APPENDIX C1 -HYDROLOGY AND HYDRAULICS

Table of Contents

1. Introduction

The U.S. Army Corps of Engineers (USACE) Philadelphia District (NAP) has conducted a coastal storm risk management study for several communities along the Delaware River and Bay, specifically within the State of Delaware. The study area includes the majority of the tidal portion of the Delaware River, and is split into northern and southern reaches, as shown in Figures 1 and 2. The ultimate goal of the study is to formulate a comprehensive coastal storm risk management plan/project for identified communities within the study area extending over a 50 year economic period of analysis that maximizes net economic benefits and is technically and environmentally feasible.

The purpose of this appendix is to describe the hydrologic and hydraulic input driving both initial screening and more detailed evaluation for plan formulation. For the northern reach, this includes more simplified use of readily available data. For the southern reach, this includes all necessary Beach-fx input data, including developing the representative storm suite, historic shoreline change conditions, and profile response to the array of storm events using SBEACH.

1.1 Study Area

As mentioned above, the subject study area covers a majority of the tidal extent of the Delaware River along the State of Delaware. As such, it was expected that the overall driving forces with respect to flood risk management and coastal processes (e.g. wave action, shoreline erosion, etc.) would vary significantly between study sites. Locations in the lower bay (southern reach) are subject to a more coastal environment, with more severe wave action and shoreline erosion, while the upper extent of the study area (northern reach), although still tidal, is less impacted by those coastal forces. To account for these variations, the study locations were split into two groups, based on anticipated impact of coastal forces, for analysis utilizing two different methods. The lower bay study locations, that were expected to be subject to the more severe coastal processes, were analyzed by U.S. Army Engineer Research and Development Center (ERDC) using the more rigorous Beach-fx model, whereas the remaining study areas were analyzed using a more simplified approach using readily available North Atlantic Coastal Comprehensive Study (NACCS) model results. Figures 1 and 2 depict both initial screening sites, and the final study locations analyzed for the feasibility phase. Subsequent discussion below pertains to the study locations analyzed during screening cycles using NACCS data (northern reach), and necessary inputs to the Beach-fx modeling (southern reach). Discussion of the Beach-fx modeling is provided in a separate appendix: Appendix A - Economic Analysis.

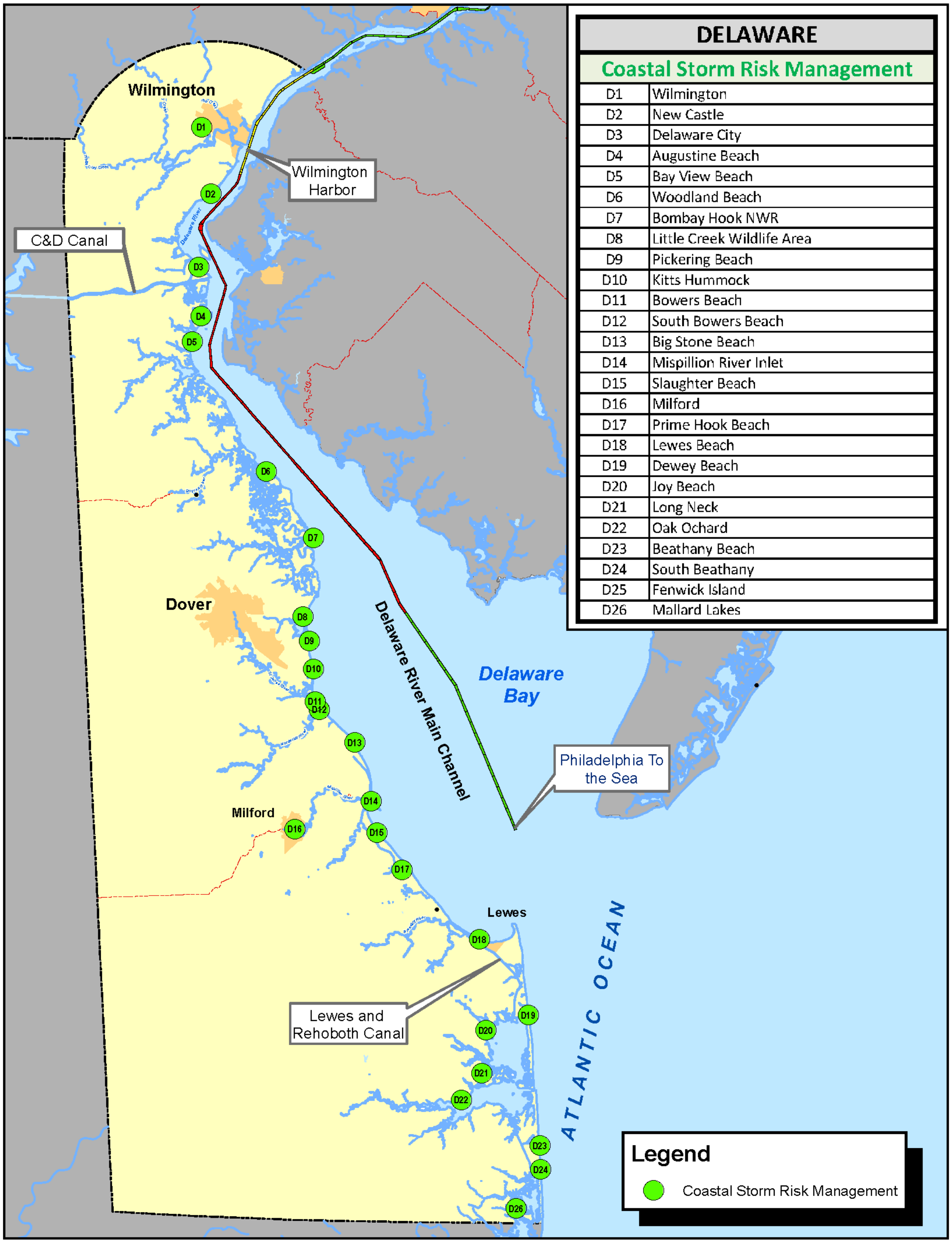
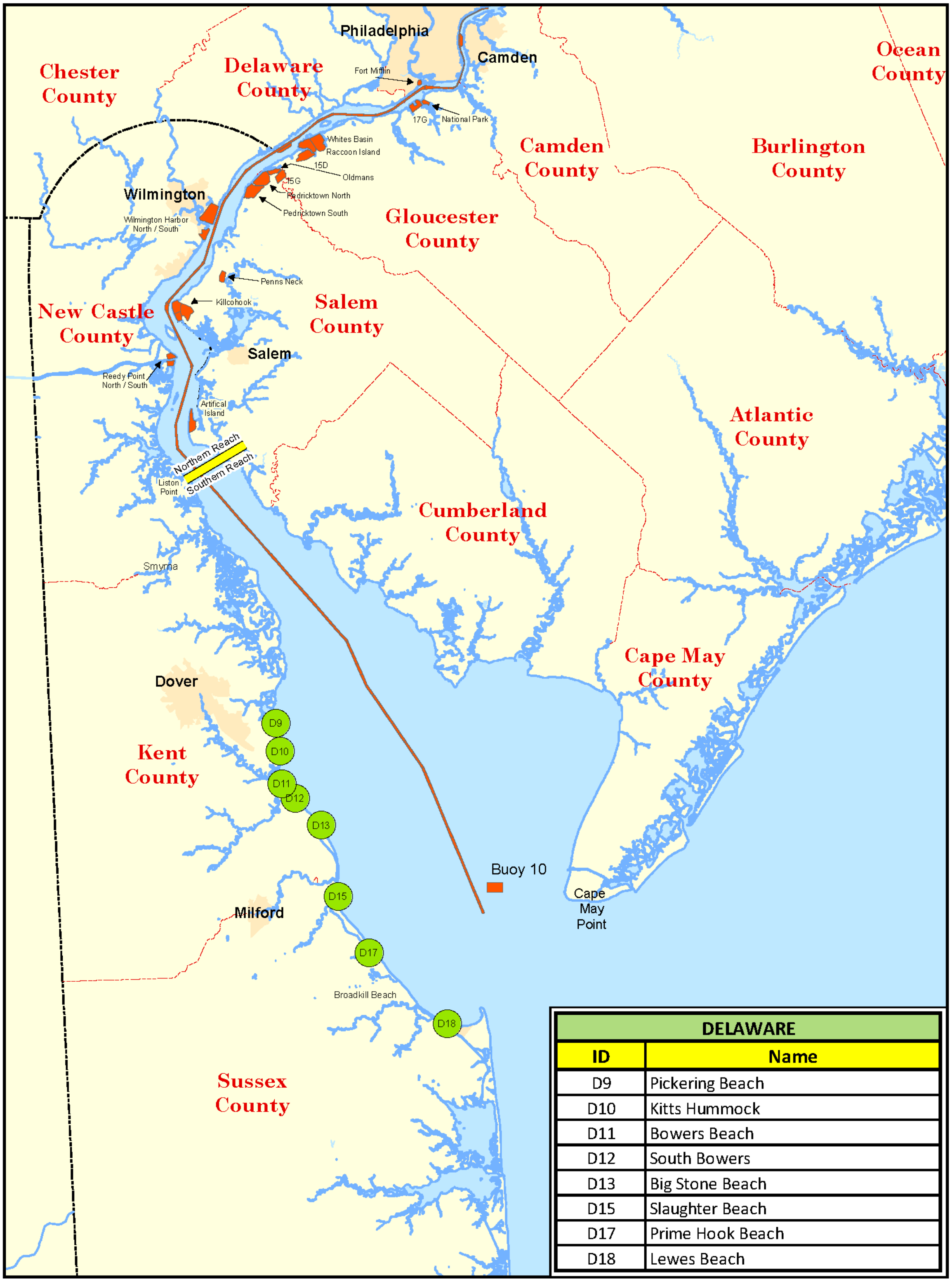


Figure 1 Initial Locations for Screening



DELAWARE	
ID	Name
D9	Pickering Beach
D10	Kitts Hummock
D11	Bowers Beach
D12	South Bowers
D13	Big Stone Beach
D15	Slaughter Beach
D17	Prime Hook Beach
D18	Lewes Beach

Figure 2 - Planning Reach Delineation

2. Screening Level Assessment

2.1 NACCS Stage-Probability Data Compilation

For the northern reach, stage-probability data for each of the DMU project sites were obtained directly from ERDC in November 2015. These data were compiled by ERDC from the NACCS study results, originally finalized in January 2015, but subsequently updated to incorporate model refinements, and new data as they became available.

NACCS modeling output supplied by ERDC was reported at each model node, or save point, which is a point in the modeled area at which results such as water surface elevation, wave height, etc., are saved, for a total of 18,977 discrete locations throughout the NACCS study area. These data were provided in both spreadsheet form, and as .KML format for use in GIS systems. As the NACCS numerical modeling utilized a coupled surge and wave model (ADCIRC + STWAVE), and for the results utilized for screening (Base+Tides conditions), reported water levels explicitly accounted for effects of storm surge, wave setup, and tides, but required incorporation of actual wave height effects (i.e. wave crest elevations). As such, two separate data sets were supplied by ERDC: one for static water level or stillwater elevation (SWEL), and one for wave height, again reported at each model node in the NACCS study area. Both data sets were supplied at various average recurrence intervals (ARI) from 1- to 10,000-yr, with the mean (average) value reported, including multiple upper confidence limits (84th, 90th, 95th percentile, etc.). For later incorporation into HEC-FDA, conversion from ARI to annual exceedance probability (AEP) was completed using the reciprocal (e.g. 2-yr ARI = 1/2, or an AEP of 0.5, or 50% annual chance exceedance (ACE)). NACCS model results were originally supplied in metric units, and were subsequently converted from meters, MSL to feet, NAVD88 through conversion values provided by ERDC.

Following data conversion, one half (0.5) the wave height was added linearly to the SWEL to account for wave effects, resulting in the wave crest elevation, or total water level (TWL), at each model save point, again across various ARI, and multiple confidence intervals. The one half (0.5) fraction is an approximation based on the simplifying assumption of linear wave theory. Wave height is the difference in elevation between the wave crest and wave trough. In linear wave theory, the total wave height (crest to trough) is vertically symmetrical about the still water level - that is, the wave crest is 1/2 the of the wave height above the still water level. This was deemed sufficiently detailed for screening level decisions.

For each study location within the northern reach, multiple proximate save points (typically 3 to 5) were compiled. SWEL, wave height, and TWL data for compiled save points were plotted and reviewed to determine a representative save point at each study location. Additionally, as uncertainty varied spatially throughout the NACCS modeling domain, ERDC also provided estimates of epistemic uncertainty for each save point, to further qualify confidence in the model results, allowing screening of save points for use at each of the DMU study locations. In general, stage-probability data varied only slightly across each individual study location, and as such it was determined that data from a single representative save point was sufficient to describe anticipated water levels at each study location, to inform project screening. In total, two base stage-probability curves were determined for each study location: SWEL, and SWEL + ½ Wave Height, each reported with the mean and multiple confidence limits. Figure 3 below depicts example location with NACCS Save Points used in screening assessment, with Table 1 showing all NACCS

Save Points used during screening, by location. Figure 4 shows an example of output data from NACCS analysis for one location.

Figure 3 – Example NACCS Save Point Map

Table 1 –NACCS Save Points Used for Initial Screening

Site ID	D2	D4	D5	D6	D9	D10	D11	D12	D13	D14	D17	D18
Location / Municipality	New Castle	Augustine Beach	Bayview Beach	Woodland Beach	Pickering Beach	Kitts Hummock	Bowers Beach	South Bowers Beach	Big Stone Beach	Mispillion River Inlet / Slaughter Beach	Prime Hook Beach	Lewes Beach
NACCS Save Point ID	13295	13290	13290	11019	11163	11162	7167	7167	11160	15204	15203	15202
	5349	13292	13292	11138	11162	11163	11159	11159	15246	15248	15250	7172
	11102	13289	13289	11150	11155	11155	11160	11160	15205	15249	15251	15201
	11024	11134	11134		11164	11156	11161	11161	15247	15253	15252	6130
	7601	11022	11022									
	11028											
	5350											
	7158											
	11027											

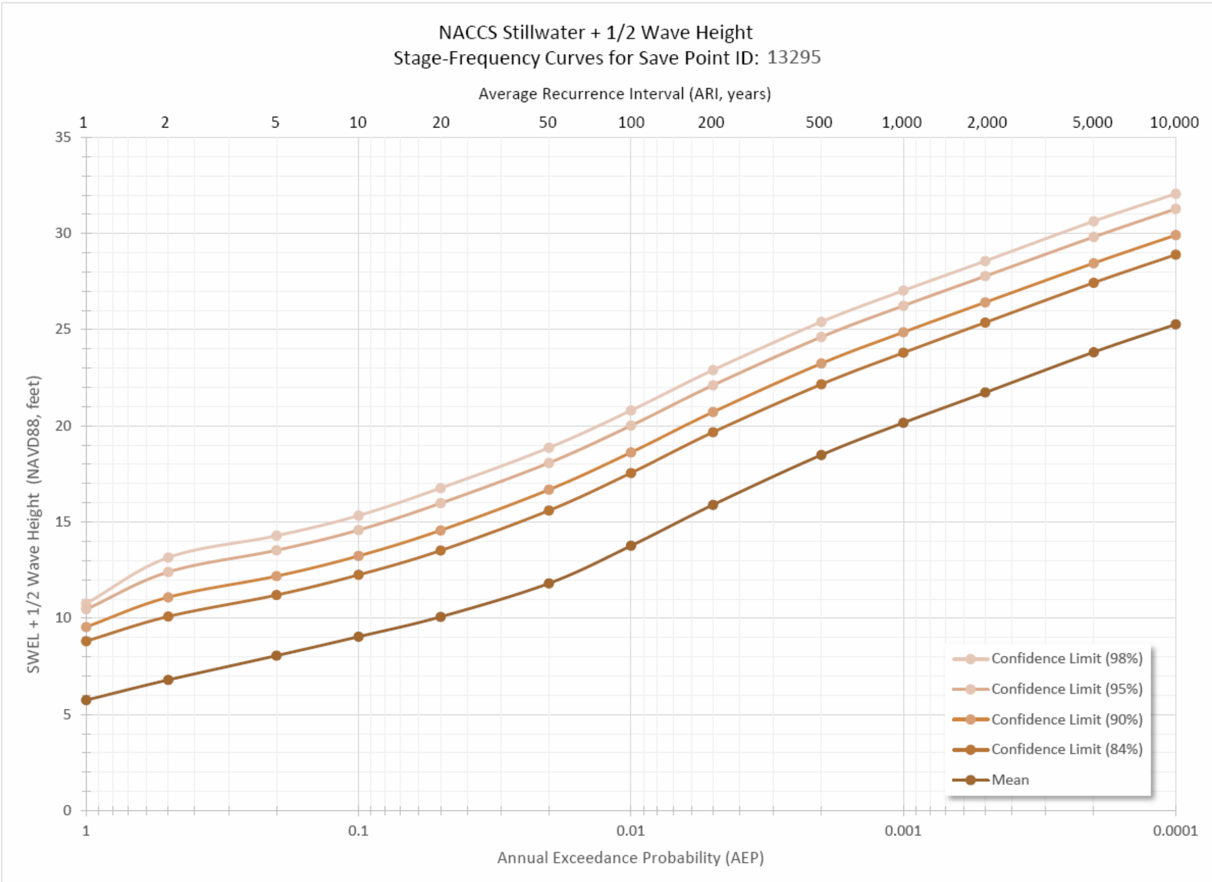


Figure 4 – Example NACCS Save Point Output compiled for screening

2.2 Screening Level Relative Sea Level Change (RSLC) Analysis

In accordance with USACE ER 1100-2-8162, potential effects of RSLC on overall water levels were analyzed for each study location, over a 50-yr economic analysis period and a 100-yr planning horizon. Given the size and scope of potential projects, and associated anticipated timing, a base year for RSLC analysis of 2020 was used, with future years of 2070 and 2120. For each study location, the most appropriate NOAA gage (typically closest geographically) was determined, and RSLC adjustments were calculated for the future years using published RSLC rates, for the three recommended curves: USACE Low, USACE Intermediate, and USACE High. Table 2 summarizes the NOAA gage utilized for each study location, and Table 3 shows relevant RSLC adjustments for each gage. For screening purposes, these RSLC adjustments were added linearly to the base stage-probability curves discussed above, resulting in a total of eight stage probability curves compiled for each study location, again each with mean and multiple confidence limits for the economic analysis. These stage-probability curves are:

- Base year (2020) SWEL
- Future year (2070) SWEL + RSLC USACE Low

- Future year (2070) SWEL + RSLC USACE Intermediate
- Future year (2070) SWEL + RSLC USACE High
- Base year (2020) SWEL + 1/2 Wave Height
- Future year (2070) SWEL + 1/2 Wave Height + RSLC USACE Low
- Future year (2070) SWEL + 1/2 Wave Height + RSLC USACE Intermediate
- Future year (2070) SWEL + 1/2 Wave Height + RSLC USACE High

Given the anticipated size of any protection features, and negligible effects to stage of the tidal Delaware River and Bay, all stage-probability curves were utilized for both without and with-project conditions. As discussed above, at study locations where wave data was unreported, only SWEL curves were produced, for four total curves rather than eight.

