HASHAMOMUCK COVE, SOUTHOLD, NEW YORK, COASTAL STORM RISK MANAGEMENT

FEASIBILITY STUDY

APPENDIX C:

COASTAL ENGINEERING APPENDIX

U.S. Army Corps of Engineers

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1.0 INTRODUCTION

1.1 Coastal Engineering for Hashamomuck Cove

The U.S. Army Corps of Engineers (USACE) New York District is conducting a coastal storm risk management (CSRM) feasibility study for Hashamomuck Cove, in the Town of Southold, NY (Suffolk County). The study area includes approximately 1.5 miles as shown in Figure 1. The ultimate goal of the study is to formulate a coastal storm risk management plan/project for the Hashamomuck study area covering a 50 year period of analysis with a projected construction start date of 2019 that maximizes net economic benefits and is feasible from both an environmental and constructability standpoint.

Figure 1: Project Location

The purpose of this appendix is to describe, in detail, the Coastal Engineering input driving the Beach-fx software for the Hashamomuck Cove study area. This includes developing the representative reaches for the study area, a historical storm suite, historic shoreline change conditions, and profile response to the array of storm events using SBEACH.

In response to the comments received during the District Review process, the USACE is reevaluating the TSP with a specific focus on establishing the required renourishment volumes for the various plans while taking any planform losses as well as project feasibility under various scenarios of Sea Level Change (SLC) into account.

1.2 Prior Reports

Prior reports that have been prepared documenting coastal erosion and storm damages along the north shore of Long Island Sound and the Hashamomuck Cove Study Area in Southold, New York include:

- USACE, New York District, June 2008, Section 905(b) Reconnaissance Study, New York District. The report recommended a Feasibility Study that included the Hashamomuck Cove study area.
- Long Island North Shore Heritage Area Planning Commission, 2005, Long Island North Shore Heritage Area Management Plan. This report includes information on resources in the study area.
- USACE, New York District, 1995, North Shore of Long Island, New York, Storm Damage Protection and Beach Erosion Reconnaissance Study, New York District. This report further described erosion (including erosion rates) and coastal storm damage along the north shore of Long Island, including discussion of the Hashamomuck Cove area.
- New York State University, circa 1973, North Shore of Long Island Sound, Technical Report #18. Report evaluates areas along the north shore but did not include the Hashamomuck Cove study area specifically.
- USACE, New York District, 1969 Survey Report of the North Shore of Long Island. This Survey Report addressed conditions along the entire north shore of Long Island, including within the study area. Erosion and coastal storm damage problems were identified, and general opportunities to address these problems for the North Shore of Long Island were discussed.

2.0 COASTAL SETTING AND PERTINENT DATA

This section provides a summary of the key environmental conditions, active coastal processes, and the geological framework that characterize the vulnerability of Hashamomuck Cove to economic losses through coastal storm-induced damages to existing infrastructure.

2.1 Climate

Suffolk County has a moderate coastal climate with warm, humid summers and moderately cold winters. The temperature averages 51 degrees Fahrenheit (°F) annually, ranging from a low monthly average of 32°F in February to a high monthly average of 72°F in July. The average annual precipitation ranges from 40 to 45 inches and is fairly evenly distributed throughout the year.

2.2 Sediment Grain Size Analysis

Twenty-eight sediment samples were analyzed for grain size distribution (ASTM D 422-63, reapproved 2002) in the New England District's Environmental Laboratory. Sediment samples were collected from ten transects within the Study Area, three in West Cove, four in Central Cove, and three in East Cove as part of environmental sampling for the study (see Appendix A2). Within these transects, samples were collected from the low intertidal zone, the medium intertidal zone, and the high intertidal zone and submitted for grain size analyses. The locations of the transects are illustrated in Figure 2.

Figure 2: Sediment Transects

The results of the grain size analysis are summarized in Table 1 below. The sediments collected from all stations were generally represented by various fractions of gravel and sand. The data show that 10 stations were dominated by gravel, 5 stations were dominated by sand, 12 stations had a similar mix of sand and gravel, and 1 station was dominated by cobble. The presence of cobble at all stations may be underrepresented due to the nature of the sediment sampling device used (a 0.003 m^2 core), however, it is noted that cobble was not specifically avoided during sampling.

Table 1: Grain Size Summary

Sample ID	% Cobble	% Gravel		% Sand			% Fines
		Coarse	Fine	Coarse	Medium	Fine	
T1-H	0.0	11.0	35.6	13.6	33.3	2.7	3.8
T2-H	0.0	64.5	0.4	0.4	22.9	11.8	0.0
T3-H	0.0	53.2	16.1	0.5	26.3	4.0	0.0
T4-H	0.0	15.1	62.8	6.4	15.3	0.4	0.0
T6-H	0.0	34.8	2.5	1.1	26.6	35.0	0.0
T7-H	0.0	52.1	10.1	0.1	22.8	14.8	0.0
T8-H	0.0	28.6	24.4	4.0	41.2	1.8	0.0
T9-H	0.0	35.2	18.0	0.5	40.3	6.0	0.0
T10-H	0.0	24.3	48.0	6.4	18.0	3.4	0.0
T1-M	0.0	6.2	38.7	24.1	29.8	1.2	0.0
T2-M	0.0	7.0	22.0	32.6	36.2	2.2	0.0
T3-M	0.0	19.7	39.4	19.7	19.8	1.4	0.0
T4-M	0.0	35.9	44.0	9.8	9.8	0.4	0.0
T6-M	0.0	9.2	17.7	8.3	49.3	15.4	0.0
T7-M	0.0	17.0	25.8	14.8	39.8	2.5	0.0
T8-M	0.0	44.8	31.3	8.0	14.5	1.5	0.0
T9-M	0.0	31.3	22.5	9.2	36.1	0.8	0.0
T10-M	0.0	39.8	45.4	10.6	4.1	0.1	0.0
T1-L	0.0	15.5	77.0	6.7	0.9	0.0	0.0
T2-L	0.0	7.1	40.9	24.7	24.5	2.7	0.0
T3-L	0.0	14.0	31.9	34.4	19.3	0.5	0.0
T4-L	78.3	15.6	3.3	1.3	1.4	0.1	0.0
T5-L	0.0	3.5	17.2	13.9	63.3	2.0	0.0
T6-L	0.0	27.3	31.6	9.5	26.5	5.1	0.0
T7-L	0.0	7.5	24.2	12.3	45.1	10.9	0.0
T8-L	0.0	28.4	31.2	13.3	22.5	4.6	0.0
T9-L	40.3	51.7	5.0	1.8	1.2	0.0	0.0
T10-L	0.0	13.0	63.1	5.7	15.3	2.9	0.0

The sediment to be used for initial fill and future nourishment will be compatible with the native beach material. Additional data to characterize the beach material including the foreshore will be collected during pre-construction engineering and design (PED). A map showing locations of 3 upland sand sources on Long Island are provided in the main report.

1. Ranco Sand & Stone

2. East Coast Mines

3. Sagaponack

A range of grain sizes are available from these quarries. Specific grain size requirements will be determined in PED.

The median grain size is estimate to be 0.5 mm.

2.3 Beach Profiles

Beach profile data was obtained during a profile survey completed in December 2014. More detail on the Beach profiles is provided in section 3.3.1.

2.4 Shoreline Erosion

2.4.1 Background Erosion

Coastal erosion is a shore process that reduces the width of the beach. The underlying physical processes include long-shore and cross-shore sediment transport resulting from both typical and storm induced wave conditions.

Background erosion can refer to historical erosion as determined from previous survey or aerial photography data. In some cases, the storm-induced erosion component of coastal erosion, although with severe consequences to human development, may be short-term in nature. Following storms, a natural sandy coastline tends to reshape itself into its former configuration, and some of the sand displaced from the beach by a storm is returned by wave action during periods of calm weather. The beach shape then conforms to the prevailing wave climate and littoral processes. However, over time portions of the beach can experience permanent land loss. Erosion is generally caused by gradients in the net longshore sediment transport and in some instances cross-shore processes play a role. Cross-shore processes can transport sediment to the deeper offshore regions. Sediment is then effectively taken out of the nearshore sediment balance, ultimately resulting in a reduction in berm width. In developed areas, bulkheads and revetments will help to limit landward erosion because they define the landward limit of the shoreline (assuming they are maintained and do not fail). However, bulkheads have the potential to accelerate vertical erosion as waves reflect off them and cause scour downwards.

Finally, in areas where the dune position is maintained in place and sea level change trends are such that sea level rise is prevailing, erosion is observed as a reduction of dry beach over time. Coastal erosion as a result of sea level rise is typically part of the background erosion process. Sea level rise is further discussed in section 2.6.

2.4.2 Hashamomuck Shoreline Position Changes

For this project area, there is no historic survey data available from which to extract the mean high water position which is typically used to determine shoreline change. As a result, the method used to calculate the rate of change was through comparison of historic aerial photography. Images were located and rectified for the project location from five time periods. Specifically, October 19, 1960, April 15, 1974, April 5, 1993, June 1, 2001, and June 10, 2010.

A shoreline change rate baseline for the project area was developed that followed the general contour of the land. From this baseline, 45 shoreline perpendicular transect locations were established as locations to calculate the shoreline change (Figure 28). From the available imagery, the wet/dry shoreline was extracted along the project length at each transect location for each time period. A least squares regression was calculated through the extracted shoreline locations for each transect to develop the initial shoreline change rates. The rates were then smoothed by creating moving averages of the four surrounding rates for each transect. Table 2 displays the calculated shoreline change rate for each transect. For reference Table 2 also includes the economic reach number the transect lies within.

For the Hashamomuck Cove Study area the average shoreline change rate is -0.65ft/yr, where the minus sign indicated erosive behavior.

Figure 3: Shoreline Change Baseline

Table 2: Shoreline change rate (ft/yr) and moving average for each transect. Economic reach numbers are included for future reference (see section 3.0 for Beach-fx modeling – note that transect 45 did not fall within an Economic Reach).

Shoreline Transect Location	Change Rate (ft/yr)	Moving Average (ft/yr)	Economic
1	-0.37	-0.06	E1
2	0.18	-0.37	E1
3	0.00	-0.60	E1
4	-1.29	-0.84	E2
5	-1.54	-1.22	E2
6	-1.57	-1.53	E2
7	-1.70	-1.57	E2
8	-1.55	-1.49	E3
9	-1.50	-1.38	E3
10	-1.13	-1.18	E3
11	-0.99	-0.99	E3
12	-0.70	-0.84	E3
13	-0.64	-0.75	E3
14	-0.72	-0.70	E4
15	-0.72	-0.70	E4
16	-0.74	-0.67	E4
17	-0.69	-0.62	E4
18	-0.46	-0.59	E4
19	-0.50	-0.51	E4
20	-0.54	-0.47	E5
21	-0.36	-0.56	E6
22	-0.48	-0.71	E6
23	-0.91	-0.87	E6
24	-1.24	-1.09	E7
25	-1.38	-1.28	E8
26	-1.46	-1.37	E8
27	-1.39	-1.30	E8
28	-1.36	-1.15	E8
29	-0.90	-0.96	E8
30	-0.63	-0.78	E9
31	-0.53	-0.65	E9
32	-0.51	-0.61	E10
33	-0.69	-0.55	E10
34	-0.66	-0.51	E11
35	-0.33	-0.44	E12
36	-0.34	-0.46	E12
37	-0.16	-0.37	E12
38	-0.79	-0.33	E13
39	-0.24	-0.26	E14
40	-0.13	-0.25	E14
41	0.04	-0.15	E14
42	-0.12	-0.20	E15
43	-0.29	-0.30	E15
44	-0.50	-0.38	E15
45	-0.61	-0.47	

2.4.3 Beach Nourishment Diffusion

Beach nourishment is typically carried out in areas where a background erosion or historical erosion persists. The background erosion will be accounted for in the design of the beach nourishment project as it affects the project performance. It is assumed that the causes of the background erosion will not be addressed by the project and will continue to persist.

A beach nourishment project constructed on a long beach represents a perturbation, which under wave action will spread out along the shoreline[1] (a process called diffusion). If the wave action is minor, then the rate at which the anomaly resulting from the beach nourishment is spread out from the placement area will likewise be small[1] and vice versa under the influence of moderate to large wave action the rate of diffusion will be moderate to high.

Hashamomuck Cove did not receive any significant volume of sand from past beach nourishment projects and thus beach nourishment diffusion is not relevant for the future without project conditions. However, for the future with project conditions beach nourishment diffusion will be considered. It is important to note that beach nourishment diffusion is a separate process from background shoreline erosion and is only a result of the implementation of a project.

2.5 Coastal Storm Climatology and Wave Data

2.5.1 Historical Storms

Two types of storms of primary significance along the North Shore of Long Island are tropical storms (hurricanes), which typically impact the New York area in summer and fall, and extratropical storms (nor'easters), which are primarily winter storms. Nor'easters are usually less intense than hurricanes but tend to have longer durations. Both types of storms often cause high water levels and moderate to high wave conditions and in the past have been responsible for significant erosion and flooding throughout the coastal region of the north shore. For general information purposes, Table 3 lists several storms that impacted the New York area.

[1] Dean, R. G., 2005. "Beach Nourishment Theory and Practice," World Scientific Publishing Co., Hackensak, NJ.

