin	(mg/kg)	0.11	0.48	0.005	0.1	**0.01385**	U	**0.0137**	U	**0.01275**	U	**0.01345**	U	**0.01275**	U	**0.01315**	U
Endosulfan I	(mg/kg)			2.4	102	0.00715	U	0.00705	U	0.00655	U	0.00695	U	0.00655	U	0.0068	U
Endosulfan II	(mg/kg)			2.4	102	0.01385	U	0.0137	U	0.01275	U	0.01345	U	0.01275	U	0.01315	U
Endosulfan Sulfate	(mg/kg)			2.4	1000	0.01385	U	0.0137	U	0.01275	U	0.01345	U	0.01275	U	0.01315	U
Endrin	(mg/kg)			0.014	0.06	0.01385	U	0.0137	U	0.01275	U	0.01345	U	0.01275	U	0.01315	U
Ethylbenzene	(mg/kg)			1	1	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Fluoranthene	(mg/kg)			100	1000	0.327		0.602		0.219		0.247		0.339		0.516	
Fluorene	(mg/kg)			30	386	0.0875	U	0.082	U	0.0805	U	0.0855	U	0.08	U	0.078	U
gamma-BHC	(mg/kg)			0.1	0.1	0.00715	U	0.00705	U	0.00655	U	0.00695	U	0.00655	U	0.0068	U
Heptachlor	(mg/kg)			0.042	0.38	0.00715	U	0.00705	U	0.00655	U	0.00695	U	0.00655	U	0.0068	U
Hexachlorobenzene	(mg/kg)			0.33	3.2	0.0875	U	0.082	U	0.0805	U	0.0855	U	0.08	U	0.078	U
Hexavalent Chromium	(mg/kg)					1.75	U	1.7	U	1.6	U	1.7	U	1.6	U	1.7	U
Indeno(1,2,3-cd)pyrene	(mg/kg)			0.5	8.2	0.176		0.274		0.115	J	0.12	J	0.154	J	0.226	
Lead, Total	(mg/kg)	47	218	63	450	30.7		33.6		54		30.6		**65.7**		61.5	
Manganese, Total	(mg/kg)			1600	2000	102		119		200		111		186		193	
Mercury, Total	(mg/kg)	0.17	1	0.18	0.73	**0.4**		**0.36**		**0.46**		**0.38**		**0.49**		**0.57**	
Methyl t-Butyl Ether	(mg/kg)			0.93	0.93	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Methylene Chloride	(mg/kg)			0.05	0.05	0.0326		0.0295		0.0298		0.0245		0.0193		0.0266	
Moisture	%					44.2		40.9		38.6		42.2		38.5		39.7	
mp-Cresol	(mg/kg)			0.33	0.33	0.2355	U	0.221	U	0.217	U	0.2305	U	0.2165	U	0.211	U
Naphthalene	(mg/kg)			12	12	0.0875	U	0.082	U	0.0805	U	0.0855	U	0.08	U	0.078	U
n-Butylbenzene	(mg/kg)			12	12	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Nickel, Total	(mg/kg)			30	130	8.3		9.7		14.7		8.5		15.8		15.7	

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		West											
		Class B	Class C	Unrestricted Use	Protection of Groundwater	2012_9		2013_28		2014_19		2071_12		HB06_11		HB06_12	
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/21/2015		9/21/2015		9/21/2015		9/21/2015		9/21/2015		9/21/2015	
n-Propylbenzene	(mg/kg)			3.9	3.9	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
o-Cresol	(mg/kg)			0.33	0.33	0.2355	U	0.221	U	0.217	U	0.2305	U	0.2165	U	0.211	U
Pentachlorophenol	(mg/kg)			0.8	0.8	0.1745	U	0.1635	U	0.1605	U	0.171	U	0.1605	U	0.1565	U
Phenanthrene	(mg/kg)			100	1000	0.116	J	0.258		0.0834	J	0.113	J	0.141	J	0.198	
Phenol	(mg/kg)			0.33	0.33	0.2355	U	0.221	U	0.217	U	0.2305	U	0.2165	U	0.211	U
Pyrene	(mg/kg)			100	1000	0.305		0.488		0.237		0.23		0.349		0.493	
sec-Butylbenzene	(mg/kg)			11	11	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Selenium, Total	(mg/kg)			3.9	4	2	U	2	U	1.3	J	1.95	U	1.7	J	2.4	J
Silver, Total	(mg/kg)			2	8.3	0.8	U	0.8	U	0.83	J	0.8	U	0.99	J	0.94	J
tert-Butylbenzene	(mg/kg)			5.9	5.9	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Tetrachloroethene	(mg/kg)			1.3	1.3	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Toluene	(mg/kg)			0.7	0.7	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Total Polychlorinated Biphenyl	(mg/kg)	0.1	1	0.1	3.2	0.0275	U	0.0275	U	0.0255	U	0.027	U	0.0255	U	0.0265	U
Total Solids	%					55.8		59.1		61.4		57.8		61.5		60.3	
Total Xylenes	(mg/kg)			0.26	1.6	0.005	U	0.005	U	0.0047	U	0.00445	U	0.00295	U	0.0044	U
trans-1,2-Dichloroethene	(mg/kg)			0.19	0.19	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Trichloroethene	(mg/kg)			0.47	0.47	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Trivalent Chromium	(mg/kg)					15.7		18.4		28.5		16.2		33		31.1	
Vinyl Chloride	(mg/kg)			0.02	0.02	0.00165	U	0.00165	U	0.00155	U	0.0015	U	0.001	U	0.00145	U
Zinc, Total	(mg/kg)			109	2480	77.8		85.3		**136**		79		**141**		**151**	
Σ DDT, Calculated	(mg/kg)	0.003	0.03			0		0		0		0		0.0116		0.0064	
Total PAH, Calculated	(mg/kg)	4	45			2.3309		3.5024		1.5777		1.611		2.291		3.3937	
Total BTEX, Calculated	(mg/kg)	0.96	5.9			0		0		0		0		0		0	

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		Southwest											
		Class B	Class C	Unrestricted Use	Protection of Groundwater	1129_20		1363_24		1364_6		1438_23		1439_20		1440_8	
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/24/2015		9/21/2015		9/24/2015		9/21/2015		9/24/2015		9/24/2015	
1,1,1-Trichloroethane	(mg/kg)			0.68	0.68	0.0013	U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,1-Dichloroethane	(mg/kg)			0.27	0.27	0.0013	U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,1-Dichloroethene	(mg/kg)			0.33	0.33	0.0013	U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,2,4-Trimethylbenzene	(mg/kg)			3.6	3.6	0.0013	U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,2-Dichlorobenzene	(mg/kg)			1.1	1.1	0.0013	U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,2-Dichloroethane	(mg/kg)			0.02	0.02		U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,3,5-Trimethylbenzene	(mg/kg)			8.4	8.4	0.0013	U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,3-Dichlorobenzene	(mg/kg)			2.4	2.4	0.0013	U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,4-Dichlorobenzene	(mg/kg)						U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
1,4-Dioxane	(mg/kg)			0.1	0.1	0.04955	U	0.03715	U	0.0505	U	0.04365	U	0.0485	U	0.0515	U
2,4,5-TP	(mg/kg)			0.1	0.1	0.04295	U	0.04435	U	0.0435	U	0.057	U	0.04195	U	0.0454	U
2-Butanone	(mg/kg)					0.0066	U	0.00495	U	0.00675	U	0.0058	U	0.00645	U	0.00685	U
4,4'-DDD	(mg/kg)			0.0033	17	**0.01025**	U	**0.01135**	U	**0.0105**	U	**0.01325**	U	**0.0102**	U	**0.01065**	U
4,4'-DDE	(mg/kg)			0.0033	136	**0.01025**	U	**0.01135**	U	**0.0105**	U	**0.01325**	U	**0.0102**	U	**0.01065**	U
4,4'-DDT	(mg/kg)			0.0033	14	**0.01025**	U	**0.01135**	U	**0.0105**	U	**0.01325**	U	**0.0102**	U	**0.01065**	U
Acenaphthene	(mg/kg)			20	98	0.0615	U	0.066	U	0.067	U	0.084	U	0.064	U	0.066	U
Acenaphthylene	(mg/kg)			100	107	0.0615	U	0.066	U	0.067	U	0.0655	J	0.064	U	0.066	U
Acetone	(mg/kg)			0.05	0.05	0.0066	U	0.00495	U	0.00675	U	0.0074	J	0.007	J	0.00685	U
Aldrin	(mg/kg)			0.005	0.19	**0.0053**	U	**0.00585**	U	**0.0054**	U	**0.0068**	U	**0.00525**	U	**0.0055**	U
alpha-BHC	(mg/kg)			0.02	0.02	0.0053	U	0.00585	U	0.0054	U	0.0068	U	0.00525	U	0.0055	U
alpha-Chlordane	(mg/kg)			0.094	2.9	0.0053	U	0.00585	U	0.0054	U	0.0068	U	0.00525	U	0.0055	U
Anthracene	(mg/kg)			100	1000	0.0615	U	0.066	U	0.067	U	0.104	J	0.064	U	0.066	U
Aroclor-1016	(mg/kg)					0.0205	U	0.0225	U	0.021	U	0.0265	U	0.0205	U	0.0215	U
Aroclor-1221	(mg/kg)					0.0205	U	0.0225	U	0.021	U	0.0265	U	0.0205	U	0.0215	U
Aroclor-1232	(mg/kg)					0.0205	U	0.0225	U	0.021	U	0.0265	U	0.0205	U	0.0215	U
Aroclor-1242	(mg/kg)					0.0205	U	0.0225	U	0.021	U	0.0265	U	0.0205	U	0.0215	U
Aroclor-1248	(mg/kg)					0.0205	U	0.0225	U	0.021	U	0.0265	U	0.0205	U	0.0215	U
Aroclor-1254	(mg/kg)					0.0205	U	0.0225	U	0.021	U	0.026	J	0.0205	U	0.0215	U
Aroclor-1260	(mg/kg)					0.0205	U	0.0225	U	0.021	U	0.0265	U	0.0205	U	0.0215	U
Arsenic, Total	(mg/kg)	8.2	53	13	16			3.5		2.3		4.4		1.5		3	
Barium, Total	(mg/kg)			350	820			7.3		5.1		18.6		2.8		5.4	
Benzene	(mg/kg)			0.06	0.06	0.0013	U	0.001	U	0.00135	U	0.00115	U	0.0013	U	0.00135	U
Benzo(a)anthracene	(mg/kg)			1	1	0.0615	U	0.066	U	0.067	U	0.357		0.064	U	0.066	U
Benzo(a)pyrene	(mg/kg)			1	22	0.0615	U	0.066	U	0.067	U	0.394		0.064	U	0.066	U
Benzo(b)fluoranthene	(mg/kg)			1	1.7	0.0421	J	0.066	U	0.067	U	0.494		0.064	U	0.066	U
Benzo(g,h,i)perylene	(mg/kg)			100	1000	0.0615	U	0.066	U	0.067	U	0.244		0.064	U	0.066	U
Benzo(k)fluoranthene	(mg/kg)			0.8	1.7	0.0615	U	0.066	U	0.067	U	0.178		0.064	U	0.066	U

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		Southwest					
		Class B	Class C	Unrestricted Use	Protection of Groundwater	1129_20	1363_24	1364_6	1438_23	1439_20	1440_8
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/24/2015	9/21/2015	9/24/2015	9/21/2015	9/24/2015	9/24/2015
Beryllium, Total	(mg/kg)			7.2	47	U	0.345 U	0.28 U	0.29 J	0.215 U	0.335 U
beta-BHC	(mg/kg)			0.036	0.09	0.0053 U	0.00585 U	0.0054 U	0.0068 U	0.00525 U	0.0055 U
Cadmium, Total	(mg/kg)	1.2	9.5	2.5	7.5	U	0.345 U	0.28 U	0.57 J	0.215 U	0.335 U
Carbon Tetrachloride	(mg/kg)			0.76	0.76	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Chlorobenzene	(mg/kg)			1.1	1.1	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Chloroform	(mg/kg)			0.37	0.37	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Chromium, Total	(mg/kg)			1	19		**9.5**	**8.8**	***19.3***	**6**	**10.1**
Chrysene	(mg/kg)			1	1	0.0615 U	0.066 U	0.067 U	0.375	0.064 U	0.066 U
cis-1,2-Dichloroethene	(mg/kg)			0.25	0.25	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Copper, Total	(mg/kg)	33	270	50	1720		8.6	8.8	34.5	5.9	10.5
Cyanide, Total	(mg/kg)			27	40	U	0.18 U	0.175 U	0.205 U	0.16 U	0.17 U
delta-BHC	(mg/kg)			0.04	0.25	0.0053 U	0.00585 U	0.0054 U	0.0068 U	0.00525 U	0.0055 U
Dibenzo(a,h)anthracene	(mg/kg)			0.33	1000	0.0615 U	0.066 U	0.067 U	0.0628 J	0.064 U	0.066 U
Dibenzofuran	(mg/kg)			7	210	0.0615 U	0.066 U	0.067 U	0.084 U	0.064 U	0.066 U
Dieldrin	(mg/kg)	0.11	0.48	0.005	0.1	**0.01025** U	**0.01135** U	**0.0105** U	**0.01325** U	**0.0102** U	**0.01065** U
Endosulfan I	(mg/kg)			2.4	102	0.0053 U	0.00585 U	0.0054 U	0.0068 U	0.00525 U	0.0055 U
Endosulfan II	(mg/kg)			2.4	102	0.01025 U	0.01135 U	0.0105 U	0.01325 U	0.0102 U	0.01065 U
Endosulfan Sulfate	(mg/kg)			2.4	1000	0.01025 U	0.01135 U	0.0105 U	0.01325 U	0.0102 U	0.01065 U
Endrin	(mg/kg)			0.014	0.06	0.01025 U	0.01135 U	0.0105 U	0.01325 U	0.0102 U	0.01065 U
Ethylbenzene	(mg/kg)			1	1	U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Fluoranthene	(mg/kg)			100	1000	0.0467 J	0.066 U	0.067 U	0.663	0.064 U	0.066 U
Fluorene	(mg/kg)			30	386	0.0615 U	0.066 U	0.067 U	0.084 U	0.064 U	0.066 U
gamma-BHC	(mg/kg)			0.1	0.1	0.0053 U	0.00585 U	0.0054 U	0.0068 U	0.00525 U	0.0055 U
Heptachlor	(mg/kg)			0.042	0.38	0.0053 U	0.00585 U	0.0054 U	0.0068 U	0.00525 U	0.0055 U
Hexachlorobenzene	(mg/kg)			0.33	3.2	0.0615 U	0.066 U	0.067 U	0.084 U	0.064 U	0.066 U
Hexavalent Chromium	(mg/kg)					U	1.35 U	1.35 U	1.75 U	1.25 U	1.35 U
Indeno(1,2,3-cd)pyrene	(mg/kg)			0.5	8.2	0.0615 U	0.066 U	0.067 U	0.268	0.064 U	0.066 U
Lead, Total	(mg/kg)	47	218	63	450		14	11.5	37	7.7	13.8
Manganese, Total	(mg/kg)			1600	2000		168	222	108	66.1	215
Mercury, Total	(mg/kg)	0.17	1	0.18	0.73		0.069 J	0.048 J	**0.48**	0.058	0.055 J
Methyl t-Butyl Ether	(mg/kg)			0.93	0.93	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Methylene Chloride	(mg/kg)			0.05	0.05	0.0124	0.0199	0.0153	0.0192	0.0097	0.0145
Moisture	%						27.9	25.5	41.6	22.2	26.4
mp-Cresol	(mg/kg)			0.33	0.33	0.1655 U	0.179 U	0.181 U	0.2265 U	0.1725 U	0.179 U
Naphthalene	(mg/kg)			12	12	0.0615 U	0.066 U	0.067 U	0.084 U	0.064 U	0.066 U
n-Butylbenzene	(mg/kg)			12	12	U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Nickel, Total	(mg/kg)			30	130		7.1	5.6	10.2	3.2	5.5

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		Southwest					
		Class B	Class C	Unrestricted Use	Protection of Groundwater	1129_20	1363_24	1364_6	1438_23	1439_20	1440_8
Analyte	**Units**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**9/24/2015**	**9/21/2015**	**9/24/2015**	**9/21/2015**	**9/24/2015**	**9/24/2015**
n-Propylbenzene	(mg/kg)			3.9	3.9	U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
o-Cresol	(mg/kg)			0.33	0.33	0.1655 U	0.179 U	0.181 U	0.2265 U	0.1725 U	0.179 U
Pentachlorophenol	(mg/kg)			0.8	0.8	0.1225 U	0.1325 U	0.134 U	0.168 U	0.1275 U	0.1325 U
Phenanthrene	(mg/kg)			100	1000	0.0615 U	0.066 U	0.067 U	0.302	0.064 U	0.066 U
Phenol	(mg/kg)			0.33	0.33	0.1655 U	0.179 U	0.181 U	0.2265 U	0.1725 U	0.179 U
Pyrene	(mg/kg)			100	1000	0.0615 U	0.066 U	0.067 U	0.592	0.064 U	0.066 U
sec-Butylbenzene	(mg/kg)			11	11	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Selenium, Total	(mg/kg)			3.9	4	U	1.75 U	1.4 U	2.05 U	1.1 U	1.65 U
Silver, Total	(mg/kg)			2	8.3	U	0.7 U	0.55 U	0.8 U	0.435 U	0.65 U
tert-Butylbenzene	(mg/kg)			5.9	5.9	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Tetrachloroethene	(mg/kg)			1.3	1.3	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Toluene	(mg/kg)			0.7	0.7	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Total Polychlorinated Biphenyl	(mg/kg)	0.1	1	0.1	3.2	0.0205 U	0.0225 U	0.021 U	0.0265 U	0.0205 U	0.0215 U
Total Solids	%						72.1	74.5	58.4	77.8	73.6
Total Xylenes	(mg/kg)			0.26	1.6	0.00395 U	0.00295 U	0.00405 U	0.0035 U	0.0039 U	0.0041 U
trans-1,2-Dichloroethene	(mg/kg)			0.19	0.19	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Trichloroethene	(mg/kg)			0.47	0.47	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Trivalent Chromium	(mg/kg)						9.5	8.8	19.3	6	10.1
Vinyl Chloride	(mg/kg)			0.02	0.02	0.0013 U	0.001 U	0.00135 U	0.00115 U	0.0013 U	0.00135 U
Zinc, Total	(mg/kg)			109	2480		41.4	38.6	97.3	23.6	41.8
Σ DDT, Calculated	(mg/kg)	0.003	0.03			0	0	0	0	0	0
Total PAH, Calculated	(mg/kg)	4	45			0.0888	0	0	4.0993	0	0
Total BTEX, Calculated	(mg/kg)	0.96	5.9			0	0	0	0	0	0

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		Southwest									
		Class B	Class C	Unrestricted Use	Protection of Groundwater	986_26		HB02_1		HB02_2		HB07_13		HB07_14	
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/24/2015		9/21/2015		9/21/2015		9/21/2015		9/21/2015	
1,1,1-Trichloroethane	(mg/kg)			0.68	0.68	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,1-Dichloroethane	(mg/kg)			0.27	0.27	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,1-Dichloroethene	(mg/kg)			0.33	0.33	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,2,4-Trimethylbenzene	(mg/kg)			3.6	3.6	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,2-Dichlorobenzene	(mg/kg)			1.1	1.1	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,2-Dichloroethane	(mg/kg)			0.02	0.02	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,3,5-Trimethylbenzene	(mg/kg)			8.4	8.4	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,3-Dichlorobenzene	(mg/kg)			2.4	2.4	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,4-Dichlorobenzene	(mg/kg)					0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
1,4-Dioxane	(mg/kg)			0.1	0.1	0.04875	U	0.04655	U	0.04655	U	0.03885	U	0.03725	U
2,4,5-TP	(mg/kg)			0.1	0.1	0.0426	U	0.04455	U	0.04675	U	0.0463	U	0.04695	U
2-Butanone	(mg/kg)					0.0065	U	0.0062	U	0.0062	U	0.0052	U	0.00495	U
4,4'-DDD	(mg/kg)			0.0033	17	**0.0104**	U	**0.0112**	U	**0.01145**	U	**0.01165**	U	**0.01125**	U
4,4'-DDE	(mg/kg)			0.0033	136	**0.0104**	U	**0.0112**	U	**0.01145**	U	**0.01165**	U	**0.01125**	U
4,4'-DDT	(mg/kg)			0.0033	14	**0.0104**	U	**0.0112**	U	**0.01145**	U	**0.01165**	U	**0.01125**	U
Acenaphthene	(mg/kg)			20	98	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Acenaphthylene	(mg/kg)			100	107	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Acetone	(mg/kg)			0.05	0.05	0.0088	J	0.0062	U	0.0062	U	0.0055	J	0.00495	U
Aldrin	(mg/kg)			0.005	0.19	**0.00535**	U	**0.0058**	U	**0.0059**	U	**0.006**	U	**0.0058**	U
alpha-BHC	(mg/kg)			0.02	0.02	0.00535	U	0.0058	U	0.0059	U	0.006	U	0.0058	U
alpha-Chlordane	(mg/kg)			0.094	2.9	0.00535	U	0.0058	U	0.0059	U	0.006	U	0.0058	U
Anthracene	(mg/kg)			100	1000	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Aroclor-1016	(mg/kg)					0.021	U	0.0225	U	0.023	U	0.0235	U	0.0225	U
Aroclor-1221	(mg/kg)					0.021	U	0.0225	U	0.023	U	0.0235	U	0.0225	U
Aroclor-1232	(mg/kg)					0.021	U	0.0225	U	0.023	U	0.0235	U	0.0225	U
Aroclor-1242	(mg/kg)					0.021	U	0.0225	U	0.023	U	0.0235	U	0.0225	U
Aroclor-1248	(mg/kg)					0.021	U	0.0225	U	0.023	U	0.0235	U	0.0225	U
Aroclor-1254	(mg/kg)					0.021	U	0.0225	U	0.023	U	0.0235	U	0.0225	U
Aroclor-1260	(mg/kg)					0.021	U	0.0225	U	0.023	U	0.0235	U	0.0225	U
Arsenic, Total	(mg/kg)	8.2	53	13	16	4		2.5		2.1		3.6		3.7	
Barium, Total	(mg/kg)			350	820	11.3		5.7		7		10		10.4	
Benzene	(mg/kg)			0.06	0.06	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Benzo(a)anthracene	(mg/kg)			1	1	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Benzo(a)pyrene	(mg/kg)			1	22	0.0345	J	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Benzo(b)fluoranthene	(mg/kg)			1	1.7	0.0491	J	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Benzo(g,h,i)perylene	(mg/kg)			100	1000	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Benzo(k)fluoranthene	(mg/kg)			0.8	1.7	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		Southwest									
		Class B	Class C	Unrestricted Use	Protection of Groundwater	986_26		HB02_1		HB02_2		HB07_13		HB07_14	
Analyte	**Units**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**9/24/2015**		**9/21/2015**		**9/21/2015**		**9/21/2015**		**9/21/2015**	
Beryllium, Total	(mg/kg)			7.2	47	0.23	J	0.285	U	0.335	U	0.35	U	0.22	J
beta-BHC	(mg/kg)			0.036	0.09	0.00535	U	0.0058	U	0.0059	U	0.006	U	0.0058	U
Cadmium, Total	(mg/kg)	1.2	9.5	2.5	7.5	0.2	J	0.285	U	0.335	U	0.35	U	0.24	J
Carbon Tetrachloride	(mg/kg)			0.76	0.76	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Chlorobenzene	(mg/kg)			1.1	1.1	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Chloroform	(mg/kg)			0.37	0.37	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Chromium, Total	(mg/kg)			1	19	**12.7**		**9.7**		**7.6**		**11**		**12**	
Chrysene	(mg/kg)			1	1	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
cis-1,2-Dichloroethene	(mg/kg)			0.25	0.25	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Copper, Total	(mg/kg)	33	270	50	1720	12.9		7.9		7.4		13.1		15	
Cyanide, Total	(mg/kg)			27	40	0.16	U	0.165	U	0.185	U	0.18	U	0.175	U
delta-BHC	(mg/kg)			0.04	0.25	0.00535	U	0.0058	U	0.0059	U	0.006	U	0.0058	U
Dibenzo(a,h)anthracene	(mg/kg)			0.33	1000	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Dibenzofuran	(mg/kg)			7	210	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Dieldrin	(mg/kg)	0.11	0.48	0.005	0.1	**0.0104**	U	**0.0112**	U	**0.01145**	U	**0.01165**	U	**0.01125**	U
Endosulfan I	(mg/kg)			2.4	102	0.00535	U	0.0058	U	0.0059	U	0.006	U	0.0058	U
Endosulfan II	(mg/kg)			2.4	102	0.0104	U	0.0112	U	0.01145	U	0.01165	U	0.01125	U
Endosulfan Sulfate	(mg/kg)			2.4	1000	0.0104	U	0.0112	U	0.01145	U	0.01165	U	0.01125	U
Endrin	(mg/kg)			0.014	0.06	0.0104	U	0.0112	U	0.01145	U	0.01165	U	0.01125	U
Ethylbenzene	(mg/kg)			1	1	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Fluoranthene	(mg/kg)			100	1000	0.052	J	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Fluorene	(mg/kg)			30	386	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
gamma-BHC	(mg/kg)			0.1	0.1	0.00535	U	0.0058	U	0.0059	U	0.006	U	0.0058	U
Heptachlor	(mg/kg)			0.042	0.38	0.00535	U	0.0058	U	0.0059	U	0.006	U	0.0058	U
Hexachlorobenzene	(mg/kg)			0.33	3.2	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Hexavalent Chromium	(mg/kg)					1.3	U	1.4	U	1.45	U	1.35	U	1.35	U
Indeno(1,2,3-cd)pyrene	(mg/kg)			0.5	8.2	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Lead, Total	(mg/kg)	47	218	63	450	18.6		10.9		10.8		18.1		19.2	
Manganese, Total	(mg/kg)			1600	2000	164		179		252		203		291	
Mercury, Total	(mg/kg)	0.17	1	0.18	0.73	0.054	J	0.074		0.072		0.089		0.098	
Methyl t-Butyl Ether	(mg/kg)			0.93	0.93	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Methylene Chloride	(mg/kg)			0.05	0.05	0.0109		0.0265		0.0255		0.0244		0.0216	
Moisture	%					22.1		27.4		29.7		29.5		28.7	
mp-Cresol	(mg/kg)			0.33	0.33	0.171	U	0.1745	U	0.1845	U	0.1855	U	0.1855	U
Naphthalene	(mg/kg)			12	12	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
n-Butylbenzene	(mg/kg)			12	12	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Nickel, Total	(mg/kg)			30	130	7.5		4.9		4.7		6.5		6.8	

