FORENSIC ANALYSIS:

METHODOLOGY REPORT

Prepared for:

The Hudson River Sustainable Shorelines Project

NYSDEC Hudson River National Estuarine Research Reserve

Prepared by:

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About the Hudson River Sustainable Shorelines Project

The Hudson River Sustainable Shorelines Project is a multi-year effort led by the New York State Department of Environmental Conservation Hudson River National Estuarine Research Reserve, in cooperation with the Greenway Conservancy for the Hudson River Valley. Partners in the Project include Cary Institute of Ecosystem Studies, NYSDEC Hudson River Estuary Program and Stevens Institute of Technology. The Project is facilitated by The Consensus Building Institute. The Project fulfills aspects of Goal 2 of the Action Agenda of the Hudson River Estuary Program. The Project is supported by the National Estuarine Research Reserve System Science Collaborative, a partnership of the National Oceanic and Atmospheric Administration and the University of New Hampshire. The Science Collaborative puts Reserve-based science to work for coastal communities coping with the impacts of land use change, pollution, and habitat degradation in the context of a changing climate.

Disclaimer

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BACKGROUND

Figure 1 – Project site map

The intent of the Forensic Analysis was to investigate the performance of six shoreline stabilization treatments that were impacted by Tropical Storms Irene and Lee in 2011 and Post-Tropical Storm Sandy in 2012. A combination of traditional and non-traditional shorelines with varying degrees of damage were selected for the analysis. The overall objective was to identify the factors that were critical to each project's performance, and then to determine which if any of those factors were consistent between projects. The final project locations were selected from a list of twenty potential sites compiled by the research team, with the final selections made in consultation with the project's technical advisory panel composed of engineers and landscape architects. Critical factors in the final site selection included ensuring a diverse cross-section of sites with adequate site access, and identifying a cooperative local contact with knowledge of the shoreline. The final sites which were selected included: Coxsackie Boat Launch, Esopus Meadows Preserve, Oak Point and Hunt's Point Landing in the Bronx, Habirshaw Park, and Scenic Hudson/Mathiessen Park in Irvington. The Coxsackie, Esopus Meadows, Habirshaw, and both Irvington sites only experienced minimal damage during the three storms, while Hunt's Point Landing and Oak Point were more severely impacted. Separate case studies describing each site and the impact of the three storms have been prepared. An additional report describes the common project performance factors. All eight documents can be found at http://www.hrnerr.org/shorelinesforensicanalysis. Each Forensic Analysis included the review of historic photographs and design drawings, interviews with project managers and designers, field data collection, and modeling of the hydrodynamic conditions during each of the three storms. Collectively, this information was used to create a holistic picture of each site, from which the critical project performance factors could be determined. Impacts from debris, undersized stones, improper slopes, as well as monitoring and maintenance protocols, adaptive management, and maturity of vegetation were all considered. All of this "evidence" was used to develop conclusions based on engineering judgment as to why each project performed the way it did.

Table 1 – Site locations and relative wave energy conditions

Site	Coxsackie	Esopus Meadows	Irvington	Habirshaw	Oak Point	Hunt's Point
Hudson River Mile from Battery in NYC	125	86.5	25	18	East River	East River
County	Greene	Ulster	Westchester	Westchester	Bronx	Bronx
Relative energy based on fetch (Hardaway et al. 1984)	Low	Medium	High	Moderate	High	High

HISTORICAL SHORELINE ANALYSIS

A desktop analysis of the historic shoreline variations was used to help understand the long term physical processes at each site. Understanding these processes is critical when attempting to determine the role of a stabilization structure during a storm event. Historical shoreline variability, including any previous stabilization attempts, was developed from: the analysis of available aerial photography, the collection of any available media articles or documentation, as well as personal discussions with property owners, site developers, and others. Historic aerial photographs and topographic maps of the sites were obtained from Google Earth and www.historicaerials.com. Chronic erosion patterns, shoreline hardening, and other site alterations discernable in the images were noted and used to provide objective insight into the conditions that drove the shoreline designs at each site. Time lapse videos of the shoreline changes at each site are available at https://www.hrnerr.org/hudson-river-sustainable-shorelines/shorelines-engineering/.