Table 3: List of Historical Storms

Hurricane		Nor'easter	
Date	Name	Date	Name
14 Sep 1904		03 Mar 1931	
08 Sep 1934		17 Nov 1935	
21 Sep 1938		25 Nov 1950	
14 Sep 1944	-	06 Nov 1953	
31 Aug 1954	Carol	11 Oct 1955	
02 Sep 1954	Edna	25 Sep 1956	
05 Oct 1954	Hazel	06 Mar 1962	
03 Aug 1955	Connie	05 Nov 1977	
12 Sep 1960	Donna	17 Jan 1978	
10 Sep 1961	Esther	06 Feb 1978	
20 Aug 1971	Doria	22 Jan 1979	
14 Jun 1972	Agnes	22 Oct 1980	
06 Aug 1976	Belle	28 Mar 1984	
27 Sep 1985	Gloria	09 Feb 1985	
19 Aug 1991	Bob	30 Oct 1991	
08 Oct 1996	Josephine	01 Jan 1992	
07 Sep 1999	Floyd	11 Dec 1992	
01 Sep 2006	Ernesto	02 Mar 1993	
28 Aug 2011	Irene	12 Mar 1993	
29-30 Oct 2012	Sandy	28 Feb 1994	
		21 Dec 1994	
		05 Jan 1996	
		06 Oct 1996	
		02 Feb 1998	
		14 Apr 2007	
		15 Nov 2009	Nor'Ida
		13 Mar 2010	
		25 Dec 2010 (added)	
		17 Apr 2011	
		7 Nov 2012 (added)	
		26 Dec 2012 (added)	
		January 22–24, 2016 (added)	
		January 4, 2018 (added)	"Bomb Cyclone"

Notes: Nor'easters generally have no assigned names. Hurricane Sandy affected the project area in late October, 2012, followed by two Nor'easters. This table list historical storms affecting the New York Area. Information was taken from the following source: Beach Erosion Control and Storm Damage Reduction Feasibility North Shore Of Long Island, Asharoken, New York, Engineering Appendix, Draft March 2014. Dates with "(added)" in parentheses were added to the list from the source

Existing coastal processes at Hashamomuck Cove are driven by high energy waves and water levels generated by both tropical and extratropical storms. Based on data from the North Atlantic Coast Comprehensive Study (NACCS, 2015), significant tropical storm events impacted the Hashamomuck Cove shoreline at a frequency of approximately once every 6.8 years. These tropical storms occur between June and November with 74 percent of them occurring in the months of August and September. Extratropical storms, on the other hand, are a frequently occurring storm type that impacts Hashamomuck Cove annually with significant events occurring at a rate of approximately 1.2 storms per year. Extratropical storms typically occur at the project location between early fall through the spring (October through May) with most occurring in the months of November through February. Tropical storm events are typically fast moving storms associated with elevated water levels and large waves whereas extratropical storms are slower moving with comparatively lower water level elevations and large wave conditions. Both storm types can produce beach erosion and morphologic change as well as coastal inundation leading to economic losses within the study area.

Although economic losses are most often realized in the wake of major storm events, it is long-term chronic erosion that creates the vulnerability to major economic losses through volumetric depletion of beach material in the active profile, reduction in beach berm width and reduction in dune crest elevation and dune volume. Not all storms in the storm climatology produce measurable economic damages but they do contribute to setting up vulnerability for economic losses.

2.5.2 NACCS Storm Suite

The NACCS addresses the coastal areas defined by the extent of Hurricane Sandy's storm surge in the District of Columbia and the States of New Hampshire, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Virginia. The Engineer Research and Development Center (ERDC) conducted rigorous regional statistical analysis and detailed high-fidelity numerical hydrodynamic modeling for the North Atlantic coastal region to quantify coastal storm wave, wind, and storm-driven water level extremes. The NACCS modeling efforts included the latest atmospheric, wave, and storm surge modeling and extremal statistical analysis techniques. Products from this work were incorporated into the Coastal Hazards System (CHS) database and include simulated winds, waves, and water levels for approximately 1,050 synthetic tropical events and 100 extratropical events computed at over 3 million computational locations. At a smaller number of locations (18,000 output points), the same information was saved at higher frequency for more convenient/concise data handling. The full NACCS storm suite was determined to span the range of practical storm probabilities.

Figure 4 shows the location of the storm surge (ADCIRC) and wave (STWAVE) save points in the Hashamomuck project area. Storm surge data was extracted at ADCIRC save point 5020 and STWAVE 1346 located at 41.1025 N and 72.4009 W in water depth of 12.0 m (39.4ft). This save point was considered as representative of the waves and storm surge at the farthest offshore extent of the representative profiles in the area. Table 4 provides the statistics for Still Water Level and Wave Height for the particular save point. The extratropical storms cover the period from January of 1938 to December of 2012 and as such did not include any of the more recent storms, such as the Storm of January 4th 2018.

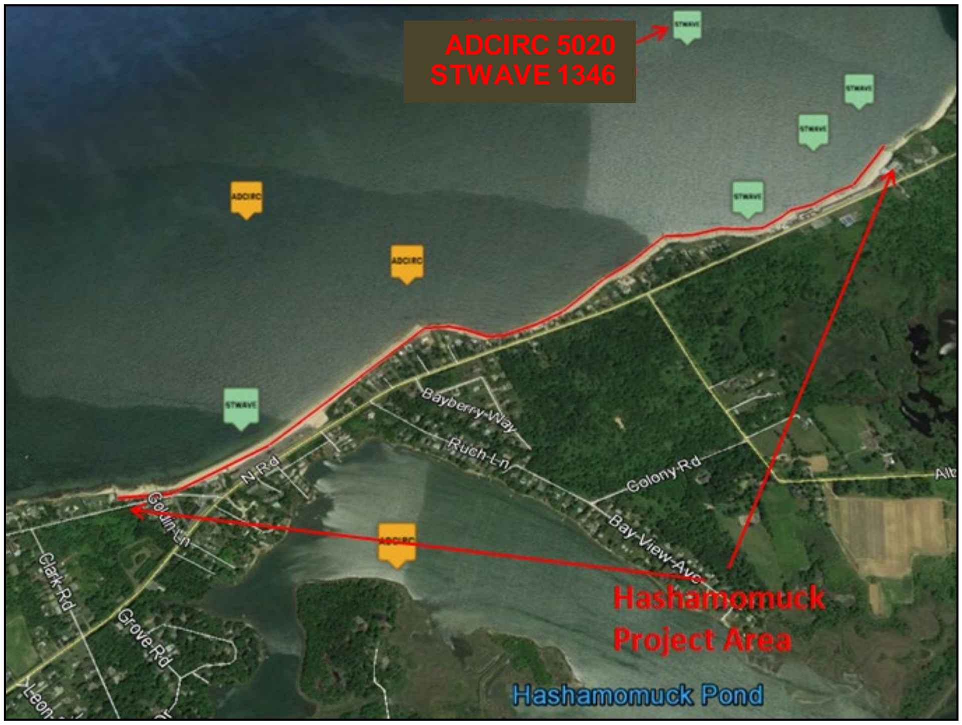

Figure 4: CHS NACCS Save Points Location Map

Table 4: Probability for Parameter values for Still Water Level (from save point 5020) excluding sea level change and for Wave Height (from save point 1346)

Average Return Period [years]	Annual Exceedance Probability (AEP) Value	Still Water Level (SWL) [ft NAVD88]	Significant Wave Height [ft]
10	10%	7.1	8.1
20	5%	7.8	8.7
50	2%	8.7	9.4
100	1%	9.6	9.9
500	0.2%	12.2	10.9

All water level elevations are referenced toe North American Vertical Datum 1988 (NAVD88) unless specifically stated otherwise. More details on the selection of storms from the NACCS storm suite for the specific application to the Hashamomuck Cove CSRM study is provided in section 3.2.

2.6 Sea Level Rise

The mean sea level trend at Montauk, New York (NOAA 8510560) is 0.00961 feet/year based on regionally corrected mean sea level data from 1947 to 2014 (Figure 5). This gauge was selected to represent the project site because it was the closest long term gauge to the project location. The only other gauge on Long Island is short term < 50 years and was therefore excluded.

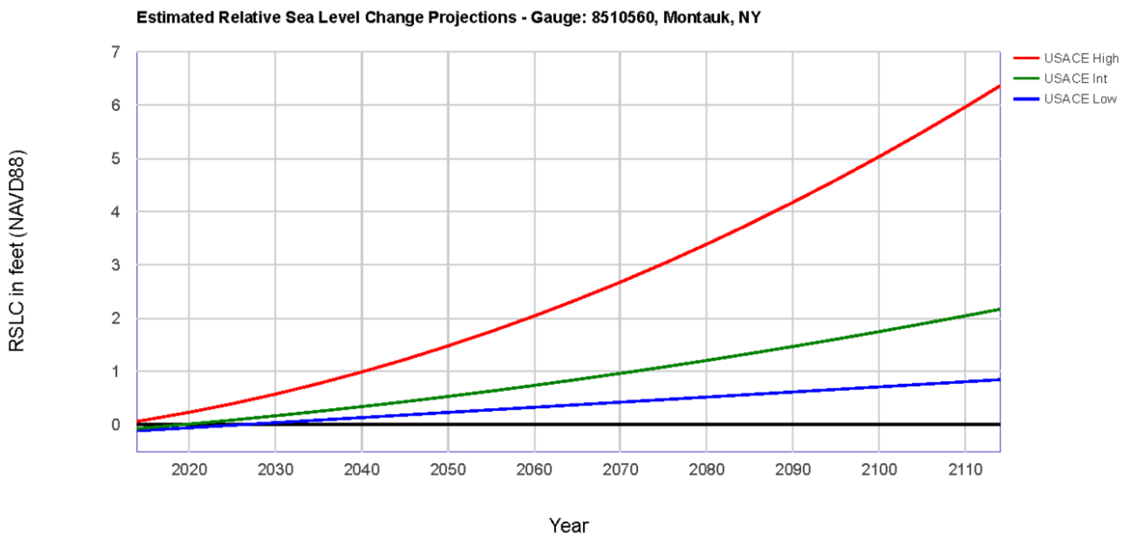

Figure 5: Mean sea level change trend at Montauk, NY.

This historical rate of mean sea level change trend is 0.00964 feet/year and represents the "Low" future rate of sea level change in accordance with ER 1100-2-8162. The "Intermediate" rate of future sea level change was computed using modified NRC Curve 1 and equations 2 and 3 in ER 1100-2-8162. The "High" rate of future sea level change was computed using modified NRC Curve III and equations 2 and 3 in ER 1100-2-8162.

Table 5: Sea Level Change for Montauk, NY in ft. NAVD88

USACE Scenario	MSL value for the year 2014 [ft]	MSL value for the year 2069 [ft]	MSL value for the year 2114 [ft]	Difference over 55 years (2069-2014)	Average Rate of Sea level change over the period 2014-2069 [ft/yr]
LOW	-0.12	0.41	0.84	0.530	0.009636
MED	-0.08	0.94	2.17	1.020	0.018545
HIGH	0.06	2.61	6.36	2.550	0.046364

3.0 SUPPORTING DATA FOR BEACH-FX MODELING

3.1 Introduction

The Hashamomuck Cove Coastal Storm Risk Management feasibility study will employ Beach-fx, the Corps' Monte Carlo life-cycle simulation model for estimating shore protection project evolution and cost benefit analyses. For a general description of the principles upon which Beach-fx operates the reader is directed to Gravens, et al. (2007).

Beach-fx is a comprehensive analytical framework for evaluating the physical performance and economic benefits and costs of shore-protection projects, particularly, beach nourishment along sandy shores. The model has been implemented as an event based Monte Carlo life cycle simulation tool.

Beach-fx is a planning-level tool used to evaluate proposed project alternatives in comparison with a similar evaluation of the "without-project" condition. Beach-fx is comprised of 4 basic elements (see Figure 6):

1) Plausible Storm Data (Meteorological data and processes)

2) Shoreline Response Data (Coastal morphology data and processes based on the SBEACH model)

3) Damage Element Data (Structure/Asset Inventory)

4) Damage Function Data (Management measures data and economic damage function data and processes)

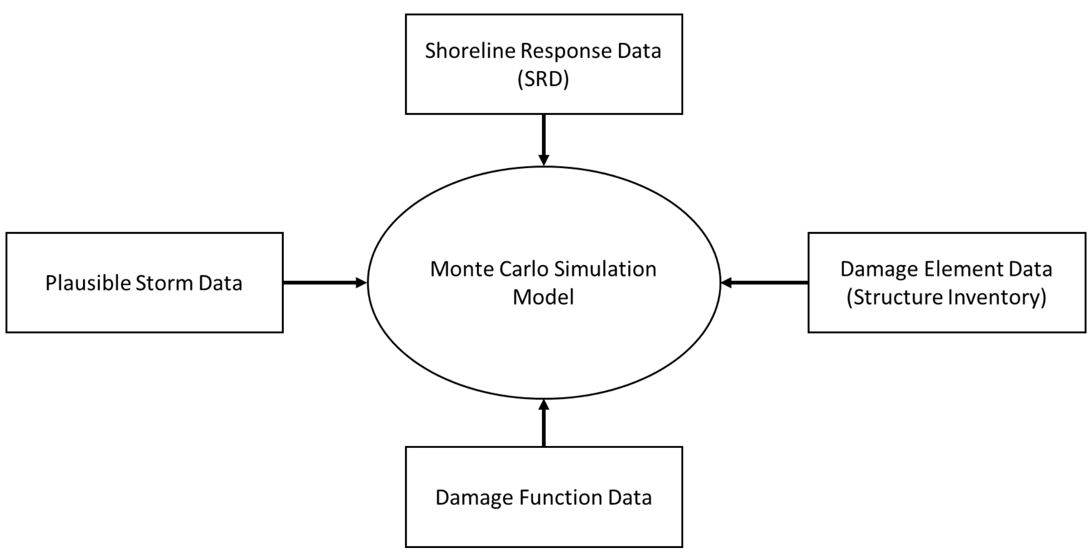

Figure 6: Elements of Beach-fx Input Database (Gravens, 2007)

The following sections describe beach-fx model input and settings, including the Plausible Storm Data and the Shoreline Response Data. The Damage Function and Damage Element data is addressed in the Economic Appendix.

3.2 Plausible Storm Suite

To generate the plausible storm suite for the Beach-fx and SBEACH models both historic data and the NACCS data (see section 2.5) were examined and analyzed.

3.2.1 Extra Tropical Storm Events

Extratropical storms were identified based on a minimum storm surge threshold of 1 foot and a minimum duration of 12 hours. Time series and peak surge and wave data were obtained from the CHS database for the 100 Extratropical storm events. Table 3 shows the number of storms occurring within specified surge and wave height ranges. Time series of wave data for storms 55, 9, 71, 97, 98, 99 and 100 were not available and accordingly, these storms were not included in the analysis. Additionally, storm 3 was ignored in the analyses because its storm surge was less than 1.0 ft. This resulted in a total of 92 storms included in the analysis over a 75 year time period.

To reduce the number of storm response runs required in SBEACH the time series of storm surge and wave height, within each range shown in Table 6, were examined and representative storms were selected for each set of storms. The 100 Extratropical storm events were reduced to 25 events listed in Table 7. Figure 7 shows the peak storm surge and wave height for the selected representative Extratropical storm events.