Table 2 –Nearest NOAA Gage used for Sea Level Change Calculations

Site ID	Location / Municipality	Nearest NOAA Gage
D2	New Castle	8551910, Reedy Point, DE
D4	Augustine Beach	8551910, Reedy Point, DE
D5	Bay View Beach	8551910, Reedy Point, DE
D6	Woodland Beach	8551910, Reedy Point, DE
D9	Pickering Beach	8557380, Lewes, DE
D10	Kitts Hummock	8557380, Lewes, DE
D11	Bowers Beach	8557380, Lewes, DE
D12	South Bowers Beach	8557380, Lewes, DE
D13	Big Stone Beach	8557380, Lewes, DE
D14	Mispillion River Inlet / Slaughter Beach	8557380, Lewes, DE
D17	Prime Hook Beach	8557380, Lewes, DE
D18	Lewes Beach	8557380, Lewes, DE

Table 3 –Relative Sea Level Change (RSLC) Adjustments applied during Screening Level Assessments

NOAA Gage ID	Project Year [2]	RSLC Adjustments [1]		
		USACE Low	USACE Int.	USACE High
8551910, Reedy Point, DE	2020	0.06	0.08	0.15
	2070	0.62	1.12	2.68
	2120	1.19	2.6	7.07
8557380, Lewes, DE	2020	0.05	0.08	0.15
	2070	0.58	1.07	2.64
	2120	1.1	2.51	6.98
8536110, Cape May, NJ	2020	0.07	0.09	0.16
	2070	0.73	1.23	2.79
	2120	1.4	2.81	7.28

[1] Calculated RSLC estimates from USACE Sea Level Change Curve Calculator (2015.46), http://www.corpsclimate.us/ccaceslcurves.cfm, using Published Rates for each gage, base year 2020, 50- and 100-yr planning horizons. Values in feet.

[2] Current NACCS results obtained from USACE ERDC November 2015 utilized for Base Year. RSLC shown for 2070 applied to Base Year data for screening level analysis. Data for 2120 shown for reference.

2.3 Screening Level Topographic Review

Available topographic data and bathymetric data at each study location was compiled and reviewed in ArcGIS to further inform initial screening. Specifically, topographic-bathymetric combination (topobathy) LiDAR data from 2014 was available for the majority of the study area. This was supplemented with topographic LiDAR from 2009 where necessary for coverage of the entire floodplain for a few locations in the upper extent of the study area. All elevation data were reprojected, and converted as necessary, to horizontal datum of State Plane Delaware, NAD83, feet, and a vertical datum of NAVD88, feet, for consistent use with the NACCS stage-probability curves.

At each study location, ArcGIS was utilized to cut profiles, laid out perpendicular to the shoreline. Multiple profiles were utilized at each location to estimate existing level of protection, continuity of protection features, as well as potential impacts of with-project features. Topography at each location was also reviewed to qualitatively assess potential incremental benefits to increasing level of protection. Further, profiles were utilized for feasibility level quantity estimates of with-project conditions at each study location. FEMA Flood Insurance Rate Maps were also utilized to inform initial screening. Figures 5 and 6 show an example of topographic profile placement and results, and Table 4 below summarizes estimated level of existing protection at each of the study locations.

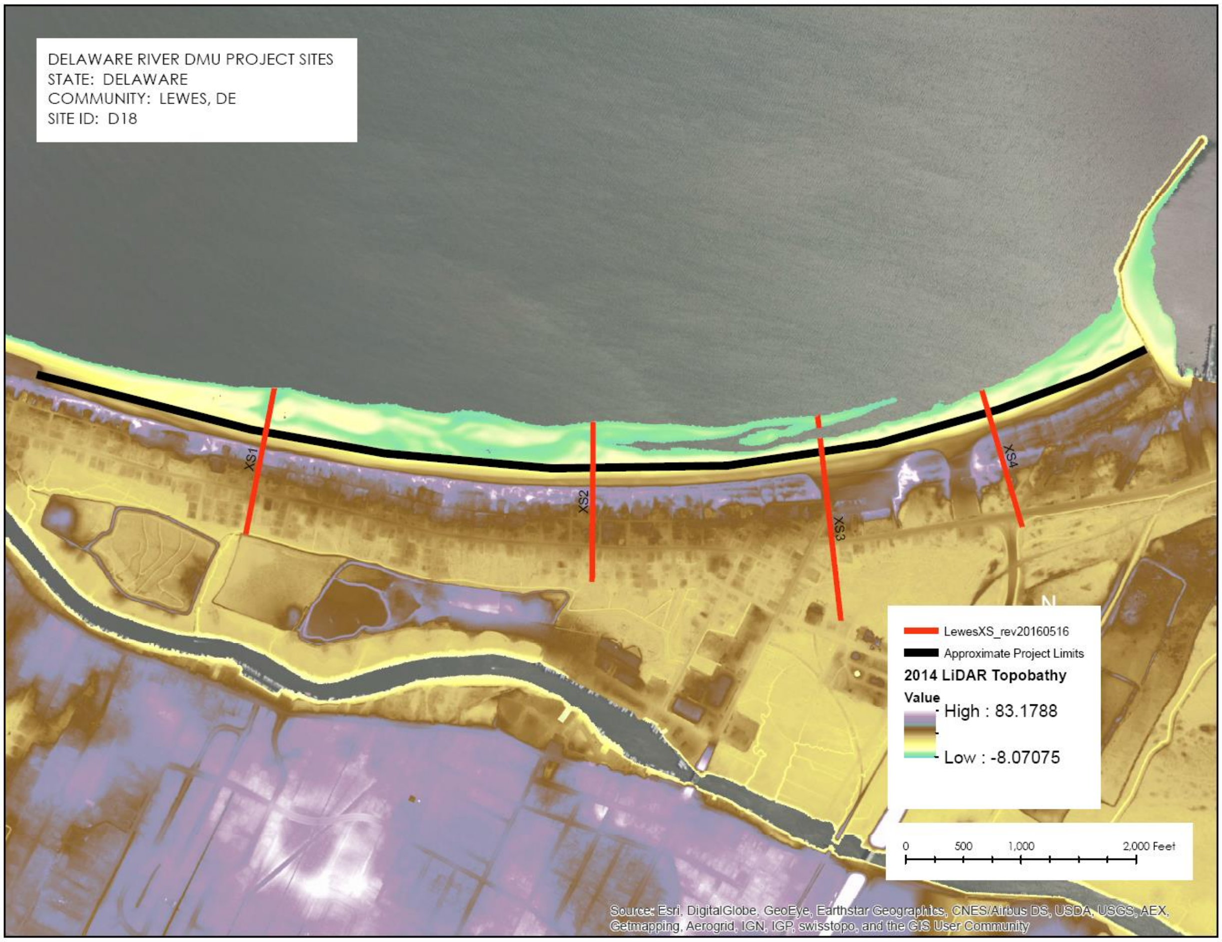


Figure 5 – Example profile locations for screening

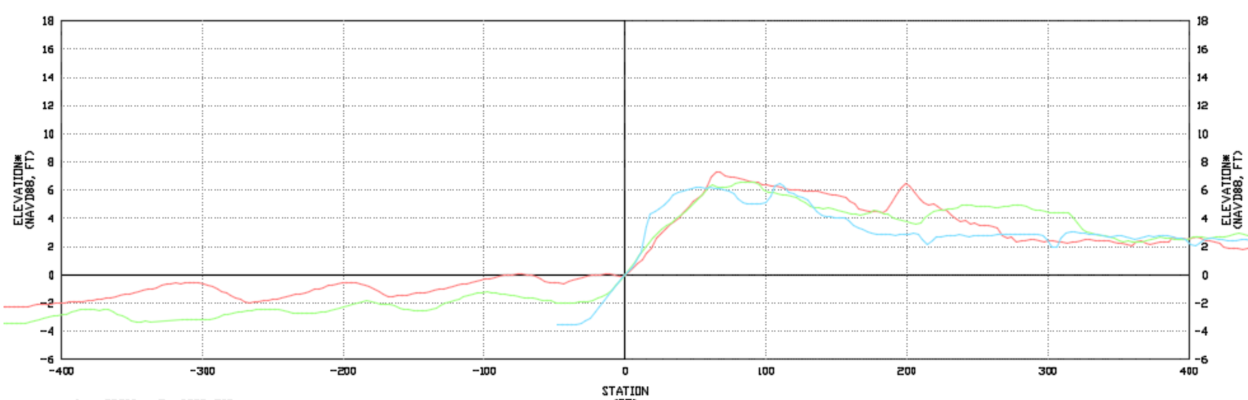


Figure 6 – Example profiles for screening assessment

Table 4 – Existing level of protection from topographic assessment

Site ID	Location / Municipality	Approx. Elevation of High Ground / Existing 'Protection' (ft, NAVD88) *
D2	New Castle	8.5 to 9.0
D4	Augustine Beach	6.0 to 7.0
D5	Bay View Beach	6.0 to 7.0
D6	Woodland Beach	6.0 to 7.0
D9	Pickering Beach	Beach-fx
D10	Kitts Hummock	Beach-fx
D11	Bowers Beach	Beach-fx
D12	South Bowers Beach	Beach-fx
D13	Big Stone Beach	Beach-fx
D14	Mispillion River Inlet / Slaughter Beach	Beach-fx
D17	Prime Hook Beach	Beach-fx
D18	Lewes Beach	Beach-fx

* Sites from Pickering Beach downstream were analyzed in Beach-fx, with entire profile(s). Estimated ranges not used during initial screening.

2.4 Screening Level Summary

Ultimately, northern most study locations (D2 through D6) were screened out, as discussed in detail in section 3.4 of the main report, for a variety of reasons, including infeasibility of using dredged material for levees, lack of high ground for line of protection tie-ins, or lack of project benefits. The remaining lower 8 study locations (D9 through D18) were further analyzed with Beach-fx, as described in subsequent sections, and other appendices.

3. Beach-fx Input Data

For the southern reach study area locations (D9 through D18), Beach-fx was used to estimate the economic benefits realized during the project life due to the placement of dredged material. In order to accomplish the economic benefits analysis, Beach-fx requires the application of the Storm-Induced Beach Change Model (SBEACH). SBEACH is a one-dimensional (cross-shore) model used to simulate the profile response to storm conditions. SBEACH is used in this study to build the Beach-fx Storm Response Database (SRD). The SRD is a lookup table that stores the morphological profile responses (i.e. change in berm width and dune width/height) and damage driving parameters (i.e. wave height, water level, and vertical erosion). The SRD is based on approximately 2 million individual SBEACH simulations for a range or possible beach profile configurations and storm conditions.

SBEACH requires an initial beach profile or profiles for the study location as well as time series of waves, water levels, and tides as driving conditions to the model. For the study locations selected for evaluation, an analysis was conducted to determine the number of profiles required to sufficiently represent this region. The methodology for selecting and developing beach profiles and storm forcing conditions for this study is presented as follows.

3.1 Data collection/initial site evaluation (representative profiles)

In order to characterize the DMU sites, it was necessary to compile: 1) historic shoreline change rates to calibrate Beach-fx, 2) native and dredged material grain sizes, 3) beach profile data (including the dune height, dune crest width, berm width, and submerged profile to the depth of closure), 4) potential damage areas, and 5) dredged material placement volumes, or more specifically, the proposed with-project profile configuration. Discussion in subsequent sections provides detail with regard to 1), 3), and 5), with discussion of the remaining data supplied in the main report text, and/or other appendices.

3.1.1 Existing Profile Analysis

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 into reaches characterized by representative beach profiles that describe the shape of the cross-shore profile and beach composition. A reach is defined as a contiguous, morphologically homogeneous stretch of beach, however morphologic features of the existing beach, such as dune height, berm width, and offshore profile shape, typically vary along a project study domain. Therefore to accurately estimate storm erosion response for the existing condition, a set of 11 representative morphologic reaches (based on analysis of 2015 profile surveys obtained by DNREC, and provided by NAP to ERDC, as well as 2014 LIDAR data) were developed to describe variations in profile shape along the seven initial project domains (D9 through D17). Morphology analysis software applications (BMAP and RMAP) were used to define morphologic reaches by analyzing profiles, grouping similar profiles, and calculating an average representative profile for each reach as described in the following paragraphs.

For the Delaware DMU study, 34 State of Delaware beach profile surveys collected in 2015 were obtained, as shown in Figure 7, however the profiles only extended to a depth of 1 to 2 m (3 to 6 ft). Table 5 indicates the profiles in the vicinity of each DMU site and shows that the initial 7 locations are contained within the northernmost 16 profiles. Densely-spaced LIDAR cuts were also obtained to fully characterize the upland portion of the profiles with a more detailed spatial description than with only the original set of profile data. For example, Figure 8 shows the 3 NAP profiles and 38 LIDAR cuts representing Slaughter Beach. The LIDAR cuts were therefore used in the profile analysis, with the original set of NAP profiles used for validation. The NACCS ADCIRC grid is based on NOAA historical surveys in the Delaware Bay region and the bathymetric data from the NACCS grid were used to extend the offshore portion of the profiles to the depth of closure. The resulting composite profile for each reach is then composed of a combination of LIDAR cuts and NACCS offshore profiles. For example, a representative profile for the central portion of Kitts Hummock is composed of three LIDAR cuts (KH9, 12, and 14) and the NACCS offshore profile, as shown in Figure 9.

Figure 7 – Initial Seven DMU sites evaluated in this study and 2015 NAP profile data locations

Table 5 – Profiles for Defining Initial Project Reaches		
DMU Site	NACCS/NAP Profile	LIDAR Cuts
Pickering	1	PB 2 ,4, 7
Kitts Hummock_1	3	KH3, 5, 7
Kitts Hummock_2	3	KH9, 12, 14
Kitts Hummock_3	3+4	KH15, 17
Bowers_1	6	BB4, 5, 6, and 9
Bowers_2	6	BB9 and 10
South Bowers	7	SB3, 4, and 8
Big Stone	10	BS1, 4, 8, 16, 12, and 20
Slaughter	12	SL12, 13, 14, 15, 17, and 19
Slaughter	12	SL21, 23, 25, 27, 29, 31, 33, and 35
Prime Hook	16	PH4, 6, 8, 10, and 12

Figure 8 – LIDAR cuts (in white) and State of Delaware survey profiles (in red) for Slaughter Beach

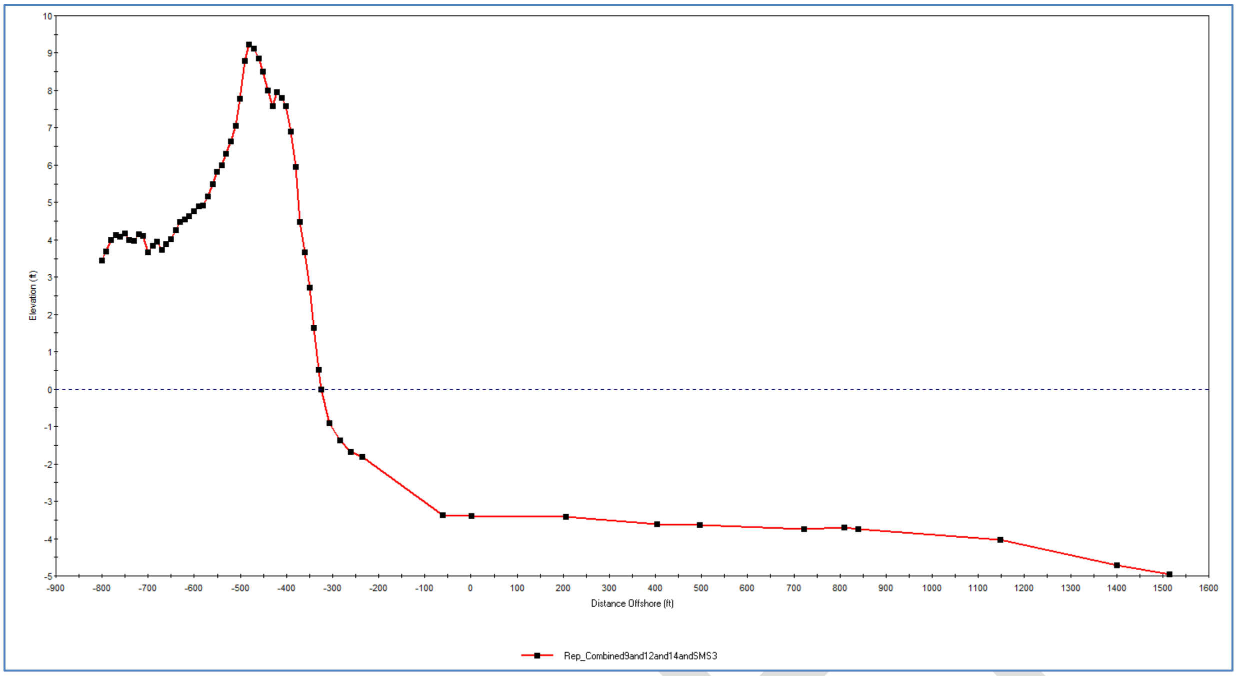


Figure 9 – Representative profile for Kitts Hummock (#2)

Because of the complexity of natural beach profiles, a simplified or idealized beach profile, representing key morphological features (dune height and width, berm height and width, dune and foreshore slope, upland elevation/width and sand grain size) is applied in SBEACH. The idealized profile, Figure 10, 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 were determined through an analysis of available NACCS bathymetric data. In order to reduce the number of required profiles in the SRD, it is assumed in Beach-fx that some of the characteristic features of the profile are constant throughout the lifetime of the project (i.e. they do not vary with the storm response). The constant profile features are the upland elevation, dune slope, berm, foreshore slope, and shape of the submerged profile. The profile characteristics that change in response to storms are the dune width, dune elevation, and berm width.