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		Southwest									
		Class B	Class C	Unrestricted Use	Protection of Groundwater	986_26		HB02_1		HB02_2		HB07_13		HB07_14	
Analyte	**Units**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**9/24/2015**		**9/21/2015**		**9/21/2015**		**9/21/2015**		**9/21/2015**	
n-Propylbenzene	(mg/kg)			3.9	3.9	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
o-Cresol	(mg/kg)			0.33	0.33	0.171	U	0.1745	U	0.1845	U	0.1855	U	0.1855	U
Pentachlorophenol	(mg/kg)			0.8	0.8	0.1265	U	0.129	U	0.137	U	0.1375	U	0.1375	U
Phenanthrene	(mg/kg)			100	1000	0.0635	U	0.0645	U	0.0685	U	0.0685	U	0.0685	U
Phenol	(mg/kg)			0.33	0.33	0.171	U	0.1745	U	0.1845	U	0.1855	U	0.1855	U
Pyrene	(mg/kg)			100	1000	0.0484	J	0.0645	U	0.0685	U	0.0685	U	0.0685	U
sec-Butylbenzene	(mg/kg)			11	11	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Selenium, Total	(mg/kg)			3.9	4	0.84	J	1.45	U	1.7	U	1.75	U	1.55	U
Silver, Total	(mg/kg)			2	8.3	0.42	U	0.55	U	0.65	U	0.7	U	0.6	U
tert-Butylbenzene	(mg/kg)			5.9	5.9	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Tetrachloroethene	(mg/kg)			1.3	1.3	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Toluene	(mg/kg)			0.7	0.7	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Total Polychlorinated Biphenyl	(mg/kg)	0.1	1	0.1	3.2	0.021	U	0.0225	U	0.023	U	0.0235	U	0.0225	U
Total Solids	%					77.9		72.6		70.3		70.5		71.3	
Total Xylenes	(mg/kg)			0.26	1.6	0.0039	U	0.0037	U	0.0037	U	0.0031	U	0.003	U
trans-1,2-Dichloroethene	(mg/kg)			0.19	0.19	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Trichloroethene	(mg/kg)			0.47	0.47	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Trivalent Chromium	(mg/kg)					12.7		9.7		7.6		11		12	
Vinyl Chloride	(mg/kg)			0.02	0.02	0.0013	U	0.00125	U	0.00125	U	0.00105	U	0.001	U
Zinc, Total	(mg/kg)			109	2480	52.9		34.3		33.2		49.3		57.2	
Σ DDT, Calculated	(mg/kg)	0.003	0.03			0		0		0		0		0	
Total PAH, Calculated	(mg/kg)	4	45			0.184		0		0		0		0	
Total BTEX, Calculated	(mg/kg)	0.96	5.9			0		0		0		0		0	

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		South											
		Class B	Class C	Unrestricted Use	Protection of Groundwater	1217_42		1374_22		1787_44		2146_25		654_9		659_7	
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/24/2015		9/24/2015		9/24/2015		9/24/2015		9/24/2015		9/24/2015	
1,1,1-Trichloroethane	(mg/kg)			0.68	0.68	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,1-Dichloroethane	(mg/kg)			0.27	0.27	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,1-Dichloroethene	(mg/kg)			0.33	0.33	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,2,4-Trimethylbenzene	(mg/kg)			3.6	3.6	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,2-Dichlorobenzene	(mg/kg)			1.1	1.1	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,2-Dichloroethane	(mg/kg)			0.02	0.02	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,3,5-Trimethylbenzene	(mg/kg)			8.4	8.4	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,3-Dichlorobenzene	(mg/kg)			2.4	2.4	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,4-Dichlorobenzene	(mg/kg)					0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
1,4-Dioxane	(mg/kg)			0.1	0.1	0.0495	U	0.04855	U	0.054	U	0.0505	U	0.0485	U	0.04895	U
2,4,5-TP	(mg/kg)			0.1	0.1	0.0435	U	0.04275	U	0.0474	U	0.0438	U	0.0419	U	0.04235	U
2-Butanone	(mg/kg)					0.0066	U	0.0065	U	0.0072	U	0.0068	U	0.00645	U	0.00655	U
4,4'-DDD	(mg/kg)			0.0033	17	**0.0105**	U	**0.01**	U	**0.01135**	U	**0.0107**	U	**0.01065**	U	**0.01045**	U
4,4'-DDE	(mg/kg)			0.0033	136	**0.0105**	U	**0.01**	U	**0.01135**	U	**0.0107**	U	**0.01065**	U	**0.01045**	U
4,4'-DDT	(mg/kg)			0.0033	14	**0.0105**	U	**0.01**	U	**0.01135**	U	**0.0107**	U	**0.01065**	U	**0.01045**	U
Acenaphthene	(mg/kg)			20	98	0.063	U	0.0615	U	0.07	U	0.0665	U	0.062	U	0.064	U
Acenaphthylene	(mg/kg)			100	107	0.063	U	0.0615	U	0.07	U	0.0665	U	0.062	U	0.064	U
Acetone	(mg/kg)			0.05	0.05	0.0081	J	0.0065	U	0.0089	J	0.0068	U	0.00645	U	0.0076	J
Aldrin	(mg/kg)			0.005	0.19	**0.0054**	U	**0.00515**	U	**0.00585**	U	**0.0055**	U	**0.0055**	U	**0.0054**	U
alpha-BHC	(mg/kg)			0.02	0.02	0.0054	U	0.00515	U	0.00585	U	0.0055	U	0.0055	U	0.0054	U
alpha-Chlordane	(mg/kg)			0.094	2.9	0.0054	U	0.00515	U	0.00585	U	0.0055	U	0.0055	U	0.0054	U
Anthracene	(mg/kg)			100	1000	0.063	U	0.0627	J	0.07	U	0.0665	U	0.062	U	0.064	U
Aroclor-1016	(mg/kg)					0.021	U	0.02	U	0.0225	U	0.0215	U	0.0215	U	0.021	U
Aroclor-1221	(mg/kg)					0.021	U	0.02	U	0.0225	U	0.0215	U	0.0215	U	0.021	U
Aroclor-1232	(mg/kg)					0.021	U	0.02	U	0.0225	U	0.0215	U	0.0215	U	0.021	U
Aroclor-1242	(mg/kg)					0.021	U	0.02	U	0.0225	U	0.0215	U	0.0215	U	0.021	U
Aroclor-1248	(mg/kg)					0.021	U	0.02	U	0.0225	U	0.0215	U	0.0215	U	0.021	U
Aroclor-1254	(mg/kg)					0.021	U	0.02	U	0.0225	U	0.0215	U	0.0215	U	0.021	U
Aroclor-1260	(mg/kg)					0.021	U	0.02	U	0.0225	U	0.0215	U	0.0215	U	0.021	U
Arsenic, Total	(mg/kg)	8.2	53	13	16	2.6		1.6	J	2.2		3.3		2.8		3.5	
Barium, Total	(mg/kg)			350	820	6.3		2.6	J	6.4		5.1		9.5		9	
Benzene	(mg/kg)			0.06	0.06	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Benzo(a)anthracene	(mg/kg)			1	1	0.063	U	0.103	J	0.07	U	0.0665	U	0.062	U	0.064	U
Benzo(a)pyrene	(mg/kg)			1	22	0.063	U	0.0816	J	0.07	U	0.0665	U	0.062	U	0.064	U
Benzo(b)fluoranthene	(mg/kg)			1	1.7	0.0435	J	0.0976	J	0.07	U	0.0665	U	0.062	U	0.064	U
Benzo(g,h,i)perylene	(mg/kg)			100	1000	0.063	U	0.051	J	0.07	U	0.0665	U	0.062	U	0.064	U
Benzo(k)fluoranthene	(mg/kg)			0.8	1.7	0.063	U	0.0615	U	0.07	U	0.0665	U	0.062	U	0.064	U

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		South											
		Class B	Class C	Unrestricted Use	Protection of Groundwater	1217_42		1374_22		1787_44		2146_25		654_9		659_7	
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/24/2015		9/24/2015		9/24/2015		9/24/2015		9/24/2015		9/24/2015	
Beryllium, Total	(mg/kg)			7.2	47	0.295	U	0.27	U	0.33	U	0.28	J	0.24	J	0.34	J
beta-BHC	(mg/kg)			0.036	0.09	0.0054	U	0.00515	U	0.00585	U	0.0055	U	0.0055	U	0.0054	U
Cadmium, Total	(mg/kg)	1.2	9.5	2.5	7.5	0.295	U	0.27	U	0.33	U	0.305	U	0.275	U	0.28	U
Carbon Tetrachloride	(mg/kg)			0.76	0.76	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Chlorobenzene	(mg/kg)			1.1	1.1	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Chloroform	(mg/kg)			0.37	0.37	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Chromium, Total	(mg/kg)			1	19	**8.9**		**4.4**		**9.5**		**11.2**		**9.6**		**11.8**	
Chrysene	(mg/kg)			1	1	0.063	U	0.0799	J	0.07	U	0.0665	U	0.062	U	0.064	U
cis-1,2-Dichloroethene	(mg/kg)			0.25	0.25	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Copper, Total	(mg/kg)	33	270	50	1720	10		5		8.9		11.3		9.8		12.9	
Cyanide, Total	(mg/kg)			27	40	0.165	U	0.165	U	0.175	U	0.17	U	0.155	U	0.155	U
delta-BHC	(mg/kg)			0.04	0.25	0.0054	U	0.00515	U	0.00585	U	0.0055	U	0.0055	U	0.0054	U
Dibenzo(a,h)anthracene	(mg/kg)			0.33	1000	0.063	U	0.0615	U	0.07	U	0.0665	U	0.062	U	0.064	U
Dibenzofuran	(mg/kg)			7	210	0.063	U	0.0615	U	0.07	U	0.0665	U	0.062	U	0.064	U
Dieldrin	(mg/kg)	0.11	0.48	0.005	0.1	**0.0105**	U	**0.01**	U	**0.01135**	U	**0.0107**	U	**0.01065**	U	**0.01045**	U
Endosulfan I	(mg/kg)			2.4	102	0.0054	U	0.00515	U	0.00585	U	0.0055	U	0.0055	U	0.0054	U
Endosulfan II	(mg/kg)			2.4	102	0.0105	U	0.01	U	0.01135	U	0.0107	U	0.01065	U	0.01045	U
Endosulfan Sulfate	(mg/kg)			2.4	1000	0.0105	U	0.01	U	0.01135	U	0.0107	U	0.01065	U	0.01045	U
Endrin	(mg/kg)			0.014	0.06	0.0105	U	0.01	U	0.01135	U	0.0107	U	0.01065	U	0.01045	U
Ethylbenzene	(mg/kg)			1	1	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Fluoranthene	(mg/kg)			100	1000	0.0479	J	0.245		0.0534	J	0.0665	U	0.062	U	0.064	U
Fluorene	(mg/kg)			30	386	0.063	U	0.0615	U	0.07	U	0.0665	U	0.062	U	0.064	U
gamma-BHC	(mg/kg)			0.1	0.1	0.0054	U	0.00515	U	0.00585	U	0.0055	U	0.0055	U	0.0054	U
Heptachlor	(mg/kg)			0.042	0.38	0.0054	U	0.00515	U	0.00585	U	0.0055	U	0.0055	U	0.0054	U
Hexachlorobenzene	(mg/kg)			0.33	3.2	0.063	U	0.0615	U	0.07	U	0.0665	U	0.062	U	0.064	U
Hexavalent Chromium	(mg/kg)					1.3	U	1.3	U	1.4	U	1.35	U	1.3	U	1.25	U
Indeno(1,2,3-cd)pyrene	(mg/kg)			0.5	8.2	0.063	U	0.0533	J	0.07	U	0.0665	U	0.062	U	0.064	U
Lead, Total	(mg/kg)	47	218	63	450	13.3		4		12.7		8.8		10.7		11.5	
Manganese, Total	(mg/kg)			1600	2000	96.6		45.4		125		130		124		131	
Mercury, Total	(mg/kg)	0.17	1	0.18	0.73	0.05	J	0.0325	U	0.056	J	0.027	J	0.037	J	0.028	J
Methyl t-Butyl Ether	(mg/kg)			0.93	0.93	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Methylene Chloride	(mg/kg)			0.05	0.05	0.0079		0.0094		0.0146		0.0123		0.0109		0.0134	
Moisture	%					23.5		22.6		30		25		22.6		22.2	
mp-Cresol	(mg/kg)			0.33	0.33	0.1695	U	0.1655	U	0.189	U	0.18	U	0.168	U	0.1725	U
Naphthalene	(mg/kg)			12	12	0.063	U	0.0615	U	0.07	U	0.0665	U	0.062	U	0.064	U
n-Butylbenzene	(mg/kg)			12	12	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Nickel, Total	(mg/kg)			30	130	5.5		3.7		5.6		9.7		7.5		8.9	

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		South											
		Class B	Class C	Unrestricted Use	Protection of Groundwater	1217_42		1374_22		1787_44		2146_25		654_9		659_7	
Analyte	**Units**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**9/24/2015**		**9/24/2015**		**9/24/2015**		**9/24/2015**		**9/24/2015**		**9/24/2015**	
n-Propylbenzene	(mg/kg)			3.9	3.9	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
o-Cresol	(mg/kg)			0.33	0.33	0.1695	U	0.1655	U	0.189	U	0.18	U	0.168	U	0.1725	U
Pentachlorophenol	(mg/kg)			0.8	0.8	0.1255	U	0.1225	U	0.14	U	0.1335	U	0.1245	U	0.1275	U
Phenanthrene	(mg/kg)			100	1000	0.063	U	0.235		0.07	U	0.0665	U	0.062	U	0.064	U
Phenol	(mg/kg)			0.33	0.33	0.1695	U	0.1655	U	0.189	U	0.18	U	0.168	U	0.1725	U
Pyrene	(mg/kg)			100	1000	0.063	U	0.198		0.0543	J	0.0665	U	0.062	U	0.064	U
sec-Butylbenzene	(mg/kg)			11	11	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Selenium, Total	(mg/kg)			3.9	4	1.5	U	1.35	U	1.65	U	1.1	J	1.35	U	1.1	J
Silver, Total	(mg/kg)			2	8.3	0.6	U	0.55	U	0.65	U	0.6	U	0.55	U	0.55	U
tert-Butylbenzene	(mg/kg)			5.9	5.9	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Tetrachloroethene	(mg/kg)			1.3	1.3	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Toluene	(mg/kg)			0.7	0.7	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Total Polychlorinated Biphenyl	(mg/kg)	0.1	1	0.1	3.2	0.021	U	0.02	U	0.0225	U	0.0215	U	0.0215	U	0.021	U
Total Solids	%					76.5		77.4		70		75		77.4		77.8	
Total Xylenes	(mg/kg)			0.26	1.6	0.004	U	0.0039	U	0.0043	U	0.0041	U	0.0039	U	0.0039	U
trans-1,2-Dichloroethene	(mg/kg)			0.19	0.19	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Trichloroethene	(mg/kg)			0.47	0.47	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Trivalent Chromium	(mg/kg)					8.9		4.4		9.5		11.2		9.6		11.8	
Vinyl Chloride	(mg/kg)			0.02	0.02	0.0013	U	0.0013	U	0.00145	U	0.0014	U	0.0013	U	0.0013	U
Zinc, Total	(mg/kg)			109	2480	40.2		16.4		39.1		37.1		38.5		40.8	
Σ DDT, Calculated	(mg/kg)	0.003	0.03			0		0		0		0		0		0	
Total PAH, Calculated	(mg/kg)	4	45			0.0914		1.2071		0.1077		0		0		0	
Total BTEX, Calculated	(mg/kg)	0.96	5.9			0		0		0		0		0		0	

Appendix E-9: Sediment Chemistry Data (continued)

		NYSDEC TOGS 5.1.9		NYSDEC Part 375		South						
		Class B	Class C	Unrestricted Use	Protection of Groundwater	714_40	717_59	720_16	HB04_6	HB04_7	HB05_8	HB05_9
Analyte	Units	mg/kg	mg/kg	mg/kg	mg/kg	9/24/2015	9/24/2015	9/24/2015	9/21/2015	9/21/2015	9/21/2015	9/21/2015
1,1,1-Trichloroethane	(mg/kg)			0.68	0.68	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,1-Dichloroethane	(mg/kg)			0.27	0.27	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,1-Dichloroethene	(mg/kg)			0.33	0.33	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,2,4-Trimethylbenzene	(mg/kg)			3.6	3.6	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,2-Dichlorobenzene	(mg/kg)			1.1	1.1	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,2-Dichloroethane	(mg/kg)			0.02	0.02	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,3,5-Trimethylbenzene	(mg/kg)			8.4	8.4	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,3-Dichlorobenzene	(mg/kg)			2.4	2.4	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,4-Dichlorobenzene	(mg/kg)					0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
1,4-Dioxane	(mg/kg)			0.1	0.1	0.0477 U	0.0482 U	0.04945 U	0.04735 U	0.0482 U	0.03755 U	0.0409 U
2,4,5-TP	(mg/kg)			0.1	0.1	0.041 U	0.0414 U	0.0438 U	0.0469 U	0.04905 U	0.04705 U	0.04645 U
2-Butanone	(mg/kg)					0.0064 U	0.0065 U	0.0066 U	0.0042 J	0.00645 U	0.0064 J	0.00545 U
4,4'-DDD	(mg/kg)			0.0033	17	**0.0099** U	**0.0099** U	**0.0104** U	**0.01145** U	**0.01185** U	**0.0115** U	**0.0115** U
4,4'-DDE	(mg/kg)			0.0033	136	**0.0099** U	**0.0099** U	**0.0104** U	**0.01145** U	**0.01185** U	**0.0115** U	**0.0115** U
4,4'-DDT	(mg/kg)			0.0033	14	**0.0099** U	**0.0099** U	**0.0104** U	**0.01145** U	**0.01185** U	**0.0115** U	**0.0115** U
Acenaphthene	(mg/kg)			20	98	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
Acenaphthylene	(mg/kg)			100	107	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
Acetone	(mg/kg)			0.05	0.05	0.0062 J	0.0085 J	0.0066 J	0.0099 J	0.0083 J	0.0149	0.00545 U
Aldrin	(mg/kg)			0.005	0.19	**0.0051** U	**0.0051** U	**0.00535** U	**0.0059** U	**0.0061** U	**0.00595** U	**0.00595** U
alpha-BHC	(mg/kg)			0.02	0.02	0.0051 U	0.0051 U	0.00535 U	0.0059 U	0.0061 U	0.00595 U	0.00595 U
alpha-Chlordane	(mg/kg)			0.094	2.9	0.0051 U	0.0051 U	0.00535 U	0.0059 U	0.0061 U	0.00595 U	0.00595 U
Anthracene	(mg/kg)			100	1000	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
Aroclor-1016	(mg/kg)					0.02 U	0.02 U	0.021 U	0.023 U	0.0235 U	0.023 U	0.023 U
Aroclor-1221	(mg/kg)					0.02 U	0.02 U	0.021 U	0.023 U	0.0235 U	0.023 U	0.023 U
Aroclor-1232	(mg/kg)					0.02 U	0.02 U	0.021 U	0.023 U	0.0235 U	0.023 U	0.023 U
Aroclor-1242	(mg/kg)					0.02 U	0.02 U	0.021 U	0.023 U	0.0235 U	0.023 U	0.023 U
Aroclor-1248	(mg/kg)					0.02 U	0.02 U	0.021 U	0.023 U	0.0235 U	0.023 U	0.023 U
Aroclor-1254	(mg/kg)					0.47	0.02 U	0.021 U	0.023 U	0.0235 U	0.023 U	0.023 U
Aroclor-1260	(mg/kg)					0.02 U	0.02 U	0.021 U	0.023 U	0.0235 U	0.023 U	0.023 U
Arsenic, Total	(mg/kg)	8.2	53	13	16	1.9	2	1.9	3.8	5.8	3.9	4.7
Barium, Total	(mg/kg)			350	820	8.1	4.6	5.8	11.2	21.4	11.3	9.9
Benzene	(mg/kg)			0.06	0.06	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
Benzo(a)anthracene	(mg/kg)			1	1	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
Benzo(a)pyrene	(mg/kg)			1	22	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
Benzo(b)fluoranthene	(mg/kg)			1	1.7	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
Benzo(g,h,i)perylene	(mg/kg)			100	1000	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
Benzo(k)fluoranthene	(mg/kg)			0.8	1.7	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U