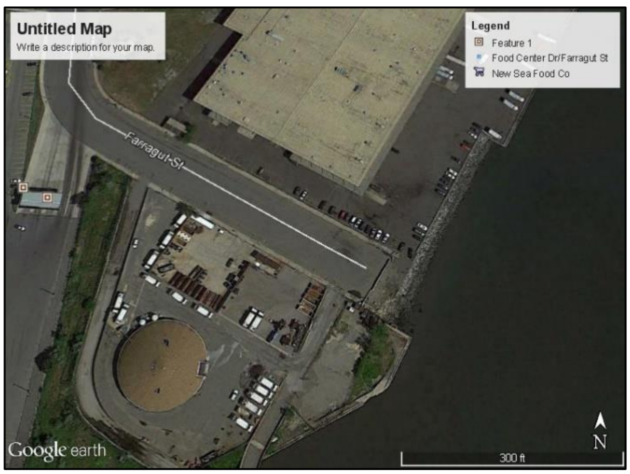

Figure 2 – Hunts Point before restoration.

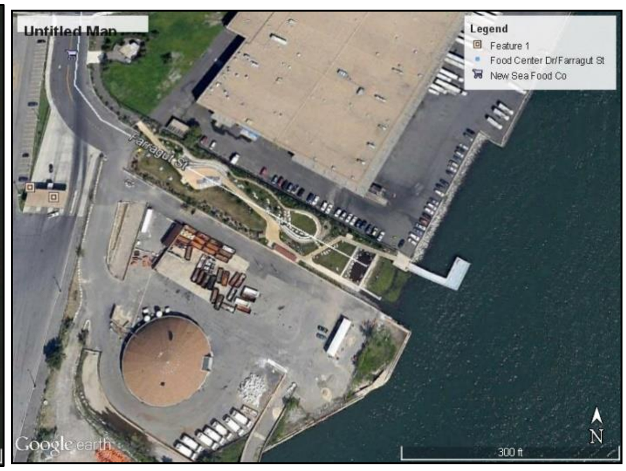

Figure 3 – Hunts Point after restoration.

CHARACTERIZATION OF SITE CONDITIONS

The conditions at each site were determined from a combination of desktop analyses and initial site visits during which qualitative information was collected. The initial site visits were conducted to become more familiar with each of the shorelines, and when possible meet with locals having knowledge of the shoreline in question. Some of the features that were noted during the initial site visit included:

- the location of the intertidal zone
- typical wave, wake, and current patterns
- any noticeable end effects/scour
- the presence and health of any native/invasive vegetation
- erosion from upland sources
- noticeable impacts from inundation, overtopping and wave action

Examples of the wide range of damage observed related to storm impacts is shown below in Figure 4. Observed damage included: eroded areas of sediment, displaced armor stones, and debris covered marshes. Upland disturbances included: uprooted trees, loss of vegetation due to salinity intrusion, and the displacement/damage of upland fixtures (i.e. fountains, lights, etc.)

Figure 4– Typical storm impacts observed after Post-Tropical Storm Sandy at Irvington, NY

Information from the site visits was supplemented with information obtained from a variety of other sources. FEMA flood maps were downloaded and used to establish the flood zone and Base Flood Elevation (BFE) for each site. The BFE was used to help determine the likelihood of inundation during the historic storms (see table 5). The BFE defines the water level expected during the 1% annual chance of occurrence storm, and is the boundary used by the national flood insurance program to determine insurance rates. In addition, local building codes typically reference the BFE in defining minimum standards for coastal construction. The flood zone designation was used to help establish the likelihood of a site experiencing significant wave activity during a storm. Sites located in or adjacent to a V-zone are sites where 3 ft waves are expected during the 1% annual chance of occurrence storm. Some of the newer maps also have a boundary designating the Limit of Moderate Wave Action (LMWA), which identifies the location where 1.5 ft wave heights can be expected.