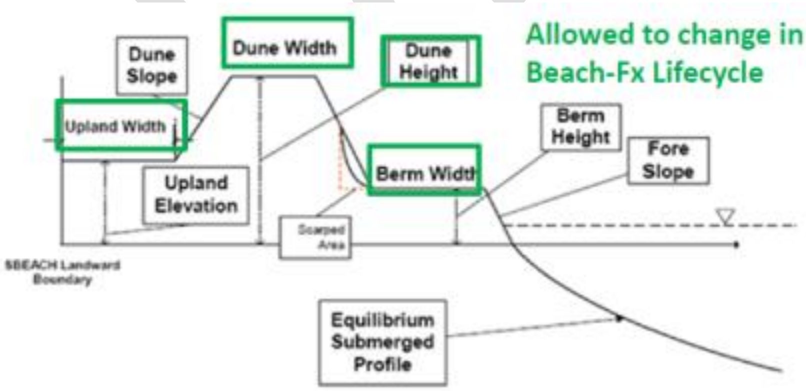


Figure 10 – Beach-fx Simplified Profile

The representative and idealized profile for the central portion of Kitts Hummock is shown in Figure 11 and the land portion of the profile is given in Figure 12. The land portion of all 11 idealized profiles is given in Figures 34 – 44.

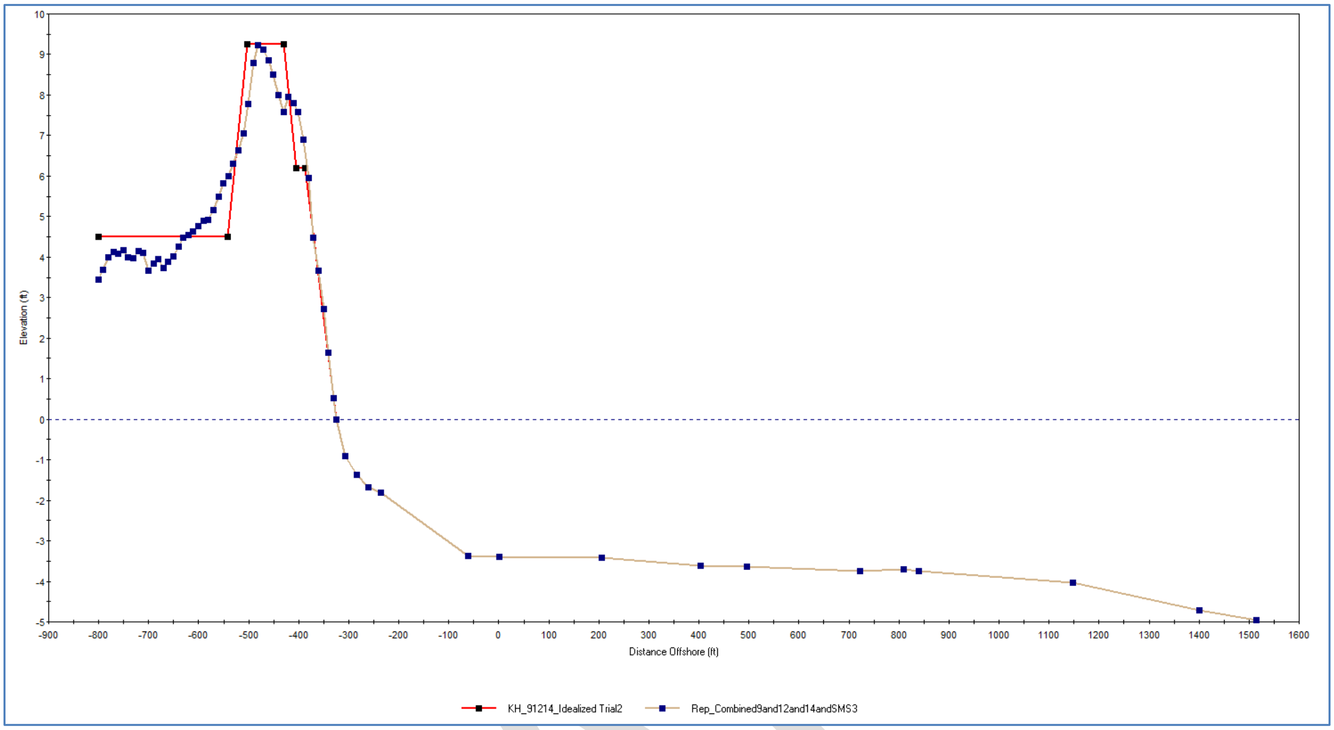


Figure 11 – Representative and idealized profile for Kitts Hummock (#2)

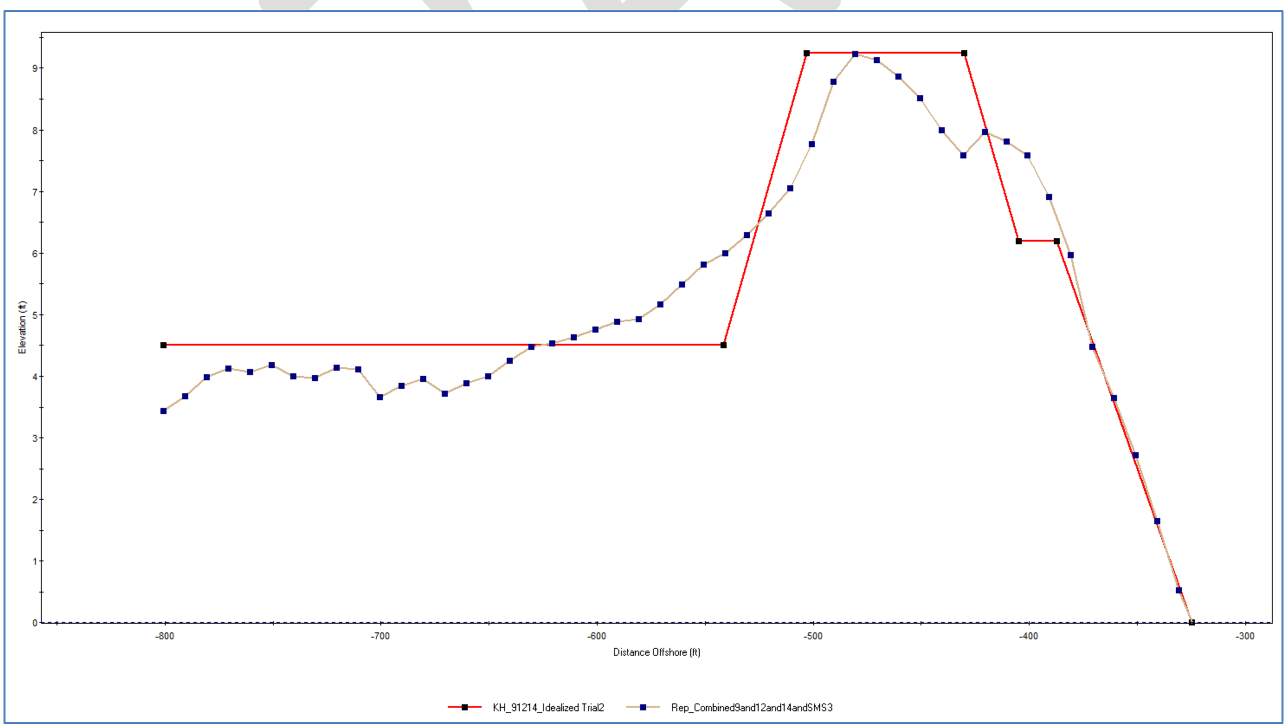


Figure 12 – Enlarged view of Representative and idealized profile for Kitts Hummock (#2)

Subsequent to the analysis of the initial 7 study locations, Lewes, DE was added to the group of study locations, for a total of 8 study locations, and analyzed using similar methods, as described below. Using the same profile data sources cited above, for Lewes, Profiles 30 through 34 (also referred to as SMS Profiles 113 through SMS117, as shown in Figure 13) were analyzed to determine representative profiles for existing conditions. Two representative profiles were deemed sufficient to represent this area and are referred to as Lewes1 and Lewes2. Lewes1 represents the region from Profile 30 through Profile 32 and Lewes2 represents the region from Profiles 33 through 34. The profile analysis to determine a representative profile for these regions is as follows:

Lewes1

Profiles 30 through 32 were idealized by first aligning the profiles along the dune face at elevation 13 ft NAVD88, then averaging the three aligned profiles (Figure 14 and 15). Additional analysis of the offshore portions of the profile resulted in the representative profile shown in Figure 16. An idealization of the representative profile was determined by selecting a uniform upland elevation, dune height, and berm height as well as a representative dune width and slope that closely follows the representative profile (Figures 17-19).

Lewes2

Profiles 33 and 34 were idealized by first aligning the profiles along the dune face at elevation 10 ft NAVD88, then averaging the two profiles (Figure 20). Additional analysis was required to align the offshore berm portion of the profile, which were then combined with the dune aligned portion of the profile, resulting in a representative profile shown in Figure 21. An idealization of the representative profile was determined by selecting a uniform upland elevation, dune height, and berm height as well as a representative dune width and slope that closely follows the representative profile (Figure 22).

Figure 13 – Lewes, DE Profile locations

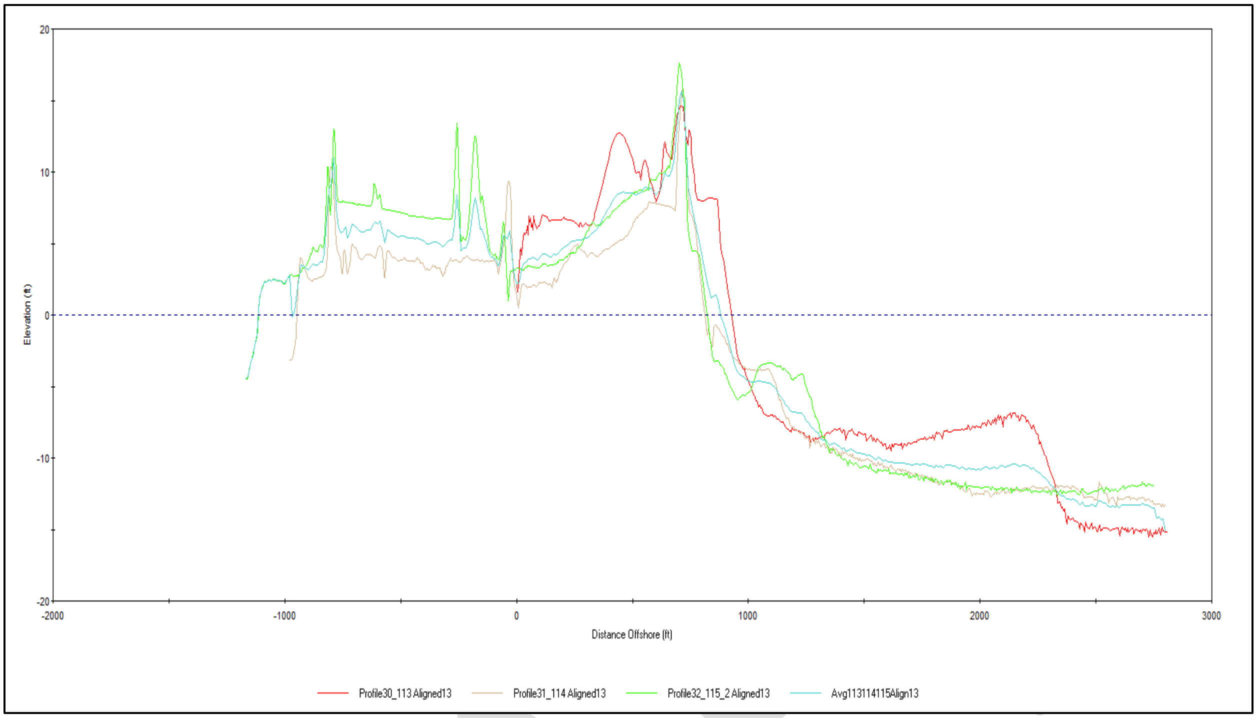


Figure 14 - Profiles 30-32 aligned and averaged along the dune slope at elevation 13 ft NAVD88

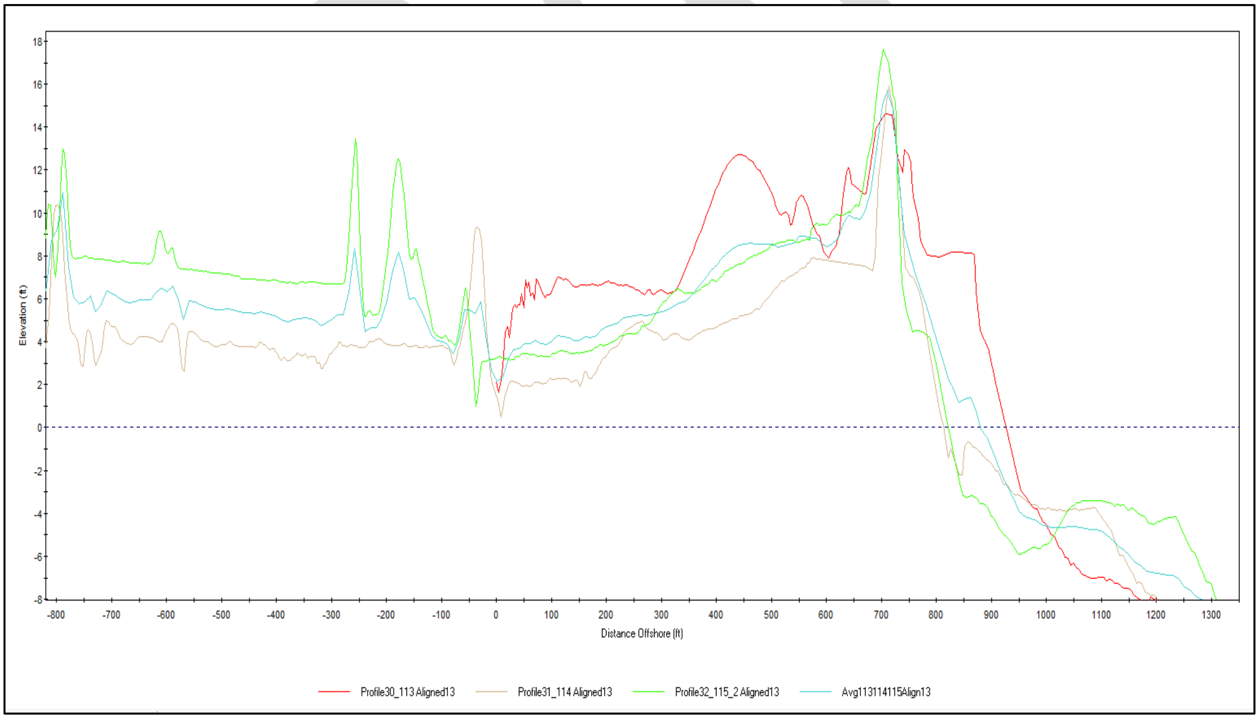


Figure 15 - Zoomed view of Profiles 30-32 aligned and averaged along the dune slope at elevation 13 ft NAVD88