Appendix E-9: Sediment Chemistry Data (continued)

Analyte	Units	NYSDEC TOGS 5.1.9 Class B mg/kg	NYSDEC TOGS 5.1.9 Class C mg/kg	NYSDEC Part 375 Unrestricted Use mg/kg	NYSDEC Part 375 Protection of Groundwater mg/kg	South 714_40 9/24/2015		South 717_59 9/24/2015		South 720_16 9/24/2015		South HB04_6 9/21/2015		South HB04_7 9/21/2015		South HB05_8 9/21/2015		South HB05_9 9/21/2015	
Beryllium, Total	(mg/kg)			7.2	47	0.2	J	0.24	J	0.305	U	0.33	U	0.3	J	0.26	J	0.25	J
beta-BHC	(mg/kg)			0.036	0.09	0.0051	U	0.0051	U	0.00535	U	0.0059	U	0.0061	U	0.00595	U	0.00595	U
Cadmium, Total	(mg/kg)	1.2	9.5	2.5	7.5	0.235	U	0.27	U	0.305	U	0.34	J	0.5	J	0.295	U	0.31	U
Carbon Tetrachloride	(mg/kg)			0.76	0.76	0.0013	U	0.0013	U	0.0013	U	0.00125	U	0.0013	U	0.001	U	0.0011	U
Chlorobenzene	(mg/kg)			1.1	1.1	0.0013	U	0.0013	U	0.0013	U	0.00125	U	0.0013	U	0.001	U	0.0011	U
Chloroform	(mg/kg)			0.37	0.37	0.0013	U	0.0013	U	0.0013	U	0.00125	U	0.0013	U	0.001	U	0.0011	U
Chromium, Total	(mg/kg)			1	19	**9.8**		**11**		**7.5**		**14.7**		***20.4***		**14**		**13.2**	
Chrysene	(mg/kg)			1	1	0.06	U	0.0605	U	0.064	U	0.0705	U	0.0745	U	0.0695	U	0.0705	U
cis-1,2-Dichloroethene	(mg/kg)			0.25	0.25	0.0013	U	0.0013	U	0.0013	U	0.00125	U	0.0013	U	0.001	U	0.0011	U
Copper, Total	(mg/kg)	33	270	50	1720	9.4		15.8		7.3		20.1		25.2		8.4		9.2	
Cyanide, Total	(mg/kg)			27	40	0.155	U	0.155	U	0.17	U	0.18	U	0.19	U	0.18	U	0.17	U
delta-BHC	(mg/kg)			0.04	0.25	0.0051	U	0.0051	U	0.00535	U	0.0059	U	0.0061	U	0.00595	U	0.00595	U
Dibenzo(a,h)anthracene	(mg/kg)			0.33	1000	0.06	U	0.0605	U	0.064	U	0.0705	U	0.0745	U	0.0695	U	0.0705	U
Dibenzofuran	(mg/kg)			7	210	0.06	U	0.0605	U	0.064	U	0.0705	U	0.0745	U	0.0695	U	0.0705	U
Dieldrin	(mg/kg)	0.11	0.48	0.005	0.1	**0.0099**	U	**0.0099**	U	**0.0104**	U	**0.01145**	U	**0.01185**	U	**0.0115**	U	**0.0115**	U
Endosulfan I	(mg/kg)			2.4	102	0.0051	U	0.0051	U	0.00535	U	0.0059	U	0.0061	U	0.00595	U	0.00595	U
Endosulfan II	(mg/kg)			2.4	102	0.0099	U	0.0099	U	0.0104	U	0.01145	U	0.01185	U	0.0115	U	0.0115	U
Endosulfan Sulfate	(mg/kg)			2.4	1000	0.0099	U	0.0099	U	0.0104	U	0.01145	U	0.01185	U	0.0115	U	0.0115	U
Endrin	(mg/kg)			0.014	0.06	0.0099	U	0.0099	U	0.0104	U	0.01145	U	0.01185	U	0.0115	U	0.0115	U
Ethylbenzene	(mg/kg)			1	1	0.0013	U	0.0013	U	0.0013	U	0.00125	U	0.0013	U	0.001	U	0.0011	U
Fluoranthene	(mg/kg)			100	1000	0.06	U	0.0605	U	0.064	U	0.0705	U	0.0745	U	0.0695	U	0.0705	U
Fluorene	(mg/kg)			30	386	0.06	U	0.0605	U	0.064	U	0.0705	U	0.0745	U	0.0695	U	0.0705	U
gamma-BHC	(mg/kg)			0.1	0.1	0.0051	U	0.0051	U	0.00535	U	0.0059	U	0.0061	U	0.00595	U	0.00595	U
Heptachlor	(mg/kg)			0.042	0.38	0.0051	U	0.0051	U	0.00535	U	0.0059	U	0.0061	U	0.00595	U	0.00595	U
Hexachlorobenzene	(mg/kg)			0.33	3.2	0.06	U	0.0605	U	0.064	U	0.0705	U	0.0745	U	0.0695	U	0.0705	U
Hexavalent Chromium	(mg/kg)					1.2	U	1.3	U	1.3	U	1.4	U	1.4	U	1.45	U	1.35	U
Indeno(1,2,3-cd)pyrene	(mg/kg)			0.5	8.2	0.06	U	0.0605	U	0.064	U	0.0705	U	0.0745	U	0.0695	U	0.0705	U
Lead, Total	(mg/kg)	47	218	63	450	7.6		7.1		8.2		24.5		36.2		19		20.1	
Manganese, Total	(mg/kg)			1600	2000	78.3		80.8		84.3		335		490		298		282	
Mercury, Total	(mg/kg)	0.17	1	0.18	0.73	0.022	J	0.0275	U	0.028	J	0.17		**0.22**		0.066	J	0.07	
Methyl t-Butyl Ether	(mg/kg)			0.93	0.93	0.0013	U	0.0013	U	0.0013	U	0.00125	U	0.0013	U	0.0005	J	0.0011	U
Methylene Chloride	(mg/kg)			0.05	0.05	0.0133		0.0141		0.0107		0.0261		0.0267		0.023		0.0219	
Moisture	%					20.2		21.4		23.6		31.1		33		29.7		29.3	
mp-Cresol	(mg/kg)			0.33	0.33	0.1615	U	0.163	U	0.173	U	0.1895	U	0.2015	U	0.1885	U	0.191	U
Naphthalene	(mg/kg)			12	12	0.06	U	0.0605	U	0.064	U	0.0705	U	0.0745	U	0.0695	U	0.0705	U
n-Butylbenzene	(mg/kg)			12	12	0.0013	U	0.0013	U	0.0013	U	0.00125	U	0.0013	U	0.001	U	0.0011	U
Nickel, Total	(mg/kg)			30	130	8.8		7.7		5.9		8.4		10.7		9.3		9	

Appendix E-9: Sediment Chemistry Data (continued)

Analyte	Units	NYSDEC TOGS 5.1.9 Class B mg/kg	NYSDEC TOGS 5.1.9 Class C mg/kg	NYSDEC Part 375 Unrestricted Use mg/kg	NYSDEC Part 375 Protection of Groundwater mg/kg	South 714_40 9/24/2015	South 717_59 9/24/2015	South 720_16 9/24/2015	South HB04_6 9/21/2015	South HB04_7 9/21/2015	South HB05_8 9/21/2015	South HB05_9 9/21/2015
n-Propylbenzene	(mg/kg)			3.9	3.9	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
o-Cresol	(mg/kg)			0.33	0.33	0.1615 U	0.163 U	0.173 U	0.1895 U	0.2015 U	0.1885 U	0.191 U
Pentachlorophenol	(mg/kg)			0.8	0.8	0.1195 U	0.121 U	0.128 U	0.1405 U	0.1495 U	0.1395 U	0.1415 U
Phenanthrene	(mg/kg)			100	1000	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
Phenol	(mg/kg)			0.33	0.33	0.1615 U	0.163 U	0.173 U	0.1895 U	0.2015 U	0.1885 U	0.191 U
Pyrene	(mg/kg)			100	1000	0.06 U	0.0605 U	0.064 U	0.0705 U	0.0745 U	0.0695 U	0.0705 U
sec-Butylbenzene	(mg/kg)			11	11	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
Selenium, Total	(mg/kg)			3.9	4	0.97 J	0.98 J	1.5 U	1.65 U	1.2 J	1.5 U	1.55 U
Silver, Total	(mg/kg)			2	8.3	0.475 U	0.55 U	0.6 U	0.65 U	0.75 U	0.6 U	0.6 U
tert-Butylbenzene	(mg/kg)			5.9	5.9	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
Tetrachloroethene	(mg/kg)			1.3	1.3	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
Toluene	(mg/kg)			0.7	0.7	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
Total Polychlorinated Biphenyl	(mg/kg)	0.1	1	0.1	3.2	**0.47**	0.02 U	0.021 U	0.023 U	0.0235 U	0.023 U	0.023 U
Total Solids	%					79.8	78.6	76.4	68.9	67	70.3	70.7
Total Xylenes	(mg/kg)			0.26	1.6	0.0038 U	0.0039 U	0.00395 U	0.0038 U	0.00385 U	0.003 U	0.00325 U
trans-1,2-Dichloroethene	(mg/kg)			0.19	0.19	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
Trichloroethene	(mg/kg)			0.47	0.47	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
Trivalent Chromium	(mg/kg)					9.8	11	7.5	14.7	20.4	14	13.2
Vinyl Chloride	(mg/kg)			0.02	0.02	0.0013 U	0.0013 U	0.0013 U	0.00125 U	0.0013 U	0.001 U	0.0011 U
Zinc, Total	(mg/kg)			109	2480	27.2	28.3	29.7	68.9	87.4	58.5	59
Σ DDT, Calculated	(mg/kg)	0.003	0.03			0	0	0	0	0	0	0
Total PAH, Calculated	(mg/kg)	4	45			0	0	0	0	0	0	0
Total BTEX, Calculated	(mg/kg)	0.96	5.9			0	0	0	0	0	0	0

Note:
Below detection values reported at 0.5 * reporting limit for individual parameters, reported as 0 when comparing against summed values.

NYSDEC TOGS 5.1.9 - Class B Exceedance
NYSDEC TOGS 5.1.9 - Class C Exceedance
NYSDEC Part 375 Unrestricted Use Exceedance
NYSDEC Part 375 Protection of Groundwater Exceedance

Appendix E-10
Existing Conditions Site Photographs

PHOTO 1 - VIEW OF THE BEACH AND FORESTED UPLANDS ON THE NORTHEASTERN PORTION OF THE STUDY AREA, FACING SOUTH.

PHOTO 2 - VIEW OF THE BEACH AND ARTIFICIAL TEMPORARY WITHIN THE STUDY AREA, FACING SOUTH.

PHOTO 3 - VIEW FROM THE TOP OF THE ARTIFICIAL TEMPORARY DUNES, BEACH, AND VEGETATED UPLAND, FACING NORTH.

PHOTO 4 - VIEW OF THE UNMAPPED COMMON REED (*PHRAGMITES AUSTRALIS*) DOMINATED MARSH WITHIN THE STUDY AREA, FACING WEST.

PHOTO 5- VIEW OF THE BEACH AND VEGETATED DUNES WITHIN THE STUDY AREA, FACING EAST.

PHOTO 6 - VIEW OF THE VEGETATED DUNES AND FORESTED UPLANDS ON THE SOUTHERN PORTION OF THE STUDY AREA, FACING WEST.

PHOTO 7 - VIEW OF THE SOUTHERN SUCCESSIONAL HARDWOOD COMMUNITY FROM THE BEACH, FACING WEST.

Appendix E-11
Calculation of Available Surface Area and Marine Habitat Generated for Living Breakwaters—Memo

MEMO

Date: November 28, 2016
From: SCAPE, OCC, SEARC
To: AKRF, GOSR
Cc:
Re: **Calculation of Available Surface Area and Marine Habitat Generated for Living Breakwaters**

The Living Breakwaters team has calculated the amount of marine habitat generated and displaced by the project, taking into consideration both the breakwater structures and the potential beach fill proposed. This memo defines the habitats considered and describes the methods used for calculating the approximate areas of each of these habitats created and displaced by the project. Back up documentation and summary areas are provided in the attachments.

SUMMARY OF TYPES OF HABITAT DISPLACED AND CREATED

The elements of the project included in this estimation of habitat created and displaced include in-water surface piercing breakwaters constructed of a combination of rock and bio-enhancing concrete units, and a single stretch of beach fill consisting of sand.

The existing habitats in the locations where the project elements (breakwaters and beach fill) will be located consist largely of small and large grain (sand and gravel) subtidal and intertidal habitat.

The **breakwaters** will replace existing subtidal small and large grained bottom habitat with subtidal, intertidal, and emergent hard / rocky habitat, comprised of rock and bio-enhancing concrete of varying sizes depending on their function and location on the breakwater.

The **beach fill** will replace subtidal and intertidal small and large grained habitat (sand, gravel and pebbles) with subtidal, intertidal, and emergent small grained habitat (sand).

Habitat Type Definitions

As described in the Living Breakwaters 30% Design Report, habitat types have been defined by (1) their substrate or grain size and (2) their location within the tidal column.

Substrate / Grain Size Definitions:

- **Hard / rocky bottom:** Greater than 64mm (2.5”). Substrate includes small cobbles to boulders. The breakwater structures are considered to be hard / rocky bottomed

habitat. Habitats are observed or will occur in emergent, intertidal, and subtidal conditions.

- **Large grain:** 64mm (2.5”) to 2mm (.07”). Substrates in this category include gravel, pebbles, and shells. Habitats are observed or will occur in intertidal and subtidal conditions.
- **Small grain:** 2mm (.07”) to .063mm (.002”). Substrate includes sand. This includes existing sandy bottomed habitats. Habitats are observed or will occur in emergent, intertidal, and subtidal conditions.
- **Fine grain:** Less than .063mm (.002”). Substrate in this category include silt and clay and is characterized by generally cohesive material. This condition is not observed in the area where breakwaters are proposed, nor is it anticipated to be generated by the breakwaters’ interactions with their surroundings.
- **Vegetated:** This habitat includes submerged aquatic vegetation (SAV) and intertidal vegetation, usually occurring in small to fine grained conditions. While this habitat may form over time as a result of the project, it is not being directly constructed as part of the project.

Location in the Tidal Column Definitions:

- **Emergent:** above mean high water (MHW), includes the supra-littoral zone (an area above MHW which is mostly effected by sea-spray and gets water cover, by surge or waves, only in storms).
- **Intertidal:** An area of tidal amplitude, between mean low water (MLW) and MHW. Organisms in this area are most effected by waves and tidal fluctuations, as their level of water coverage varies. Also “littoral”.
- **Subtidal:** An area below low tide, below MLW. This area is always covered with water, and if exposed, only for a very short time period. Also “sublittoral”.

For a more detailed description of the habitats types and the species they may serve, refer to the 30% Design Report Appendix M: Target Functional Groups and Habitats.

Due to the specificity of existing habitat surveys, it is not possible to determine the specific extents and areas of small grained (sand) versus large grained (gravel and pebbles) habitat, so for the purposes of this habitat quantification process, these two habitat types have been combined.

APPROACH TO QUANTIFYING HABITATS DISPLACED AND CREATED

Habitats Included / Excluded From These Calculations

For the purpose of these calculations, only marine (intertidal and subtidal) habitat has been quantified. Neither the emergent habitat created by the breakwaters and beach fill, nor any emergent habitat displaced by the beach fill are included. No emergent habitat will be displaced by the breakwaters. Though the emergent areas of the breakwaters will provide habitat potential (such as seal haul out areas or bird roosts), it is not directly related to surface area and is not inhabited in the same way that the niches and crevices created by the subtidal and intertidal rocks and bio-enhancing armor units will be. As the productive surface area is less easily quantifiable and function differently than the subtidal and intertidal habitats, their benefits will be noted qualitatively, but they are excluded from these quantitative calculations.

Method Used For Calculating Breakwater Habitat Created

The breakwaters will create hard / rocky habitat consisting of rock and bio-enhancing concrete units ranging from 12” to 40” in diameter. Given their size relative to the target species / functional groups, these materials will create niches and crevices between individual units that are usable by the target species / functional groups, thus generating habitat area significantly greater than the planar surface area of the simple breakwater structure.

In order to estimate the actual area of hard / rock subtidal and intertidal habitat created by the breakwaters, an approximation of Accessible Surface Area (ASA) was developed.

In order to calculate the Accessible Surface Area (ASA), and from it the available habitat generated by the various areas of the breakwater, the following methodology was used:

1. Calculate the total volume of the material in the identified portion of the breakwater using geometric approximation (see below for assumptions made regarding the geometry of materials for different areas of the breakwaters).
2. Calculate the volume of the voids within the total volume using porosity for rough, random placement of the units.
3. Calculate the total number of units using the volume of a sphere to idealize a single unit.
4. Calculate the Available Surface Area (ASA) by multiplying the number of units by the surface area of the idealized unit.
5. Calculate the Available Habitat by multiplying the ASA by 70%

Using this methodology, the areas created by the main breakwater segment and the reef ridges / streets were calculated separately and combined to generate an estimation of the total ASA of hard / rocky intertidal and subtidal habitat created by the breakwaters.

A number of assumptions and geometric approximations were required to use this methodology:

- The shape of the stones or bio-enhancing concrete units (regardless of size) comprising the different parts of the breakwater is a sphere with a constant diameter equal to the median stone size (D_{50}).
- A simplified geometry (length, width, thickness) is used to calculate the volume, which negates irregularities due to stone/unit placement.
- The porosity is based on values given in Table VI-5-51 of the Coastal Engineering Manual (USACE EM 1110-2-1100) for a two-layer, randomly placed rough quarry stone.
- The available habitat created is dependent on different factors, which vary with the penetration into the subsurface such as grain/stone size, dissolved oxygen, nutrient flux, light, temp, etc. These factors dictate the actual percentage of the ASA, which can be regarded as the available habitat. Since it is difficult to quantify the above-mentioned variables at this point in the design process, we recommend calculating the available habitat using a conservative assessment of 70% of the ASA as a rule of thumb. This number will present the available habitat as the area of the ASA not effected by limiting or overloading environmental factures, which can be considered as an Essential Fish Habitat. Thus, this will provide habitat for a diversity of sessile and algae species which serve as food and cover for fish and other foraging organisms (NOAA Fisheries Greater Atlantic Region).

In addition, the following assumptions regarding material composition and size were made:

- For the main breakwater segment:
    - To calculate the ASA for the armored portion of the main breakwaters and average geometric approximation of both armor and toe armor units (both rock and bio-enhancing concrete) was made; units were assumed to have an average diameter of 30” and be present at a consistent thickness of two layers for all breakwater types.
    - The ASA of the scour apron, where it extended beyond the armored portion of the main breakwater, was calculated separately from the armor portion; units of the

scour apron were assumed to consist of bedding stone with an average diameter of 12” and thickness of one layer of stone for all breakwater types.

- For the reef ridges & streets:
  - To calculate the ASA for the armored portion of the main breakwaters and average geometric approximation of the various materials comprising the reef streets—riprap and toe armor units (both stone and bio-enhancing concrete)—was made; units were assumed to have an average diameter of 30” and thickness was assumed to vary by breakwater type.
  - The ASA of the scour apron, where it extends between (reef streets) and beyond the reef ridges was calculated separately from the riprap and armor units of the reef ridges; units of the scour apron were assumed to consist of bedding stone with an average diameter of 12” and thickness of one layer of stone for all breakwater types.

The above method and assumptions were used to calculate the ASA of the intertidal and subtidal hard / rocky marine habitat generated by the living breakwaters. The backup calculations prepared to estimate the habitat surface area created by the breakwaters are provided in *Table 2: Volume, Void, and Surface Area Backup Calculations*.

As the design is further refined, additional factors such as surface texture / roughness can be considered as part of the habitat creating factors for more detailed habitat quantity estimates.

Method for Calculating Beach Fill Habitat Created

It is assumed that the beach fill will consist of sand (small grained habitat, grain sizes will range between 2mm (.07”) to .063mm (.002”)). Thus, for the beach fill habitat area calculations, a planar area (square footage) was calculated to estimate the area of small grained habitat created by the beach fill as the void between grains are too small to appreciably influence the ASA of the habitat created by small grained material.

Method for Calculating Habitat Displaced

All of the habitat displaced is small and large grained habitat (grain size between .063mm (.002”) and .64mm (2.5”)). Thus, for these habitat area calculations a planar area (square footage) was calculated to estimate the area of small grained habitat displaced as the void between grains are too small to appreciably influence the ASA of the habitat created by small and large grained material.

SUMMARY

Table 1: Summary of Habitat Displaced and Created by the Living Breakwaters (attached) contains a summary of the marine habitat that is anticipated to be displaced and created by the project, according to the methodology outlined above. The overall totals according to this methodology show that a net change of +27.2 acres of marine habitat will be created below the MHW line (subtidal and intertidal). Table 1 includes a summary of the surface area of intertidal and subtidal habitat displaced and created (small/large grained habitat and hard/rocky habitat). This estimate includes habitat created and displaces by both the breakwater structures (inclusive of reef streets) and the beach fill.