Additional information about the wave heights expected at each site was obtained by conducting a fetch analysis. The fetch is the open water distance over which wave growth can occur. The average and maximum fetch were calculated for each site as shown in Figure 6 and each site was classified as low, moderate, or high energy based on the criteria developed by Hardaway et al. (1984). The classification system is reproduced in Table 2.

The typical hydrodynamic conditions for each site were determined from a physical forces climatology developed during a previous phase of the sustainable shorelines project (https://www.hrnerr.org/hudson-river-sustainable-shorelines/spatial-information-designing-shoreline/). The climatology was based on a one year numerical simulation of conditions within the Hudson, generated using an ultra-high resolution version of the NYHOPS numerical model (Bruno et al., 2004). The climatology was developed based on the conditions during a typical year (2010), and included one significant Nor'easter. The results were analyzed and statistically significant values such as the maximum, median, mean and 95% level (value exceeded only 5% of the time during a typical year) were extracted for critical parameters such as wave height (H_{max}), water level (WL_{max}) and current velocity (see Table 3). The modeling data was supplemented by observational data on ice and wakes. Ten years of daily ice reports collected by the United States Coast Guard (USCG) during the typical ice season (December to March) were compiled and statistically analyzed. Statistically significant values such as the median (Ice $t_{med)}$ and 90% level (Ice $t_{90\%}$) (value exceeded only 10% of the time during a typical ice season) were extracted for parameters such as percent ice cover and ice thickness. The ice data is discussed at https://www.hrnerr.org/hudson-river-sustainable-shorelines/shorelines-engineering/ice-conditions/. Wake data, including wake height (H_{wake}) was collected over two weeks during the summer of 2012 and 2013 by students at 32 locations along the Hudson River. Students spent six hours at each location

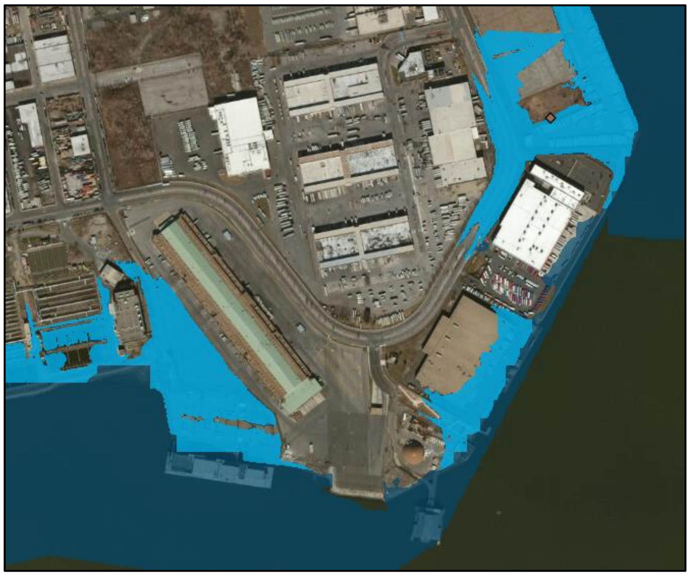

Figure 5 - Example inundation map

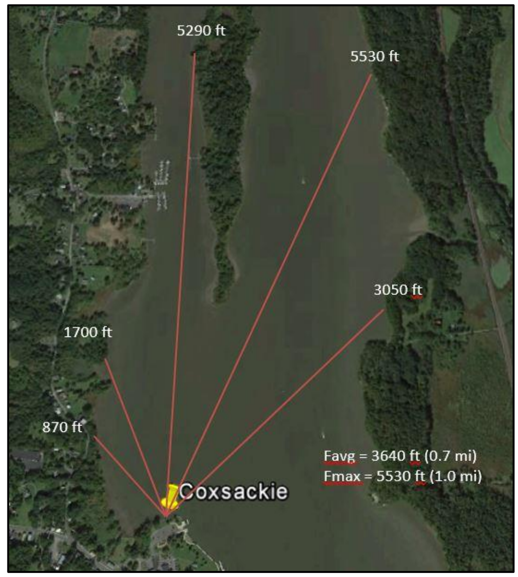

Figure 6 – Example fetch analysis

and most sites were visited in both 2012 and 2013. A summary of the data obtained from the physical forces climatology for the Coxsackie, NY site is shown in Table 3. The physical forces data were used to develop a baseline representing the typical conditions against which the historic storms could be compared.