Figure 16 - Zoomed view of Profiles 30-32 aligned and the representative profile

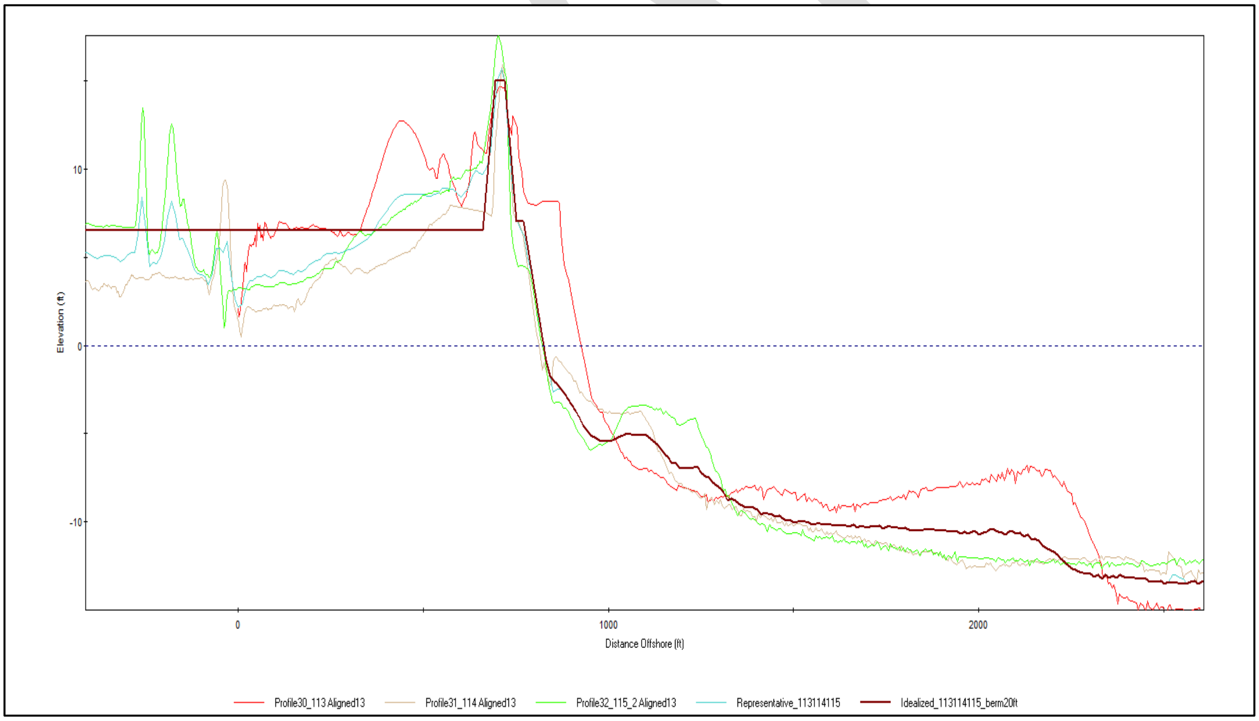


Figure 17 - Profiles 30-32, the representative profile, and the idealized profile representing Profiles 30-32

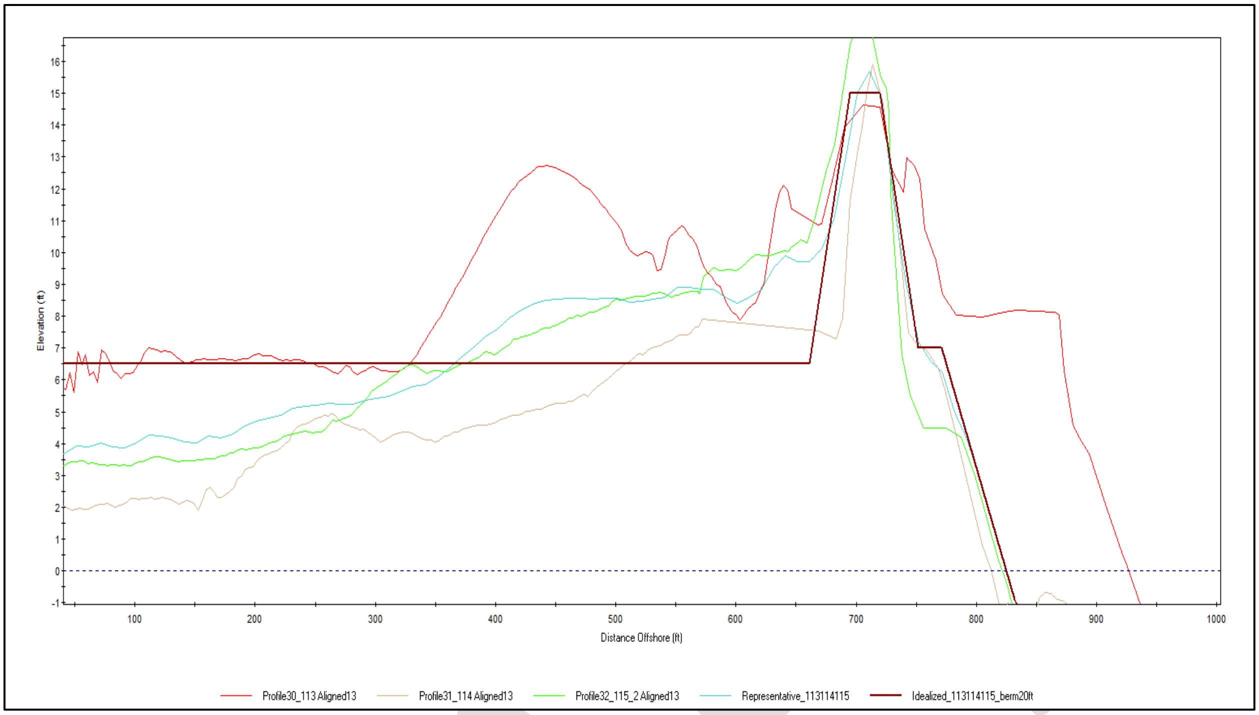


Figure 18 - Zoom view of Profiles 30-32, the representative profile, and the idealized profile

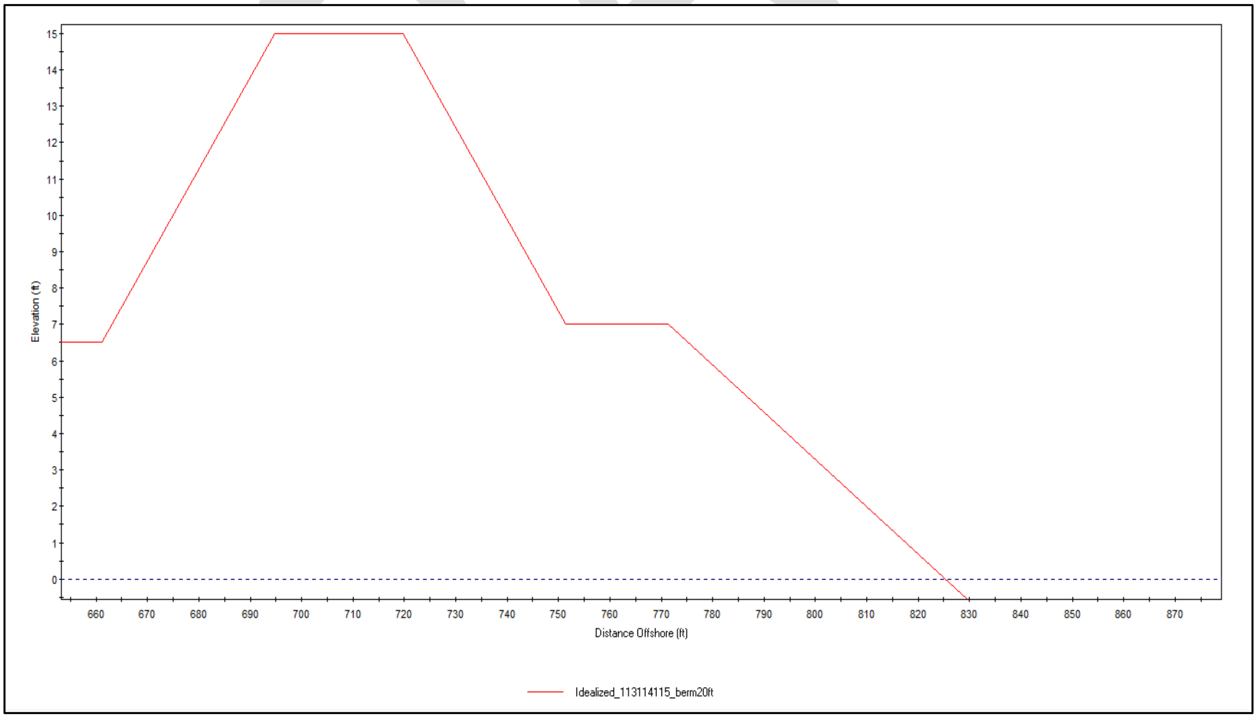


Figure 19 - Zoomed view of the emergent portion of the Idealized Profile representing Profiles 30-32

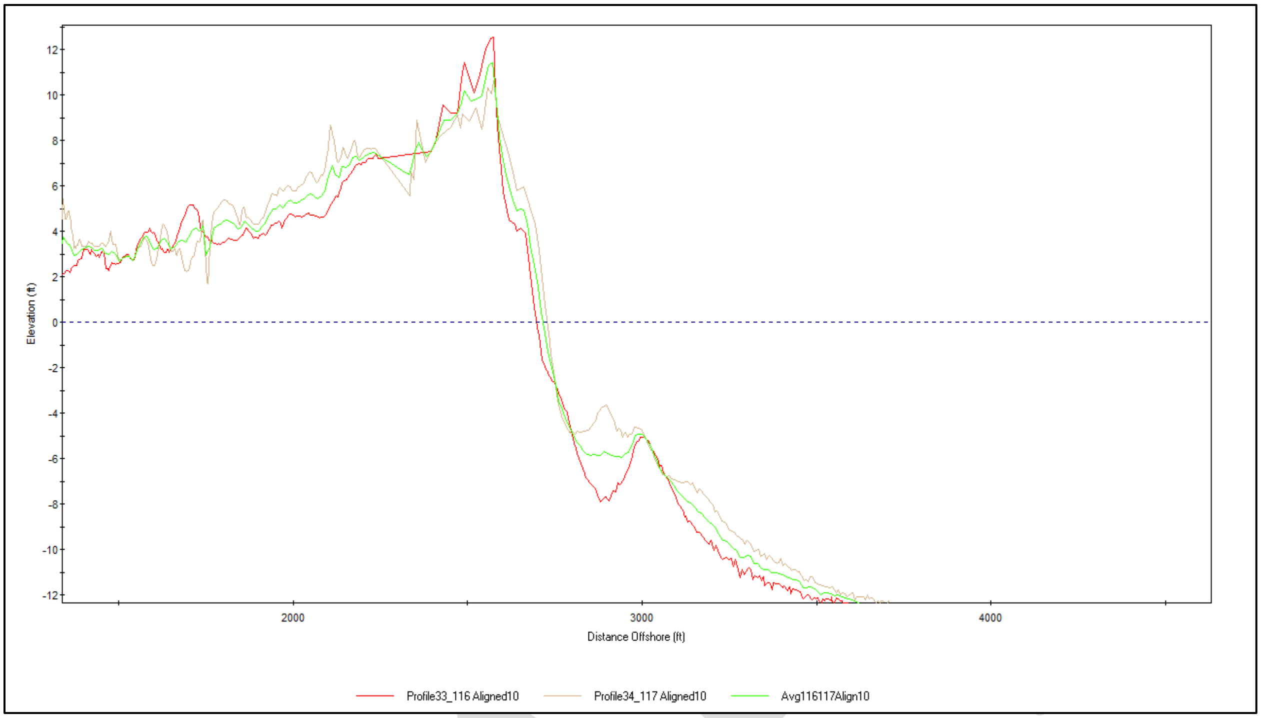


Figure 20 - Profiles 33-34 aligned and averaged along the dune slope at elevation 10 ft NAVD88

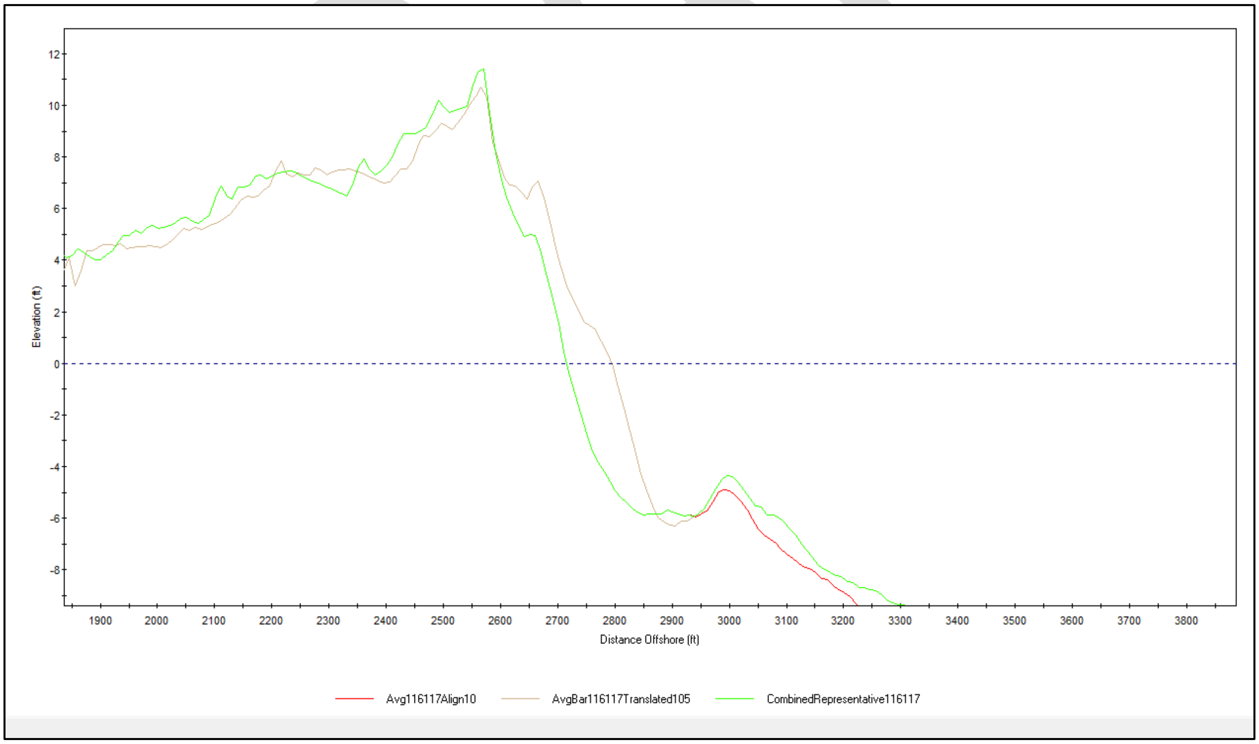


Figure 21 - Representative profile (green line) composed of the Average of Profiles 33 and 34 (for the emergent portion) and the average of Profile 33 and the translated Profile 34 to align the submerged berms (for the submerged portion)

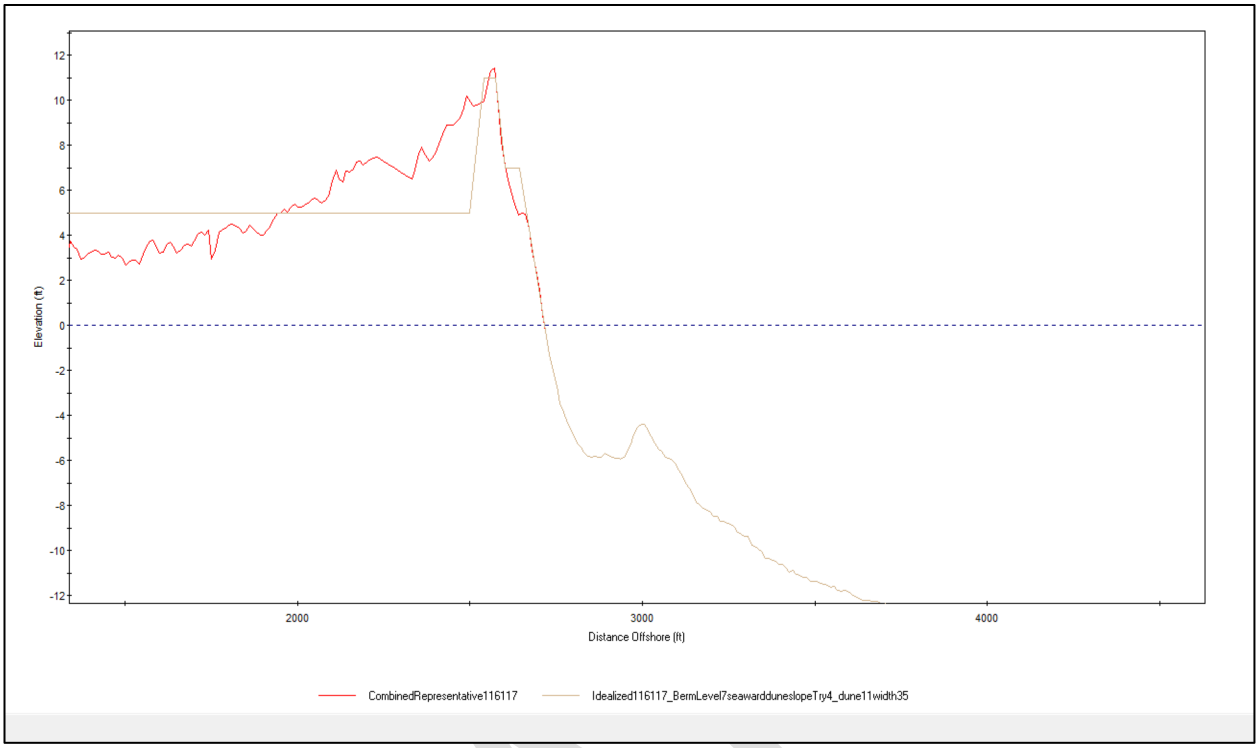


Figure 22 - Representative profile and idealized profile for Profiles 33 and 34

The parameters that define the idealized profiles for all study locations are given in Table 6. The upland width is specified based on a computation of the distance from the estimated location of the shoreward dune toe to the shoreward limit of potential coastal damage. The idealized profiles, and perturbations of the idealized profiles, were used for performing SBEACH model simulations