SUPPORTING CALCULATIONS AND DOCUMENTATION (ATTACHED)

Table 1. Summary of Habitat Displaced and Created by the Living Breakwaters (30% Design Scenario)

Table 2: Volume, Void, and Surface Area Backup Calculations

Figure 1. Breakwater Habitat Types

Figure 2. Breakwater Materials and their Sizes

Figure 3. Breakwater Habitat Areas and Available Surface Area (ASA) Calculation Method

TABLE 1: SUMMARY OF HABITAT DISPLACED AND CREATED BY LIVING BREAKWATERS (30% DESIGN SCENARIO)

	Habitat Areas [squre feet]			Habitat Areas [acres]			Beach Fill [square feet]			Breakwater Core [square feet]			Reef Streets [square feet]		
	Displaced	Created	NET change	Displaced	Created	NET change	Displaced	Created	NET change	Displaced	Created	NET change	Displaced	Created	NET change
intertidal small and large grained (sand and gravel)*	39,091	56,984	17,893	0.9	1.3	0.4	39,091	56,984	17,893	0	0	0	0	0	0
subtidal small and large grained (sand and gravel)*	654,383	30,991	-623,392	15.0	0.7	-14.3	103,289	30,991	-72,298	429,779	0	-429,779	121,315	0	-121,315
hard / rocky (hard bottom) intertidal	0	564,837	564,837	0.0	13.0	13.0	0	0	0	0	492,199	492,199	0	72,638	72,638
hard / rocky (hard bottom) subtidal	0	1,231,626	1,231,626	0.0	28.3	28.3	0	0	0	0	599,803	599,803	0	631,822	631,822
total below MHW (subtidal & intertidal)	693,474	1,884,437	1,190,963	15.9	43.3	27.3	142,380	87,975	-54,405	429,779	1,092,002	662,223	121,315	704,460	583,145

	BW TOTAL (core + reef street)		
	Displaced	Created	NET change
intertidal small and large grained (sand and gravel)*	0	0	0
subtidal small and large grained (sand and gravel)*	551,094	0	-551,094
hard / rocky (hard bottom) intertidal	0	564,837	564,837
hard / rocky (hard bottom) subtidal	0	1,231,626	1,231,626
total below MHW (subtidal & intertidal)	551,094	1,796,463	1,245,368

TABLE 2: VOLUME, VOID, AND SURFACE AREA BACKUP CALCULATIONS (1 OF 2)

INTERTIDAL CALCULATIONS

location	material	BW type	Length of Armor Layer per Breakwater (A)	Armor Layer Thickness (B)	Armor Layer Height (C)	Total Volume (A)*(B)*(C) /sinθ (D)	Porosity n=Vvoid/Vtotal (E)	Volume of Voids Vvoid=Vtotal*n (D)*(E) (F)	Volume of Armor Units (D)-(F) (G)	Volume of Idealized Armor Unit Sphere of diameter 3.3' V=4/3*PI*(ø/2)^3 (H)	Number of Units Possible within Volume (G)/(H) (I)
Main Breakwater	both stone and bio-enhancing concrete armor units and toe armor units, D50=30"	Type 'A'	990.00	6.60	4.70	67,644.15	0.37	25,028.33	42,615.81	18.82	2,264.80
		Type 'B'	724.00	6.60	4.70	49,469.05	0.37	18,303.55	31,165.50	18.82	1,656.28
		Type 'C'	1,330.00	6.60	4.70	90,875.47	0.37	33,623.92	57,251.55	18.82	3,042.61

location	material		Length of Ridges per Breakwater (A)	Ridge Section Area at Core (B)	Ridge Section Area at End (C)	Total Volume (A)* [(B)+(C)]/2 (D)	Porosity n=Vvoid/Vtotal (E)	Volume of Voids Vvoid=Vtotal*n (D)*(E) (F)	Volume of Reef Units (D)-(F) (G)	Volume of Idealized Reef Unit Sphere of diameter 2.5' V=4/3*PI*(ø/2)^3 (H)	Number of Units Possible within Volume (G)/(H) (I)
Reef Ridges & Streets (reef ridge)	Rip Rap (#1 & 2) and Toe Armor Units; D50=30"	Type 'A'	520.00	35.00	0.00	9,100.00	0.37	3,367.00	5,733.00	8.18	700.75
		Type 'B'	410.00	32.00	0.00	6,560.00	0.37	2,427.20	4,132.80	8.18	505.16
		Type 'C'	410.00	27.00	0.00	5,535.00	0.37	2,047.95	3,487.05	8.18	426.23

SUBTIDAL CALCULATIONS

location	material	BW type	Length of Armor Layer per Breakwater (A)	Armor Layer Thickness (B)	Armor Layer Height (C)	Total Volume (A)*(B)*(C) /sinθ (D)	Porosity n=Vvoid/Vtotal (E)	Volume of Voids Vvoid=Vtotal*n (D)*(E) (F)	Volume of Armor Units (D)-(F) (G)	Volume of Idealized Armor Unit Sphere of diameter 3.3' V=4/3*PI*(ø/2)^3 (H)	Number of Units Possible within Volume (G)/(H) (I)
Main Breakwater	both stone and bio-enhancing concrete armor units and toe armor units, D50=30"	Type 'A'	990.00	6.60	1.38	19,861.47	0.37	7,348.74	12,512.73	18.82	664.98
		Type 'B'	724.00	6.60	3.38	35,575.62	0.37	13,162.98	22,412.64	18.82	1,191.11
		Type 'C'	1,330.00	6.60	6.38	123,358.62	0.37	45,642.69	77,715.93	18.82	4,130.19

location	material	BW type	Length of Apron per Breakwater (A)	Avg. Apron Layer Width (B)	Apron Layer Height (C)	Total Volume (A)*(B)*(C) (D)	Porosity n=Vvoid/Vtotal (E)	Volume of Voids Vvoid=Vtotal*n (D)*(E) (F)	Volume of Reef Units (D)-(F) (G)	Volume of Idealized Apron Stone Sphere of diameter 1.0' V=4/3*PI*(ø/2)^3 (H)	Number of Stones Possible within Volume (G)/(H) (I)
Main Breakwater (scour apron)	bedding stone; D50=12"	Type 'A'	838.00	10.00	1.00	8,380.00	0.37	3,100.60	5,279.40	0.52	10,082.91
		Type 'B'	594.00	10.00	1.00	5,940.00	0.37	2,197.80	3,742.20	0.52	7,147.08
		Type 'C'	1,140.00	10.00	1.00	11,400.00	0.37	4,218.00	7,182.00	0.52	13,716.61

location	material	BW type	Length of Ridges per Breakwater (A)	Ridge Section Area at Core (B)	Ridge Section Area at End (C)	Total Volume (A)*[(B)+(C)] /2 (D)	Porosity n=Vvoid/Vtotal (E)	Volume of Voids Vvoid=Vtotal*n (D)*(E) (F)	Volume of Reef Units (D)-(F) (G)	Volume of Idealized Reef Unit Sphere of diameter 2.5' V=4/3*PI*(ø/2)^3 (H)	Number of Units Possible within Volume (G)/(H) (I)
Reef Ridges & Streets (reef ridge)	Rip Rap (#1 & 2) and Toe Armor Units; D50=30"	Type 'A'	520.00	18.00	18.00	9,360.00	0.37	3,463.20	5,896.80	8.18	720.77
		Type 'B'	410.00	85.00	85.00	34,850.00	0.37	12,894.50	21,955.50	8.18	2,683.64
		Type 'C'	410.00	216.00	216.00	88,560.00	0.37	32,767.20	55,792.80	8.18	6,819.61

location	material	BW type	Length of Apron per Breakwater (A)	Avg. Apron Layer Width (B)	Apron Layer Height (C)	Total Volume (A)*(B)*(C) (D)	Porosity n=Vvoid/Vtotal (E)	Volume of Voids Vvoid=Vtotal*n (D)*(E) (F)	Volume of Reef Units (D)-(F) (G)	Volume of Idealized Apron Stone Sphere of diameter 1.0' V=4/3*PI*(ø/2)^3 (H)	Number of Stones Possible within Volume (G)/(H) (I)
Reef Ridges & Streets (scour apron)	bedding stone; D50=12"	Type 'A'	1,192.00	4.00	1.00	4,768.00	0.37	1,764.16	3,003.84	0.52	5,736.91
		Type 'B'	950.00	8.40	1.00	7,980.00	0.37	2,952.60	5,027.40	0.52	9,601.63
		Type 'C'	1,010.00	9.60	1.00	9,696.00	0.37	3,587.52	6,108.48	0.52	11,666.34

notes / assumptions

Scour apron length only includes exposed areas (not covered by reef ridge or armor layer)
Scour apron width includes slope and flat
Ridge layer width = Width at base + (2) 40" toe units
Ridge layer assumes 30" average unit size. Toe unit D50=40", Riprap Stone 1 D50=30", Riprap stone 2 D50 = 24"

TABLE 2: VOLUME, VOID, AND SURFACE AREA BACKUP CALCULATIONS (2 OF 2)

INTERTIDAL CALCULATIONS 564,837

location	material	BW type	Surface Area of Armor Unit SA=4*PI*(ø/2)^2 (J)	Total Surface Area of All Armor Units (Accessable Surface Area) (I)*(J) (K)	Available Habitat 70% of ASA (K)*0.7 (L)	Number of Breakwaters (M)	Total Available Habitat [sf] (L)*(M) (N)
Main Breakwater	both stone and bio-enhancing concrete armor units and toe armor units, D50=30"	Type 'A'	34.21	77,483.30	54,238.31	2	108,477
		Type 'B'	34.21	56,664.55	39,665.19	6	237,991
		Type 'C'	34.21	104,093.72	72,865.60	2	145,731
						Total [sf]	492,199

location	material		Surface Area of Reef Unit SA=4*PI*(ø/2)^2 (J)	Total Surface Area of All Reef Units (Accessable Surface Area) (I)*(J) (K)	Available Habitat 70% of ASA (K)*0.7 (L)	Number of Breakwaters (M)	Total Available Habitat [sf] (L)*(M) (N)
Reef Ridges & Streets (reef ridge)	Rip Rap (#1 & 2) and Toe Armor Units; D50=30"	Type 'A'	19.63	13,759.20	9,631.44	2	19,263
		Type 'B'	19.63	9,918.72	6,943.10	6	41,659
		Type 'C'	19.63	8,368.92	5,858.24	2	11,716
						Total [sf]	72,638

SUBTIDAL CALCULATIONS 1,231,626

location	material	BW type	Surface Area of Armor Unit SA=4*PI*(ø/2)^2 (J)	Total Surface Area of All Armor Units (Accessable Surface Area) (I)*(J) (K)	Available Habitat 70% of ASA (K)*0.7 (L)	Number of Breakwaters (M)	Total Available Habitat [sf] (L)*(M) (N)
Main Breakwater	both stone and bio-enhancing concrete armor units and toe armor units, D50=30"	Type 'A'	34.21	22,750.41	15,925.29	2	31,851
		Type 'B'	34.21	40,750.25	28,525.18	6	171,151
		Type 'C'	34.21	141,301.69	98,911.18	2	197,822
						Total [sf]	400,824

location	material	BW type	Surface Area of Apron Stone SA=4*PI*(ø/2)^2 (J)	Total Surface Area of All Reef Units (Accessable Surface Area) (I)*(J) (K)	Available Habitat 70% of ASA (K)*0.7 (L)	Number of Breakwaters (M)	Total Available Habitat [sf] (L)*(M) (N)
Main Breakwater (scour apron)	bedding stone; D50=12"	Type 'A'	3.14	31,676.40	22,173.48	2	44,347
		Type 'B'	3.14	22,453.20	15,717.24	6	94,303
		Type 'C'	3.14	43,092.00	30,164.40	2	60,329
						Total [sf]	198,979

location	material	BW type	Surface Area of Reef Unit SA=4*PI*(ø/2)^2 (J)	Total Surface Area of All Reef Units (Accessable Surface Area) (I)*(J) (K)	Available Habitat 70% of ASA (K)*0.7 (L)	Number of Breakwaters (M)	Total Available Habitat [sf] (L)*(M) (N)
Reef Ridges & Streets (reef ridge)	Rip Rap (#1 & 2) and Toe Armor Units; D50=30"	Type 'A'	19.63	14,152.32	9,906.62	2	19,813
		Type 'B'	19.63	52,693.20	36,885.24	6	221,311
		Type 'C'	19.63	133,902.72	93,731.90	2	187,464
						Total [sf]	428,588

location	material	BW type	Surface Area of Apron Stone SA=4*PI*(ø/2)^2 (J)	Total Surface Area of All Reef Units (Accessable Surface Area) (I)*(J) (K)	Available Habitat 70% of ASA (K)*0.7 (L)	Number of Breakwaters (M)	Total Available Habitat [sf] (L)*(M) (N)
Reef Ridges & Streets (scour apron)	bedding stone; D50=12"	Type 'A'	3.14	18,023.04	12,616.13	2	25,232
		Type 'B'	3.14	30,164.40	21,115.08	6	126,690
		Type 'C'	3.14	36,650.88	25,655.62	2	51,311
						Total [sf]	203,234

notes / assumptions

FIGURE 1: BREAKWATER HABITAT TYPES

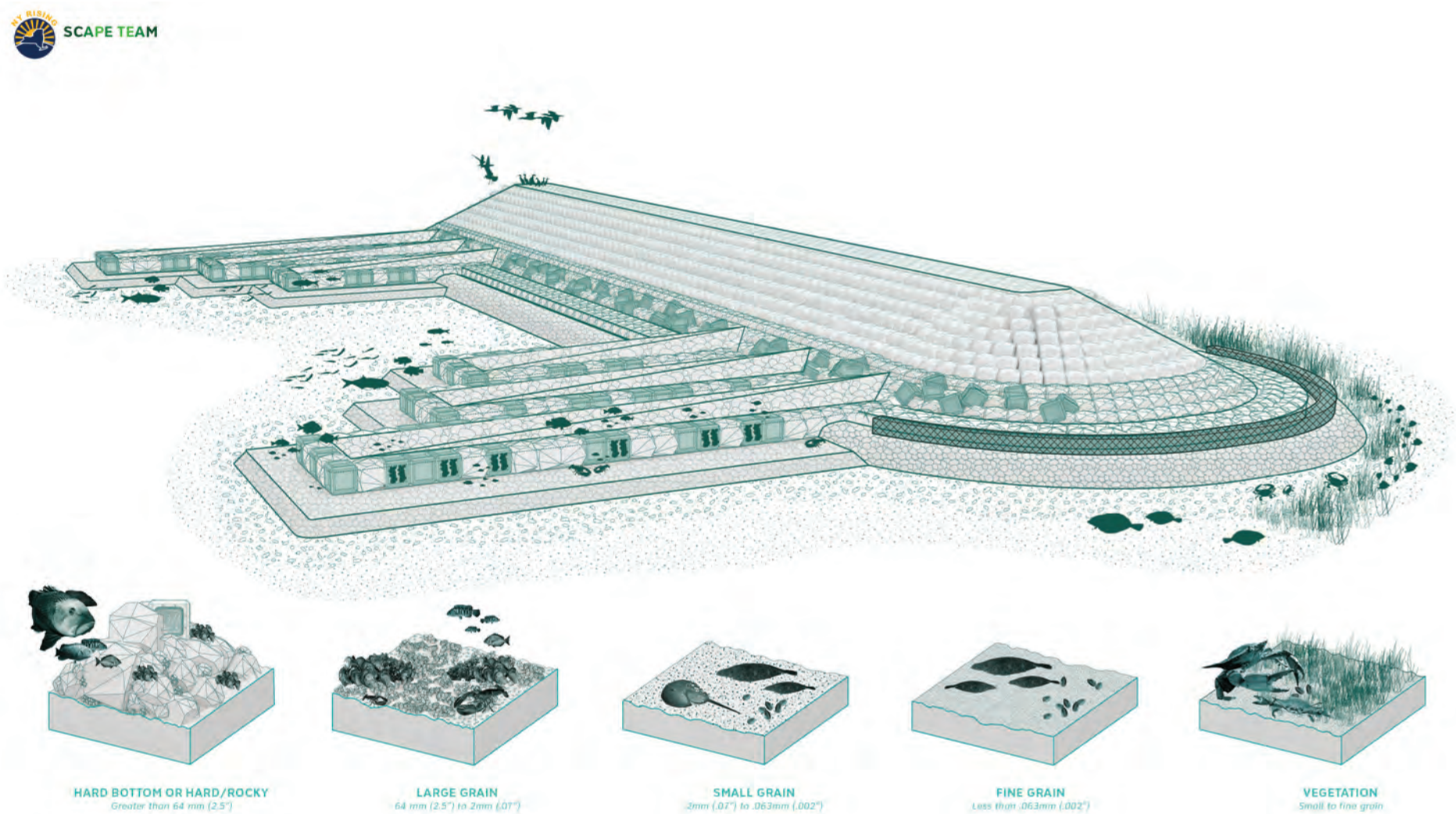


FIGURE 2: BREAKWATER MATERIALS AND THEIR SIZES

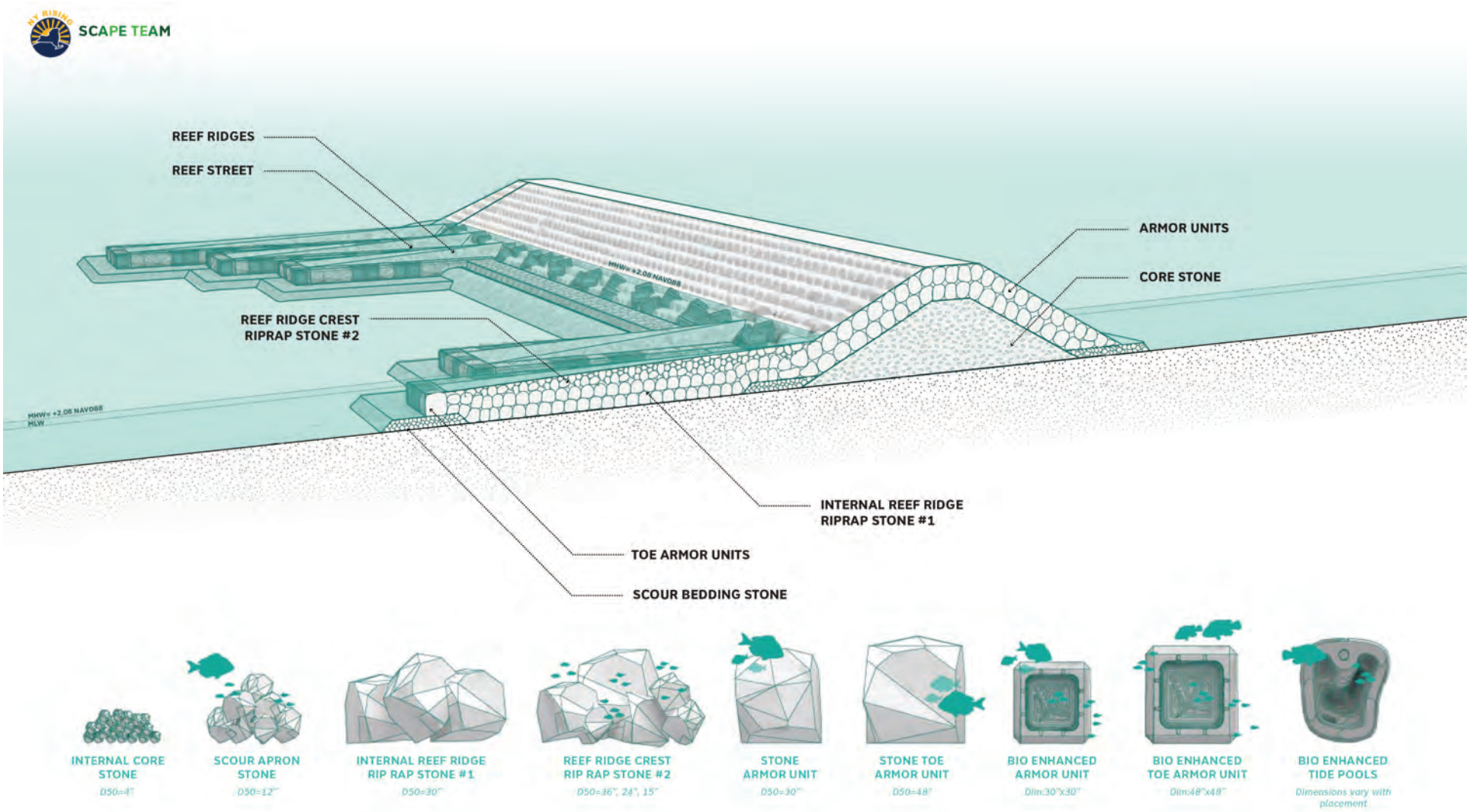
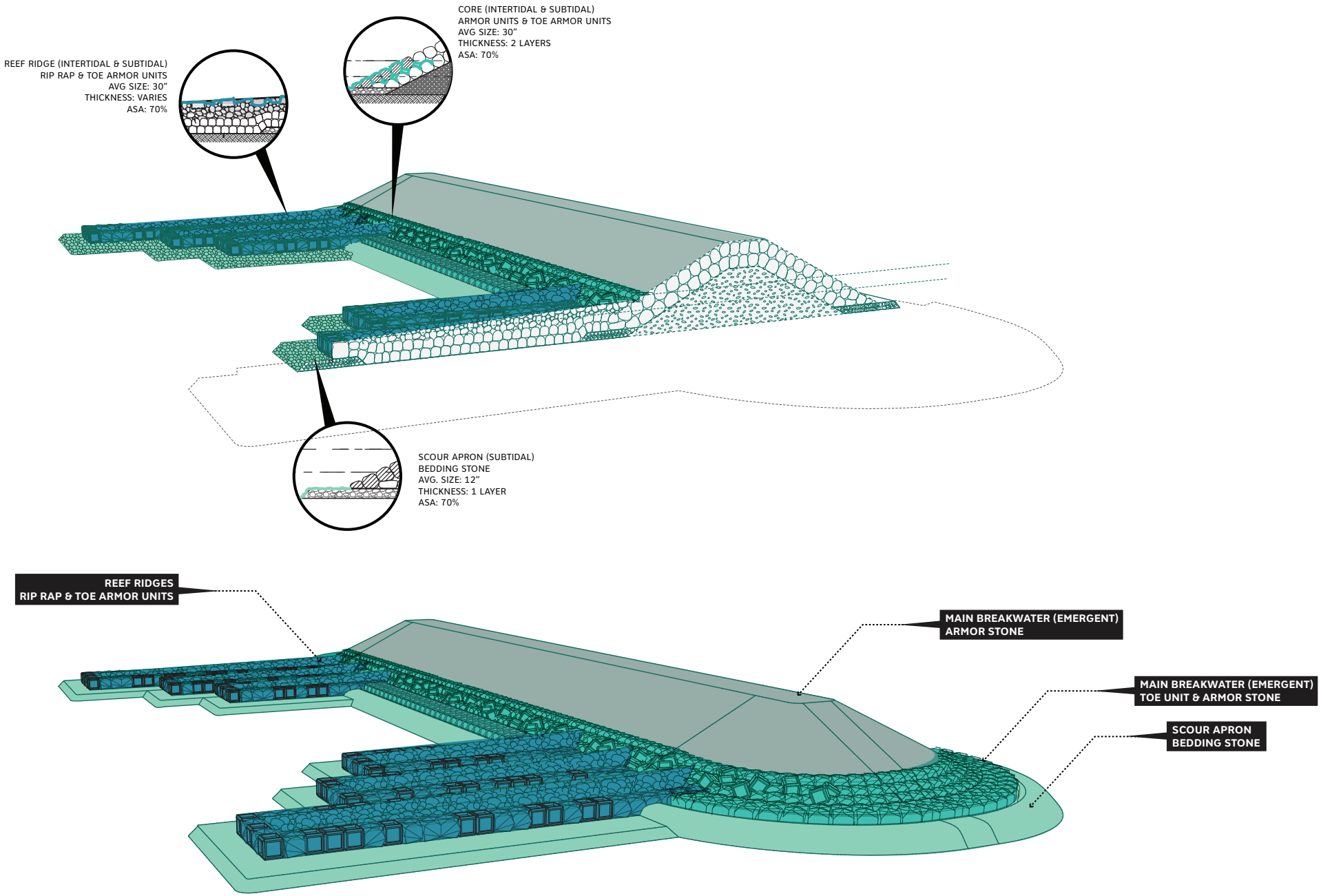


FIGURE 3: BREAKWATER HABITAT AREAS AND AVAILABLE SURFACE AREA (ASA) CALCULATION METHOD



MEMO

Date: 03 October 2017

From: SeArc, SCAPE

To: AKRF, GOSR

Cc: COWI, ARCADIS

Re: **Habitat Creation / Ecosystem Uplift Evidence and Rationale**

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PURPOSE OF MEMO

This memo is intended to provide additional clarification and references for the basis of the aquatic habitat design; the assumptions made regarding the anticipated species utilization of the porous rock structures; and to address some of the questions raised during our July 17th call regarding assumptions made in calculating the habitat surface areas anticipated to be provided by the breakwaters.