Table 6: Extra Tropical Storm Events

Peak Storm Surge [ft]	Peak Significant Wave Height [ft]	Storms	Representative Storm
> 5		7,62,11,27,37,41,35	7,62,11,27,37,41,35
5-4	>5	21,26,33,13,22,39	26,33,13,39
	5>Hs>4	25,23,50,60	50
	4>Hs>1	4,31,86	31
3.5-4	>5	2,29,54	29
	5>Hs>4	49,20,17,5	17
	4>Hs>1	28	28
3-3.5	>5	68,64,67	67
	5>Hs>4	53,90,69,19,14,58,15,43	58
	4>Hs>1	16,66,94,72	
2.5-3	>5	24,6,83,88,18,12	83
	5>Hs>4	56,70,77	77
	4>Hs>1	47,34,48,1,78,51,93,61,52	1
2-2.5	>5	32,30,57,81,8,74	32
	5>Hs>4	73	
	4>Hs>1	65,40,80,63,79,44,89,10	10
2-1	>5	96,36,45	96
	5>Hs>4		
	4>Hs>1	91,76,95,75,42,85,84,92,59,87,38,82,46	75

Table 7: Selected Extratropical storm events dates

Storm Event No.	Start Date		End Date	
1	21-Jan-38	0:10:00	29-Jan-38	0:00:00
7	21-Nov-50	0:10:00	29-Nov-50	0:00:00
10	17-Nov-52	0:10:00	25-Nov-52	0:00:00
11	3-Nov-53	0:10:00	11-Nov-53	0:00:00
13	15-Feb-60	0:10:00	23-Feb-60	0:00:00
17	3-Mar-62	0:10:00	11-Mar-62	0:00:00
26	31-Jan-72	0:10:00	8-Feb-72	0:00:00
27	15-Feb-72	0:10:00	23-Feb-72	0:00:00
28	5-Nov-72	0:10:00	13-Nov-72	0:00:00
29	12-Dec-72	0:10:00	20-Dec-72	0:00:00
31	28-Nov-74	0:10:00	6-Dec-74	0:00:00
32	29-Jan-76	0:10:00	6-Feb-76	0:00:00
33	6-Jan-77	0:10:00	14-Jan-77	0:00:00
35	16-Jan-78	0:10:00	24-Jan-78	0:00:00
37	3-Feb-78	0:10:00	11-Feb-78	0:00:00
39	21-Dec-78	0:10:00	29-Dec-78	0:00:00
41	21-Oct-80	0:10:00	29-Oct-80	0:00:00
50	25-Mar-84	0:10:00	2-Apr-84	0:00:00
58	26-Oct-91	0:10:00	3-Nov-91	0:00:00
62	10-Mar-93	0:10:00	18-Mar-93	0:00:00
67	20-Dec-94	0:10:00	28-Dec-94	0:00:00
75	15-Apr-97	0:10:00	23-Apr-97	0:00:00
77	1-Feb-98	0:10:00	9-Feb-98	0:00:00
83	24-Oct-06	0:10:00	30-Oct-06	7:00:00
96	11-Oct-10	0:10:00	19-Oct-10	0:00:00

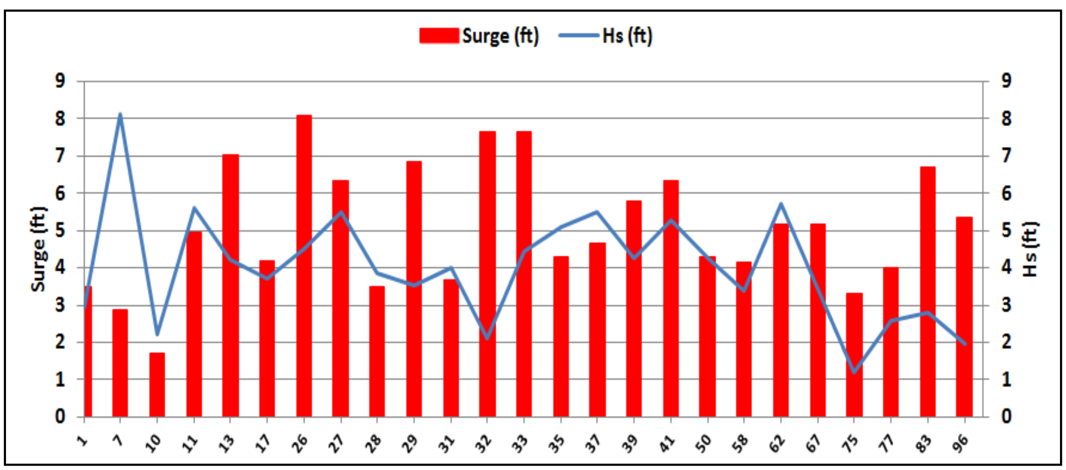

Figure 7: Peak Storm Surge and Significant Wave Height (Extratropical Storm Events)

A visual quality assessment was conducted on each storm by examining the storm duration and the numerical stability of the data. The portion of storm that was judged to be important in the context of beach profile response modeling was retained while pre- and post-storm time series data were clipped off. Time series of wave data was estimated, mainly at the beginning and end of some storms, to match the trend in rising and falling tides around the peak storm surge event. Also, for some storms, the wave data was shifted in time due to incompatibility between the timing of the surge and wave data. In such cases the wave data was shifted in time such that the wave height peak coincides with the surge peak (Gravens, 2005). Figure 8 shows an example of the original and the adjusted clipped storm data.

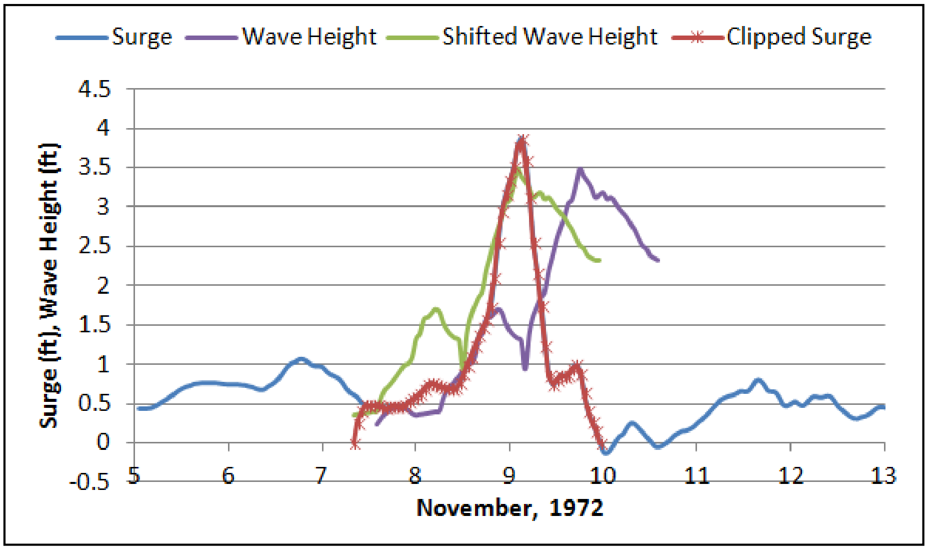

Figure 8: Original and adjusted storm data

3.2.2 Tropical Storm Events

Time series and peak surge and wave data were obtained from the Coastal Hazards Systems database for the 1,050 synthetic tropical storm events. The method of analyses for the tropical storms adopted for use in this study was developed by ERDC. The extratropical storm analyses was completed before obtaining ERDC tropical analyses approach and consequently the ERDC approach was not addressed in the selection of the representative extratropical representative storms. The synthetic tropical storms are separated into Region1, Region2, and Region3 bypass and landfall groups (Melby and Green, 2015). The storm tracks occurring within a circle with a 200 km radius around Hashamomuck (Figure 9) were extracted from the above-mentioned groups. Within this area of influence, 432 storms occurred of which 66 storms did not exceed the 1-Year return period storm surge level. The remaining 366 storm events were clustered according to stage frequency for different storm return periods. Time series of storm surge values for storms within each cluster were examined, and peak surge values were aligned to select representative storms for each cluster. Figure 10 shows the aligned storm surge hydrographs for the 50-Year return period cluster with the black bold lines depicting the representative storms. From the cluster of 366 storms, 31 representative storms were selected. Table 8 shows the number of storms occurring within each cluster and the selected representative storm ID numbers. The portion of each storm that was judged to be important in the context of beach profile response modeling was clipped and the corresponding wave height and period time series was prepared with matching time interval.

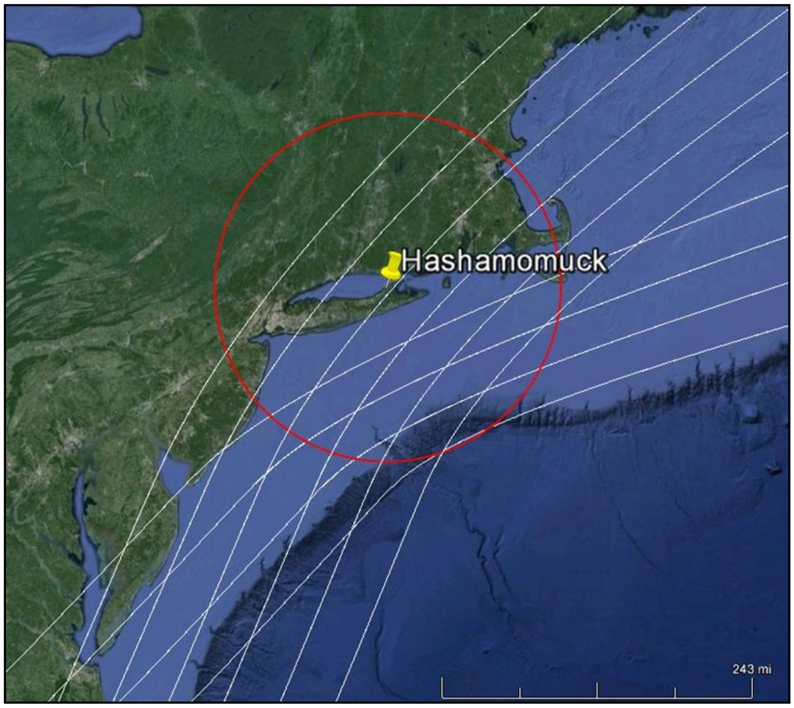

Figure 9: Storm tracks within a 200 KM radius of Hashamomuck

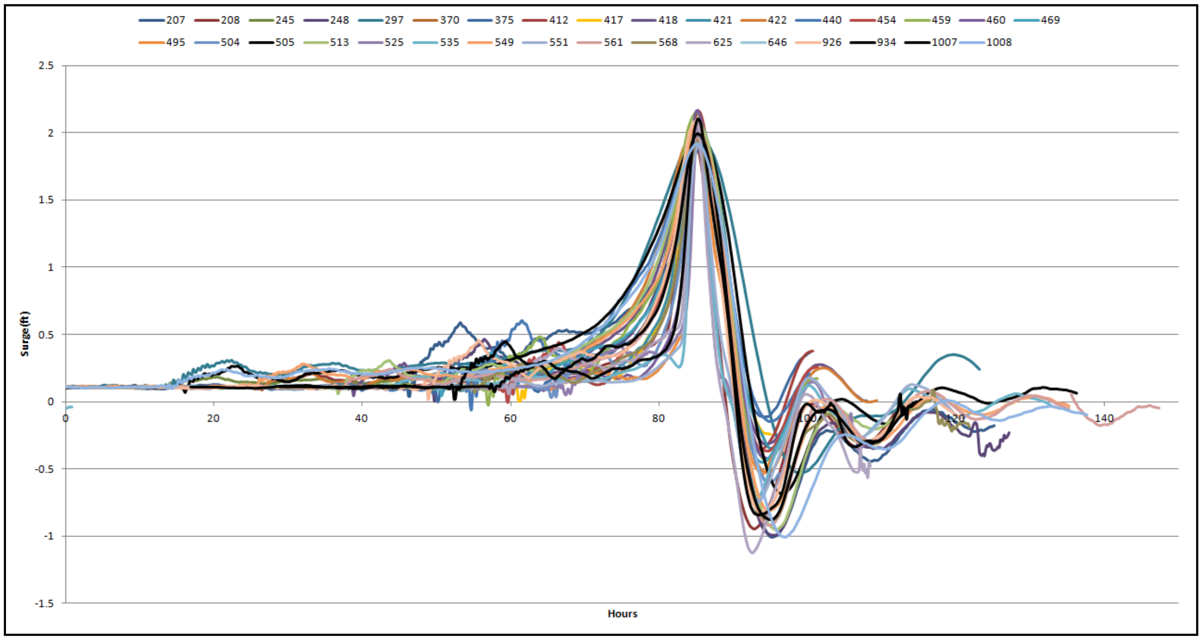

Figure 10: Surge hydrographs for the 50-Year return period cluster (black bold lines depict the representative storms)

Table 8: Selected synthetic tropical storms

Storm Return Period (Yr)	Stage (Ft)	No. of Storms (in each cluster)	Selected Storms IDs
1	0.88	21	281, 663
2	1.21	107	253,472,790,941,1011,1022
5	1.58	73	510,564,844,932,1019
10	1.84	47	462,648,943,1016
20	2.09	36	362,406,935
50	2.42	33	505,934,1007
100	2.69	18	463,494
200	3.02	17	557,925
500	3.48	8	634
1000	3.78	4	458
2000	4.06	1	415
5000	4.38	1	457
10000	4.61		

Each storm surge hydrograph (extratropical and synthetic tropical) was combined with a cosine representation of the astronomical tide to generate a plausible total water level elevation. Each storm surge was combined with three representative tidal ranges (spring, mean, and neap) and the peak surge elevation was aligned with four tidal phases (high tide, mid-tide falling, low tide, and mid-tide rising) to create a suite of 12 storms of each historical storm surge hydrograph. The spring, mean and neap tidal ranges (3.42, 2.52 and 1.93 ft) were obtained from 20-year-long equilibrium tide at ADCIRC station 368 (Figure 11).