Table 6 - Idealized Profile Parameters

Site	Foreshore Slope	Berm Elevation (ft, NAVD88)	Berm Width (ft)	Dune Slope	Dune Width (ft)	Dune Elevation (ft, NAVD88)	Upland Elevation (ft, NAVD88)	Upland Width (ft)
Pickering	0.125	5.0	35	0.2000	30	8.0	6.0	300
Kitts Hummock_1	0.099	6.2	0	0.1000	50	8.2	5.0	300
Kitts Hummock_2	0.099	6.2	17.77	0.1230	73	9.25	4.5	500
Kitts Hummock_3	0.099	6.2	13	0.1180	103	8.0	4.5	700
Bowers_1	0.105	4.5	5	0.1725	60	9.0	4.5	500
Bowers_2	0.105	4.5	5	0.2061	47.48	9.6	5.75	500
South Bowers	0.105	4.5	0	0.0831	94.16	7.0	3.6	420
Big Stone	0.118	4.5	10	0.1050	10	8.6	6.5	200
Slaughter_1	0.100	5.5	0	0.1000	60	8.5	4.5	600
Slaughter_2	0.100	5.5	0	0.1000	60	10.0	6.0	500
Prime Hook	0.100	6.0	10	0.1550	60	11.5	5.0	680
Lewes 1	0.1300	7.0	20	0.2525	25	15	6.5	1400
Lewes 2	0.0962	7.0	40	0.1437	35	11	5.0	1700

3.1.2 Proposed Project Profiles

Based on the summary of existing conditions at each site, the range of existing project dimensions along Delaware Bay, and the design purpose to provide storm damage reduction benefits and the assumption that the design will include periodic nourishment, the PDT developed the with-project template. At 7 of the 8 dredged material placement locations, excluding Lewes, the proposed design template features a berm of 25' width at a height of 7' (NAVD 88) with a 1V:10H foreslope extending bayward to depth of closure of -5.0' (NAVD 88). The berm is topped with a dune whose crest width is 25' at a height of 12' (NAVD 88). The dune transitions both bayward to the berm and landward to existing grade on a slope of 1V:5H., as indicated on Figure 23.

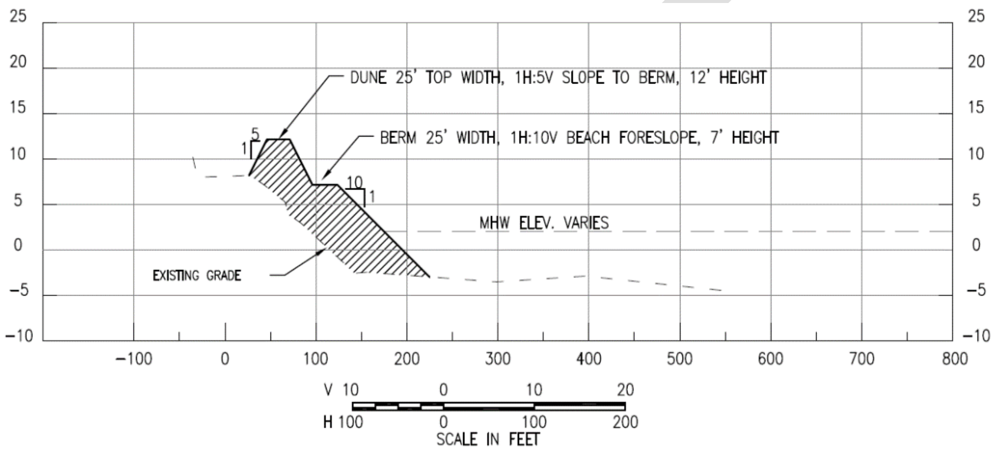


Figure 23 - Dredged Material Placement Locations Design Template (initial 7 sites)

For Lewes Beach, the design template was intended to extend the alongshore footprint of an existing authorized project 10,100' to the southeast. The authorized project consists of a dune and berm extending from Roosevelt Inlet approximately 900 feet southeast with a 500 feet taper. Initial construction included the reconstruction of the adjacent terminal groin for Roosevelt Inlet for the purpose of navigation and the aforementioned beachfill that consisted of a 15' wide berm with an elevation of 8' (NAVD 88) extending bayward at a slope of 1V:10H above MHW, and a dune with a 25' crest width with an elevation of 14' (NAVD 88) for the purpose of coastal storm damage reduction, as shown in Figure 24.

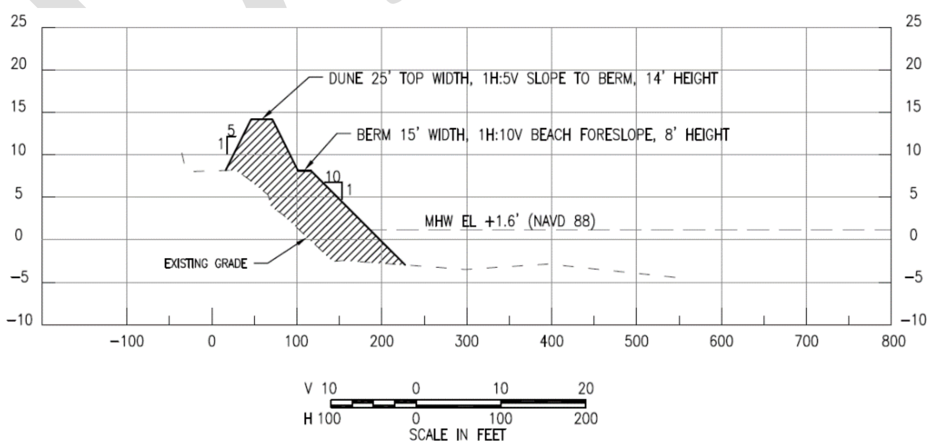


Figure 24 - Dredged Material Placement Locations Design Template (Lewes)

For all locations, a 4-year periodic nourishment cycle is proposed and in line with the operation and maintenance (O&M) dredging to be performed in the proposed dredged material source area.

3.2 Storm Characterization and Storm Response Database Development

3.2.1 Analysis of Stage Frequency Curves for Selection of the Number of Forcing Locations

As previously mentioned, SBEACH is forced with time series of waves and water levels (including tides). Since the DMU sites are in fairly close proximity to one another, an analysis was conducted to determine if one set of driving conditions could be applied to all DMU sites that are to be modeled.

The recently completed North Atlantic Coast Comprehensive Study (NACCS) generated stage frequency curves for many locations in Delaware Bay, including the DMU study sites. These data are stored and accessed through the Coastal Hazards System (CHS) data storage and mining system web tool. Stage frequency information for six points in Delaware Bay offshore of the DMU sites was extracted from the CHS to determine the similarity/difference in response in this region (Figures 25 - 27; Table 7). The locations were selected offshore of the DMU sites in approximately 5-15 m, NAVD88 water depth. From these curves, an 11-13% difference in the 100- and 500-yr water levels is observed. The CHS water level station 7169 is in the shallowest water depth (5 m) and co-located with NOS Station 8555889 (Brandywine Shoal Light). CHS water level station 11015 (water depth of 7.1 m) is the northernmost point in the analysis and produces the highest curve of the six locations analyzed. CHS water level station 7168 (water depth of 9.0 m) is centrally located and produces the mid-level curve of the six locations analyzed and is therefore considered representative of the wave and surge response in this region. CHS Station 7168 is selected for extracting water level and wave forcing conditions to the SBEACH model.

Figure 25 - ADCIRC water level stations from the NACCS study (accessed through the CHS)

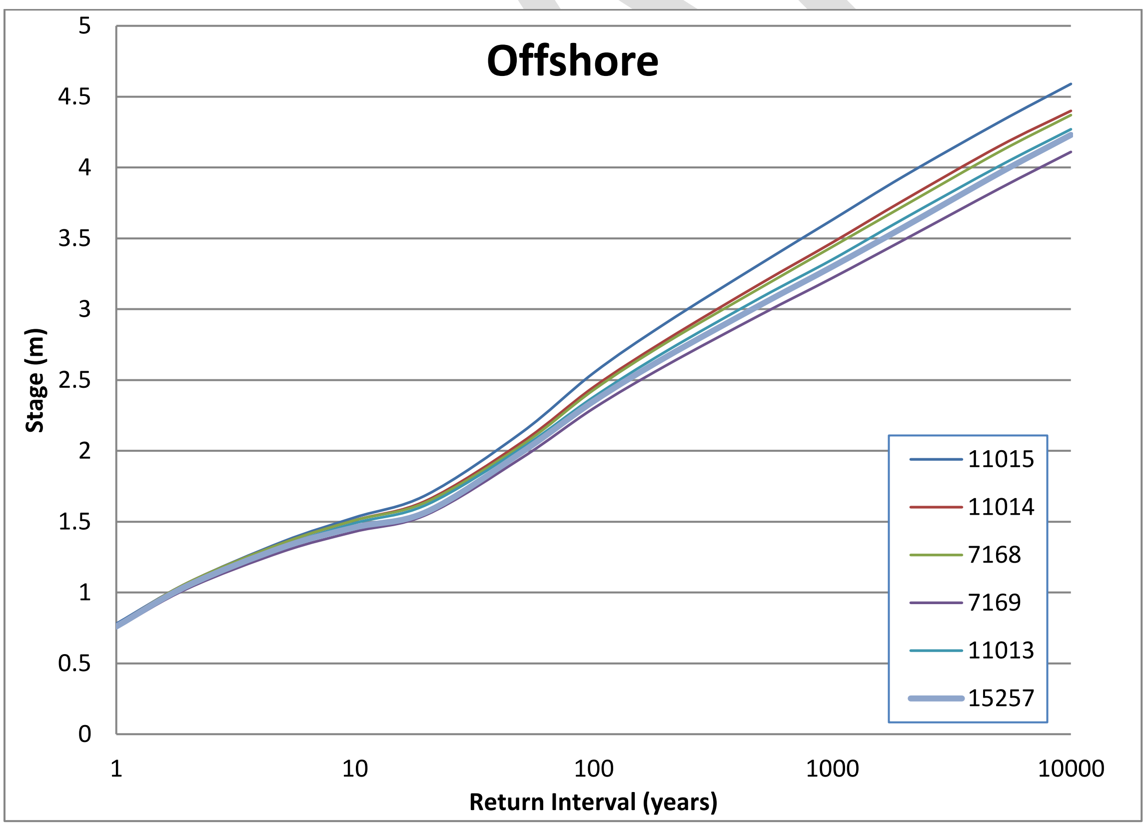


Figure 26 - Stage frequency curves at NACCS stations in Delaware Bay near DMU sites

Table 7 - CHS Water level (m) at select return periods for Stations in Delaware Bay (Tropical Storms Only)

Station	11015	11014	7168	11013	7169	15257
Return						
1	0.78	0.77	0.77	0.77	0.75	0.76
2	1.07	1.07	1.07	1.06	1.03	1.05
5	1.36	1.35	1.35	1.33	1.29	1.32
10	1.53	1.51	1.51	1.49	1.43	1.46
20	1.69	1.65	1.64	1.62	1.55	1.57
50	2.13	2.06	2.04	2.02	1.95	1.99
100	2.55	2.45	2.43	2.38	2.3	2.35
200	2.9	2.78	2.76	2.7	2.6	2.66
500	3.32	3.18	3.15	3.08	2.96	3.03
1000	3.63	3.47	3.44	3.35	3.22	3.3
2000	3.94	3.77	3.73	3.64	3.49	3.58
5000	4.32	4.15	4.11	4.01	3.85	3.96
10000	4.59	4.4	4.37	4.27	4.11	4.23

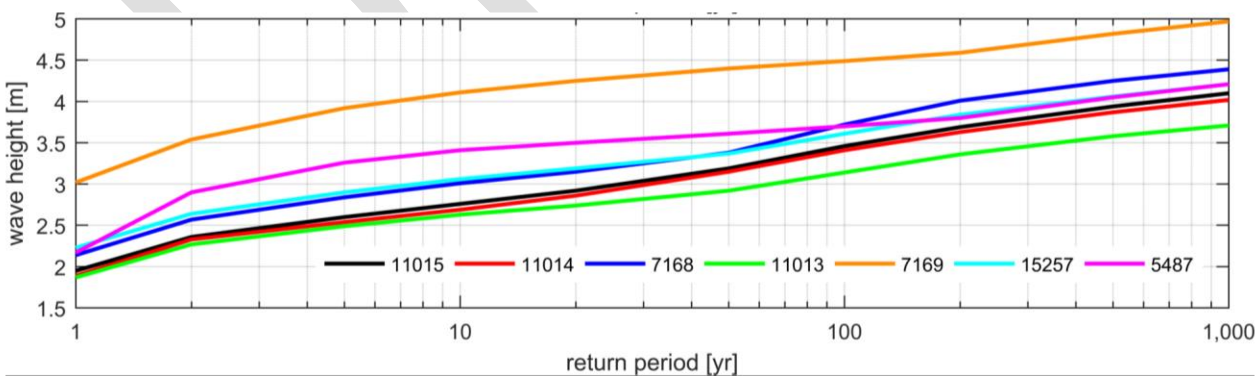


Figure 27 – Comparison of wave height at NACCS stations in Delaware Bay near DMU sites

3.2.2 Time Series Analysis for Tidal Amplitudes

Future storms can occur at any time during the spring-neap tidal cycle, therefore, the inclusion of the range of tidal amplitudes and the timing of occurrence of the tide (tide phase) must be accounted for and combined with the storm surge hydrograph. This was accomplished using a statistically defensible simplified (cosine) tidal signal representing the expected tidal ranges (high, mean, and low). The cosine curve will be combined with the surge hydrograph at four phases of the tide such that peak surge occurred at high tide, mean tide falling, low tide, and mean tide rising. As a first step, the representative high, mean, and low tide amplitudes for the study area (at CHS Station 7168) were determined as follows:

As part of the NACCS study, the validation of the storm surge model ADCIRC included a tidal harmonic analysis (Cialone et al. 2015). Constituent information at CHS Station 7168 (Tidal Harmonic Mesh Node 1810900) was used to reconstitute a 19-yr time series (at a 10-min time interval) with the ultimate goal of estimating high, mean, and low tidal amplitudes to be combined with the surge hydrographs at the SBEACH model forcing location (CHS Station 7168). The 19-year tidal time series was partitioned into 5188 water level bins, each with a water level increment of 0.0005-m. Probabilities of each water level were computed based on the number of values in each bin. The cumulative distribution function (CDF) at this location is given in Figure 28. The extreme 12.5% water level values in the CDF represent the high tide range, therefore the extreme highest 6.25% water levels and the extreme lowest 6.25% water levels, weighted by their percent occurrence were used to compute the high tide amplitude. From this analysis a representative high tide amplitude of 0.91 m was computed. The next most extreme 25% (representing the CDF curve from 0.0625 to 0.1875 and from 0.8125 to 0.9375) were weighted by their percent occurrence to compute the representative mean tide amplitude. From this analysis a mean tide amplitude of 0.66 m was computed. Lastly, the representative low tide range was computed based on the next 12.5% water levels (0.1875 to 0.25 and 0.75 to 0.8125) weighted by their percent occurrence. From this analysis a low tide amplitude of 0.52 m was computed.

A cosine tidal signal representing each of the three expected tidal ranges (high, mean, and low) for the study location was computed and will be combined with the selected surge hydrographs at four phases of the tide such that the peak surge occurred at high tide, mean tide falling, low tide, and mean tide rising. This analysis will result in 12 total water level (surge-tide) time series that represent a single storm occurring at four representative tidal phases and three representative tidal amplitudes. These 12 total water level time series will be used as a forcing condition to SBEACH.