While the Living Breakwaters are designed to meet specific risk reduction goals (storm wave attenuation and coastal erosion reduction) and comply with structural performance goals, they are also being designed to meet ecosystem enhancement goals (to increase the diversity of aquatic habitats consistent with the Hudson-Raritan Estuary plan priorities of restoring a mosaic of diverse, quality habitats intermixed throughout the estuary to benefit many life stages for a range of resident, transient, and migratory fish, as well as crab and lobster populations. The Living Breakwaters would provide structurally complex habitats, which would provide refuge from predators and additional foraging habitat for species attracted to structural habitat, while minimizing the loss of sandy bottom habitat abundant within Raritan Bay.

This memo is not a comprehensive description of the project's habitat design and ecosystem services, but is intended to provide references and documentation in support of the habitat / ecosystem benefits provided by the Living Breakwaters and for the assumptions made in the habitat calculations provided for the project.

This memo summarizes the basis for the following general assumptions regarding habitat areas and species utilization:

- That porous rocky structures have been observed to provide effective aquatic habitat for multiple species including those in the project's target functional groups, especially juvenile fish, which are a major portion of the target species and functional groups.
- That this habitat benefit/ecosystem uplift is observed on the interior as well as exterior surfaces and crevices of such structures.
- The available surface area (ASA) of rocks and bio-enhancing concrete armor units in such structures is site specific. The actual species utilization of the ASA may be between a few percentages and up to 100%. In the Living Breakwaters, a 70% assumption was used.
- That a sphere is a suitable, even conservative, shape for approximating the surface area of individual armor units.

In addition, this memo provides a brief description of the basis for the ecological design of specific habitat features included in the Living Breakwaters project and references supporting the assertion that these features will promote increased utilization of the structures as habitat by the project's target functional groups. These features include:

- The incorporation of bio-enhancing concrete units.
- Reef Streets and Reef Ridges.
- Expansion of the intertidal zone through the addition of design features with moderately sloped to horizontal surfaces in the intertidal zone.
- The incorporation of water retaining elements at the intertidal zone.

Finally, the memo addresses concerns expressed regarding sedimentation patterns around the breakwaters, specifically the concerns expressed that sedimentation within the reef streets or on the lee side surfaces of the structure might occur and reduce anticipated habitat benefits.

SOURCES

The following sources were used to inform the habitat design of the Living Breakwaters:

- Case studies and peer reviewed literature on the performance of natural vs. artificial aquatic habitats, species utilization of rocky habitats, interaction and connectivity of natural and artificial aquatic habitats, and the effect of substrate orientation on community structure. A full bibliography of the literature that informed the design is included at the end of this memo and key sources are cited in the findings and design recommendations described below.
- Base line aquatic surveys of the existing conditions at the project area, in particular an “Adjacent Artificial Habitat Survey” performed in September 2015 by SeArc Ecological Marine Consulting on existing artificial hard structures near the project site. This survey characterized the benthic communities inhabiting these structures and provided input to the breakwater design process for maximum ecological performance.
- Results of FLOW3D modeling. Using available data collected from Acoustic Doppler Profiling (ADCP) units collecting wave and current data on site and other site data, the model predicted potential current velocities, sediment suspension, and sediment settlement patterns around the breakwaters and inside the reef streets.

SPECIES UTILIZATION OF ARTIFICIAL ROCK STRUCTURES

General evidence of species utilization of porous rock structures

Urbanization and industrialization of coastal areas has meant that artificial structures have become common and extensive features of many marine environments (Walker 1988, Glasby and Connell 1999), often replacing natural habitats such as rocky reefs. Typically, invertebrates and algae (epibiota) rapidly colonize the surfaces of these artificial structures, which become new habitats for these organisms (Knott et al. 2004). Infrastructure placed in any natural environment will inevitably become colonized by primary settlers such as epibenthic marine organisms and biofoulers (Evans 2016).

Porous defense structures such as breakwaters, are seen to be more environmentally friendly than solid coastal defense structures, such as sea walls or other solid defenses, because they have a smaller physical volume in the water column and create less disturbance to benthic soft sediment organisms in the nearfield area (Koraim and Rageh 2013). Studies have shown that local enhancement of biomass and production of commercial fish species have been associated with artificial structures. These structures provide a higher complexity habitat in areas where such habitat is not present, or is the limiting factor controlling populations (Bohnsack et al. 1997, Carr and Hixon 1997, Pickering and Whitmarsh 1997).

Lindquist et al. (1985) has found that rubble mound structures in the coasts of North Carolina provide a habitat for non-cryptic warm-temperate reef, pelagic, and sandy shore fish species, and that these fish utilize the structure for both food and shelter. The authors have recommended that future rubble-mound structures be constructed to provide maximum depth (vertical relief) and maximum surface area of the littoral zone. These features would increase the abundance of small forage species (e.g., small porgies) that would, in turn, be attractive to pelagic sport fishes such as mackerel, bluefish, and amberjack. Maximum littoral surface area would allow greater development of attached floral and faunal food resources.

A survey of rocky structures adjacent to the project area, especially the rubble mounds that provide the foundation for the channel markers along the federal navigation channel, revealed rich, hard substrate habitat, with a total of 43 taxa including algae, invertebrates, fish, and birds (SeArc 2015). The survey results indicted a similar tendency to the one stated above within the project area, with algae dominating the shallows and sessile invertebrates dominating deeper water, while the most abundant taxa observed were tube worms (Polychaetes). A noteworthy, biogenic buildup capability was noted (nearly 1 kg per m^2, ~2lb per 9sqft) and supported by the species found in the survey, which are known for their significant calcium carbonate deposition (such as barnacles, tube worms, and oysters). The most recent deployed structure sampled in this survey was the Dorothy Fitzpatrick Fishing Pier in Lemon Creek Park. This station presented relatively high dry weight values, which suggests that the overall deposition rates in the area are quite high and comparable to values found in the literature for regions supporting biogenic reef formation in temperate environments.

Internal vs. External Surfaces

Porous defense structures provide habitat complexity and protection within their interstices, encouraging higher biodiversity than other types of coastal defense designs (Sherrard et al. 2016). They enable water flow within the structure, providing access to food and submersion for periods of time, which is essential for many intertidal species in providing refuge to allow for foraging, reduced exposure to waves and scour, desiccation, and potential predation (Silva et al. 2008, Sherrard et al. 2016).

Internal and external environments of rubble mound structures are known to present significantly different biological communities, with literature supporting that internal surfaces can support twice as many species of both invertebrates and algae than the external environment, particularly mobile species (Sherrard et al. 2016). Multiple factors, including light, sedimentation, water flow, and predation have been proposed to explain this pattern. A more benign environment of internal surfaces reduces the competition for light availability with algae and protects from desiccation stress and scouring by mobile sediments. In contrast, external surfaces are subject to those forces in addition to higher levels of disturbance from maintenance or fishing activities, which often limit the potential ecological contribution this area of the artificial habitat might otherwise develop (Airoldi and Bulleri 2011).

The higher species richness associated with internal habitats on porous defense structures is linked mainly to inter- and intraspecific competition for space and reducing biodiversity in highly exposed areas due to the dominance of algae (Brodie et al. 2007, Bunker et al. 2010). Light availability and competition with algae are considered the strongest factors limiting sessile invertebrates largely due to shaded habitats such as walls, caves, undersides of rubble, and rocky interstices in shallow water as shading increases sessile invertebrate abundance and negatively affects algae both in natural habitats (Reed et al. 2006), and artificial ones (Glasby 1999).

The adjacent artificial habitat survey revealed that species inhabited both internal and external surfaces of the structure, with surface utilization of these structures extended as far as was visible by the divers (8'-10' from structures external surface). See Figure 1

Importance of Voids & Crevices

The motile benthic community that utilizes crevices and voids as habitat (Cryptofauna), is considered as the most diverse community of organisms on a coral reef, on a global scale (NOAA-FISHERIES).

Different structural factors have been found to affect community assemblages and species utilization of a structure. The size and number of internal spaces has been correlated with the size and number of certain fish on artificial reefs (Higo et al. 1980, Buckley 1982), midwater and bottom fish do not inhabit reef interiors if chambers are too large, (chambers with openings of 2m [6.56'] or greater were considered too large; the best size opening was between 0.15m [0.49'] and 1.5m [4.92']) (Ogawa 1982, Grove and

Sonu 1983); the avoidance of enclosed chambers with only one opening (Shinn 1974); and the preference of shelters with secondary escape exits by fish and motile invertebrates (Cobb 1971, Grove and Sonu 1983). In addition, the order of substrate placement and size may influence fish activity and diversity – a reef that comprised an orderly aggregated construction of relatively large rocks with large interstitial spaces has been found to support greater fish activity and diversity in comparison to a reef that was arranged as a randomly aggregated pile of relatively small rocks (Abelson and Shlesinger 2002). (see Figure 2)

The adjacent artificial habitat survey revealed that different void sizes between rocks corresponded to different species assemblages. Rock spacing varied from 1cm (0.5”) to 1m (40“). Some of the formed spaces had more than one opening to the water column. Areas that had a variety of spacing sizes had the greatest diversity and abundance of both fish communities and motile invertebrates.

The external layers of the living breakwaters—the outer two layers of armor stone and rip rap on both main breakwater segments and reef ridges--are highly porous (average 37% porosity). Void spaces ranging in size between a few inches to a few feet will provide important niches and crevices for motile species and some variety in crevice size to accommodate species diversity.

Substrate orientation – subtidal v. intertidal zones

Dramatic shifts in community composition occur between vertical and horizontal rocky surfaces in subtidal environments worldwide, as vertical rock walls are often covered by lush, diverse communities of sessile suspension-feeding invertebrates, while adjacent horizontal substrate are dominated by algae, or corals in the tropics (Miller and Etter 2008). Several physical and biological factors appear to differ between vertical and horizontal surfaces and may play a role in creating the differences in the cover of invertebrates on the two orientations, the most dominant being sediment load (Knott et al. 2004). This observation is also true for subtidal overhang surfaces such as cave ceilings, underside of armor rocks and armor units, where these surfaces revealed a significantly higher percentage of colonization, which is related to lower sedimentation levels, and lower light exposure (Boaventura et al. 2006).

The same trends were noted in the project area (SeArc 2015), where within the intertidal zone, horizontal surfaces had a larger cover and more diverse observed benthic community than vertical and steeply inclined surfaces. Below the intertidal zone, the opposite was noted, with vertical or steeply inclined surfaces presenting higher cover and diversity than horizontal ones on subtidal zones of rubble mound structures. At the time of the survey, the areas with the highest sediment accumulation were in the first few feet of water (1-3 ft. deep) mainly due to the high algal cover at these depths, which captures the sediment more effectively than the fouling community deeper in the water column.

Both the main segment of the breakwater and the reef ridges will comprise rocks and armor units of various shapes and sizes. Thus, the resulting surface orientations will be both horizontal and vertical and

will be utilized as habitat by sessile and motile organisms (See Figure 3) and are taken into account in the calculation of the Available Surface Area.

BASIS FOR ASSUMPTIONS OF HABITAT DEPTH AND AVAILABLE SURFACE AREA

There are no definite numbers for how deep inside a porous rock structure, or percentage of the surface, that is utilized as habitat by marine species. These conditions are specific to site, environmental conditions, and structure type. Habitat depth, for example, is mostly driven by light availability and nutrient flux within the crevices and voids, which are dependent on rock size and the gaps between them, and as such, affects the ASA.

In the Living Breakwaters Project, the planned size for armor rocks, that will comprise the majority of the main breakwater segments and the bottom, outer edges of the reef ridges, is 40”-48” (D_{50}), and at the crests and side-slopes of the reef ridges, the rock sizes vary between 24”-48” (D_{50}). Thus, with two layers of armor units, the habitat depth will be up to 6’ (based on CIRIA rock manual formulas) (*see Figure 4*). With structure porosity of approximately 37% (based on engineering judgment and the CIRIA rock manual), and according to the findings of the adjacent artificial habitat survey (SeArc 2015) and the literature cited in the prior sections, it is anticipated that at least the external two-layers will provide habitat conditions supporting utilization by sessile and motile species.

To calculate the ASA for the armored portion of the breakwaters, an average geometric approximation of both armor and toe armor units (rock and bio-enhancing concrete) was made. Average stone size used for the armor was 40" and for the ridges was 30". Units were assumed to have a consistent thickness of two layers for all breakwater types (*See Figure 5*). As the porosity for the armor layer is approximated at 37%, the gaps between armor units can vary between a few inches to a few feet with an average depth of 60”. Theoretically, based on natural rocky/coral reef habitat conditions and the findings of the adjacent artificial habitat survey, these voids and crevices sizes should provide favorable habitat conditions (dissolved oxygen, nutrient flux, light, temp, etc.) throughout the ASA for the size of the target species and their life stage (sessile and motile invertebrates and juvenile fish) (*See Figure 6*).

As optimal conditions are rarely found throughout a specific area, we recommend calculating only 70% of the ASA as available habitat as a conservative assessment due to:

1. The different sizes of the species in the target functional groups including sponges, bryozoans, and other sessile invertebrates that can utilize small spaces and grooves (see Attachment 1 Target Functional Groups and Habitats) in the structure, thus minimizing the ASA which will not provide habitat (Kostylev et al. 2005).
2. The correlation between rock/grain size to species diversity, species richness, and abundance (Shumway et al. 2007). The ASA calculation is based on 30” units, but in practice, the Living

Breakwaters will be constructed from rocks at varying sizes ranging between 15”-48”. It is assumed that armor units will touch at some points, and that some crevices and voids might be too small or too large to provide suitable habitat conditions due to factors like silt/sand accumulation, predator accessibility, etc., and thus, we assume 30% of the habit generated by the Living Breakwaters will be low quality or inaccessible. See Figure 7

KEY HABITAT DESIGN FEATURES AND THEIR ADDITIONAL BENEFITS

Most coastal defense structures are typically less topographically complex than natural rocky shores, reducing habitat and microhabitat provision (Martins et al. 2010, Hawkins 2012). As such, these structures, are frequently viewed as poor substitutes for natural rocky shores, and are typically anticipated to support lower species diversity than naturally occurring structures (Bulleri and Airoldi 2005, Bulleri et al. 2005, Moschella et al. 2005, Chapman and Blockley 2009).

However, with the addition of slight structural modifications to increase habitat heterogeneity and surface complexity, increased colonization and enhanced biodiversity of marine species on artificial substrates can be encouraged (Firth et al. 2013a, Firth et al. 2013b, Firth et al. 2014a, Firth et al. 2014b, Evans et al. 2016).

The Living Breakwaters Project provide enhanced habitat conditions above and beyond standard rubble mound breakwater structures through specific design modifications and principles as described below.

Design Principles

The literature widely supports the notion that non-uniformity of niches and crevice/void sizes enhances the heterogeneity of the habitat provided by structures (Musetta-Lambert et al. 2015). Moreover, the characteristic community expected to colonize man-made structures is significantly dependent on the structure’s broad shape, position in the intertidal zone, and abundance of microhabitats (Evans 2016). High density of organisms, with extensive live cover and higher biodiversity are found in areas characterized by a high degree of macro and micro topographic complexity (Firth et al. 2014a, Foley et al. 2014, Firth et al. 2016a).

In order to increase the diversity of aquatic habitats provided – as established in the project’s Purpose and Need – the Living Breakwaters Project is integrating a suite of environmentally sensitive design modifications and technologies creating a set of ecological niches usually absent from standard rubble mound breakwater structures. These include the following: incorporation of bio-enhancing concrete material, reef ridges and reef streets, inclusion of water retaining features in the intertidal zone, integration of varying levels of elevation and inclination, and creation of a wide range of structural complexity. The anticipated ecological benefits resulting from this ecological design are: moderately sloped intertidal habitat with confined water bodies, steep and complex subtidal sheltered habitats for fish and invertebrates, and overall higher diversity and species richness of both flora and fauna.

Key design features

The utilization of Bio-enhancing Concrete Units

Concrete bio-enhancing technology is scientifically tested and is based on specially developed concrete composition, micro-surface texture, and designs that encourage growth of desired marine flora and fauna (Perkol-Finkel and Sella 2014, 2015, Sella and Perkol-Finkel 2015, Perkol-Finkel et al. 2017). Promotion of engineering species like oysters, tube worms, and barnacles, which create biogenic build-up by depositing a calcium carbonate layer on the concrete surface, not only increases the availability and heterogeneity of biological niches on the structure, but also contributes to the structures' stability and longevity via Bioprotection[1] (Risinger 2012, Coombes et al. 2013).

While the majority of the breakwaters will be constructed of stone, bio-enhancing concrete tide pools and armor units will be integrated as structural elements of both the main breakwater segment and the reef ridges. The addition of these units is aimed at increasing the complexity of the structure, as the variation in shapes between the armor rock, armor units, and tide pools, will create different crevices and voids and an overall higher heterogeneity. In addition, the units themselves have micro-surface texture and support different add-ons, which further increase complexity.

5% of the breakwater armor stone within the subtidal and intertidal zones will comprise these bio-enhancing concrete units, with 45% being tide pools and 55% being armor units. This accounts for 6% of the calculated subtidal and 4% of the calculated intertidal habitat surface area.

Specifically, the project intends to use ECOncrete®, which uses elements that are designed to enhance the ecological and biological values of the project, while contributing to its structural performance (Perkol-Finkel and Sella 2014). The design, composition, and benefits of bio-enhancing concrete and specifically ECOncrete®, is described in more detail Attachment 2 "Use of ECOncrete® in the Living Breakwaters Project" dated July 16th 2016. *See Figure 8.*

Reef Ridges / Reef Streets

Overall basis for design: Spur and Groove (SAG) Formations

The reef ridge / reef street features are designed to mimic naturally occurring Spur and Groove formations observed in various naturally occurring reef habitats.

Spur and Groove (SAG) reefs are a common feature of windward shores, likely due to the continued effects of erosion caused by swell and trade wind waves (Roberts et al. 1992). The topography of these structures consists of parallel linear Spurs (rises, "ridges") separated by Grooves (sinks, "streets") of accumulated sediment and biogenic debris. SAG formation range from 8 to 65 meters in width and up to

[1] Bioprotection is a process in which animals and plants protect the surfaces they colonize from weathering and erosion (http://www.biogeomorph.org/coastal/bioprotection/).

10 meters in height, can be found at depths of up to 45 meters, and act as effective natural breakwaters that dissipate wave energy and current intensity (Roberts et al. 1992). SAG formations are found on many reefs worldwide, primarily present on the fore reefs in wave-dominated environments (Rogers et al. 2013), in both tropical and temperate environments, and can be found in coral reefs, oyster beds, and mangrove shorelines in different layouts (Bertness et al. 2014). SAG formations create large sloping faces with higher available surface area for species colonization than a porous breakwater structure alone (Foley et al. 2014). The undulating surface of the Spur and Grooves creates habitat for a diverse range of sessile invertebrates that are preferential to different water depths.

When the spur and groove structures interact with shoaling waves, nearshore circulation cells are induced (Rogers et al. 2013). Water motion is known to be of great importance to the biological and ecological functioning of reefs (Jokiel 2008, Nakamura 2010). The wave-induced currents transport larvae and remove smothering fine sediments from the spurs, and deposit them in the grooves where they are carried away from the reef system by draining tides (Storlazzi et al. 2004). In areas with high sediment loads (Ziemann 2003), this mechanism could be crucial for the development of a robust reef ecosystem.

In the analysis performed with the ***FLOW-3D*** numerical model using tidal current data collected from Acoustic Doppler Current Profiling (ADCP) sited in the Living Breakwaters project area for the past (almost) two years, it was determined that the area's predominant sediment grain size (0.35 mm, based on sediment surveys performed bi-annually for two years) would not be transported under normal mean tidal velocities. Fine sediments transported from other sources may interact with the structure. However, based on these sediments' negligible settling velocity against the turbulence and flow acceleration around the structure, deposition around the structure or within the reef streets is highly unlikely.

FLOW-3D model simulations on the 30% design layout shows little penetration of the oncoming flow into the reef streets, as the bulk of the flow preferentially goes around the breakwater structure, with any deposition likely to only occur directly in front of the reef streets. Thus, it was concluded that there is little concern that there will be any significant sedimentation on the breakwaters or within the reef street structures. Rather, they will sustain circulation and flushing rates appropriate to support the desired habitat conditions and target species utilization. *See Figure 9.*

The ***FLOW-3D*** model results also informed the layout and design of the reef streets and reef ridges. The design team analyzed the model results to determine areas that may be more prone to scour and designed the parameters (length, width, and orientation) of the reef streets to reduce the potential for scour and promote adequate flushing and water circulation within the reef streets.