Table 2 – Fetch classification scheme

Fetch	Energy
<1 mi	Low
1-5 mi	Moderate
>5 mi	High

Table 3 – Example climatology summary

Parameter	Climatology
WL_{max} (ft NAVD 88)	6.06
H_{max} (ft)	0.91
H_{med} (ft)	0.09
Ice t_{med} (in)	0.39
Ice $t_{90\%}$ (in)	10.7
H_{wake} (ft)	0.3-0.7

COLLECTION OF ENGINEERING DATA

Information on the design of each project was requested from engineers, landscape architects, developers, permit staff, and others familiar with each site. The intent of compiling this information was to examine some of the design assumptions that were utilized and to ultimately compare the design conditions with the conditions experienced during the three historic storm events. As expected, the degree of cooperation with the research staff and hence the quality of the information obtained, varied from site to site. The information that was shared ranged from detailed engineering designs accompanied by extensive discussions for some sites, to limited discussions accompanied by photographic evidence for other sites. The type of information that was made available for each site is discussed in more detail in the individual forensic analysis reports, and is summarized in Table 4. Special focus was given to identifying project elements that provide enhanced ecosystem services, or serve to increase a structures resilience.

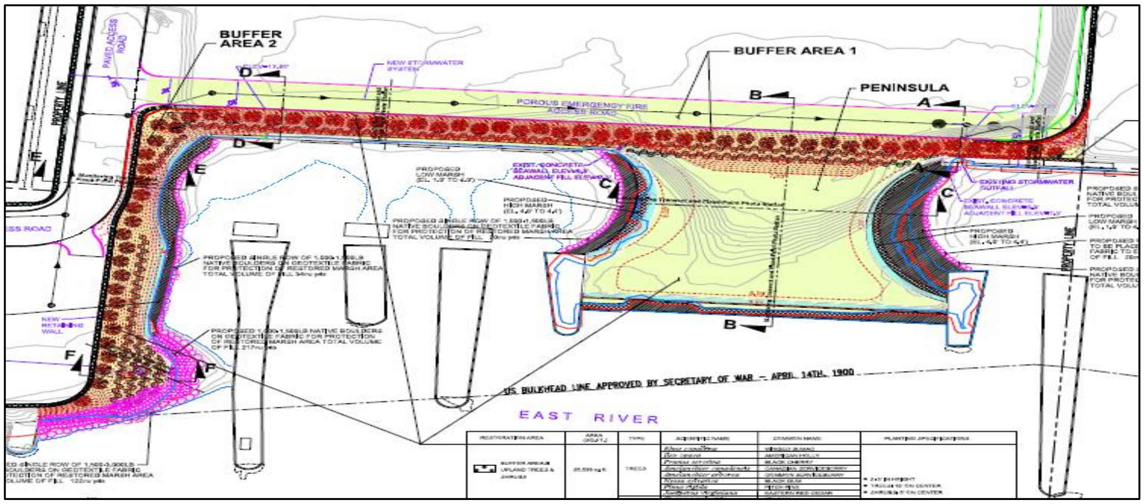

Figure 7 – Example of engineering information obtained (Oak Point Property LLC)

FIELD DATA COLLECTION

A second, more detailed site visit was conducted to follow up on any factors identified during the initial site visit and desktop analyses. During the second site visit, more quantitative information was collected. Some of the data that was collected during the second site visit included data on upland use, vegetation, soil conditions, upland slope, shoreline slope, offshore slope, offshore depth, and the condition of key structural elements. Topographic and bathymetric surveys of the site were conducted to obtain detailed information about upland elevations, nearshore slopes, and offshore depths. The survey was completed using a real time kinematic (RTK) GPS, echosounder, and computer, mounted on the back of a personal watercraft (Miller et al., 2009). A sample of the data collected during each survey is shown in Figure 8. In conjunction with the survey, an ecological rapid assessment was performed utilizing the procedure developed by the Cary Institute of Ecosystem Studies (https://www.hrnerr.org/hudson-river-