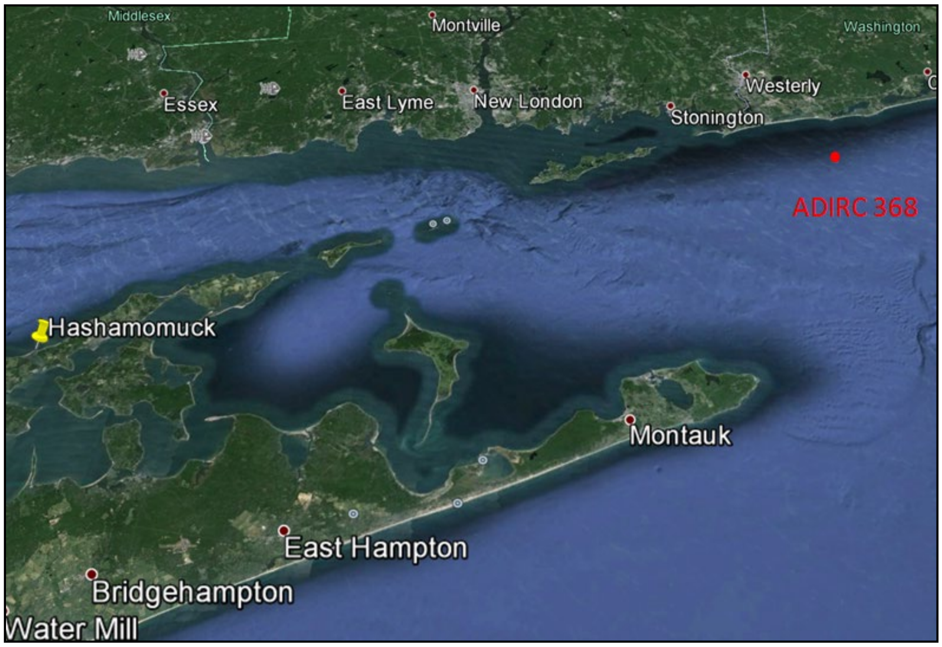

Figure 11: ADCIRC station 368

Combining N number of storm events with three (3) tidal ranges at four (4) phases will result in a total of NX3X4 storm events. The water level information to this point in section 3.2 has been referenced to Mean Sea Level (MSL). Datum conversion to NAVD88 was performed for compatibility with the profile input to SBEACH. The National Oceanic and Atmospheric Administration **(**NOAA**)** station 8510560 (Montauk, NY) datum data was adopted in this study. Datum conversion from MSL to NAVD88 was calculated by subtracting 0.33ft from the output water elevation.

3.2.3 Generation of the Plausible Storm Suite

A MATLAB script was used to read the ASCII input files containing the clipped and adjusted storm surge hydrograph time series or both extra tropical and tropical storm events. The script finds the peak storm surge elevation and computes the offset start indices such that the peak surge elevation will align with the Cosine tide at high tide, mean tide falling, low tide and mean tide rising when the two are combined. The 12 plausible variants of the total water level hydrograph are then computed. Also, the script plots the storm surge hydrograph, the Cosine tide signal for each of the three tide ranges with markers indicating the location of the peak surge and the locations on the Cosine tide where the peak surge will be combined, and the resulting twelve total water level hydrographs as illustrated in Figure 12.

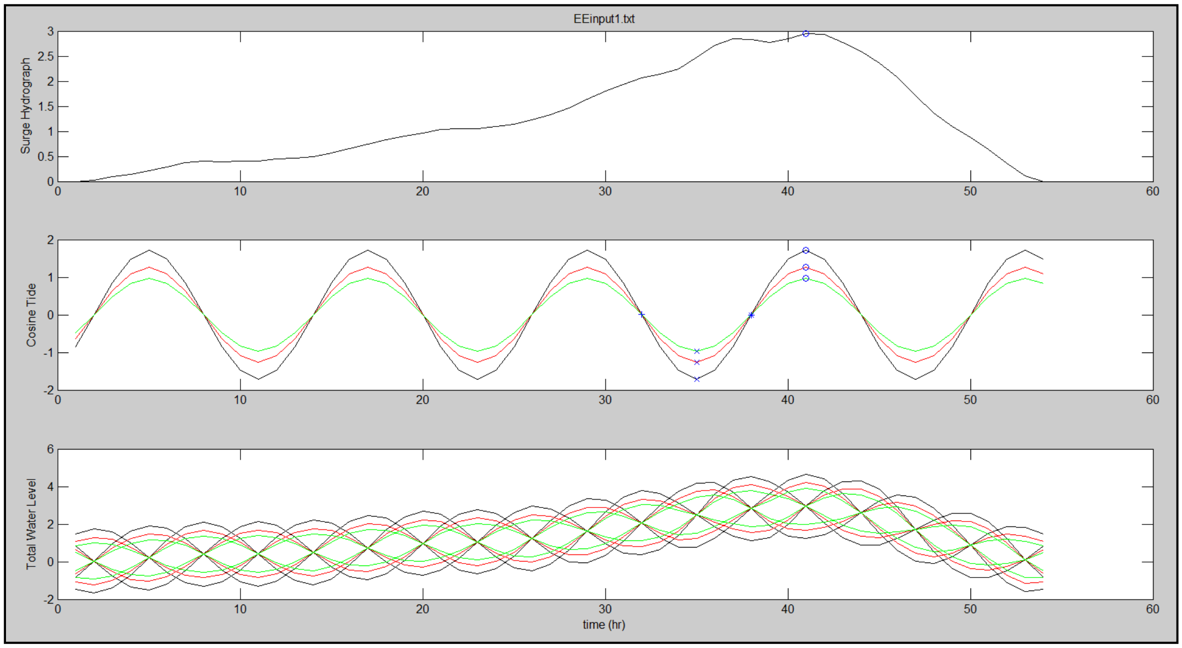

Figure 12: Storm Surge Hydrograph, Cosine Tide and 12 Total Water Levels Extratropical Storm Event 1

The script will also open 12 output files (*.elv) and write the computed total water level hydrograph to the output applying any required datum shift in the process. The output files are named according to the input file name with an appended alpha numeric suffix where H designates high tide range, M designates mean tide range and L designates low tide range. The number that follows the tide range character specifies the tide phase at which the peak surge was aligned; 1 indicates high tide, 2 mean tide falling, 3 low tide and 4 mean tide rising. The script will also create ASCII files (*.wav) containing the wave height and period information for input to SBEACH for each of the significant storm events. The 25 extratropical storms were expanded to a plausible storm suite consisting of 300 events and the 31 Tropical storms were expanded to a plausible storm suite consisting of 372 events for a total of 672 storm events.

3.3 Shoreline Response Data

In Beach-fx the beach profile responses due to plausible storms are determined by applying a coastal processes response model to a simplified profile, i.e. the SBEACH model (Larson and Kraus 1989) is used to calculate the response of the profile to individual storms.

3.3.1 Representative Beach Profiles

Morphologic features of the existing beach, such as dune height, berm width, and offshore profile shape, typically vary along the project study domain. To accurately estimate storm erosion response for the existing condition, the CEM suggests developing a set of representative morphologic reaches to describe variations in profile shape along the project domain. Morphology analysis software applications such as BMAP or RMAP can be used to define morphologic reaches by analyzing profiles, grouping similar profiles, and calculating an average representative profile for each reach. According to the CEM, the profile characteristics that should be considered when developing morphologic reaches include dune height and width, berm width, nearshore and offshore profile slopes, sand grain size, presence of seawalls or other structures, and proximity to inlets.

An overview of the general hierarchical data structure employed in Beach-fx is provided in Figure 13. Within Beach-fx the overall unit of analysis is the “project,” a shoreline area for which the analysis is to be performed. The project is divided, for purposes of analysis, into “reaches,” which are contiguous, morphologically homogeneous areas. The structures within a reach are referred to as Damage Elements (DEs), and are located within lots. All locations are geospatially referenced using a cartographic coordinate system such as state plane coordinates. This project definition scheme is shown schematically in Figure 14, in which the shoreline is linearized into reaches. Each reach is associated with a representative beach profile that describes the shape of the cross-shore profile and beach composition.

The profile is the basic unit of beach response. Natural beach profiles are complex; for the modeling, a simplified or idealized beach profile is used, representing key morphological features defined by points. As shown in Figure 15, the idealized profile represents a single trapezoidal dune with a horizontal berm and a horizontal upland landward of the dune feature.

The submerged portion of the profile is represented by a detailed series of distance-elevation points that are determined through an analysis of available beach profile information. For the Hashamomuck Cove project, the detailed submerged beach profile was developed by averaging across multiple surveyed beach transects containing similar offshore slopes.

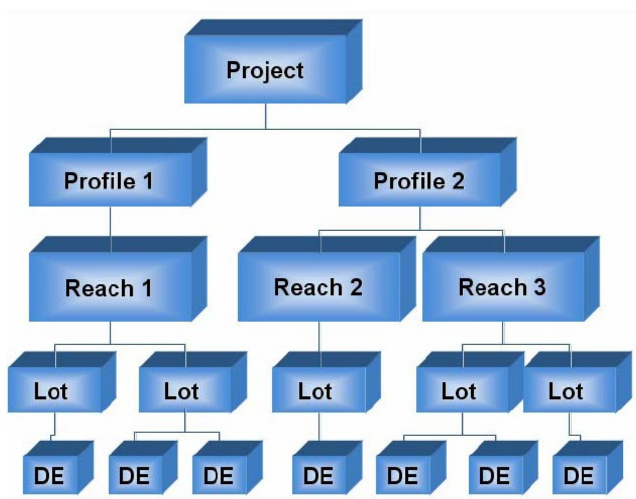

Figure 13: Hierarchical representation of Beach-fx data elements (taken from Beach-fx Users Manual, Version 1.0).

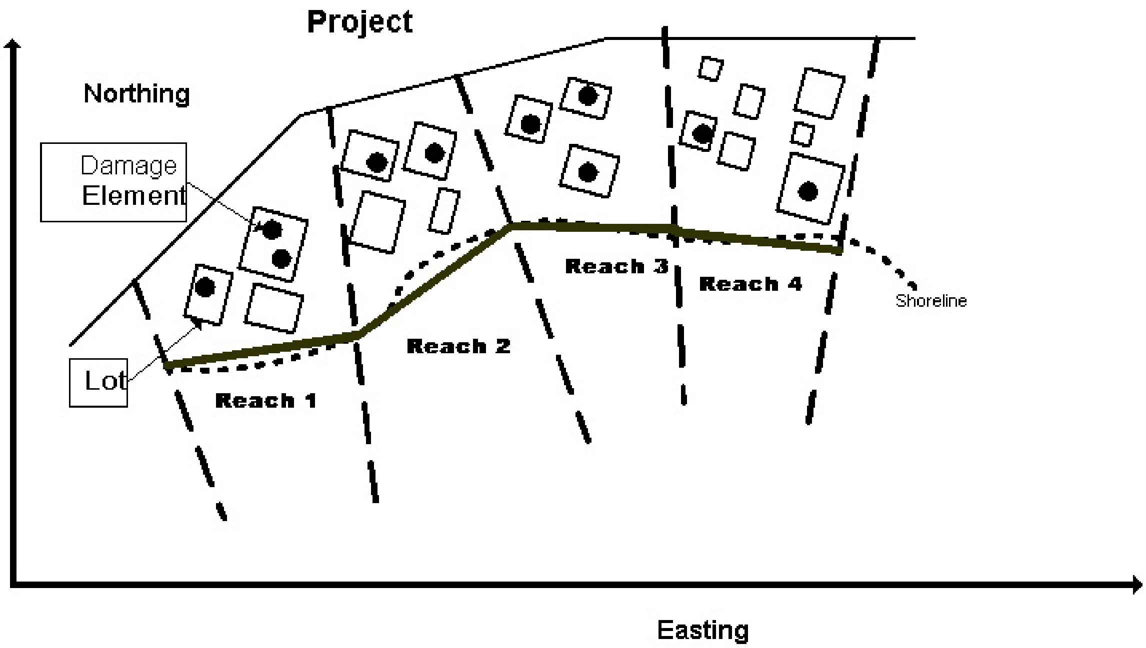

Figure 14: Beach-fx schematization of the project study area.

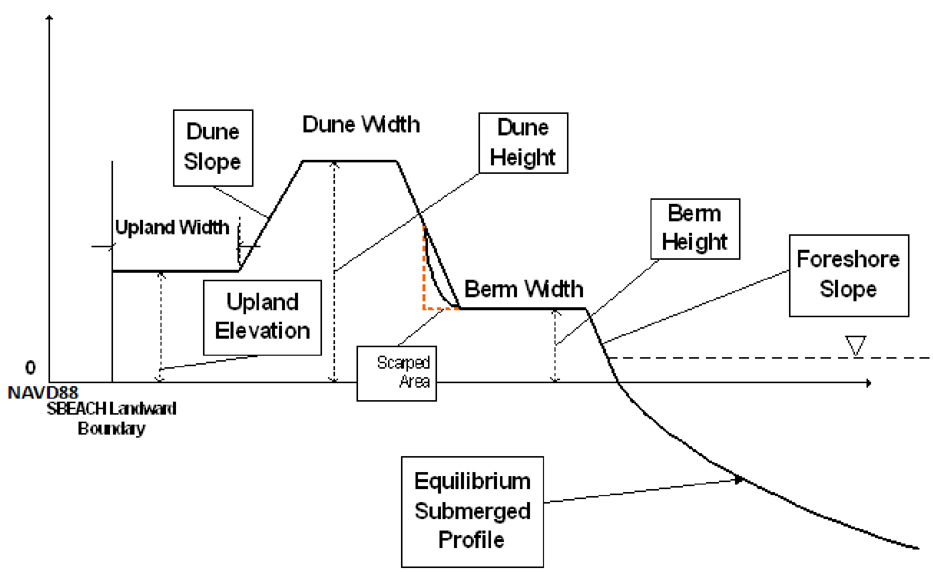

Figure 15: Beach-fx idealized beach profile.

The beach morphology of Hashamomuck Cove is heavily influenced by the presence of the groins, which are spaced as close as 150 feet to as far apart as 2000 feet and vary greatly in construction type and functionality. The initial project layout was selected to terminate at each end at the location of one of these groin locations in order to eliminate/reduce planform losses. The project consists of three cove areas as shown in Figure 16 and each cove was developed as a separate Beach-fx study (project). These three Beach-fx projects were named HashEast, HashCentral, and HashWest.

The beach profile analysis that lead to the development of the idealized representative beach profile was based on a combination of available LIDAR data from 2012 and a single profile survey that was obtained in December 2014 (Figure 17). After an extensive data search, there were no additional historic profiles available for analysis. However, there was a 1969 (USACE, 1969) beach erosion control study report that contained some hand drawn data that was used to compare the general shape of the profile with the current condition. Due to the curved shoreline located within each of the three cove project areas, the SBEACH reaches were relatively small. The size of the reaches was influenced by the fact that it is important to have the cross shore profile close to perpendicular to the SBEACH representative shoreline. The curved shoreline resulted in 13 SBEACH reaches (R1-R13) as seen in Figure 14. These 13 SBEACH reaches are further grouped into Economic reaches that use the same profile responses as the SBEACH reach they are contained within, but are grouped by economic factors such as structure type, value, etc. The 13 SBEACH reaches in this project were divided into 15 such economic reaches (E1-E15) represented by the blue lines in Figure 17.