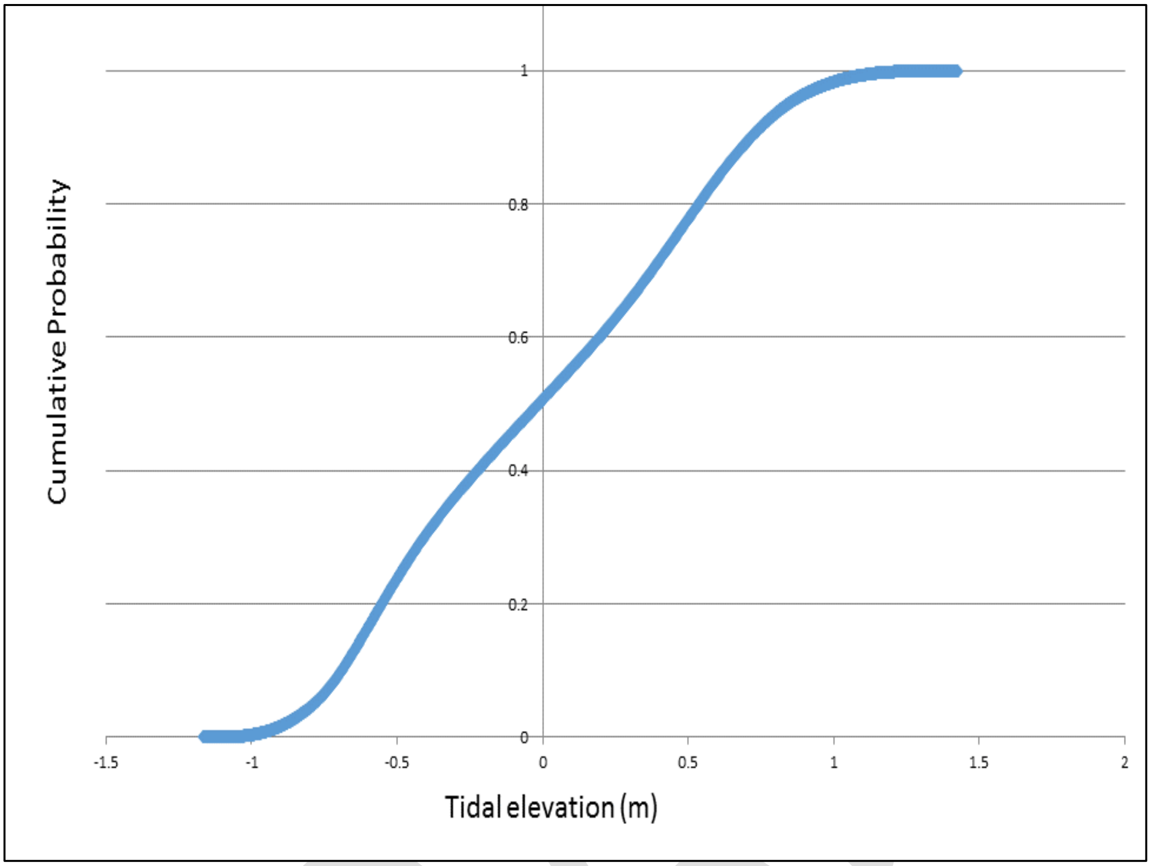


Figure 28 - Tide elevation (m) vs cumulative probability.

3.2.3 Selection of Storms at Forcing Location

3.2.3.1 Minimum Water Level Threshold

The selection of storm hydrographs to use as part of the forcing conditions for the SBEACH model simulations required an examination of all potential NACCS storms and then the selection of storms that best represents the water level responses at the Coastal Hazard System (CHS) Station 7168. The first criterion in selecting storms was that a given storm peak water level at Station 7168, including the low tide amplitude of 0.52 m, exceeds the NACCS 1-year return period of 1.5 m for Tropical Base+Tide conditions. Employing this criterion reduced the number of potential tropical storms from 1050 to 238. The same analysis was performed for the extratropical storm events resulted in 89 extratropical storms exceeding the minimum threshold (1.18 m) Water levels for various return periods are shown in Table 8.

Table 8 - Tropical and Extratropical CHS Water level (m) at select return periods for Station 7168 in Delaware Bay

Station	Tropical		Extratropical	
Return	Base Only	Base + Tide	Base Only	Base + Tide
1	0.77	1.5	0.66	1.18
2	1.07	1.69	0.97	1.41
5	1.35	1.92	1.25	1.64
10	1.51	2.08	1.40	1.78
20	1.64	2.25	1.50	1.90
50	2.04	2.57	1.60	2.01
100	2.43	2.92	1.64	2.09
200	2.76	3.28	1.68	2.14
500	3.15	3.71	1.71	2.20
1000	3.44	4	1.72	2.24
2000	3.73	4.29	1.74	2.27
5000	4.11	4.67	1.75	2.30
10000	4.37	4.94	1.75	2.31

3.2.3.2 Identification of regional synthetic tropical storms of significance

The 1050 NACCS synthetic tropical storms were designed along the 130 tracks shown in Figure 29. As a second criterion for tropical storm selection, storms passing within a 200 km radius of the DMU project area were identified as "regional synthetic tropical storms of significance." The 200-km zone is considered the area of influence for each NACCS synthetic storm event (Nadal-Caraballo et al. 2015) and the storm climatology at the project site is considered sufficiently characterized by the regional synthetic storms of significance storms. Tropical storms not passing within a 200 km radius of the DMU project area were removed from further consideration. Using this criteria, 46 tracks representing 430 storms were identified for simulation in this study. The regional synthetic storms of significance were cross-referenced with the storms selected in section 3.2.3.1, resulting in the removal of 9 tropical storms, leaving a population of 229 storms to be used in the next step of the analysis.

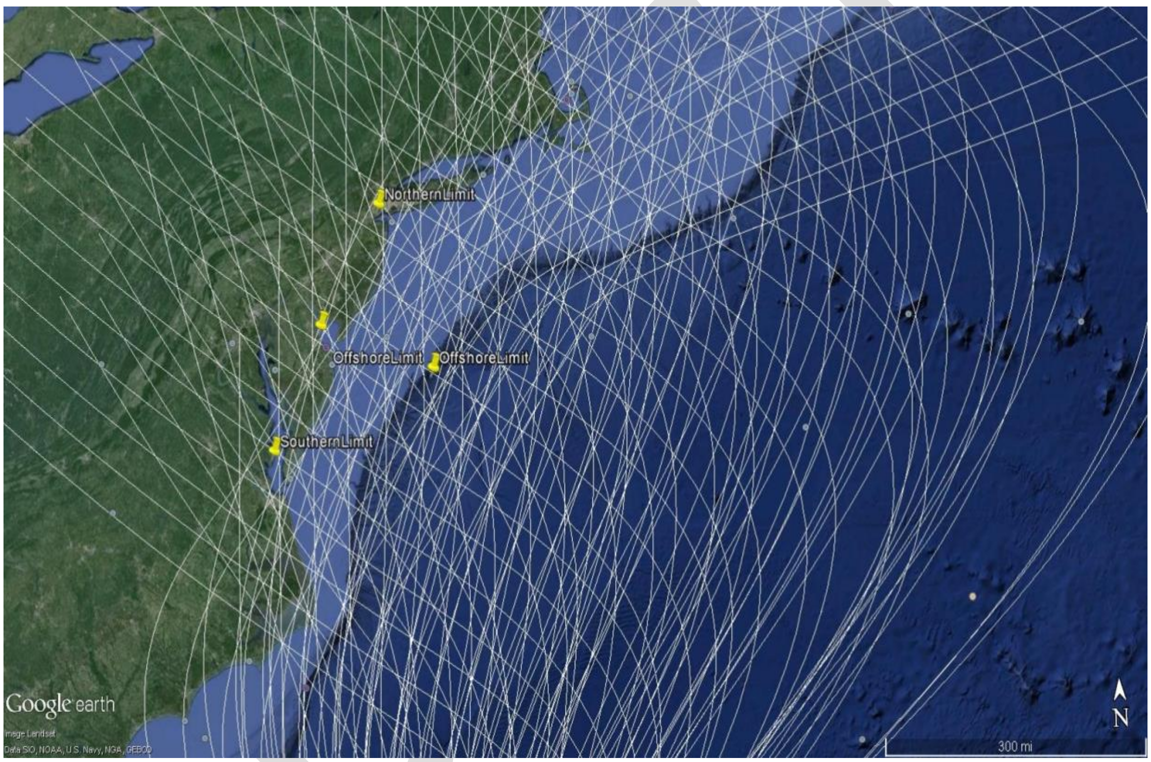


Figure 29 - Tropical storm tracks from the NACCS Study

3.2.3.3 Binning of Storms

To further reduce the number of unique storms in the storm suite, the storm surge hydrograph time series, within each frequency range, were examined and representative storms were selected to characterize storms within that bin. For the 318 remaining storms, the 229 storms characterizing the tropical storm climatology were binned into 10 groups based on peak water level including the mean tide amplitude of 0.66 m to represent Base+Tide return periods of 1, 2, 5, 10, 20, 50, 100, 200, 500, and 1,000-yr or less frequent. Storm hydrographs in each of the 10 groups were then aligned by the storm peaks and plotted together to see the similarity or differences in the time history of water level to achieve a given peak water level. If all storms in a given group have water level time histories that looked similar (hydrographs of similar shape), then one storm was selected to represent that group. If the time histories had markedly different hydrographs, then several storms were selected to represent that portion of the stage-frequency curve.

As an example, all storms with peak surge+mean tide that fall into the 200-year Base+Tide return period bin were grouped or binned together. The 200-year bin is defined from the mid-point between the 100- and 200-yr return period values ((3.1 m) to the mid-point of the 200- and 500-year return periods (3.50 m). The tropical storms that met these criteria were selected and base hydrographs are given in Figure 30. Note that the plots in Figure 30 do not include the mean tide, therefore the peaks are in the 2.44 to 2.835 m range. These storms were analyzed to determine a representative storm or storms for that bin and storms 78 and 169 were selected for this tropical storm return period. The same procedure was done for the 89 storms characterizing the extratropical climatology. The number of storms occurring within each cluster and the selected representative storm ID numbers are documented in Table 9. The 89 extratropical storm events were reduced to 11 events and the 229 tropical storm events were reduced to 19 events. Lower return period storm events are assigned a greater relative probability than the high return period storm events to ensure that the Beach-fx Monte Carlo simulations generate a realistic distribution of storm events.

It is important to note that total water level is the most dominant parameter driving beach profile response, however waves and duration of event were also considered in conjunction with total water level, when determining representative storm selection. For example, one frequency response level can be achieved by a peaked or a broad duration storm. Several storms over a range of conditions were simulated to capture this, and ultimately determine the final bin thresholds.

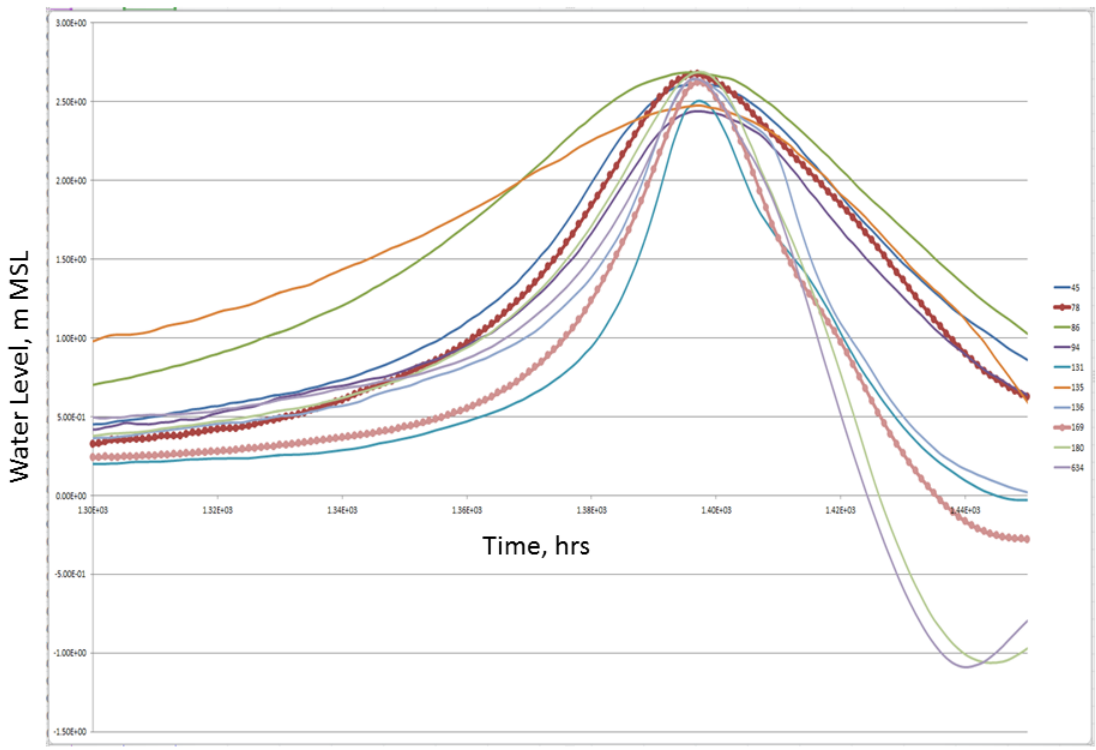


Figure 30 - All tropical storm with peak water levels within the 200-yr return period bin

Table 9 - Bin thresholds and selected storms								
Storm Return Period (Yr)	Peak Water Level Tropical storms Base + tide (m, MSL)	Peak Water Level Tropical Storm Mid Points (m, MSL)	No. of storms in each cluster	Selected Tropical Storm ID	Peak Water Level ET storms, Base + tide (m, MSL)	Peak Water Level ET Storms Mid Points (m, MSL)	No. of storms in each cluster	Selected ET Storm ID
1	1.50	<1.500	0	---	1.18	<1.18	31	68
2	1.69	1.595	48	87	1.41	1.30	20	24, 53
5	1.92	1.805	39	313, 541	1.64	1.53	18	68, 98
10	2.08	2.000	27	213, 299, 639	1.78	1.71	12	35, 76
20	2.25	2.165	35	81, 222, 132	1.90	1.84	2	51
50	2.57	2.410	36	999, 645, 171	2.01	1.96	2	22
100	2.92	2.745	22	997, 207	2.09	2.05	0	
200	3.28	3.100	10	78, 169	2.14	2.11	3	17
500	3.71	3.495	7	167	2.20	2.17	0	
1000	4.00	3.855	4	92	2.24	2.22	0	
2000	4.29	4.145	0	---	2.27	2.25	1	7
5000	4.67	4.480	0	---	2.30	2.28	---	
10000	4.94	4.805	1	43	2.31	2.31	---	

3.2.4 Aligning Surge and Wave Times

Once storms have been selected based on the surge peak hydrographs, the associated wave height and period were extracted from the NACCS database because SBEACH requires a time series of waves as well as water levels to drive to the model. In addition, the wave model output from STWAVE is less frequent and for a shorter period of time than the surge model output from ADCIRC. STWAVE output is provided at either 15-, 30- or 60-min time steps, depending on the forward speed of the modeled storm. All ADCIRC outputs are provided at 10 minute intervals. Therefore, the surge model output from ADCIRC was extracted and aligned with the time period of the wave model output from STWAVE so that the SBEACH model will have full forcing conditions for the entire simulation. Both the wave and surge NACCS model results were also converted from meters to feet as required by SBEACH. The water level datum conversion from MSL to NAVD88 took place during the step the combines surge and tide. For example, Figures 31 through 33 show the full surge hydrograph, the 48-hr portion of the surge hydrograph corresponding to the 48-hr wave time period, and the wave time series for Storm 78, respectively. Figures 45-63 show the full surge hydrographs for all 19 tropical storm events.

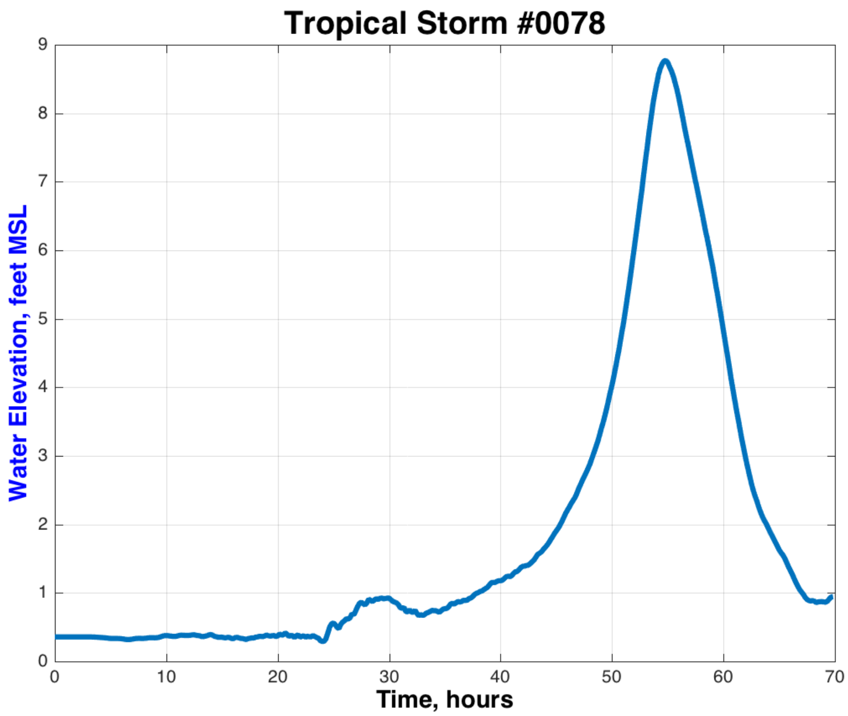


Figure 31 - Surge hydrograph for a selected 200-yr event (Storm 78)