Reef ridges and reef streets are included in the design in order to enhance and expand the quantity and quality of hard structured habitat of the project. They are designed to create the target habitat types and recruitment of target functional groups described in the report "Functional Groups and Habitats" prepared for the 30% Design. Key spatial design (dimensional) parameters addressing the shape, orientation,

width, and length of both ridges and streets and are described in the memo “Ecological Design Update – Preliminary 60% Design” dated June 16th 2017.

Added complexity of structure

The Living Breakwater’s intertidal and subtidal reef streets are designed to be submerged during storm events, and can thus support a higher variety of rock sizes and topographies. Thus, the reef ridges and reef streets have been designed to include a wide range of substrate sizes, generating great variety in the size of the niches and crevices provided, further enhancing the anticipated species variety and utilization for these areas of the breakwaters. This wide variety in rock size is not feasible in all areas of the breakwater as greater uniformity in armor stone is required in the upper tidal and emergent areas of the main breakwater to ensure the overall breakwater’s resistance to wave impact. However, wherever it is structurally feasible, greater variety in rock sizing and surface complexity is provided to support this increased habitat heterogeneity. For example, by the addition of the bio-enhancing concrete armor units and tide pools (see section above).

Substrate orientation – subtidal v. intertidal zones

As noted above, the role of substrate orientation is critical to the development of benthic communities at the intertidal and subtidal zones. This conclusion has been incorporated into to the breakwater design by avoiding, as much as possible, horizontal surfaces in the subtidal habitat design, both on main segments and along the reef ridges in order to reduce algae cover. Algae cover not only competes with the sessile invertebrate community on the ASA, but also increases sediment accumulation on the structure, further decreasing the ASA. Therefore, vertical surfaces were designed in the subtidal zone by utilizing bio-enhancing concrete armor units in the reef streets and the lee side of the breakwaters.

Conversely, horizontal to moderately-sloped surfaces are required in the intertidal zone in order to increase the surface area affected by the tides as well as the overall ASA. The crests of the reef ridges, the crenulated crest of the low-crested, type A, breakwaters, and the intertidal berm on breakwater C2, were all designed accordingly.

Inter-tidal water-retaining elements

Natural rock pools (tide pools) are ubiquitous features of rocky shores across the world. They provide important nursery grounds, feeding habitat and refuge for a wide range of organisms (Firth et al. 2014a). Biological communities of tide pools differ greatly from those on emergent rock, as the pools extend the upper vertical limits of many organisms that are susceptible to desiccation (Perkol-Finkel and Sella 2015). In response to the growing need to defend infrastructure from sea level rise and coastal erosion, hard substrate defense structures are becoming ubiquitous features of coastal landscapes in intertidal and shallow subtidal environments (Airoldi et al. 2005, Bulleri and Chapman 2010, Airoldi and Bulleri 2011, Chapman and Underwood 2011, Firth and Hawkins 2011, Firth et al. 2013b, Perkol-Finkel and Sella 2015). Recent studies of artificial coastal defense structures in intertidal habitats (e.g. seawalls, breakwaters, and groins) have revealed that the incorporation of water-retaining features that mimic

natural rock pools can dramatically increase the diversity of colonizing epibiota (Chapman and Blockley 2009, Browne and Chapman 2011, Chapman and Underwood 2011, Browne and Chapman 2014, Firth et al. 2014a, Perkol-Finkel and Sella 2015). Artificial tide pools perform an important and missing ecological function in concrete marine infrastructure, which commonly does not facilitate the retaining of water at low tides or storm conditions. Artificial tide pools are utilized by numerous species that are otherwise not recorded on surrounding emergent rock surfaces, including taxa that have frequently been reported to be absent or scarce on coastal defenses (e.g. mobile fauna, lower-shore taxa and proportionally-rarer taxa) (Perkol-Finkel and Sella 2015, Evans 2016). Furthermore, artificial pools were found to be just as productive as natural rock pools and supported a comparable number of species (Firth et al. 2013a, Firth et al. 2013b, Firth et al. 2014a, Evans 2016, Firth et al. 2016a, Firth et al. 2016b).

The rubble mound structures sampled in the adjacent artificial habitat survey did not have any water retaining elements on them. However, a recent pilot study, which was conducted in Brooklyn Bridge Park, included the integration of seven designed tide pools into the newly constructed pier 4 beach at BBP within the Mean Higher High-Water zone. Each pool retains a volume of 13 gallons (59 liters) and creates a submerged habitat disconnected from the open water at low tide (Perkol-Finkel and Sella 2015). After less than a year the tide pools showed a live cover of 89% – 100% of the water-retaining portions of the pools, and presented a diverse community composed of filamentous green algae, branching brown algae, copepods, amphipods, isopods, as well as sabellidae and spirorbid worms. In addition, individuals of the Harris mud crab (*Rithropanopeus harrisii*) and of juvenile/post-larval fish were noted in the pools. The study's control area presented only a few patches of algae, found mostly at lower parts of the rocks where moist areas were noted, and no invertebrate species.

The integration of water-retaining elements in the intertidal zone is a key component of the ecological design of the Living Breakwaters Project. Tide pools will be integrated on almost every breakwater segment – on the shallow-sloping crests of the reef ridges and berms, in the saddles of the crenulated crests of the type A breakwaters, and on the lee side of the main breakwater segments. These tide pools, with varying depths, inclines, and shore heights will provide a range of habitats and increase environmental heterogeneity, thus creating more possible ecological niches and promoting local biodiversity (Beck 2000, Aguilera et al. 2014, Firth et al. 2014a).

SECONDARY BENEFITS TO BE ACCRUED OVER TIME

Structure's Sediment "Halo"

It is widely agreed that hard substrates create a habitation halo wherein habitat benefits are provided to species using the central hard substrate habitat. Such a halo or mound is typical to offshore structures and can be found around breakwaters, jetties, and oil rigs (Schroeder and Love 2004).

During the adjacent artificial habitat survey, it was observed that all hard substrate structures sampled were surrounded by a belt of broken shells and other calcium carbonate fractions originating from marine organisms. The width of the “calcium fractions belt” differed between stations, where the lighthouses presented roughly the same width of ~10m (30’), the concrete pier piles ~3m (9’), and the underwater rock pile (AR5) ~1m (3’).

While not currently accounted for in the habitat creation and ecosystem uplift anticipated to be provided by the project, it should be noted that observations and literature suggest that cores of large grained habitat are likely to accumulate around the breakwaters and may provide additional ecosystem benefits in the form of additional habitat diversity offset from the actual structures. This belt creates a unique habitat where the edge of the hard substrate connects with the sediment. Due to the relatively large grain size within this halo, biogenic material does not seem to clog the crevices in the structure (as might have been the case if finer grain size sediment was found in the area). Therefore, this halo is likely to provide additional habitat for cryptic species, and potentially contribute to reducing the overall sedimentation of the structure, which is often found near the bottom. This, in effect, opens the lower parts of the structure to colonization by organisms which are less tolerant to high sedimentation loads, such as encrusting bryozoans and calcium carbonate secreting tube worms (Serpulidae), both of which are high contributors to biogenic buildup processes. *See Figure 10*

Statistical base of design: benefits to be generated through monitoring

The design addresses the need to generate solid applicable data from the project which can be implemented in other future projects in the region. A statistically robust layout is important to the design of the project so that the performance of ecological design features can be evaluated and used to inform adaptive management and future designs for ecologically enhanced breakwaters, revetments, and groins. By using a variety of different types / combinations of enhancements, the project will provide valuable information on the relative effectiveness of different combinations of ecosystem enhancement treatments. Control areas with no or limited ecological treatments were designed into the layout, and will serve as control reference for the enhanced breakwater structures, reef ridges / reef streets , and positioning and effectiveness of treatments within the breakwaters. For proposed statistical layout refer to the figures provided in Attachment 3.

Monitoring and performance evaluation of the various breakwaters ecological enhancement measures will be performed on all selected breakwater typologies including reef streets, crest areas, and intertidal and subtidal habitats, with references to the different enhancement methods (such as bio-enhancing concrete armor units of various treatments, tide pools). Each typology will be sampled according to its function, and compared to relevant controls comprising unenhanced breakwater sections of equivalent size, and to adjacent hard bottom habitats when applicable. Some of the habitats to be generated by the project are

the result of direct enhancements such as creating designed niches (armor units of various treatments, tide pools, and gabions). . Other improvements will be the result of non-direct enhancements such as shell mound that will be accumulated around the breakwaters with time, or the utilization of the hard structure as a base for mammals and birds. Monitoring will allow the documentation of the magnitude and conditions that optimize habitat and ecosystem benefits in order to inform adaptive management and future efforts. *See Figure 11.*

ATTACHMENTS

Habitat Creation / Ecosystem Uplift Evidence and Rationale Figures (figures for this memo)

Attachment 1—Functional Groups and Habitats, appendix from 30% Design Report (10/6/2016)

Attachment 2—Use of ECOncrete® in the Living Breakwaters Project (7/6/2016)

Attachment 3—Layout of Ecological Treatments on the Living Breakwaters, figures from latest Quarterly Design Report (6/16/2017)

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FIGURE 9 ..... **11**

FIGURE 10 ..... **12**

FIGURE 11 ..... **13**

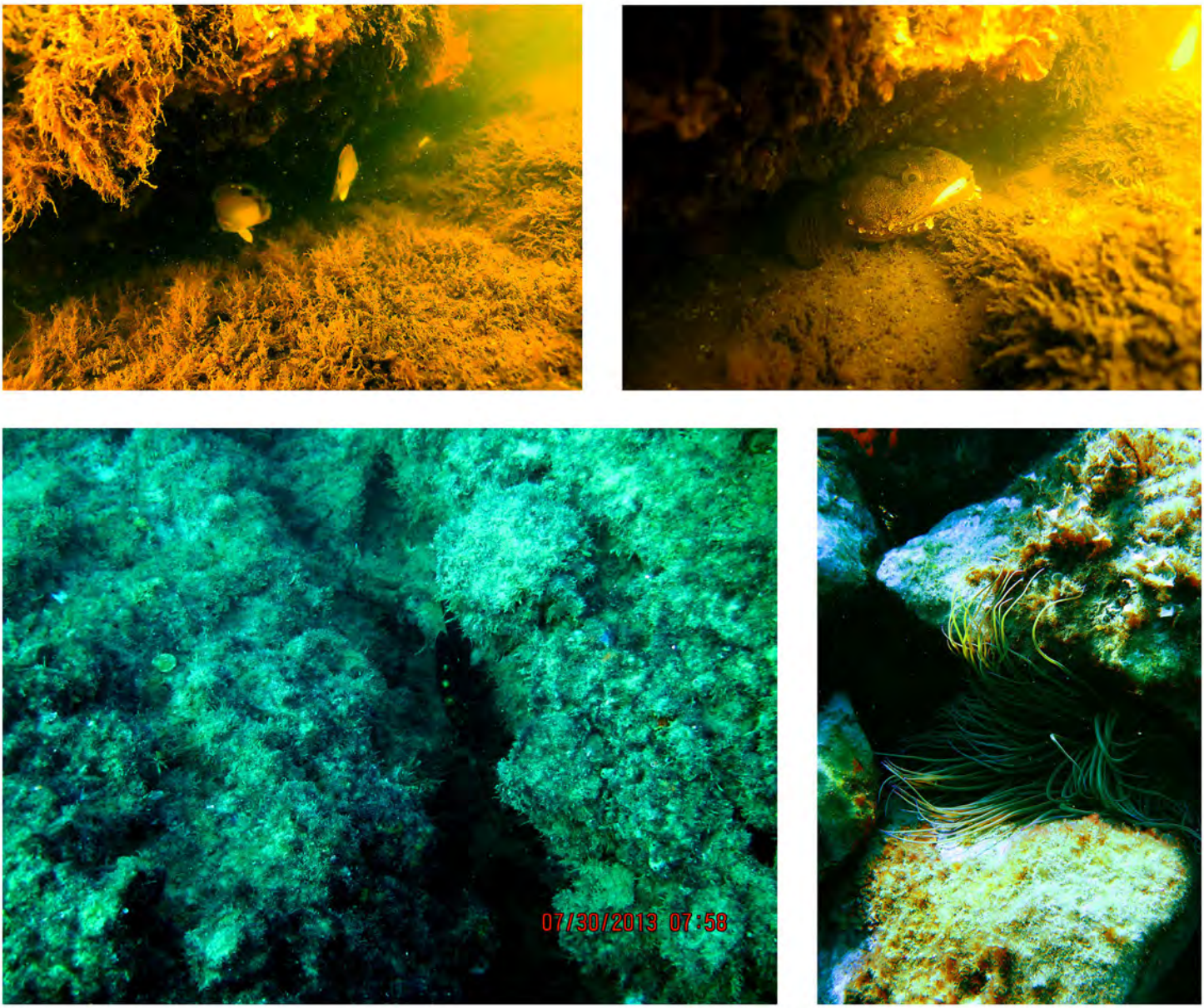


FIGURE 1

Fish and invertebrate species utilize the crevices between boulders as habitat, refuge, and foraging territory. Additionally, extensive live cover of algae and encrusting invertebrates blanket the rock surfaces, regardless of slope orientation.

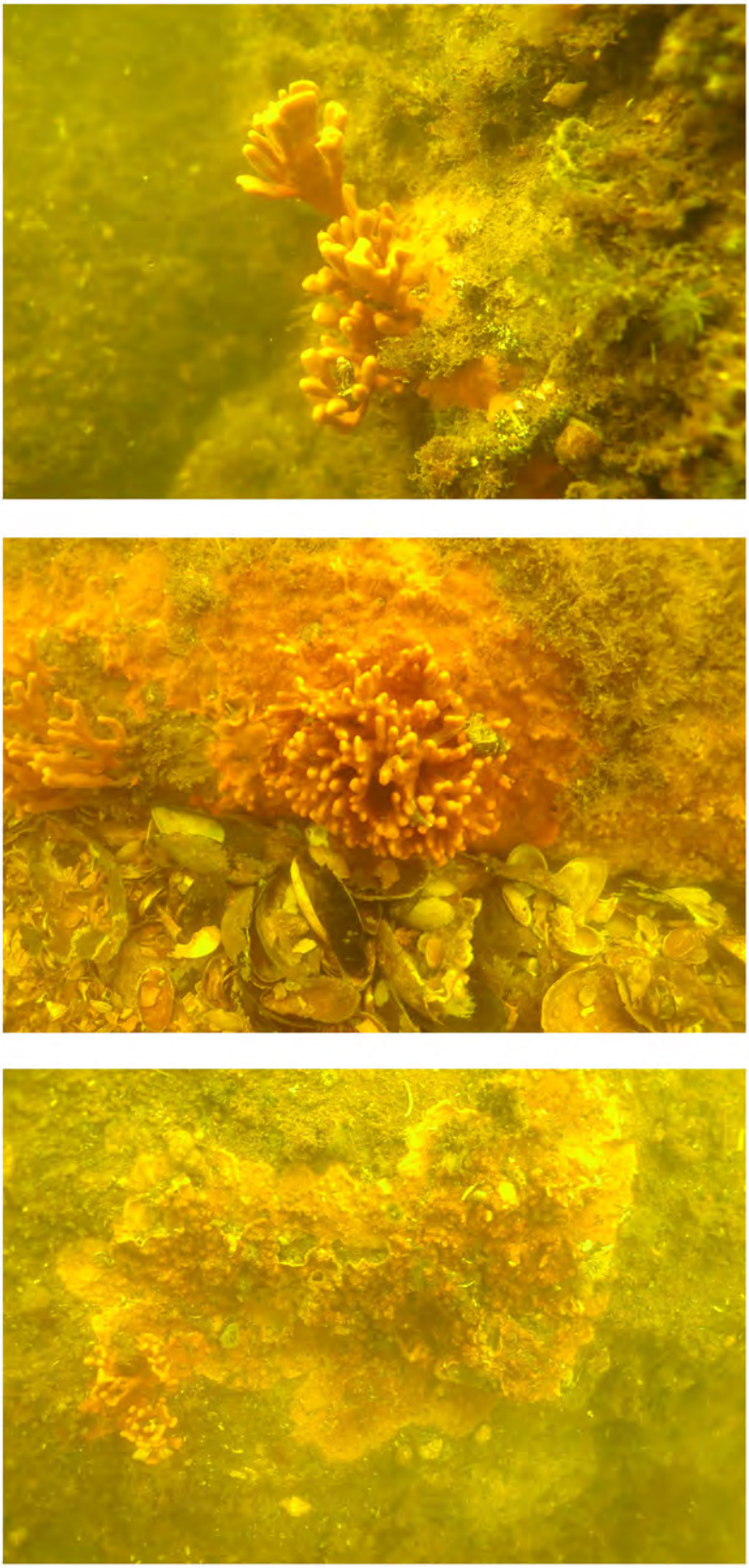


FIGURE 2

Live cover on steeply-inclined, vertical surfaces in the subtidal zone.

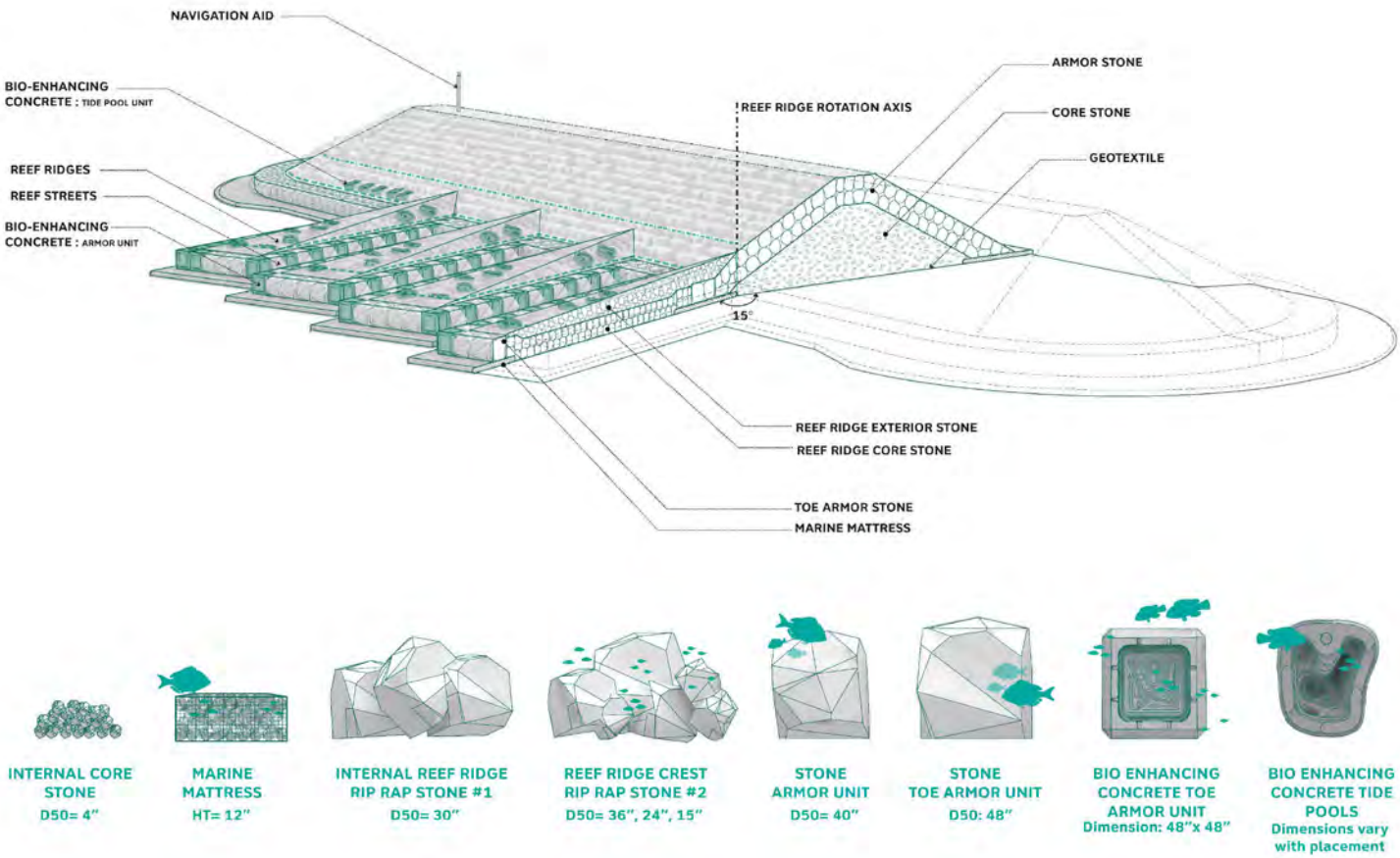


FIGURE 3

Living Breakwater material: locations and sizes.

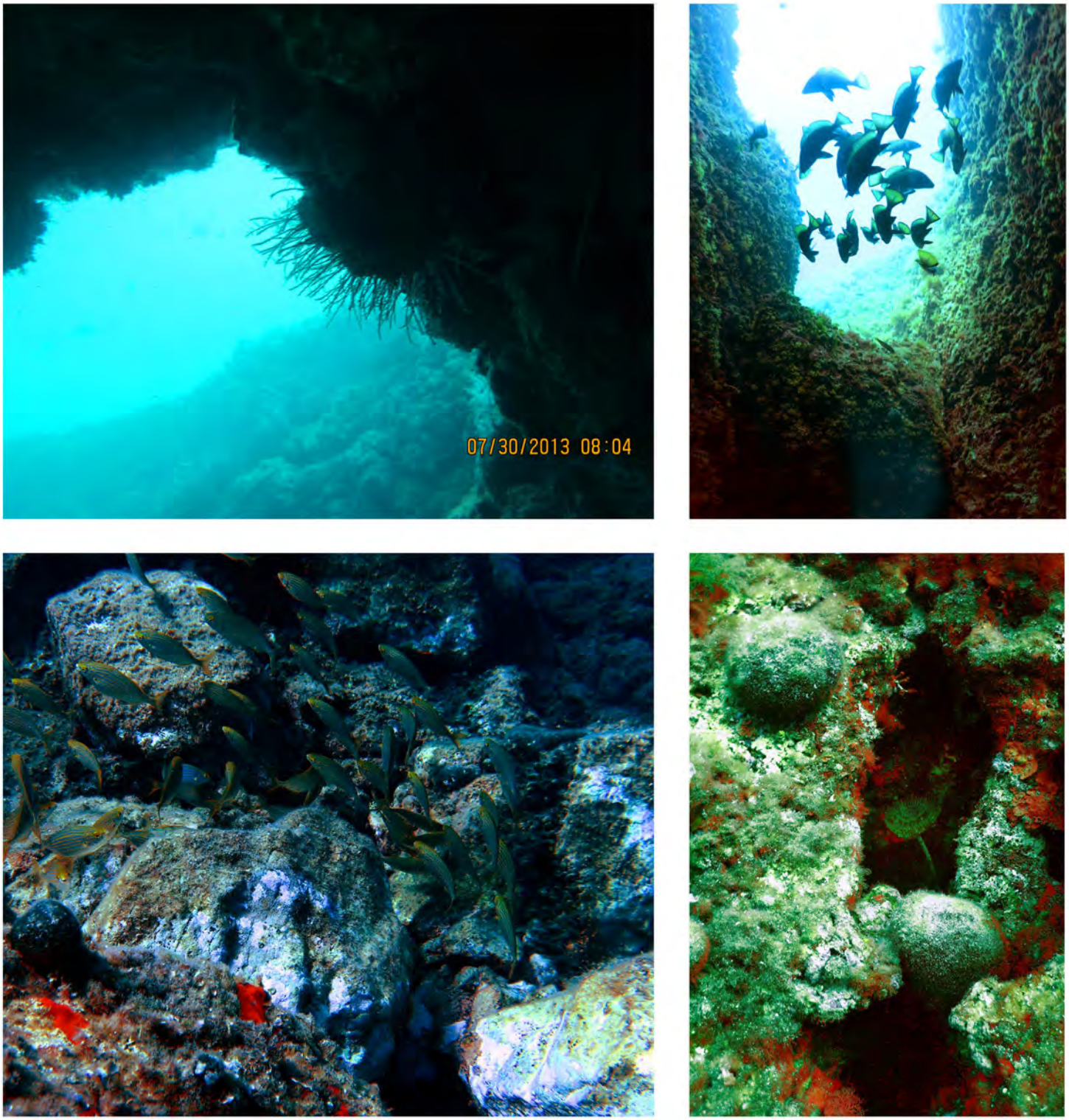


FIGURE 4

Fish and invertebrate species utilize the gap between boulders as habitat, refuge, and foraging territory. Available surface area includes the expanse of all faces and slopes of the rock structure.