Figure 16: Beach-fx project Areas

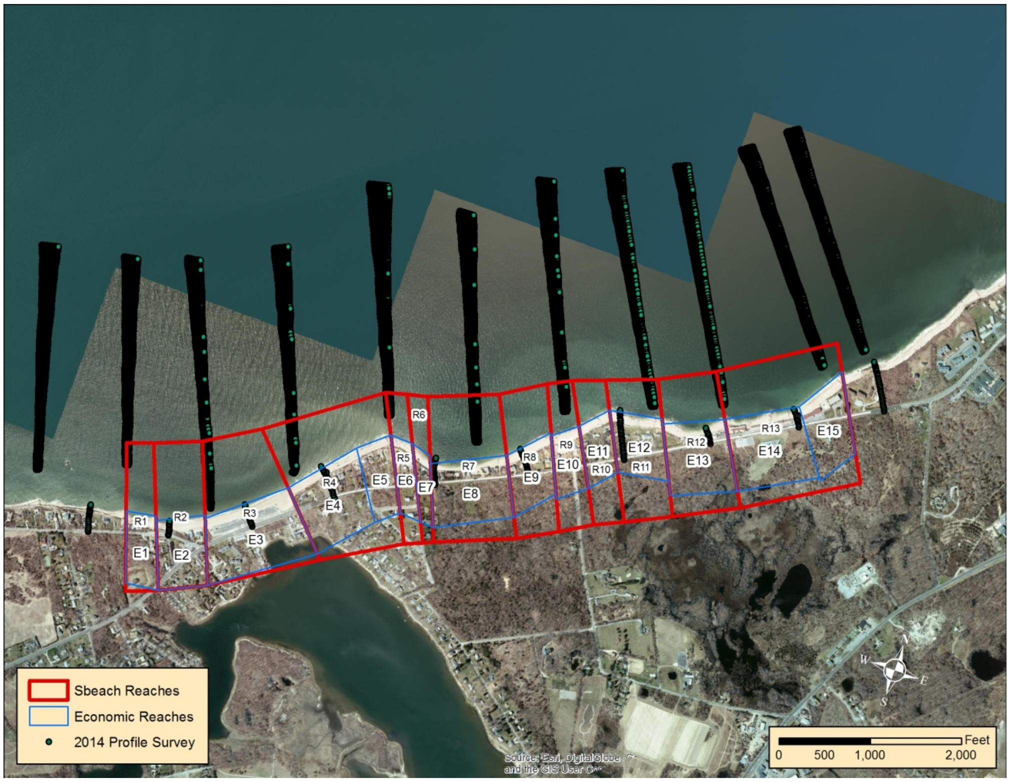

Figure 17: Profile Survey Transects

To develop the representative profiles for each reach, the 2014 profile survey was merged with the 2012 LIDAR data to fill in areas of missing data landward of the profile data to develop a shore perpendicular profile . The corresponding representative profiles are displayed in Sub-Appendix A.

3.3.2 SBEACH

The numerical model for simulating storm-induced beach change (SBEACH), (Larson and Kraus, 1990) was used to estimate beach profile responses to each of the storms contained in the plausible storm suite.

The availability of a large database that captures beach profile responses to each storm in a plausible storm suite is central to the operation of Beach-fx. This database is known to Beach-fx modelers as the shore response database (SDB). Two kinds of data are stored in the SDB for each storm/profile simulation: changes in berm width, dune width, dune height and upland width; and cross-shore profile erosion distance, maximum wave height, and total water elevation. The morphology changes (berm width, dune width, dune height and upland width) are used to modify the pre-storm beach profile to obtain the post-storm profile. The damage driving parameters (cross-shore profile of erosion, maximum wave height, and total water elevation) are used in the estimation of damages to damage elements within reaches associated with that representative profile. The SDB is a pre-generated set of beach profile responses to storms comprising the plausible storm suite, for a range of profile configurations that are expected to exist for different sequences of storm events and management action scenarios. A companion range of beach profile configurations were developed to encompass all expected beach configurations encountered under each of the evaluated with and without-project scenarios. Profiles were developed at 25 ft increments on berm width, 10 to 25 ft increments on dune width, and 2 ft increments on dune height between the most robust and most vulnerable beach profiles. This procedure generated a total of 2,535 unique beach profiles. The response of each of these beach profiles to the entire storm suite consisting of 672 plausible storm events was simulated using the SBEACH model. A total of 1,764,360 SBEACH simulations were performed and the results were imported to populate the SDB used as input to each of the three Beach-fx models. Because of the large size of the resulting SDB, the Hashamomuck project was divided into three project domains as discussed earlier:

1. Hashamomuck West: R1 (E1), R2 (E2), R3 (E3), and R4 (E4 & E5).

2. Hashamomuck Central: R5 (E6), R6 (E7), R7 (E8), R8 (E9), R9 (E10), and R10 (E11).

3. Hashamomuck East: R11 (E12), R12 (E13), and R13 (E14 & E15).

3.4 Beach-fx Calibration

The next step required to fully implement the Hashamomuck Cove Project in Beach-fx is calibration of Beach-fx such that the model produces, on average multiple lifecycle simulations, the historical shoreline change rate. Historical shoreline change rates (background erosion) were presented in section 2.4.

The calculated change rates were averaged per economic reach (Table 9/Figure 18) producing the final background erosion rates to which the Beach-fx model was calibrated. It is assumed that the background erosion rates will continue at the same rate as before the project.

Table 9: Shoreline change rate (ft/yr) by Economic Reach. The average shoreline change rate over all reaches is -0.69 ft/yr.

Economic Reach	SL Change Rate (ft/yr)	Moving Average (ft/yr)
E1	-0.06	-0.35
E2	-1.53	-1.29
E3	-1.09	-1.10
E4	-0.64	-0.63
E5	-0.54	-0.47
E6	-0.59	-0.71
E7	-1.24	-1.09
E8	-1.30	-1.21
E9	-0.58	-0.72
E10	-0.60	-0.58
E11	-0.66	-0.51
E12	-0.28	-0.42
E13	-0.79	-0.33
E14	-0.11	-0.22
E15	-0.30	-0.29

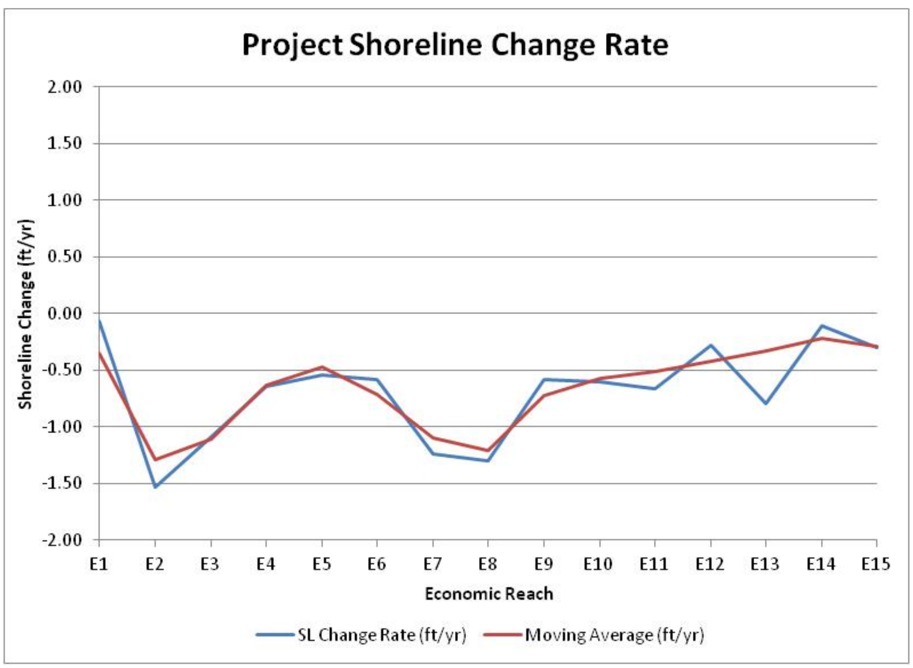

Figure 18: Project Change Rates (ft/yr)

The calibration procedure for Beach-fx involves specification and tuning of a reach-level attribute known as the applied erosion rate. The applied erosion rate accounts for long-term shoreline change not attributed to storm-induced shoreline changes which are captured within the model by the random sampling of storm events as the model progresses through the lifecycle simulation. The concept is that there are two essentially separable components of beach evolution. The first is cross-shore transport dominated shoreline change due to storm events which is mostly recoverable due to post-storm berm width recovery. The second is longshore transport dominated shoreline change that is driven by longshore sediment transport gradients, underlying geological setting, and other factors such as relative sea level change. This second component of beach evolution is considered non-recoverable. The Beach-fx calibration concept is that the combination of these two drivers of beach evolution should, on average, over multiple simulated project lifecycles, return the long-term average rate of shoreline change. Because the Beach-fx simulated life cycle iteration employs a random sequence of storm events, the returned shoreline change rate differs for each lifecycle simulated. The Beach-fx calibration task is to determine an appropriate applied erosion rate for each reach such that the computed average rate of shoreline change on a reach-by-reach basis is equal to the estimated target historical shoreline change rate over multiple lifecycle simulations.

For the Hashamomuck Cove project, Beach-fx was calibrated across 300 iterations of a 55-year lifecycle using an assigned depth of closure specification of -21 ft NAVD. The depth of closure estimate was developed based on an analysis of the available beach profile data from the recent 2014 survey, the 1969 survey report, and local knowledge. The 55-year lifecycle duration stems from the use of the December 2014 beach profile survey to define the initial condition leading to a start year specification of 2015 and the specification of year 2019 as the base year for calculating the economics and an economic analysis horizon corresponding to a 50-year project life. The use of 300 iterations was selected to obtain a stabilization of the model results.

After a number of iterations, Beach-fx was calibrated to reproduce the target historical shoreline change rate on average over 300 55-year lifecycles. Details and discussion of this calibration are included within the Economic Appendix (Appendix B).

3.5 Beach-fx Morphology and Parameter Settings

In addition to the storm-induced morphology changes and the applied erosion rate as discussed in the previous section, Beach-fx provides for two additional mechanisms for morphologic change, i.e. Project induced shoreline change rate and Post-Storm Berm Recovery Rate. It should be noted that a description of the Beach-fx input parameters is contained in Appendix B. Below only a brief introduction of morphological parameter settings is provided.

3.5.1 Project Induced Shoreline Change Rate

The Project Induced Shoreline Change Rate accounts for the alongshore dispersion of the placed beach nourishment material, i.e. the beach nourishment diffusion as introduced in section 2.4.3. Estimates of this rate are dependent on the planform of the beach nourishment and are further discussed in the next section.

3.5.2 Post-Storm Berm Width Recovery

Post-storm recovery of eroded berm width is recognized by the coastal engineering community (Dean, Dalrymple, 2002) although the present state of coastal engineering practice has limited predictive capability for estimating this process. Consequently, within beach-fx, post-storm recovery is represented as an ad-hoc procedure in which the user specifies the percentage of the estimated berm width loss during the storm that is recovered over a user specified recovery interval (Gravens et al. 2000). For the Hashamomuck Project the Berm Width recovery was set to 98%.

3.5.3 Sea Level Change Settings

The relationships for future sea level change as outlined in ER 1100-2-8162 are coded within Beach-fx and sea level change is internally computed continuously throughout the simulated project lifecycle. The historical rate of mean sea level change equal to +0.00961 feet/year was applied in all Beach-fx simulations for alternative evaluation. Further evaluation and sensitivity of the TSP specifically to sea level change variations is discussed in Appendix B.

4.0 ANALYSIS OF BEACH NOURISHMENT PLANFORM BEHAVIOR

4.1 Introduction

In addition to the Beach-fx optimization of Project alternatives an analysis has been completed to better understand the required renourishment volumes for the various plans while considering planform losses for the project. An analytical algorithm has been developed as a tool to aid in addressing this objective. The analytical approach also allows for deterministic analysis of planform shoreline behavior, with and without project under varying conditions of background erosion, Sea Level Change (SLC) and renourishment frequencies. Lastly the algorithm can be used to corroborate the Beach-fx model outputs.

4.2 Beach Nourishment Planform Behavior

4.2.1 Pelnard-Considere equation

The one-dimensional diffusion equation or Pelnard-Considere equation for planform evolution is derived from combining the conservation of sediment equation with the total longshore sediment transport equation and describes the planform shoreline position over time for a diffusing beach nourishment.

The application of the Pelnard-Considere equation is also described in the Coastal Engineering Manual III-2-3, and the analytical equation computes post-nourishment shoreline position at various time intervals. The initial post-nourished shoreline position is assumed to be a uniform rectangular dry beach width (berm width) calculated based on fill volume, fill length, height of the berm, depth to which the fill extends and sand characteristics. The shoreline position change calculated using the analytical solutions is, thus, based on an idealized initial post-nourished shoreline, which is shown in Figure 19.

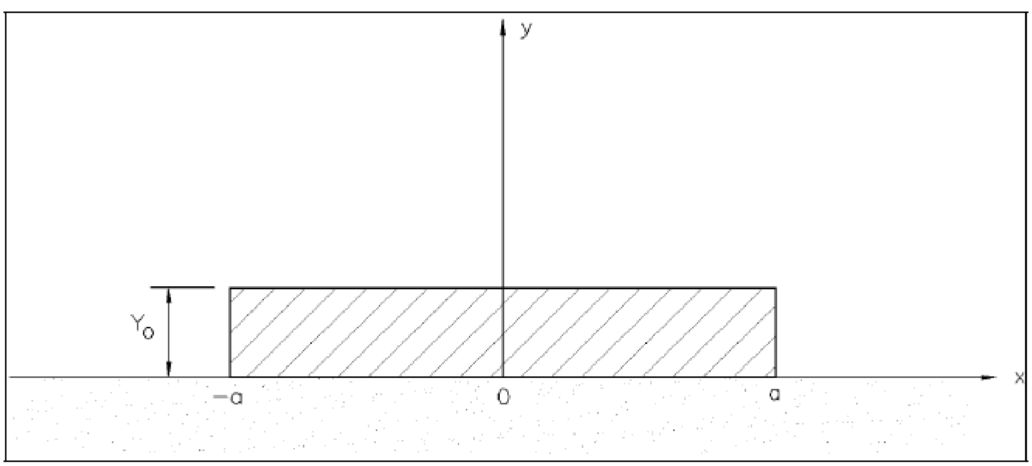

Figure 19: Rectangular Beach Nourishment

The main equation that describes the shoreline position at any location, x, at time, t, is given below,

$$y = \frac{Y_0}{2}\left\{erf\left[\left(\frac{a}{2\sqrt{\varepsilon t}}\right)\left(1-\frac{x}{a}\right)\right] + erf\left[\left(\frac{a}{2\sqrt{\varepsilon t}}\right)\left(1+\frac{x}{a}\right)\right]\right\} \quad \text{(Eq. 1)}$$

where,

Y_0 is the dry beach width,

a is the half-length of the beach fill extent,

ε is the longshore diffusivity coefficient, and

erf denotes the error function

The longshore diffusivity coefficient is calculated using fill and native sand properties, and a characteristic wave height, using the following equation.

$$\varepsilon = \frac{KH^2C_g}{8}\left(\frac{\rho}{\rho_s - \rho}\right)\left(\frac{1}{1-n}\right)\left(\frac{1}{d_B + d_c}\right) \quad \text{(Eq. 2)}$$

where,

$K = 1.4e^{-2.5*d_{50}}$ is the sediment transport coefficient,

d_{50} is the median sediment grain diameter in mm,

H is the effective wave height,

C_g is the wave celerity

ρ is the sea water density,

ρ_s is the fill sand density,

n is the sand porosity,

d_B is the height of the berm, and

d_c is the depth of closure (i.e. the depth of appreciable sand transport)

Rectangular Beach nourishment

The non-dimensional results (following Eq. 1) for a rectangular beach nourishment project with alongshore length l, cross-shore width Y, and time t are shown in Figure 20 below and illustrates that the planform location after some time "t" is proportional to $1/l^2$. As a result, the performance of the beach nourishment is very sensitive to the alongshore length of the beachfill project.