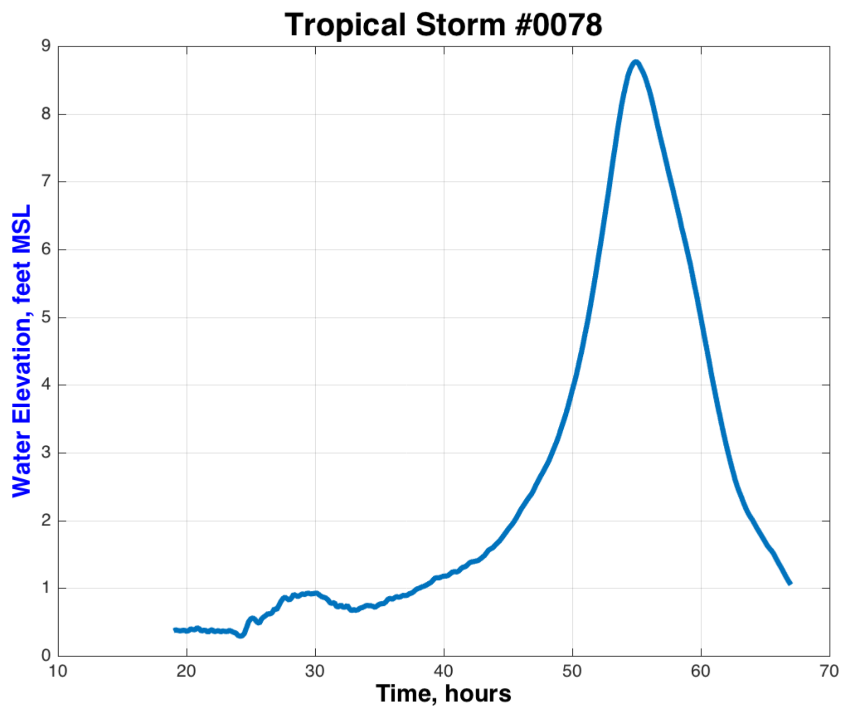


Figure 32 - Portion of the surge hydrograph for a selected 200-yr event (Storm 78) corresponding to the period of wave forcing

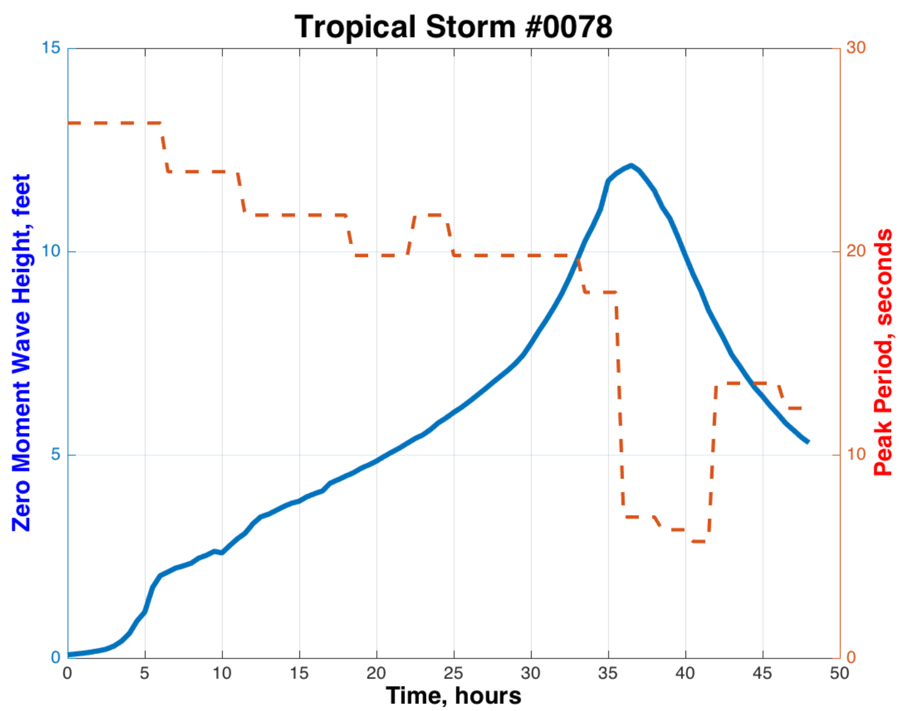


Figure 33 - Wave height and period time series for a selected 200-yr event (Storm 78).

(Note: T=19 in Figure 32 is equal to T=0 in Figure 33)

In total, 19 tropical and 11 extratropical storms were selected for simulation (30 storms) and were combined with the tides for 4 tidal phases and 3 tide ranges. This resulted in 360 unique storm events (30 x 4 x 3) to be simulated.

3.2.5 SBEACH Compilation for Beach-fx

With the range of storm events defined, SBEACH configuration input files were then generated, including perturbations of each of the 11 profiles by incrementally changing the dune width, dune elevation, and berm width. The combination of profile configurations and storm forcing conditions resulted in a total of 20,000 to 100,000 individual SBEACH runs for each profile. For example, the idealized profile for Lewes1 consisted of 4 berm widths (0 to 30 ft at a10-ft increment), 6 dune widths (0 to 25 at a 5-ft increment), and 9 dune elevations (7-15 ft at a 1-ft increment) for a total of 216 profiles to be simulated for Lewes1. SBEACH parameter variables for all study locations are shown in Table 10. For all SBEACH runs, default values were utilized for all parameters, with the exception of the overwash parameter, which was modified based on past applications and experience. Calibration of SBEACH modeling was not possible due to lack of data, however representative shoreline responses from SBEACH for both with and without project conditions were thoroughly reviewed by ERDC, and deemed reasonable. Results from these SBEACH runs for all study locations populate the storm response database utilized as input to the subsequent Beach-fx model runs.

Table 10 - SBEACH Perturbation Ranges

Site	Fixed SBEACH Parameters					Variable SBEACH Parameters			# Profile Pertubations	# Storms	# Simulations
	Submerged Profile	Upland Elevation (ft, NAVD88)	Berm Elevation (ft, NAVD88)	Dune Slope	Foreshore Slope	Dune Elevations (ft, NAVD88)	Range of Dune Widths (ft) (5 ft increments)	Berm Widths (ft)			
Pickering - Existing	Pickering 1	6	5	0.2	0.125	6, 7, 8	0-30	0,10,20,30,40	105	360	37,800
Pickering - Design	Pickering 1	6	5	0.2	0.125	9, 10, 11, 12	0-30	0,10,20,30,40	140	360	50,400
KH1 - Existing	KH1	5	6	0.1	0.099	6, 7, 8	0-50	0,10,20,30	132	360	47,520
KH1 - Design	KH1	5	6	0.2	0.099	8, 9, 10, 11, 12	0-50	0,10,20,30	220	360	79,200
KH2 - Existing	KH2	4.5	6.2	0.123	0.099	6.5,7.5,8.5,9.5	0-75	0,10,20,30	256	360	92,160
KH2 - Design	KH2	4.5	6.2	0.2	0.099	10.5, 11.5, 12.5	0-50	0,10,20,30	132	360	47,520
KH3 - Existing	KH3	4.5	6.2	0.118	0.099	6.5, 7.5, 8.5	0-105	0,10,20,30	264	360	95,040
KH3 - Design	KH3	4.5	6.2	0.2	0.099	9.5, 10.5, 11.5, 12.5	0-50	0,10,20,30	176	360	63,360
Bowers1 Existing	Bowers1	4.5	4.5	0.173	0.105	5,6,7,8,9	0-60	0,10,20,30	260	360	93,600
Bowers1 Design	Bowers1	4.5	4.5	0.2	0.105	10,11,12	0-60	0,10,20,30	156	360	56,160
Bowers2 Existing	Bowers2	5.75	4.5	0.206	0.105	6,7,8,9,10	0-50	0,10,20,30	220	360	79,200
Bowers2 Design	Bowers2	5.75	4.5	0.2	0.105	11,12	0-50	0,10,20,30	88	360	31,680
South Bowers Existing	SouthBowers	3.6	4.5	0.083	0.105	5,6,7	0-95	0,10,20,30	240	360	86,400
South Bowers Design	SouthBowers	3.6	4.5	0.2	0.105	8,9,10,11,12	0-50	0,10,20,30	220	360	79,200
Big Stone Existing	BigStone	6.5	4.5	0.105	0.118	7,8,9	0-25	0,10,20,30	72	360	25,920
Big Stone Design	BigStone	6.5	4.5	0.2	0.118	10,11,12	0-25	0,10,20,30	72	360	25,920
Slaughter1 Existing	Slaughter1	4.5	5.5	0.1	0.1	6,7,8,9	0-40	0,10,20,30	208	360	74,880
Slaughter1 Design	Slaughter1	4.5	5.5	0.2	0.1	10,11,12	0-40	0,10,20,30	156	360	56,160
Slaughter2 Existing	Slaughter2	6	5.5	0.1	0.1	6,7,8,9,10	0-40	0,10,20,30	260	360	93,600
Slaughter2 Design	Slaughter2	6	5.5	0.2	0.1	11,12	0-40	0,10,20,30	104	360	37,440
Prime Hook E&D	PrimeHook	5	6	0.155	0.1	6,7,8,9,10,11,12	0-60	0,10,20,30	364	360	131,040
Lewes1 E&D	Lewes1	6.5	7	0.253	0.13	7,8,9,10,11,12,13,14,15	0-25	0,10,20,30	216	360	77,760
Lewes2 Existing	Lewes2	5	7	0.144	0.0962	7,8,9,10,11	0-35	0,10,20,30,40	200	360	72,000
Lewes2 Design	Lewes2	5	7	0.2	0.0962	12, 13,14	0-25	0,10,20,30	72	360	25,920