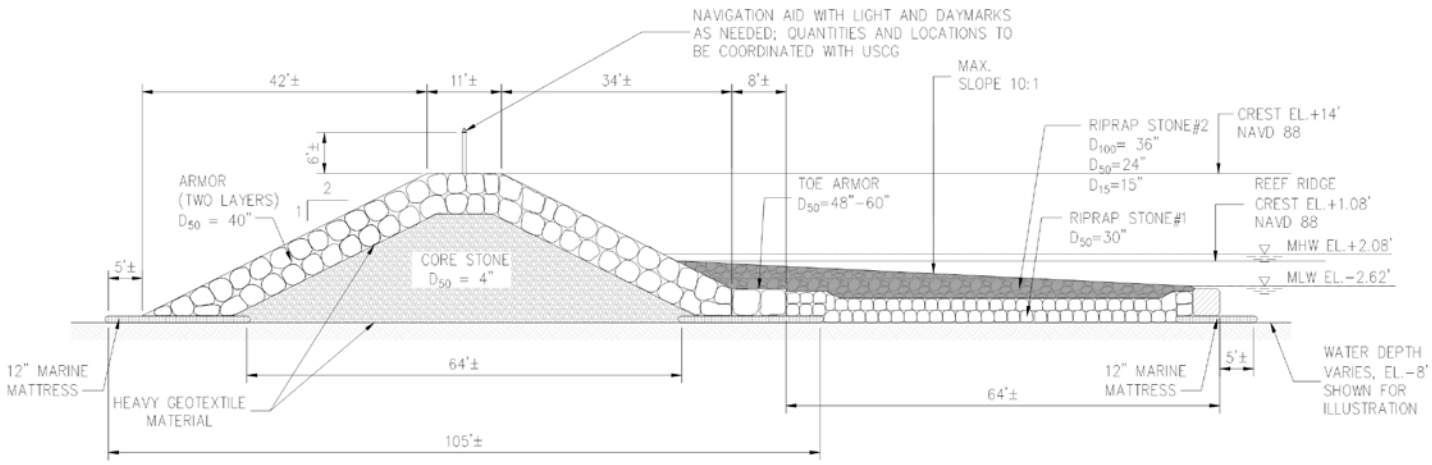


FIGURE 5

Living Breakwater Cross Section.

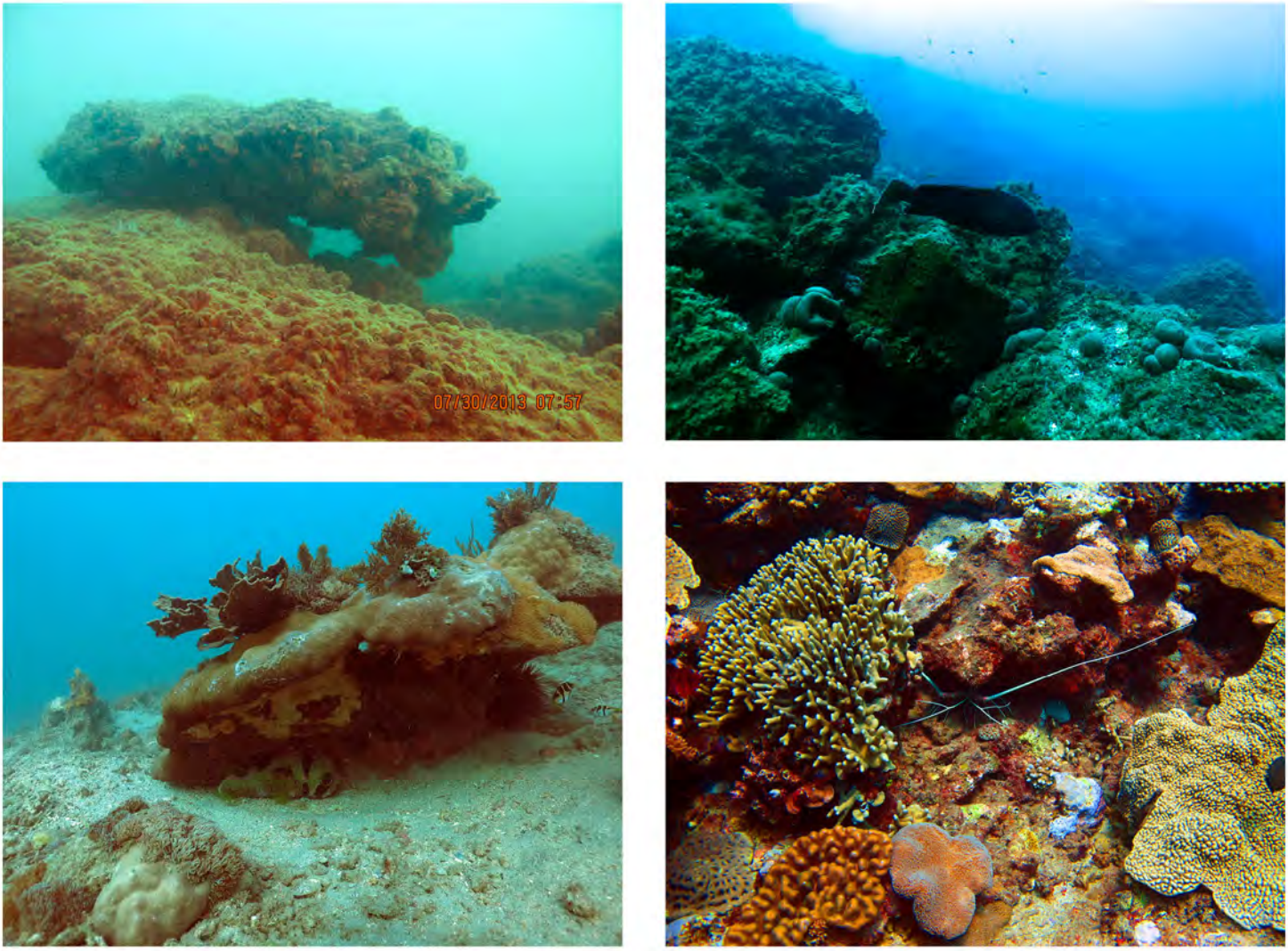


FIGURE 6

Natural reef formations display encrusting invertebrates, corals and algae on all available slopes and surfaces. Fish and motile invertebrates utilize these formations as habitat.

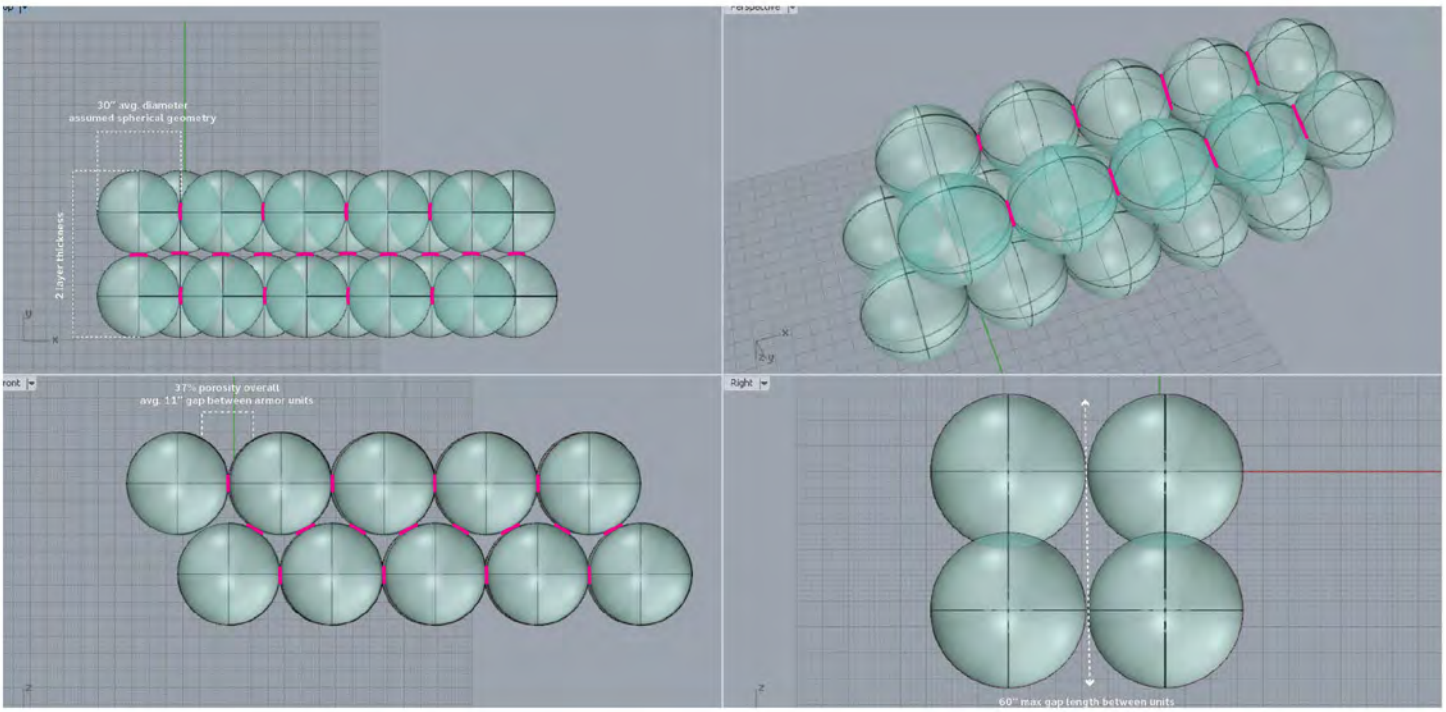


FIGURE 7

Breakwater habitat areas and available surface area (ASA) calculation method.

FIGURE 8 (CONT. ON FOLLOWING PAGE)

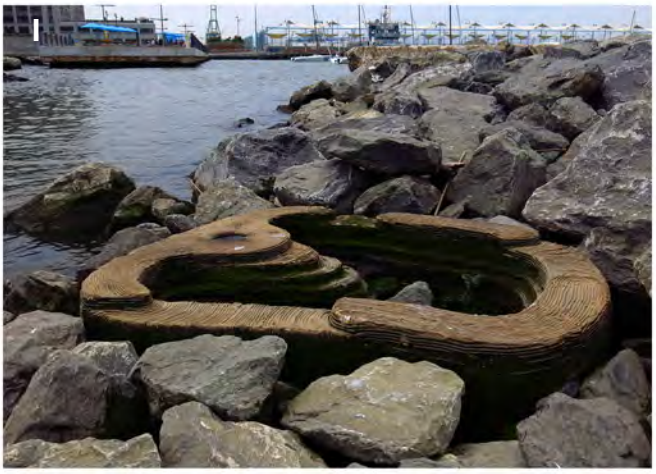
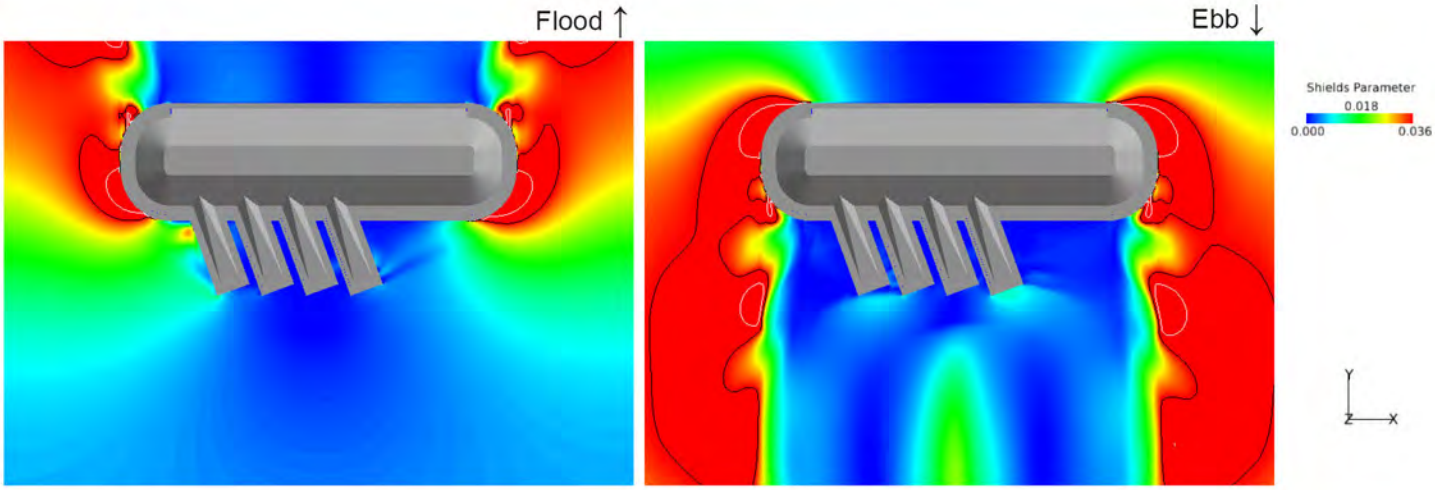


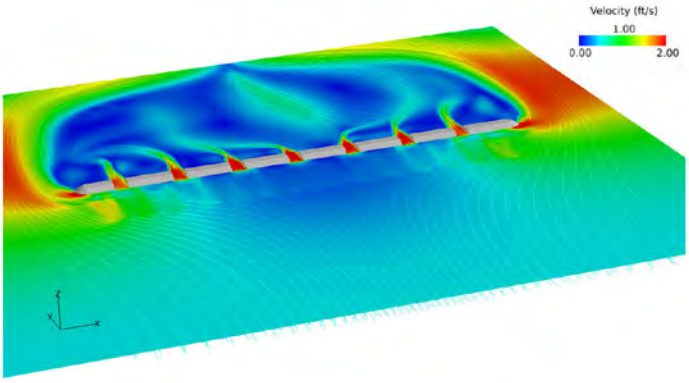
Figure 8 cont.

Integration of ECOncrete armor units into armor rocks (A - F), and ECOncrete tide pools units integrated into rip-rap (G - J). Note the various void and crevice sizes created between adjacent units.

With the addition of ecological add-ons (ie, ECOncrete disks, and mesh with rocks) further enhancement occurs with the added micro-complexity (D - F).

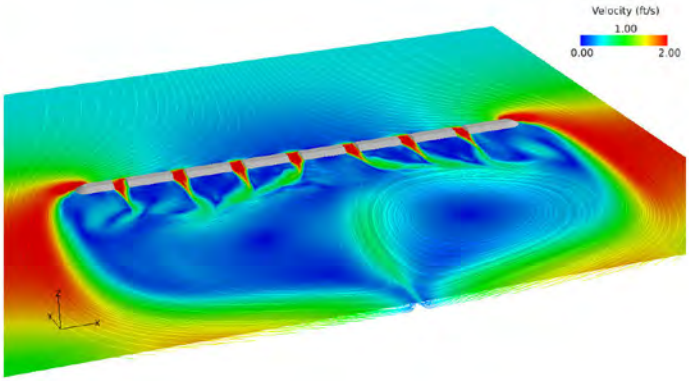


Angling the streets towards the center reduces the scour potential on the outer-most reef ridge
de results look similar.



At MHW Their wakes interact with the recirculation region - which largely sets the direction of the crenel wake.

z = bottom of saddle

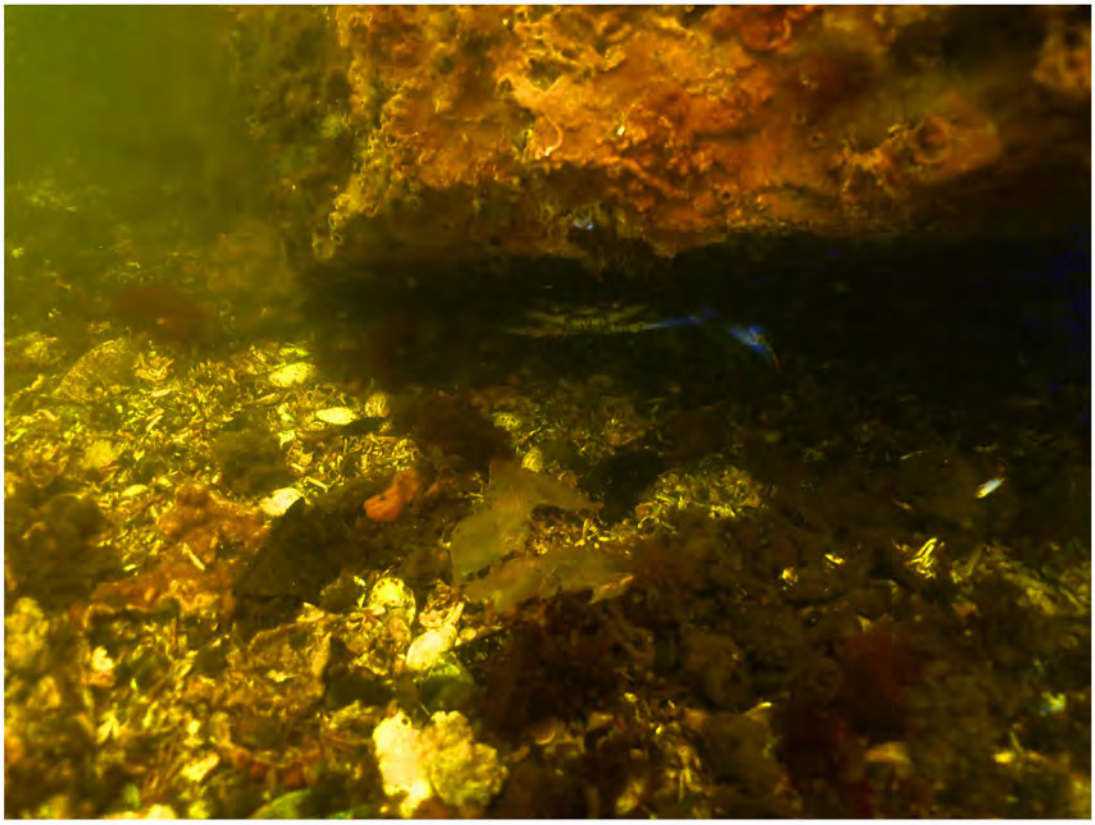


Flow in the center crenels is turned toward the ends of the ected into their streets.

z = bottom of saddle

FIGURE 9

FLOW3D model results.



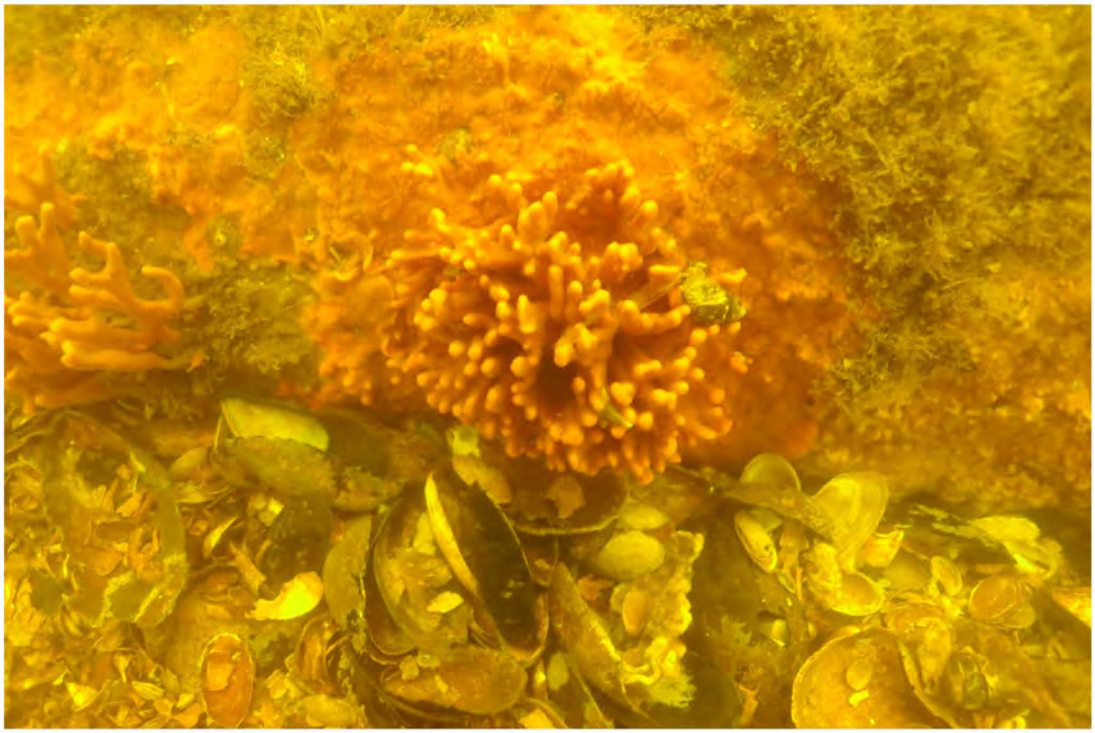


FIGURE 10

Encrusting organisms grow on vertical slopes of boulders. The "shell halo" created around the base of a rock structure becomes additional habitat for settling organisms and algae.