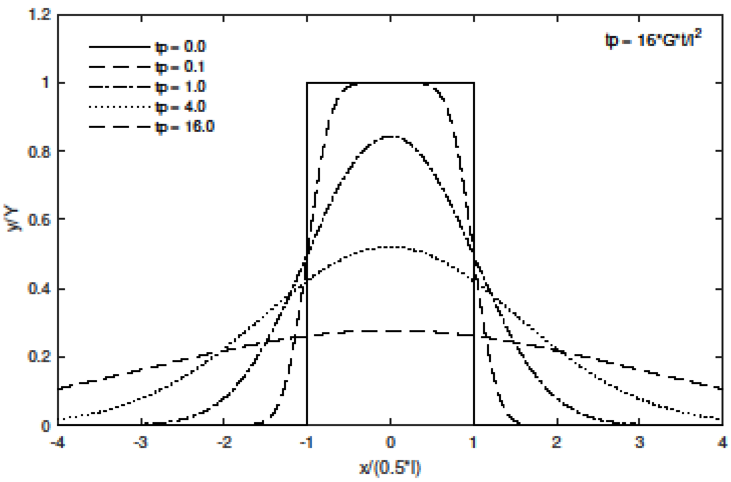

Figure 20: Nondimensional Beach Nourishment Evolution Based on Diffusion Equation

Figure 21 further demonstrates the sensitivity of the performance of a beach nourishment project to the alongshore length by plotting the fraction of volume remaining, M(t), versus non-dimensional time, $\sqrt{Gt}/l$. The solid black line shows the solution to the Pelnard-Considere equation, and the four markers present the volume remaining after 4 years for beach nourishment projects at Western Fire Island (41,800 feet), Fire Island Pines (6,400 feet), Davis Park (4,200), and Eastern Fire Island (19,400 feet). It is important to note that the results in Figure 21 are in the absence of background erosion. For illustrative purposes the graph also includes results for exponential decay and demonstrates the slower decay rate of the Pelnard-Considere equation as time progresses.

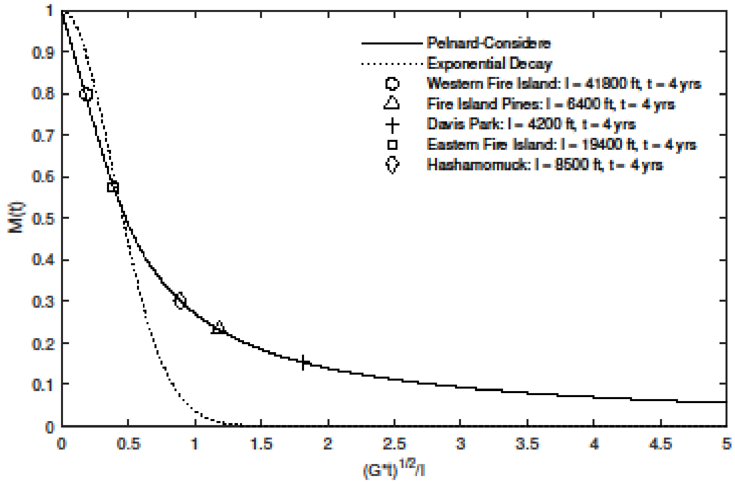

Figure 21: Theoretical Longevity (Volume Remaining) of Beach Nourishment (excluding background Erosion) for previously simulated projects in the Hashamomuck region

<u>Incorporating Background Erosion</u>

The combined effect of diffusion and background erosion, $\partial E / \partial t$, can be accounted for by adding an additional term to solutions for a rectangular beach nourishment:

$$y(x,t) = \ldots - \frac{\partial E}{\partial t}$$

<u>Incorporating Multiple Nourishments</u>

The evaluation of the diffusion of a beach nourishment with multiple recurring renourishments can be studied with the Pelnard-Considere equation as well. The diffusion of each individual nourishment can be treated independently and the solutions can be superimposed to obtain the shoreline position at various time intervals.

4.2.2 Pelnard-Considere Equation inputs for Hashamomuck Cove

Equation 1 has been incorporated into a Matlab algorithm to assess multiple nourishment options for Hashamomuck Cove. The following section describes the input settings and derivation of parameter values. Please note that the dry Beach Width (Y_0) and the Project Length (L) are dependent on the alternative project dimensions and further discussed in section 4.3.

Invariable input parameter settings are d_{50} = 0.5mm (see section 2.2), ρ = 62.4 lb/ft³, ρ_s = 165 lb/ft³, n = 0.35, d_B = 6ft and d_c = -21ft. The Effective Wave Height and the Longshore Diffusivity are key input parameters and warrant a more detailed elaboration, which is provided below.

Longshore Diffusivity

Dean and Yoo (1992) defined the effective wave as one that produces the same spreading of the beach nourishment material as the actual time-varying wave conditions (expressed as pairs of height and period). The alongshore diffusivity, *G*, controls the rate at which "spreading" or diffusion of the beach nourishment project occurs. The alongshore diffusivity is proportional to the breaking wave height raised to the 5/2 power. Since the wave conditions at a site vary over time, so too does the alongshore diffusivity. Therefore, the alongshore diffusivity can be determined by integrating *G* over time or by determining an effective wave breaking height. Since no estimates are available for the gross sediment transport rate at the site, it is impossible to back-calculate the effective breaking wave height, H_b, using the first method. Instead, an effective wave breaking height is established by analysis of the wave climate.

To estimate the effective wave height a hindcasted wave record at the location of save point 5020 (see section 2.5.2) was analyzed and the seasonal directional probability of occurrence was tabulated for all wave heights in 0.1m (0.3280ft) bins. Using the proportionality power of 5/2 (per EM 1110-2-1100, commonly referred to as the CERC formula) the morphological effect of each individual bin can be calculated and summed (units $m^{2.5}$). The sum raised to the 1/2.5 power provides an estimate for the effective wave height (units m) that would equate to the same annual morphological action of all waves combined. Using this approach and the wave data from Table 10 the effective wave height is estimated to be 0.5m (1.6ft).

Table 10: Probability of occurrence of wave heights classified in 0.1m bins per month of the year for save point 5020 (from the hindcast record covering the period of 2014 through 2015)

Range, m	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.00 - 0.10	20.16%	24.11%	18.55%	31.25%	36.29%	51.25%	36.69%	54.44%	41.67%	14.52%	16.67%	8.06%
0.10 - 0.20	5.65%	5.80%	8.47%	8.33%	11.69%	16.25%	9.68%	8.47%	15.00%	9.68%	5.00%	5.24%
0.20 - 0.30	6.05%	8.48%	10.48%	10.42%	15.32%	19.17%	23.79%	20.16%	13.75%	14.52%	5.83%	13.71%
0.30 - 0.40	8.47%	12.50%	16.53%	17.08%	18.95%	7.50%	14.92%	10.08%	12.50%	18.95%	12.08%	16.53%
0.40 - 0.50	9.68%	12.95%	12.10%	12.92%	8.87%	3.75%	5.65%	4.84%	7.92%	10.08%	11.67%	13.71%
0.50 - 0.60	7.66%	7.59%	6.85%	6.67%	4.03%	1.25%	2.42%	1.61%	4.58%	8.06%	10.42%	13.31%
0.60 - 0.70	6.05%	5.80%	9.27%	4.58%	2.02%	0.42%	3.23%	0.40%	3.75%	8.47%	6.67%	6.45%
0.70 - 0.80	6.05%	4.46%	4.44%	2.08%	2.02%	0.42%	0.81%		0.83%	4.03%	4.58%	4.84%
0.80 - 0.90	7.26%	6.70%	4.84%	1.67%	0.40%		0.40%			3.23%	2.92%	3.23%
0.90 - 1.00	5.24%	2.68%	1.61%	2.50%	0.40%		0.81%			1.21%	6.67%	4.84%
1.00 - 1.10	4.84%	1.34%	0.81%	1.25%			0.00%			1.61%	5.42%	3.23%
1.10 - 1.20	3.63%	0.00%	0.81%	0.83%			0.40%			1.61%	2.08%	2.02%
1.20 - 1.30	3.23%	2.23%	0.40%	0.00%			0.81%			1.21%	2.08%	2.82%
1.30 - 1.40	1.61%	0.00%	0.81%	0.42%			0.40%			0.81%	2.08%	1.21%
1.40 - 1.50	0.81%	0.89%	1.21%							0.81%	2.08%	0.00%
1.50 - 1.60	1.61%	1.34%	1.61%							0.00%	1.67%	0.00%
1.60 - 1.70	0.81%	0.89%	0.00%							0.00%	1.25%	0.00%
1.70 - 1.80	0.81%	0.89%	0.40%							0.81%	0.42%	0.40%
1.80 - 1.90	0.00%	0.45%	0.40%							0.00%	0.42%	0.00%
1.90 - 2.00	0.00%	0.00%	0.00%							0.00%		0.40%
> 2.00	0.40%	0.89%	0.40%							0.40%		

The alongshore diffusivity was reduced by 60% to account for stabilizing effect of wave refraction around the beach nourishment project (Dean, 2003). The longshore diffusivity parameter value for Hashamomuck is 0.019 ft^2/s.

Calibration of Longshore Diffusivity:

The objective of a calibration exercise would be to minimize the mean difference between measured and predicted shoreline positions for various historical events. Unfortunately, no previous beach renourishment projects were constructed for Hashamomuck Cove and as such, no calibration can be performed. To provide some validation to the value of the longshore diffusivity parameter a comparison was provided amongst theoretical longevity of beachfill projects for other studied projects on Long Island (see Figure 22). In addition, it is noted that (unadjusted for wave stabilizing effects) values in the range of 0.02 to 0.09 ft^2/s are reported for West Coast of Florida (Dean, 2003). Thus, the Longshore Diffusivity parameter value for Hashamomuck is on the lower end of the realistic reported range from its application in prior studies.

4.2.3 Application and limitations of the Pelnard-Considere Equation

The Pelnard-Considere equation is useful for preliminary design and the theoretical results allow for the establishment of principles of beach nourishment design and performance. At the same time the equation allows for the evaluation of multiple scenarios and test sensitivity to input parameter settings. The equation however is merely a schematization of the processes that drive longshore sediment transport and its results are dependent on selected input parameters. E.g. the equation requires a single effective wave height which, for a long straight shoreline, will yield the same evolution as the actual time varying wave field. Furthermore the longshore diffusivity, G, depends strongly on the breaking wave height and secondarily on the active depth of the beach profile and the sediment transport coefficient K. As stated above, for the Hashamomuck project area no data is available to perform a detailed calibration procedure and results should be evaluated taking this caveat into account. In addition, the grainsize distribution of the native beach material at Hashamomuck Cove includes a sizable fraction of gravel while this analysis, as well as the SBEACH modeling has been performed using a representative d50 of 0.5mm (coarse sand). Additional data to characterize the beach material including the foreshore will be collected during PED and sand sources and characteristics of the beachfill material will be determined during the PED phase of the project. It is recommended to confirm the assumptions that were used to define input parameters to the Pelnard-Considere equation as well as the SBEACH model and that additional process-based morphological modeling would be completed during PED to more accurately assess the beach nourishment design and performance.

4.3 Planform Behavior of Hashamomuck CSRM Alternatives

The inclusion of the Pelnard-Considere equation in a MATLAB algorithm allows for deterministic analysis of planform shoreline behavior, with and without project in lieu of Beach-fx. It further allows to quickly test the planform response under varying conditions of background erosion, Sea Level Change (SLC) and renourishment frequencies and ultimately provide the planform erosion rates per reach for varying alternatives which are input parameters in the Beach-fx model.

For study purposes the Hashamomuck area has been divided into three coves and consists of the West, Central and East Cove. The alongshore length of the individual coves is 3,400ft, 2,600ft and 2,200ft for the West, Central and East Cove respectively. For the simple analytical approach applied here, the three coves combined are treated as a single stand-alone project to which the Pelnard–Considere equation is applied to assess planform behavior. Beach nourishment berm width can be varied on a cove by cove basis or reach by reach basis if needed. In practice, the diffusion of the beach nourishment project in a cove like setting may be slightly less than on a straight coastline. More sophisticated shoreline modeling approaches (e.g. GENESIS) would be required to simulate the combined performance of beach nourishment alternatives across all three coves in relation to the initial shoreline position. The simple analytical approach taken here is conservative and assumed to be suitable for determining the relative differences in the planform erosion rates between the alternatives and provide input parameters to Beach-fx.

Table 11 presents the six individual beach nourishment projects and the proposed planform template (i.e. berm width per cove) that were studied. A future without project (FWOP) condition alternative was included in the analysis as well to validate the basic algorithm settings and assess the shoreline recession and volume loss due to the background erosion.

Table 11: Alternative Beach Nourishment Planform Templates – Berm Width Variation per Cove (all plans have a renourishment cycle of 5 years)

Project	West Cove	Central Cove	East Cove
FWOP	No action	No action	No action
Plan 1	25ft berm	25ft berm	25ft berm
Plan 2	50ft berm	50ft berm	50ft berm
Plan 3	75ft berm	75ft berm	75ft berm
Plan 4	25ft berm	25ft berm with a 75ft berm in Economic Reach 8	25ft berm
Plan 8	25ft berm	0	75ft berm
Plan 9	25ft berm	25ft berm	75ft berm

A couple of basic finding from the analytical analysis include the volume needed to balance the background erosion rate. As presented in section 4.3 the average background erosion rate for the Study area is -0.69ft/yr. With a project length of approximately 8000ft and a project life of 50 years a volume of 268,000 Cubic Yards of sand would be needed to maintain the current shoreline position. Furthermore, with a closure depth of -21ft and a berm height of +6.0ft the total active beach profile height is 27ft. The initial placement volume (in cubic yards), not accounting for transport losses or placement losses can be conveniently calculated by multiplying the project length (in feet) by the berm width (in feet).