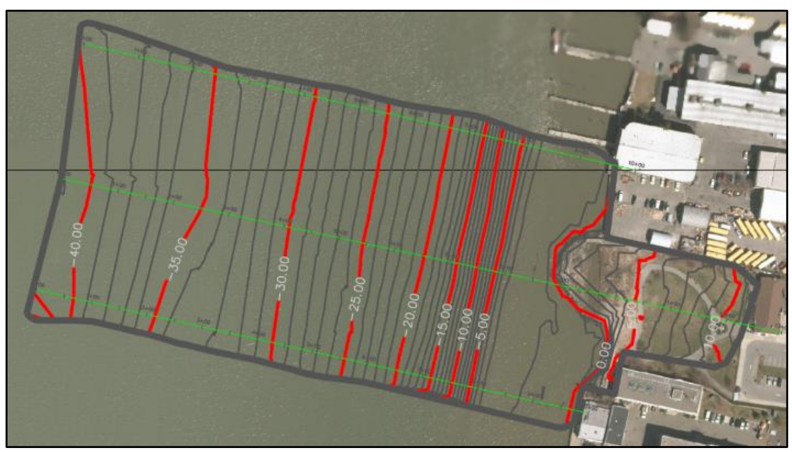

Figure 8 - Example survey results

sustainable-shorelines/shorelines-ecology/). The rapid assessment involves a combination of field and desktop analyses. Some of the information collected included: shore length, shore sinuosity, slope, substrate cover, vegetation type and height, upland land use and the presence of wrack and large wooden debris. While useful for documenting the conditions at the time of the site visit, the utility of the rapid assessment procedure was diminished by the lack of a pre-storm data set for comparison. As such, the ecological rapid assessments are only discussed minimally in the individual forensic reports; however they do provide a valuable baseline for future comparisons.

HINDCASTING STORM CONDITIONS

Conditions during the three historic storms (Sandy, Irene, and Lee) were hindcast using the NYHOPS numerical model (Bruno et al., 2006). The high-resolution version of NYHOPS developed for the physical forces work conducted in Phase II of the Sustainable Shorelines project (Georgas and Miller, 2013) was used for the Hudson River hindcasts, while the operational version of NYHOPS model was used for the two East River sites. The wave heights and water levels were compared to the characteristic conditions determined from the physical forces climatology (Miller and Georgas, 2015). Example comparisons for water elevation and wave height are presented below in Figure 9. Water level hindcasts were combined with the survey data to determine if the sites were inundated during the historic storms. Field data from the USGS and FEMA collected after Sandy were used to confirm these determinations. While all three storms were significant, generally the wave heights and water levels produced by Sandy were the largest and therefore the majority of the focus is placed on those results. In some cases, the results from Lee are excluded from the figures presented in the individual site reports because the hindcast wave heights and water levels were so much smaller than for the other two storms.