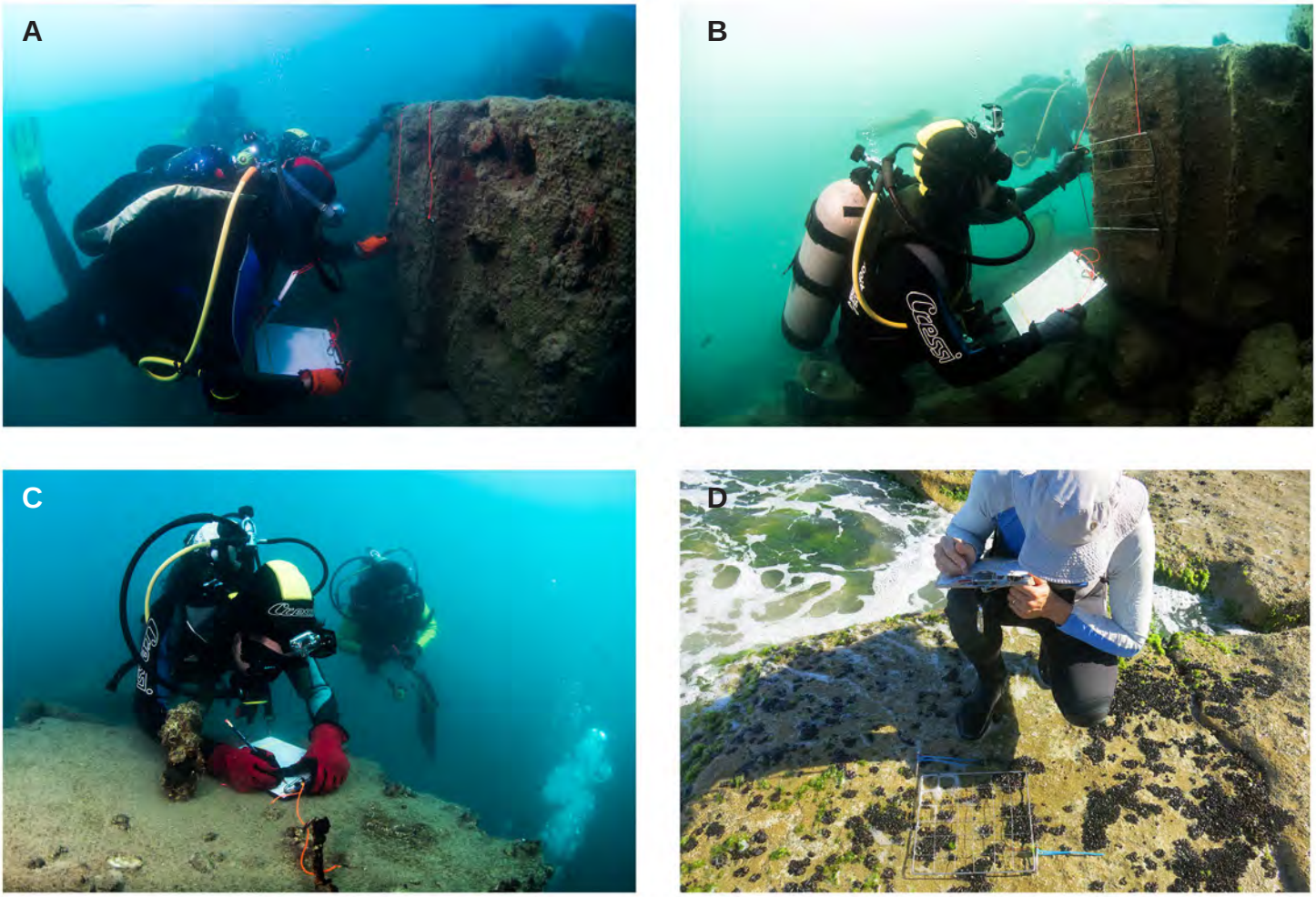


FIGURE 11 (CONT. ON FOLLOWING PAGE)

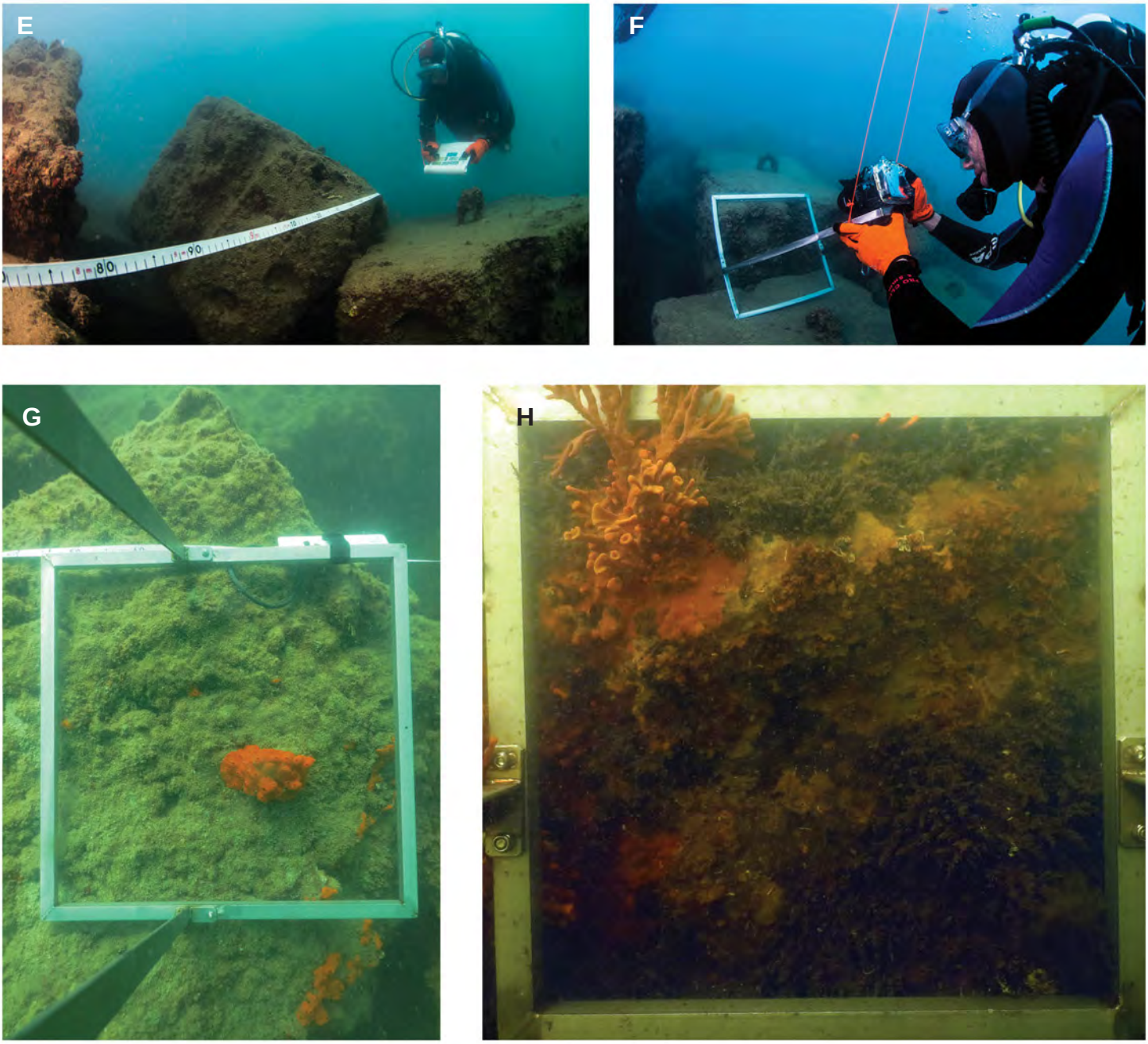


FIGURE 11 CONT.

Monitoring methods: live cover observation through counting species inside a known area in the subtidal and intertidal zones (A, B, C, D); sessile invertebrate census along a transect (E); photo documentation of a "photo qudrat" for computer analysis (F, G, H).

Volume and area summary for intetidal zone located between MLW-MHW

Summary of marine habitat displaced & created (square feet), using available habitat = 70% ASA assumption

	Total				Shoreline Restoration				Breakwaters Total				Breakwaters (Without Ridges)				Reef Ridges			
	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change
Intertidal small and large grained (sand and gravel)	45,602	42,809	42,809	-2,793	45,602	42,809	42,809	-2,793	0	0	0	0	0	0	0	0	0	0	0	0
Subtidal small and large grained (sand and gravel)	564,326	10,243	10,243	-554,083	68,812	10,243	10,243	-58,569	495,514	0	0	-495,514	376,990	0	0	-376,990	118,524	0	0	-118,524
Hard / rocky (hard bottom) intertidal	0	146,214	449,128	449,128	0	0	0	0	0	146,214	449,128	449,128	0	90,337	370,009	370,009	0	55,877	79,118	79,118
Hard / rocky (hard bottom) subtidal	0	241,853	1,151,938	1,151,938	0	0	0	0	0	241,853	1,151,938	1,151,938	0	152,275	733,203	733,203	0	89,578	418,735	418,735
Total below MHW (Subtidal & Intertidal)	**609,928**	**441,119**	**1,654,117**	**1,044,189**	**114,414**	**53,052**	**53,052**	**-61,362**	**495,514**	**388,068**	**1,601,066**	**1,105,551**	**376,990**	**242,612**	**1,103,212**	**726,222**	**118,524**	**145,455**	**497,853**	**379,329**

Summary of marine habitat displaced & created (acres), using available habitat = 70% ASA assumption

	Total				Shoreline Restoration				Breakwaters Total				Breakwaters (Without Ridges)				Reef Ridges			
	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change
Intertidal small and large grained (sand and gravel)	1.0	1.0	1.0	-0.1	1.0	1.0	1.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtidal small and large grained (sand and gravel)	13.0	0.2	0.2	-12.7	1.6	0.2	0.2	-1.3	11.4	0.0	0.0	-11.4	8.7	0.0	0.0	-8.7	2.7	0.0	0.0	-2.7
Hard / rocky (hard bottom) intertidal	0.0	3.4	10.3	10.3	0.0	0.0	0.0	0.0	0.0	3.4	10.3	10.3	0.0	2.1	8.5	8.5	0.0	1.3	1.8	1.8
Hard / rocky (hard bottom) subtidal	0.0	5.6	26.4	26.4	0.0	0.0	0.0	0.0	0.0	5.6	26.4	26.4	0.0	3.5	16.8	16.8	0.0	2.1	9.6	9.6
Total below MHW (Subtidal & Intertidal)	**14.0**	**10.1**	**38.0**	**24.0**	**2.6**	**1.2**	**1.2**	**-1.4**	**11.4**	**8.9**	**36.8**	**25.4**	**8.7**	**5.6**	**25.3**	**16.7**	**2.7**	**3.3**	**11.4**	**8.7**

Summary of marine habitat displaced & created (square feet), using available habitat = 50% ASA assumption

	Total				Shoreline Restoration				Breakwaters Total				Breakwaters (Without Ridges)				Reef Ridges			
	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change
Intertidal small and large grained (sand and gravel)	45,602	42,809	42,809	-2,793	45,602	42,809	42,809	-2,793	0	0	0	0	0	0	0	0	0	0	0	0
Subtidal small and large grained (sand and gravel)	564,326	10,243	10,243	-554,083	68,812	10,243	10,243	-58,569	495,514	0	0	-495,514	376,990	0	0	-376,990	118,524	0	0	-118,524
Hard / rocky (hard bottom) intertidal	0	146,214	320,805	320,805	0	0	0	0	0	146,214	320,805	320,805	0	90,337	264,292	264,292	0	55,877	56,513	56,513
Hard / rocky (hard bottom) subtidal	0	241,853	822,813	822,813	0	0	0	0	0	241,853	822,813	822,813	0	152,275	523,716	523,716	0	89,578	299,096	299,096
Total below MHW (Subtidal & Intertidal)	**609,928**	**441,119**	**1,196,670**	**586,742**	**114,414**	**53,052**	**53,052**	**-61,362**	**495,514**	**388,068**	**1,143,618**	**648,104**	**376,990**	**242,612**	**788,009**	**411,018**	**118,524**	**145,455**	**355,610**	**237,086**

Summary of marine habitat displaced & created (acres), using available habitat = 50% ASA assumption

	Total				Shoreline Restoration				Breakwaters Total				Breakwaters (Without Ridges)				Reef Ridges			
	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change
Intertidal small and large grained (sand and gravel)	1.0	1.0	1.0	-0.1	1.0	1.0	1.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtidal small and large grained (sand and gravel)	13.0	0.2	0.2	-12.7	1.6	0.2	0.2	-1.3	11.4	0.0	0.0	-11.4	8.7	0.0	0.0	-8.7	2.7	0.0	0.0	-2.7
Hard / rocky (hard bottom) intertidal	0.0	3.4	7.4	7.4	0.0	0.0	0.0	0.0	0.0	3.4	7.4	7.4	0.0	2.1	6.1	6.1	0.0	1.3	1.3	1.3
Hard / rocky (hard bottom) subtidal	0.0	5.6	18.9	18.9	0.0	0.0	0.0	0.0	0.0	5.6	18.9	18.9	0.0	3.5	12.0	12.0	0.0	2.1	6.9	6.9
Total below MHW (Subtidal & Intertidal)	**14.0**	**10.1**	**27.5**	**13.5**	**2.6**	**1.2**	**1.2**	**-1.4**	**11.4**	**8.9**	**26.3**	**14.9**	**8.7**	**5.6**	**18.1**	**9.4**	**2.7**	**3.3**	**8.2**	**5.4**

Volume and area summary for intetidal zone located between MLW-MHWS

Summary of marine habitat displaced & created (square feet), using available habitat = 70% ASA assumption

	Total				Shoreline Restoration				Breakwaters Total				Breakwaters (Without Ridges)				Reef Ridges			
	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change
Intertidal small and large grained (sand and gravel)	48,823	45,949	45,949	-2,874	48,823	45,949	45,949	-2,874	0	0	0	0	0	0	0	0	0	0	0	0
Subtidal small and large grained (sand and gravel)	564,326	10,243	10,243	-554,083	68,812	10,243	10,243	-58,569	495,514	0	0	-495,514	376,990	0	0	-376,990	118,524	0	0	-118,524
Hard / rocky (hard bottom) intertidal	0	151,428	469,815	469,815	0	0	0	0	0	151,428	469,815	469,815	0	95,551	390,697	390,697	0	55,877	79,118	79,118
Hard / rocky (hard bottom) subtidal	0	241,853	1,151,938	1,151,938	0	0	0	0	0	241,853	1,151,938	1,151,938	0	152,275	733,203	733,203	0	89,578	418,735	418,735
Total below MHW (Subtidal & Intertidal)	**613,149**	**449,474**	**1,677,945**	**1,064,795**	**117,635**	**56,192**	**56,192**	**-61,443**	**495,514**	**393,282**	**1,621,753**	**1,126,239**	**376,990**	**247,827**	**1,123,900**	**746,909**	**118,524**	**145,455**	**497,853**	**379,329**

Summary of marine habitat displaced & created (acres), using available habitat = 70% ASA assumption

	Total				Shoreline Restoration				Breakwaters Total				Breakwaters (Without Ridges)				Reef Ridges			
	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change
Intertidal small and large grained (sand and gravel)	1.1	1.1	1.1	-0.1	1.1	1.1	1.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtidal small and large grained (sand and gravel)	13.0	0.2	0.2	-12.7	1.6	0.2	0.2	-1.3	11.4	0.0	0.0	-11.4	8.7	0.0	0.0	-8.7	2.7	0.0	0.0	-2.7
Hard / rocky (hard bottom) intertidal	0.0	3.5	10.8	10.8	0.0	0.0	0.0	0.0	0.0	3.5	10.8	10.8	0.0	2.2	9.0	9.0	0.0	1.3	1.8	1.8
Hard / rocky (hard bottom) subtidal	0.0	5.6	26.4	26.4	0.0	0.0	0.0	0.0	0.0	5.6	26.4	26.4	0.0	3.5	16.8	16.8	0.0	2.1	9.6	9.6
Total below MHW (Subtidal & Intertidal)	**14.1**	**10.3**	**38.5**	**24.4**	**2.7**	**1.3**	**1.3**	**-1.4**	**11.4**	**9.0**	**37.2**	**25.9**	**8.7**	**5.7**	**25.8**	**17.1**	**2.7**	**3.3**	**11.4**	**8.7**

Summary of marine habitat displaced & created (square feet), using available habitat = 50% ASA assumption

	Total				Shoreline Restoration				Breakwaters Total				Breakwaters (Without Ridges)				Reef Ridges			
	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change
Intertidal small and large grained (sand and gravel)	48,823	45,949	45,949	-2,874	48,823	45,949	45,949	-2,874	0	0	0	0	0	0	0	0	0	0	0	0
Subtidal small and large grained (sand and gravel)	564,326	10,243	10,243	-554,083	68,812	10,243	10,243	-58,569	495,514	0	0	-495,514	376,990	0	0	-376,990	118,524	0	0	-118,524
Hard / rocky (hard bottom) intertidal	0	151,428	335,582	335,582	0	0	0	0	0	151,428	335,582	335,582	0	95,551	279,069	279,069	0	55,877	56,513	56,513
Hard / rocky (hard bottom) subtidal	0	241,853	822,813	822,813	0	0	0	0	0	241,853	822,813	822,813	0	152,275	523,716	523,716	0	89,578	299,096	299,096
Total below MHW (Subtidal & Intertidal)	**613,149**	**449,474**	**1,214,587**	**601,437**	**117,635**	**56,192**	**56,192**	**-61,443**	**495,514**	**393,282**	**1,158,395**	**662,881**	**376,990**	**247,827**	**802,785**	**425,795**	**118,524**	**145,455**	**355,610**	**237,086**

Summary of marine habitat displaced & created (acres), using available habitat = 50% ASA assumption

	Total				Shoreline Restoration				Breakwaters Total				Breakwaters (Without Ridges)				Reef Ridges			
	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change	Displaced	Created (Planar Area)	Created (Void Area)	NET Change
Intertidal small and large grained (sand and gravel)	1.1	1.1	1.1	-0.1	1.1	1.1	1.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtidal small and large grained (sand and gravel)	13.0	0.2	0.2	-12.7	1.6	0.2	0.2	-1.3	11.4	0.0	0.0	-11.4	8.7	0.0	0.0	-8.7	2.7	0.0	0.0	-2.7
Hard / rocky (hard bottom) intertidal	0.0	3.5	7.7	7.7	0.0	0.0	0.0	0.0	0.0	3.5	7.7	7.7	0.0	2.2	6.4	6.4	0.0	1.3	1.3	1.3
Hard / rocky (hard bottom) subtidal	0.0	5.6	18.9	18.9	0.0	0.0	0.0	0.0	0.0	5.6	18.9	18.9	0.0	3.5	12.0	12.0	0.0	2.1	6.9	6.9
Total below MHW (Subtidal & Intertidal)	**14.1**	**10.3**	**27.9**	**13.8**	**2.7**	**1.3**	**1.3**	**-1.4**	**11.4**	**9.0**	**26.6**	**15.2**	**8.7**	**5.7**	**18.4**	**9.8**	**2.7**	**3.3**	**8.2**	**5.4**

Breakwater types and quantities

BREAKWATER	TOTAL LENGTH AT EL. 0 NAVD88 (FT)	TOTAL FOOTPRINT (FT^2)	TOTAL FOOTPRINT (ACRES)	FOOTPRINT SHALLOWER THAN -6' MLW (FT^2)	FOOTPRINT SHALLOWER THAN -6' MLW (ACRES)	TOTAL VOLUME (FT^3)	TOTAL VOLUME BELOW MHW (FT^3)	TOTAL VOLUME BELOW MHWS (FT^3)	TOTAL VOLUME (YD^3)	TOTAL VOLUME BELOW MHW (YD^3)	TOTAL VOLUME BELOW MHWS (YD^3)
A.1	450	54,175	1.2	54,175	1.2	244,514	231,035	233,347	9,056	8,557	8,642
A.2	450	54,175	1.2	54,175	1.2	244,514	231,035	233,347	9,056	8,557	8,642
B.1	300	35,452	0.8	35,452	0.8	359,044	249,143	254,636	13,298	9,228	9,431
B.2	300	46,765	1.1	46,765	1.1	400,284	290,384	295,877	14,825	10,755	10,958
B.3	300	46,765	1.1	44,447	1.0	400,284	290,384	295,877	14,825	10,755	10,958
B.4	300	46,765	1.1	30,869	0.7	400,284	290,384	295,877	14,825	10,755	10,958
B.5	300	46,765	1.1	14,996	0.3	400,284	290,384	295,877	14,825	10,755	10,958
C.1	350	44,461	1.0	0	0.0	496,343	365,678	372,157	18,383	13,544	13,784
C.2	450	75,146	1.7	0	0.0	778,983	606,789	615,240	28,851	22,474	22,787
TOTAL	3,200	450,468	10.3	280,878	6.4	3,724,534	2,845,215	2,892,234	137,946	105,378	107,120

+10%

BREAKWATER	TOTAL LENGTH AT EL. 0 NAVD88 (FT)	TOTAL FOOTPRINT (FT^2)	TOTAL FOOTPRINT (ACRES)	FOOTPRINT SHALLOWER THAN -6' MLW (FT^2)	FOOTPRINT SHALLOWER THAN -6' MLW (ACRES)	TOTAL VOLUME (FT^3)	TOTAL VOLUME BELOW MHW (FT^3)	TOTAL VOLUME BELOW MHWS (FT^3)	TOTAL VOLUME (YD^3)	TOTAL VOLUME BELOW MHW (YD^3)	TOTAL VOLUME BELOW MHWS (YD^3)
A.1	450	59,600	1.4	59,600	1.4	269,000	254,200	256,700	9,970	9,420	9,510
A.2	450	59,600	1.4	59,600	1.4	269,000	254,200	256,700	9,970	9,420	9,510
B.1	300	39,000	0.9	39,000	0.9	395,000	274,100	280,200	14,630	10,160	10,380
B.2	300	51,500	1.2	51,500	1.2	440,400	319,500	325,500	16,310	11,840	12,060
B.3	300	51,500	1.2	48,900	1.1	440,400	319,500	325,500	16,310	11,840	12,060
B.4	300	51,500	1.2	34,000	0.8	440,400	319,500	325,500	16,310	11,840	12,060
B.5	300	51,500	1.2	16,500	0.4	440,400	319,500	325,500	16,310	11,840	12,060
C.1	350	49,000	1.1	0	0.0	546,000	402,300	409,400	20,230	14,900	15,170
C.2	450	82,700	1.9	0	0.0	856,900	667,500	676,800	31,740	24,730	25,070
TOTAL	3,200	495,900	11.4	309,100	7.1	4,097,500	3,130,300	3,181,800	151,780	115,990	117,880