4.4 Analytical Results and Input to Beach-fx

The plans as presented in Table 11 were analytically evaluated. Renourishment was included within the analysis by assessing the difference in shoreline position and planform template on a 5-year interval and calculating the needed volume to restore the Alternative's template. The algorithm evolves the shoreline position taking both background erosion and beach nourishment diffusion into account. The figure below shows the normalized shoreline position (the initial shoreline position is subtracted for presentation clarity) at 5-year increments for a 50ft berm width for the entire project area.

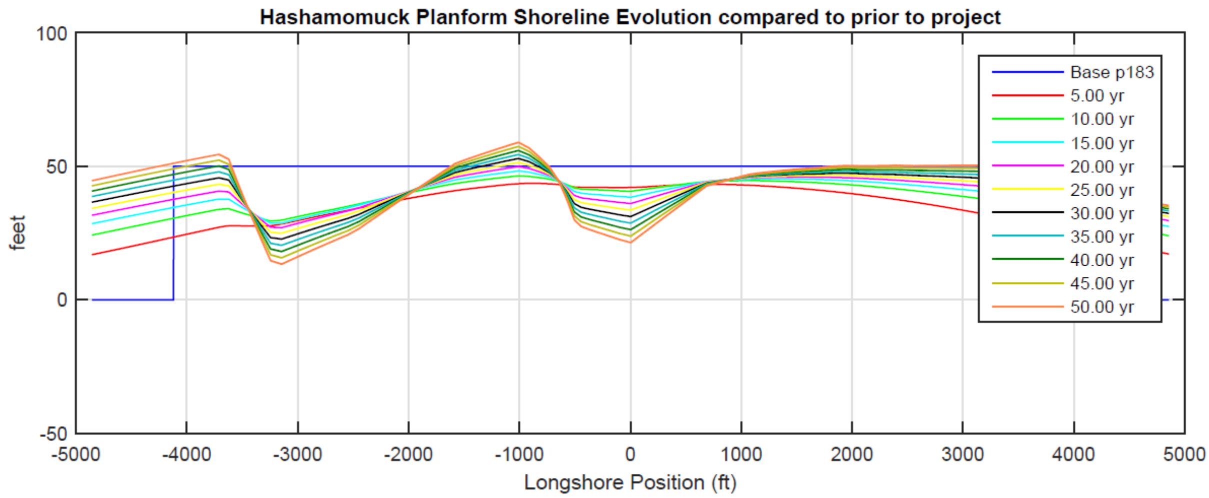

Figure 22: Analytical Results for Plan 2: 50ft Berm Width Planform for Hashamomuck Cove

The coastal engineering analysis of the existing conditions and with-project scenarios support a determination that the three coves act as a coastal system and are interconnected. In the existing condition, the littoral drift of sand (caused primarily by waves hitting the coast obliquely) is from the west to east in the project area. The existing small groin-like structures at the convex points (shoreline "spits") show accretion of sediment on the west side and erosion on the east side. The influence of existing rock structures on the littoral transport is limited as these structures are in poor condition and their impact will be further reduced as the project extends the existing shoreline seaward. The with-project analysis is based upon the consideration of project performance when and area is excluded from the plan. From Table 12, it can be seen that if one cove would be excluded from a nourishment plan an overall increase in renourishment volumes for the system is to be expected (compare Plan 9 to Plan 8). This supports the determination that the project functions as one coastal system when analyzing project cost and benefits and this approach accounts for the interconnectedness of the coves.

Table 12: Initial Placement and Planned Nourishment Placement for each Plan per the Analytical Analysis

Project	Initial Placement [CY]	Total Planned Nourishment Volume over 10 cycles (5-year cycle) [CY]	Total Volume [CY]
Plan 1	206,000	685,000	891,000
Plan 2	412,000	922,000	1,334,000
Plan 3	618,000	1,166,000	1,784,000
Plan 4	236,000	731,000	967,000
Plan 8	251,000	962,000	1,213,000
Plan 9	317,000	924,000	1,241,000

The beach nourishment diffusion analysis provides an analytical technique to predict the anticipated higher renourishment volumes for plan alternatives as a result of beach nourishment diffusion. The analysis indicates that once a beach nourishment project is constructed representative erosion rates at Hashamomuck Cove will increase significantly. The increase in erosion is a result of the losses at the edges of the planform perturbation. The background erosion and the planform erosion rate were extracted from the analytical results. Table 13 presents the background erosion rate and the initial planform erosion rate, taken as the average over the first 5 years, per reach for the six (6) Alternative Plans.

Table 13: Planform Erosion Rates for Individual Beach Nourishment Segments for all plans analyzed

		Planform Erosion Rate [ft/yr]					
Economic Reach	Background Erosion Rate [ft/yr]	Plan 1	Plan 2	Plan 3	Plan 4	Plan 8	Plan 9
E1	-0.35	-2.8	-5.6	-8.3	-2.5	-3.2	-2.7
E2	-1.29	-1.9	-3.8	-5.8	-1.4	-2.6	-1.8
E3	-1.10	-1.5	-2.9	-4.4	-0.8	-2.3	-1.2
E4	-0.63	-0.8	-1.6	-2.3	0.3	-2.0	-0.1
E5	-0.47	-0.6	-1.1	-1.7	0.7	-1.8	0.5
E6	-0.71	-0.5	-0.9	-1.4	0.8	4.7	0.8
E7	-1.09	-0.4	-0.9	-1.3	0.9	4.8	1.1
E8	-1.21	-0.4	-0.8	-1.2	-11.5	5.1	1.6
E9	-0.72	-0.5	-1.0	-1.4	0.8	5.8	2.4
E10	-0.58	-0.6	-1.3	-1.9	0.5	6.4	2.9
E11	-0.51	-0.8	-1.6	-2.3	0.3	6.7	3.1
E12	-0.42	-1.0	-2.1	-3.1	-0.1	-11.6	-9.2
E13	-0.33	-1.5	-3.1	-4.6	-0.9	-11.2	-9.3
E14	-0.22	-2.3	-4.7	-7.0	-1.9	-11.4	-10.1

		Planform Erosion Rate [ft/yr]					
Economic Reach	**Background Erosion Rate [ft/yr]**	**Plan 1**	**Plan 2**	**Plan 3**	**Plan 4**	**Plan 8**	**Plan 9**
E15	-0.29	-3.0	-6.0	-9.0	-2.7	-12.1	-11.1

As expected, and following the analytical description in Section 4.2 the performance of the beach nourishment is very sensitive to the alongshore length relative to the Beach Width. The planform erosion rates as listed in Table 13 were used as input in the Beach-fx model.

However, one should note that the analytical analysis was completed for consistent recurring renourishment cycles for all reaches. In Beach-fx, program settings could be such that beach renourishment may not occur for every reach for every renourishment cycle. Inclusion of complex program setting and renourishment scheme thresholds within the analytical analysis was beyond the scope of this analytical assessment and as such differences may exist between the renourishment volumes as calculated from the analytical algorithm and as simulated by the Beach-fx program.

4.5 Future Sea Level Change

In accordance with ER 1100-2-8162, the direct and indirect effects of future sea level change on the identified Recommended Plan (beach nourishment alternative) will be evaluated using the Beach-fx model. Relative sea level change at Hashamomuck Cove is one of rising sea levels. The historical rate of sea level rise was determined to be 0.00961 ft/year (http://corpsclimate.us/ccaceslcurves.cfm). The future low rate of sea level change was taken as a linear projection of this historical rate of change. The future intermediate rate of sea level change was computed using modified NRC Curve I and Equations 2 and 3 in ER 1100-2-8162. The future high rate of sea level change was computed using modified NRC Curve III and Equations 2 and 3 in ER 1100-2-8162. These relationships for future sea level change as defined in ER 1100-2-8162 are coded within Beach-fx and sea level change is internally computed continuously throughout the simulated project lifecycle. It can be noted however that sea level rise affects the shoreline erosion and beach renourishment quantities. As such it also effects the planform erosion of the various alternatives. The beach-fx appendix provides a section where sensitivity to sea level change is discussed. Planform erosion rates for the medium and high sea level rise scenarios were calculated for Plan 1, the plan where a 25ft berm would be constructed in each cove.

It can furthermore be noted that planform erosion rates are in general fairly comparable for the various SLC scenarios, but decrease slightly over time for the more extreme sea level change scenarios. For high rates of sea level rise the loss of beach width is more prevalent over time and as such requires higher nourishment quantities. As a result of the higher nourishment quantities the planform losses are (comparatively) less significant as time progresses due to the higher volume of sediment present within the project area and immediate vicinity which help stabilize the planform losses. Table 14 through Table 16 present the calculated planform erosion rates in ft/yr for the Low, Intermediate and High Sea Level Change scenarios. Planform erosion rates are presented as averages for each of the 5 year cycles with the first cycle starting in year 1.

Table 14: Planform erosion rates (ft/yr) for Plan 1 for the scenarios of Low Sea Level Change scenario

Economic Reach	Cycle Year									
	Year 1	Year 6	Year 11	Year 16	Year 21	Year 26	Year 31	Year 36	Year 41	Year 46
E1	-2.8	-1.9	-1.2	-0.7	-0.2	0.3	0.7	1.1	1.1	1.2
E2	-1.9	-2.2	-2.6	-3.2	-3.8	-4.3	-4.9	-5.5	-6	-6.5
E3	-1.5	-1.6	-1.9	-2.3	-2.7	-3.1	-3.4	-3.8	-4.2	-4.5
E4	-0.8	-0.4	-0.1	0.1	0.3	0.5	0.7	1	1.3	1.4
E5	-0.6	-0.1	0.3	0.7	1	1.2	1.2	1.3	1.3	1.4
E6	-0.5	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
E7	-0.4	-0.8	-1.2	-1.7	-2.2	-2.7	-3.2	-3.6	-4.1	-4.5
E8	-0.4	-0.9	-1.5	-2.1	-2.7	-3.4	-4	-4.6	-5.2	-5.7
E9	-0.5	-0.4	-0.5	-0.5	-0.6	-0.7	-0.7	-0.8	-0.9	-0.9
E10	-0.6	-0.4	-0.3	-0.2	-0.2	-0.1	0	0	0.1	0.2
E11	-0.8	-0.5	-0.3	-0.2	-0.1	0	0.1	0.2	0.4	0.5
E12	-1	-0.6	-0.4	-0.2	0	0.1	0.3	0.5	0.6	0.8
E13	-1.5	-1	-0.6	-0.4	-0.2	0	0.2	0.4	0.6	0.7
E14	-2.3	-1.6	-1.2	-0.8	-0.5	-0.3	0	0.2	0.4	0.5
E15	-3	-2.3	-1.9	-1.7	-1.5	-1.3	-1.2	-1.1	-0.9	-0.8

Table 15: Planform erosion rates (ft/yr) for Plan 1 for the scenarios of Intermediate Sea Level Change scenario

Economic Reach	Cycle Year									
	Year 1	Year 6	Year 11	Year 16	Year 21	Year 26	Year 31	Year 36	Year 41	Year 46
E1	-2.8	-1.8	-1.2	-0.6	-0.1	0.4	0.9	1	1.1	1.1
E2	-1.9	-2.1	-2.6	-3.1	-3.7	-4.2	-4.8	-5.3	-5.8	-6.3
E3	-1.5	-1.5	-1.8	-2.2	-2.6	-3	-3.3	-3.7	-4	-4.3
E4	-0.8	-0.4	-0.1	0.1	0.3	0.6	0.8	1.2	1.3	1.3
E5	-0.6	-0.1	0.3	0.7	1	1.1	1.1	1.2	1.2	1.3
E6	-0.5	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	-0.3	-0.2
E7	-0.4	-0.8	-1.2	-1.7	-2.2	-2.7	-3.1	-3.6	-4	-4.4
E8	-0.4	-0.9	-1.5	-2.1	-2.7	-3.3	-4	-4.5	-5.1	-5.6
E9	-0.5	-0.4	-0.4	-0.5	-0.6	-0.6	-0.7	-0.8	-0.8	-0.8
E10	-0.6	-0.4	-0.3	-0.2	-0.1	-0.1	0	0.1	0.2	0.4
E11	-0.8	-0.4	-0.3	-0.1	0	0.1	0.2	0.3	0.5	0.7

Economic Reach	Cycle Year									
E12	-1	-0.6	-0.3	-0.1	0	0.2	0.4	0.5	0.7	0.7
E13	-1.5	-0.9	-0.6	-0.3	-0.1	0.1	0.3	0.6	0.6	0.6
E14	-2.3	-1.5	-1.1	-0.7	-0.4	-0.2	0.1	0.4	0.5	0.5
E15	-3	-2.2	-1.8	-1.5	-1.3	-1.2	-1	-0.8	-0.6	-0.4

Table 16: Planform erosion rates (ft/yr) for Plan 1 for the scenarios of High Sea Level Change scenario

Economic Reach	Cycle Year									
	Year 1	Year 6	Year 11	Year 16	Year 21	Year 26	Year 31	Year 36	Year 41	Year 46
E1	-2.8	-1.7	-0.9	-0.2	0.4	0.7	0.7	0.8	0.8	0.8
E2	-1.9	-2	-2.4	-2.9	-3.4	-3.9	-4.3	-4.7	-5.1	-5.5
E3	-1.5	-1.5	-1.7	-2	-2.4	-2.7	-2.9	-3.2	-3.4	-3.6
E4	-0.8	-0.3	0	0.2	0.5	0.8	0.9	0.9	0.9	1
E5	-0.6	0	0.4	0.7	0.7	0.8	0.8	0.9	0.9	1
E6	-0.5	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	0	0.1	0.3
E7	-0.4	-0.8	-1.2	-1.7	-2.1	-2.5	-2.9	-3.3	-3.6	-3.9
E8	-0.4	-0.9	-1.5	-2.1	-2.7	-3.2	-3.7	-4.2	-4.7	-5.1
E9	-0.5	-0.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.4	-0.3	-0.1
E10	-0.6	-0.3	-0.2	-0.1	0	0.1	0.3	0.5	0.6	0.7
E11	-0.8	-0.4	-0.2	-0.1	0.1	0.3	0.5	0.5	0.6	0.6
E12	-1	-0.5	-0.2	0	0.2	0.4	0.4	0.5	0.5	0.5
E13	-1.5	-0.9	-0.5	-0.1	0.1	0.3	0.3	0.4	0.4	0.4
E14	-2.3	-1.4	-0.9	-0.4	-0.1	0.2	0.3	0.3	0.3	0.4
E15	-3	-2	-1.5	-1.2	-0.9	-0.6	-0.2	0.2	0.3	0.3

4.6 Beach Nourishment Construction

As noted at the start of this appendix, the ultimate goal of the study is to formulate a coastal storm risk management plan/project for the Hashamomuck study area. To construct the beach nourishment for the study area, the assumption is made that sand would be brought in by trucks (see cost engineering appendix). And although it is understood that losses over the project life time will be particularly pronounced at the ends of a project where an offset occurs between the fill section and the adjacent unfilled beach, referred to as end losses, it should also be noted that such losses could occur during the initial construction. Losses are defined here as material being transported outside the project limits. For the initial construction of the beach nourishment the relative slow production rate associated with trucking in sand would result in the diffusion of placed material during the construction process and some of the placed sand would get transported beyond the project limits. Other losses of material could occur during handling and placement, and a portion of the placed fines may get washed out and get transported out of the project area may. For planning level purposes and based on engineering judgement it is assumed that approximately 15% to 20% of the initial required construction volume would be transported out of the project limits during construction.