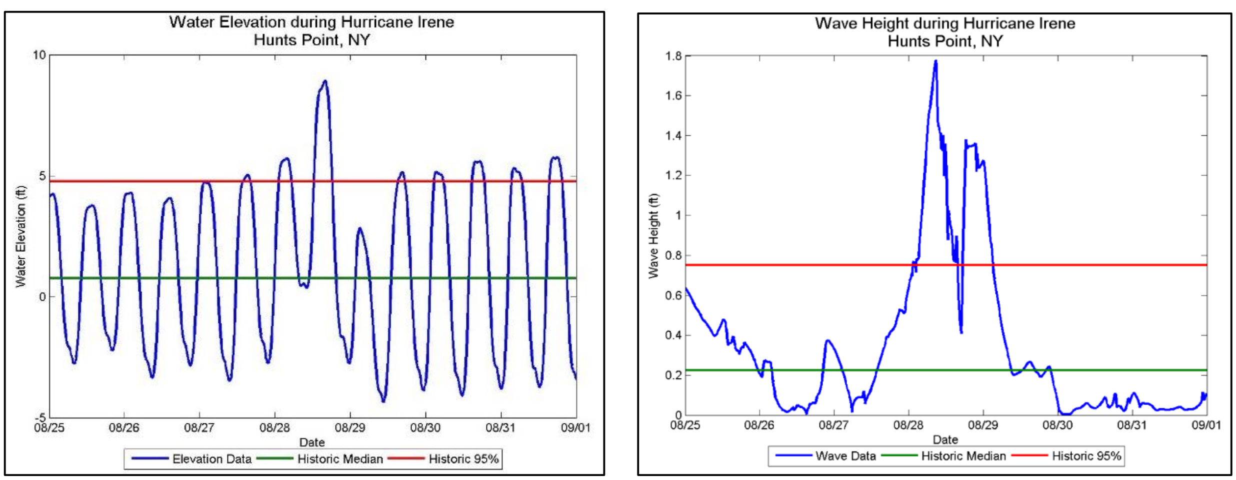

Figure 9 - Example water level and wave height hindcasts during Hurricane Irene

RESULTS

At each site, all of the available information was considered to generate a forensic analysis of shoreline behavior before, during, and after the three historic storms. The ways in which the data described above was utilized varied from site to site according to the availability, quality, and applicability of the different data sets to each site; however a common framework was applied throughout. The historic shoreline analysis and initial site characterization were used to define the context of the problem and to define the typical conditions at each site. When available, the engineering data was used to provide information about the considerations and assumptions that went into the design of each project. The second site visit was used to collect quantitative information on the shoreline and upland areas and to conduct the ecological assessment. Finally, numerical hindcasts were used to simulate the hydrodynamic conditions during the three storms. A summary of the data available for each site is presented in Table 4. While the three historic storms were the focus of the analysis, additional information was also considered. For example, several of the sites appear to have been damaged by ice during the 2013-2014 winter. At each site, all of the "evidence" was considered and an engineering assessment of the factors critical to the performance of each project was made. After each of the sites was considered individually, all six sites were considered together and common themes were identified, and used as the basis for a proposed set of recommendations for improving the design, implementation, and management of ecologically enhanced shoreline projects (Miller and Rella, 2015).

Table 4 - Resources used in forensic shorelines analysis (C – Coxsackie, H – Habirshaw, EM – Esopus Meadows, HP – Hunts Point, I – Irvington, OP – Oak Point)

Tools, studies, models, data	C	H	EM	HP	I	OP
HISTORIC ANALYSIS						
HRSSP Demonstration Site Network	Y	Y	Y	Y	N	N
Historic aerial photographs	Y	Y	Y	Y	Y	Y
Topographic maps	Y	Y	Y	Y	Y	Y
CHARACTERIZATION						
Flood Insurance Rate Maps	Y	Y	Y	Y	Y	Y
Fetch Analysis for Wind Waves	Y	Y	Y	Y	Y	Y
Initial site visit	Y	Y	Y	Y	Y	Y
Physical forces climatology	Y	Y	Y	Y	Y	Y
Ice climatology	Y	Y	Y	N	Y	N
Wake data	Y	Y	Y	N	Y	N
ENGINEERING DATA						
Photos (construction, pre and post-storm)	Y	Y	Y	Y	Y	Y
Discussions with developer/designer	Y	Y	Y	Y	N	Y
Discussion with property owner/manager	Y	Y	Y	Y	Y	Y
Engineering plans	Y	Y	N	Y	Y	Y
Correspondence with permit staff	Y	N	Y	N	Y	Y
FIELD DATA COLLECTION						
Final site visit	Y	Y	Y	Y	Y	Y
Topographic & bathymetric surveys	Y	Y	Y	Y	Y	Y
Rapid ecological assessment	Y	Y	Y	Y	Y	Y
HINDCAST						
Hindcast of storm conditions	Y	Y	Y	Y	Y	Y
FEMA Sandy Flood Extent Maps	N	Y	N	Y	N	Y

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