4.7 Project Performance

Following the selection of the 25ft berm alternative to be the Recommended Plan, documented in the economics appendix, an assessment of the performance of the Recommended Plan under selected return period storm conditions, was performed. The plan configurations considered were based on configurations with the existing dune height, existing dune width, and with a berm width of 25 feet. Responses of proposed plans were evaluated in SBEACH model under a variety of tropical and extratropical storms. The results of SBEACH simulations were then used in the evaluation of plan performance during events with specified annual probabilities, which was done with the use of the multivariate Empirical Simulation Technique (EST) procedure (Scheffner et al., 1999). The average recession for all reaches is 4.8 ft for a 5-year return period event, 9.5 ft for a 10-year event, 16.8 ft for a 25-year event, and 24.4 ft for a 50-year event. Details of project performance are provided in Appendix B.

5.0 REFERENCES:

Gravens, M. (2005). Development of a Historically-Based Plausible Tropical Storm Suite for Storm Induced Beach Morphology Response Modeling (Write-up).

Gravens, M. B., Males, R. M., and Moser, D. A., (2007). "Beach-*fx*: Monte Carlo Life-cycle Simulation Model for Estimating Shore Protection Project Evolution and Cost Benefit Analyses," *Shore and Beach* 75(1): 12-19.

Dean, R. G., and Yoo, C. H. 1992. .Beach-Nourishment Performance Predictions,. Journal of Waterway, Port, Coastal and Ocean Engineering 118(6), pp 567-585.

Dean, Robert G., and Robert A. Dalrymple. Coastal processes with engineering applications. Cambridge University Press, 2004.

Dean, Robert G. Beach nourishment: theory and practice. Vol. 18. World Scientific Publishing Co Inc, 2003.

Larson, M. and Kraus, N. C. (1990). "SBEACH: Numerical Model for Simulating Storm-Induced Beach Change, Report 2: Numerical Formulation and Model Tests", Technical Report CERC-89-9, May 1990, U.S. Army Engineer Waterways Experiment Station, Vicksburg MS.

Luettich, R.A., Westerink, J.J., and Scheffner, N.W., (1992). "ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries Report 1: Theory and Methodology of ADCIRC-2DDI and ADCIRC-3DL", Technical Report DRP-92-6, November 1992, U.S. Army Engineer Waterways Experiment Station, Vicksburg MS.

Melby, J. A. and Green, D., 2015. Coastal Hazards System (CHS) Web Tool – User Guide US Army Engineer Research and Development Center, 3909 Halls Ferry Rd, Vicksburgh, MS 39180

Scheffner, Norman W., Mark, David J., Blain, C. A., Westerink, J. J., and Luetttich, R. A. Jr., (1994). "ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries Report 5: A Tropical Storm Database for the East and Gulf of Mexico Coasts of the United States", Technical Report DRP-92-6, August 1994, U.S. Army Engineer Waterways Experiment Station, Vicksburg MS.

U.S. Army Corps of Engineers (USACE). 1969. North Shore of Long Island Beach Erosion Control and Interim Hurricane Study 1969. New York District, New York, New York. 270 pp.

U.S. Army Corps of Engineers (USACE). 1995. North Shore of Long Island, New York Storm Damage Protection and Beach Erosion Control. Reconnaissance Study. New

York District, New York, New York. 270 pp.

US Army Corps of Engineers (USACE), 2010. Feasibility Report and Environmental Impact Statement, Coastal Storm Damage Reduction, Surf City and North Topsail Beach, North Carolina. Appendix D Coastal Engineering U.S. Army Corps of Engineers (USACE). 2014a. Beach Erosion Control and Storm Damage Reduction Feasibility, North Shore of Long Island, Asharoken, New York, Engineering Appendix, Draft March 2014.

U.S. Army Corps of Engineers (USACE). 2015a. Sediment Sampling, Benthic Community Analysis and Eel Grass Survey in Support of Feasibility Investigation. December 2015. Prepared by the USACE. New England District.

APPENDIX A: REPRESENTATIVE AND IDEALIZED PROFILES PER REACH

Figure 23: Representative and idealized beach profile for Reach R1.

Figure 24: Representative and idealized beach profile for Reaches R2.

Figure 25: Representative and idealized beach profile for Reach R3.

Figure 26: Representative and idealized beach profile for Reach R4.

Figure 27: Representative and idealized beach profile for Reach R5.

Figure 28: Representative and idealized beach profile for Reaches R6.

Figure 29: Representative and idealized beach profile for Reaches R7.

Figure 30: Representative and idealized beach profile for Reach R8.

Figure 31: Representative and idealized beach profile for Reach R9.

Figure 32: Representative and idealized beach profile for Reach R10.

Figure 33: Representative and idealized beach profile for Reach R11.

Figure 34: Representative and idealized beach profile for Reach R12.

Figure 35: Representative and idealized beach profile for Reach R13.

APPENDIX B: ASSESSMENT OF PROJECT PERFORMANCE

This Appendix includes an assessment of the performance of the Recommended Plan under selected return period storm conditions, which include 10% annual chance exceedance probability event (10-year), 4% (25-year), and 2% (50-year). The plan configurations considered were based on configurations with the existing dune height, existing dune width, and with additional width of 25 feet. Responses of proposed plans were evaluated in SBEACH model under variety of tropical and extratropical storms. The results of SBEACH simulations were then used in the evaluation of plan performance during events with specified annual probabilities, which was done with the use of the multivariate Empirical Simulation Technique (EST) procedure (Scheffner et al., 1999).

Multivariate EST is a statistical procedure used to develop frequency of occurrence relationships for response parameters (i.e., contour line recess distance) as a function of the input parameters (i.e., wave, tide, and surge) that are descriptive of the storm event but have unknown joint probabilities. EST requires specifying a set of parameters that describe the dynamics of some physical system in response to tropical and extratropical storms.

Input parameters describe characteristics of the storm which have a first-order effect on the magnitude of the modeled response. The five input parameters were defined as:

- Tide amplitude—spring tide amplitude of 3.42 ft, neap tide amplitude of 1.93 ft, and mean tide amplitude of 2.52 ft

- Tide amplitude at the peak of the storm—cosine of tidal phase ranging from −1 to +1 and indicating high slack, falling tide, low slack and rising tide

- Tide slope at the peak of the storm—sine of tidal phase ranging from −1 to +1 and indicating high slack, falling tide, low slack and rising tide

- Maximum wave height during peak of the storm

- Maximum surge level during peak of the storm

The response parameter was the recession of contour line at a level of 1 ft below the upland elevation, which was computed with SBEACH for each storm (see Table 17).

Table 17: Upland Elevation and Contour Line Level

Reach	Upland Elevation, ft	Contour Line Level, ft	Reach	Upland Elevation, ft	Contour Line Level, ft
R01	6	+5	R08	8	+7
R02	12	+11	R09	8	+7
R03	8	+7	R10	12	+11
R04	12	+11	R11	10	+9
R05	18	+17	R12	9	+8
R06	14	+13	R13	11	+10
R07	9	+8			

Results of the EST evaluation are presented in Table 18. The recession of the contour line 1 ft below the upland elevation was predicted for 5-, 10-, 25-, and 50-year return period events using tropical storms alone, extratropical storms alone, and combined. The presented are mean (expected) recession distance, the 95% non-exceedance and 5% non-exceedance values, and average values for all reaches. It can be noted, that reach R01 has the lowest dune height and as a result the largest recession distance of 25.6 ft for a 5-year return period event. The average recession for all reaches is 4.8 ft for a 5-year return period event, 9.5 ft for a 10-year event, 16.8 ft for a 25-year event, and 24.4 ft for a 50-year event.

Table 18: Recession of Contour Line (1 ft below Upland Elevation) Under Tropical and Extratropical Events or in Their Combination (in feet)

RP, yr	Combined			Tropical			Extratropical		
	Mean	95%	5%	Mean	95%	5%	Mean	95%	5%
Reach R01									
5	25.6	32.2	19.0	3.0	6.0	1.1	21.8	29.1	14.4
10	37.0	43.7	29.8	10.3	17.2	4.1	34.4	42.4	26.1
25	48.9	59.2	39.4	24.9	38.0	13.0	47.3	57.7	37.5
50	58.8	74.4	45.7	36.0	52.2	19.3	57.0	72.8	44.6
Reach R02									
5	1.3	3.2	0.1	0.0	0.0	0.0	0.7	2.2	0.0
10	5.5	9.2	2.2	0.0	0.1	0.0	4.0	7.1	1.4
25	12.7	19.6	7.4	2.6	14.1	0.0	9.8	14.9	5.1
50	20.5	35.7	10.8	12.7	35.3	0.3	14.2	20.5	8.2
Reach R03									
5	6.0	9.6	2.7	0.8	1.0	0.6	4.2	7.9	1.6
10	13.2	18.8	8.4	1.3	2.0	0.9	10.8	15.5	6.2
25	23.8	33.9	16.0	7.8	22.5	1.6	19.5	28.0	12.5
50	32.9	46.6	20.7	20.3	43.2	2.9	26.9	40.4	17.3
Reach R04									
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.5	1.6	0.0	0.0	0.0	0.0	0.2	0.6	0.0
25	4.2	11.0	0.8	1.4	8.7	0.0	1.7	4.3	0.2
50	11.7	31.3	2.3	9.2	30.8	0.0	4.0	8.9	1.0
Reach R05									
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.9	5.4	0.0	0.9	5.4	0.0	0.0	0.0	0.0

RP, yr	Combined			Tropical			Extratropical		
	Mean	95%	5%	Mean	95%	5%	Mean	95%	5%
Reach R06									
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.4	2.8	0.0	0.4	2.8	0.0	0.0	0.0	0.0
50	4.2	17.8	0.0	4.2	17.8	0.0	0.0	0.0	0.0
Reach R07									
5	6.7	10.2	3.9	1.2	2.0	0.6	4.8	8.5	1.9
10	13.4	18.6	8.8	2.7	4.0	1.7	11.3	15.6	7.0
25	23.1	33.1	15.4	8.9	25.5	3.2	18.9	25.5	13.4
50	31.9	46.4	20.2	21.8	45.5	4.7	24.7	34.4	16.7
Reach R08									
5	3.2	5.6	1.7	0.9	1.0	0.7	2.3	4.6	1.2
10	9.0	14.2	4.8	1.3	1.8	0.9	7.1	11.2	3.3
25	18.4	26.3	11.3	5.2	20.4	1.5	14.6	21.1	9.0
50	26.9	41.9	16.1	17.0	40.3	2.0	20.1	28.4	12.4
Reach R09									
5	4.9	8.2	2.0	0.3	0.5	0.1	3.3	6.3	0.9
10	11.5	16.9	7.0	0.8	1.5	0.4	9.2	13.7	5.1
25	21.3	30.6	13.5	6.9	23.4	1.0	17.1	24.8	10.7
50	30.2	42.8	18.8	18.8	38.2	2.0	24.2	36.4	14.9
Reach R10									
5	0.3	1.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0
10	2.4	5.0	0.7	0.0	0.0	0.0	1.4	3.3	0.2
25	8.4	16.3	3.0	2.0	10.9	0.0	5.3	10.0	1.8
50	16.7	34.2	6.2	11.1	33.0	0.0	9.2	16.6	3.6
Reach R11									
5	0.6	1.5	0.0	0.0	0.0	0.0	0.2	0.7	0.0
10	3.1	6.1	1.0	0.0	0.3	0.0	1.8	3.9	0.4
25	10.1	19.0	4.0	3.2	14.7	0.0	6.3	11.1	2.5
50	19.1	37.3	7.3	13.8	37.3	0.7	10.5	17.8	4.6
Reach R12									
5	12.9	18.1	7.7	1.3	2.1	0.8	11.1	16.3	5.5
10	21.8	27.6	16.2	3.0	4.7	1.9	19.9	25.3	14.3
25	32.5	41.2	24.4	9.8	28.3	3.6	29.1	36.9	22.1
50	41.6	56.3	29.8	24.2	50.3	5.4	36.1	47.3	26.2

RP, yr	Combined			Tropical			Extratropical		
	Mean	**95%**	**5%**	**Mean**	**95%**	**5%**	**Mean**	**95%**	**5%**
Reach R13									
5	1.6	4.0	0.1	0.0	0.0	0.0	0.8	2.6	0.0
10	6.2	10.4	2.2	0.0	0.1	0.0	4.6	8.6	1.5
25	14.0	22.1	7.9	3.1	15.6	0.0	10.7	15.6	5.8
50	22.0	38.8	12.5	14.2	38.7	0.2	15.2	21.6	9.3
Average									
5	4.8	7.2	2.9	0.6	1.0	0.3	3.8	6.0	2.0
10	9.5	13.3	6.2	1.5	2.4	0.8	8.1	11.3	5.0
25	16.8	24.2	11.0	5.9	17.3	1.8	13.9	19.2	9.3
50	24.4	39.1	14.6	15.7	36.0	2.9	18.6	26.5	12.2

Reference: Scheffner, N.W., Clausner, J.E., Militello, A., Borgman, L.E., Edge, B.L., and P.J. Grace (1999) "Use and Application of the Empirical Simulation Technique: User's Guide", Technical Report CHL-99-21, December 1999, Engineer Research and Development Center, U.S. Army Corps of Engineers.