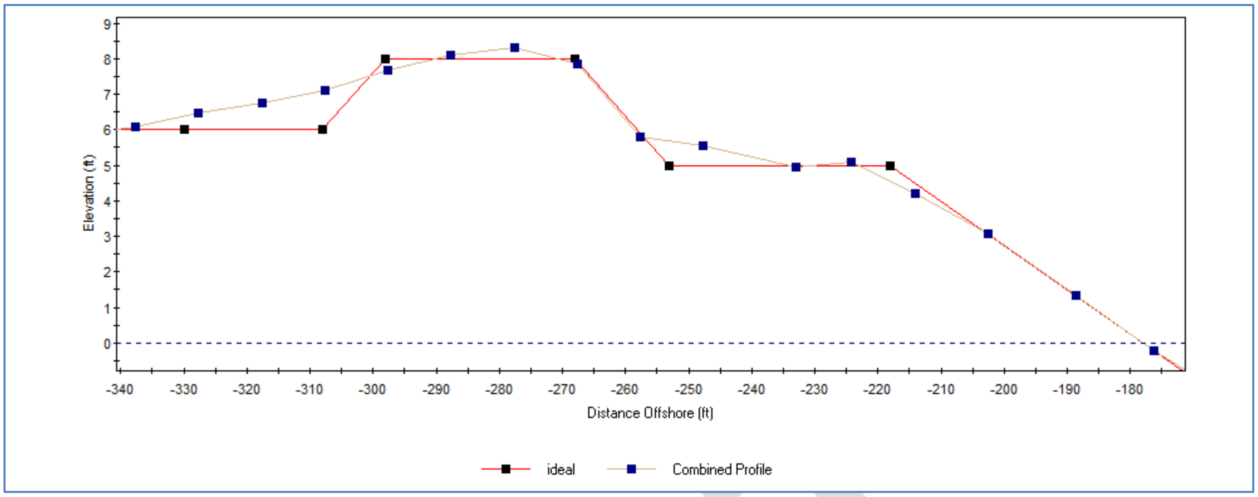


Figure 34 - Idealized Profile for Pickering Beach

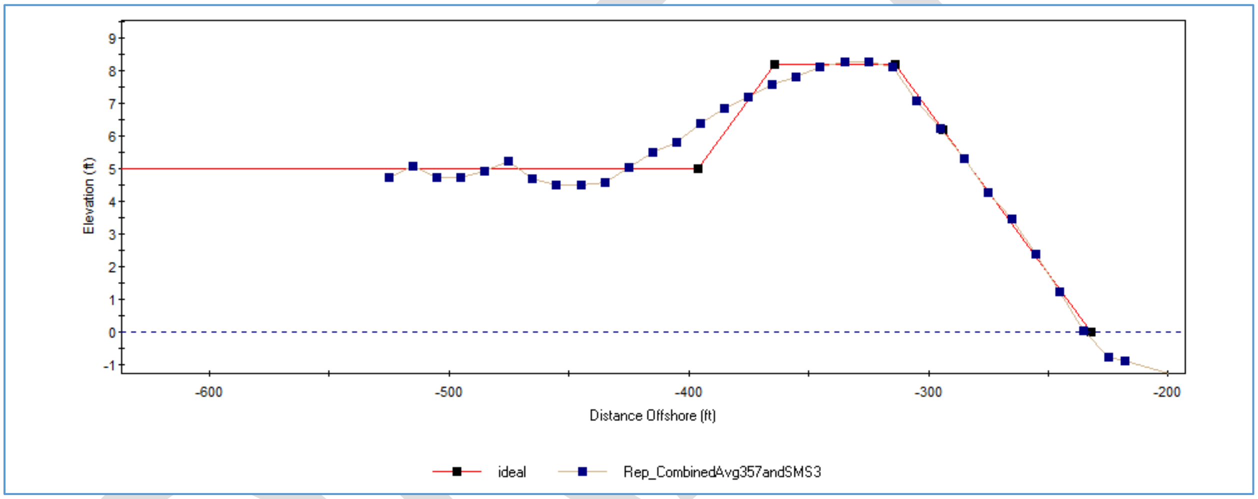


Figure 35 - Idealized Profile for Kitts Hummock #1

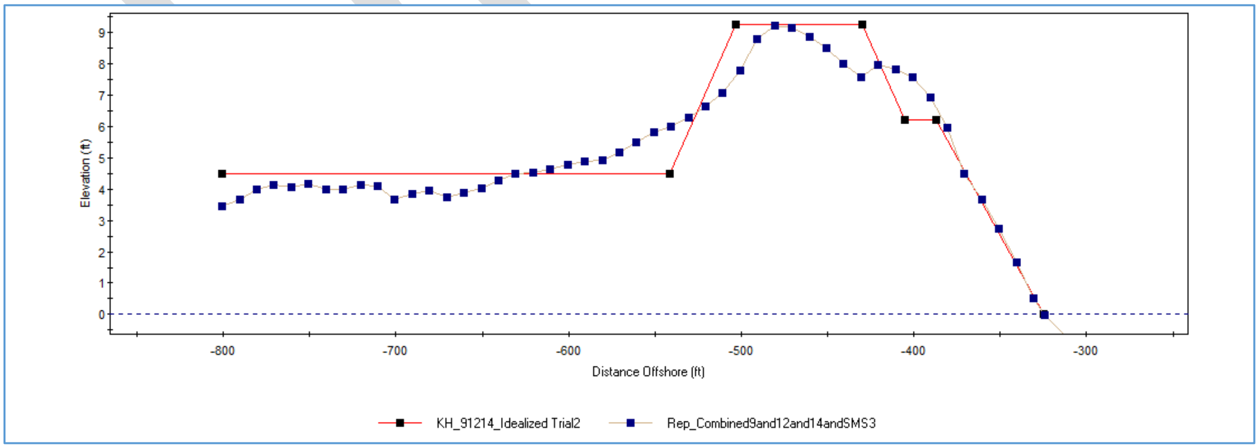


Figure 36 - Idealized Profile for Kitts Hummock #2

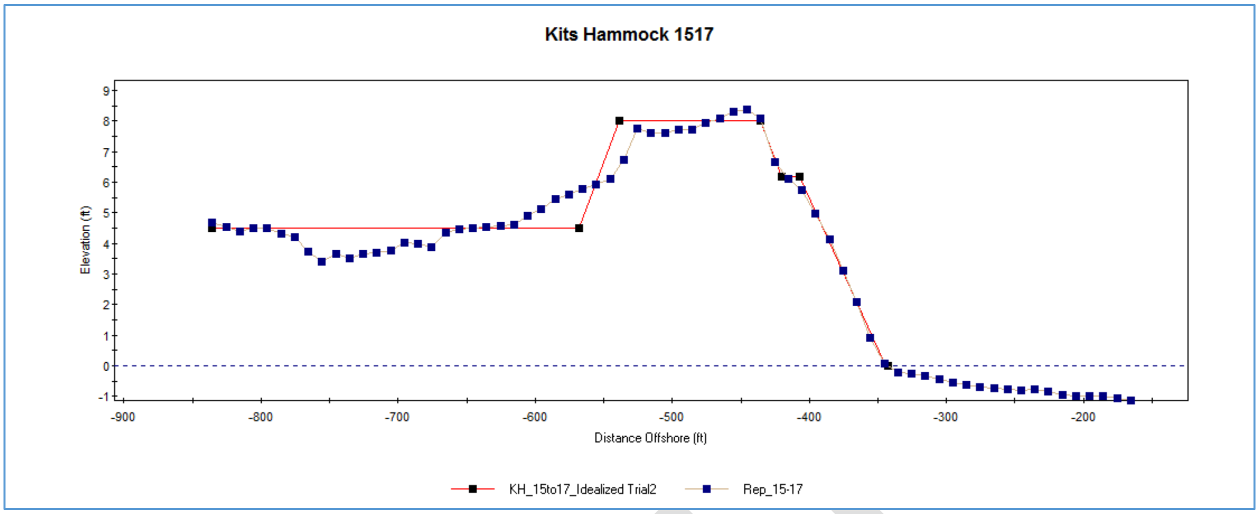


Figure 37 - Idealized Profile for Kitts Hummock #3

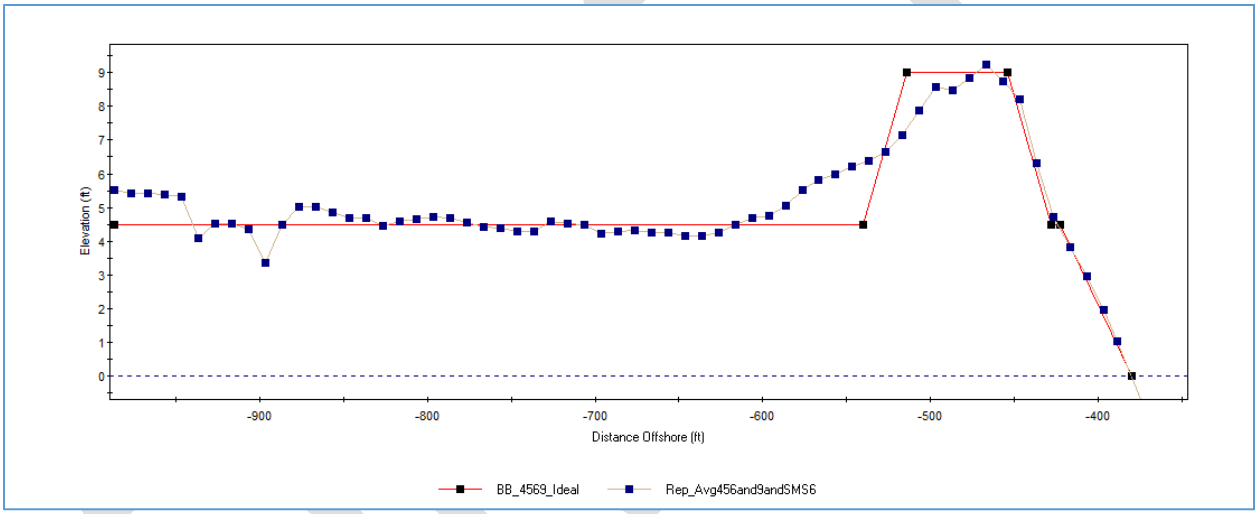


Figure 38 - Idealized Profile for Bowers Beach #1

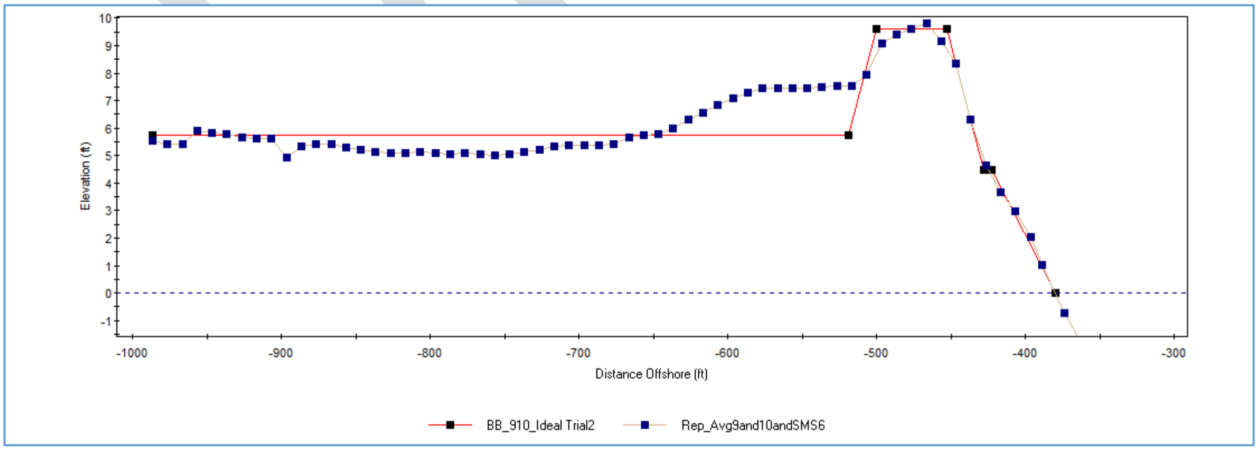


Figure 39 - Idealized Profile for Bowers Beach #2

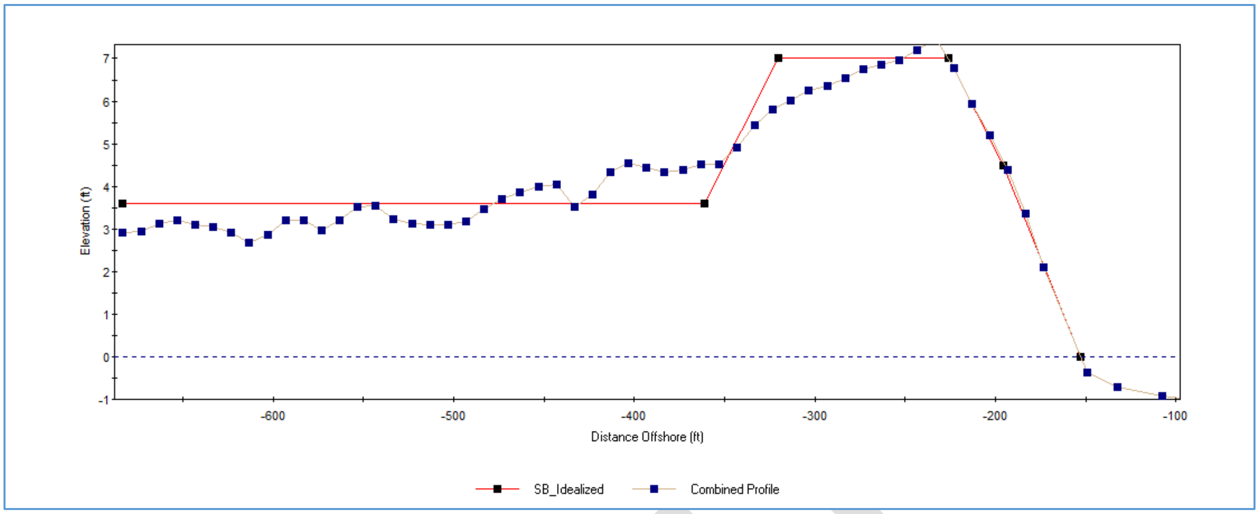


Figure 40 - Idealized Profile for South Bowers Beach

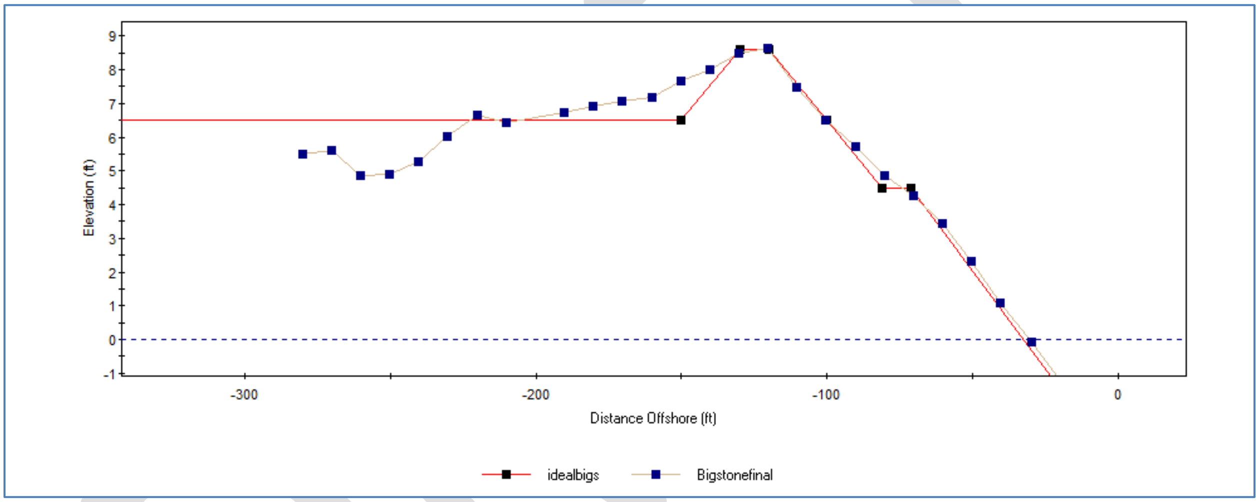


Figure 41 - Idealized Profile for Big Stone

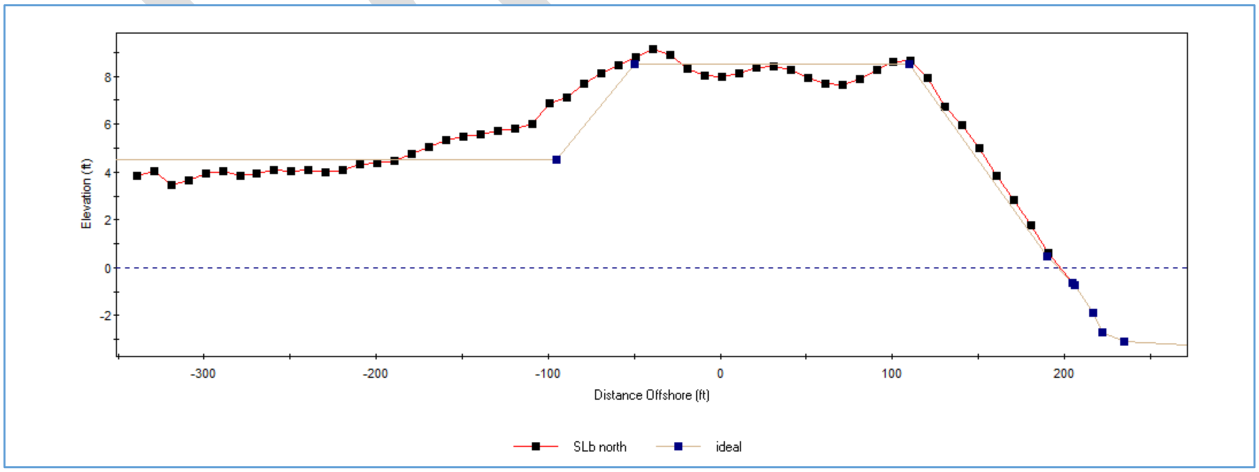


Figure 42 - Idealized Profile for Slaughter Beach #1

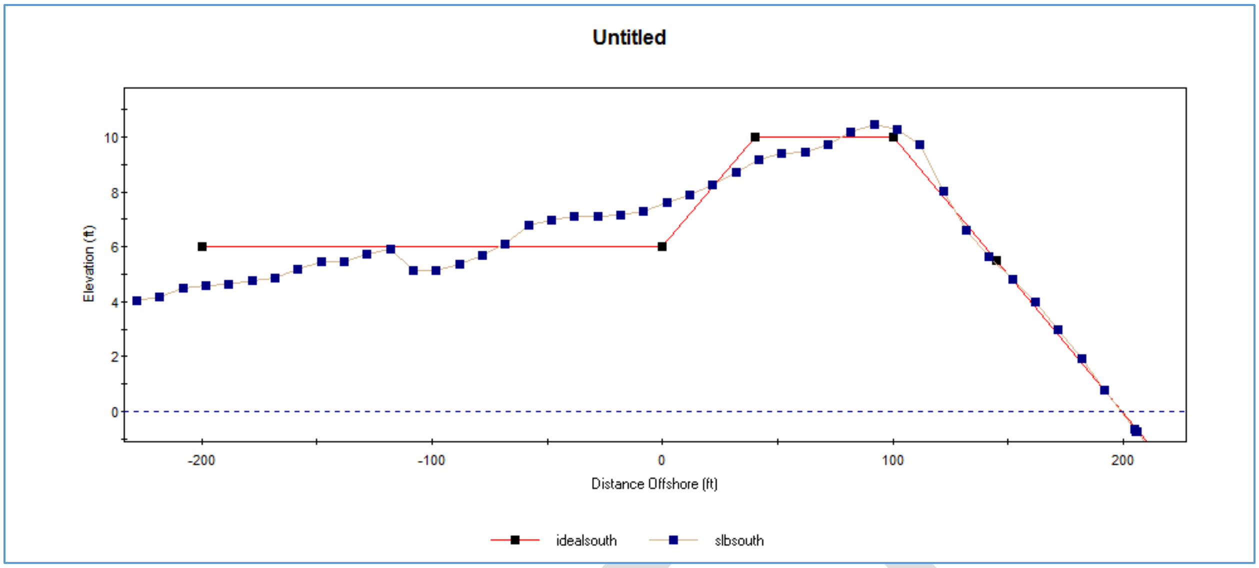


Figure 43 - Idealized Profile for Slaughter Beach #2

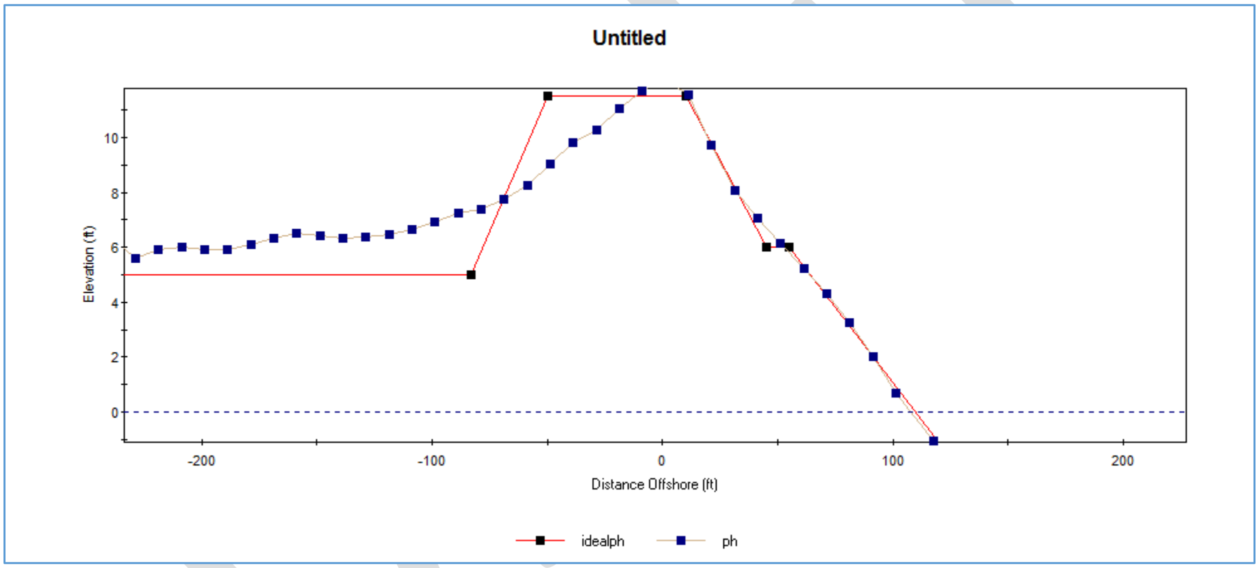
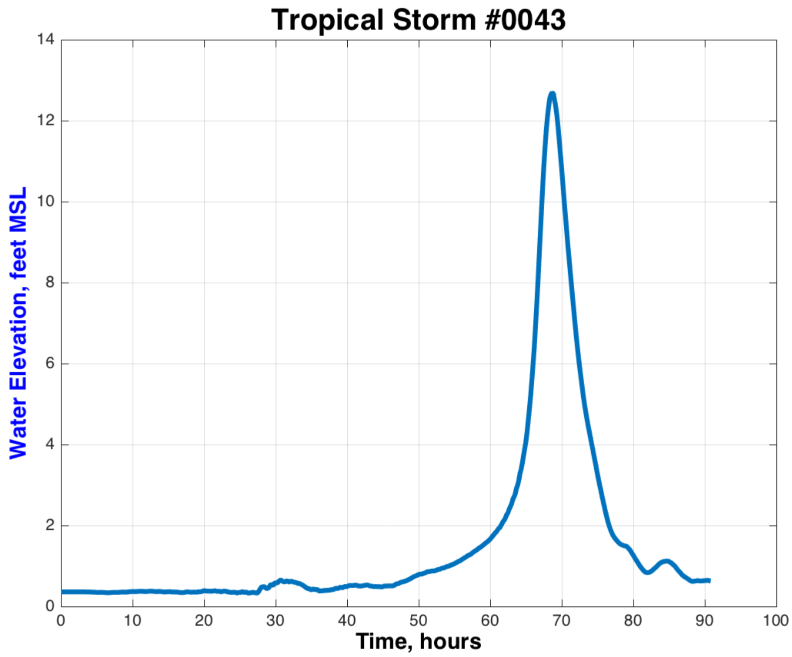
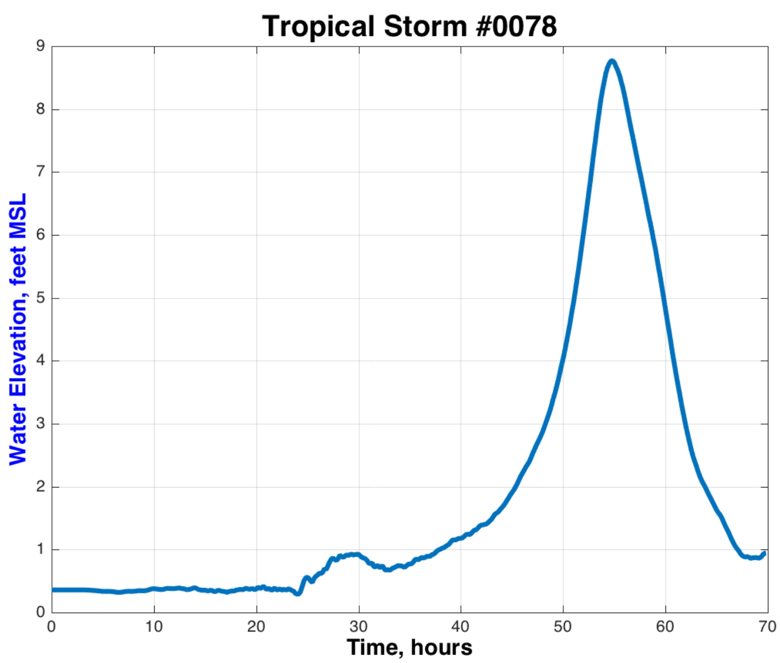
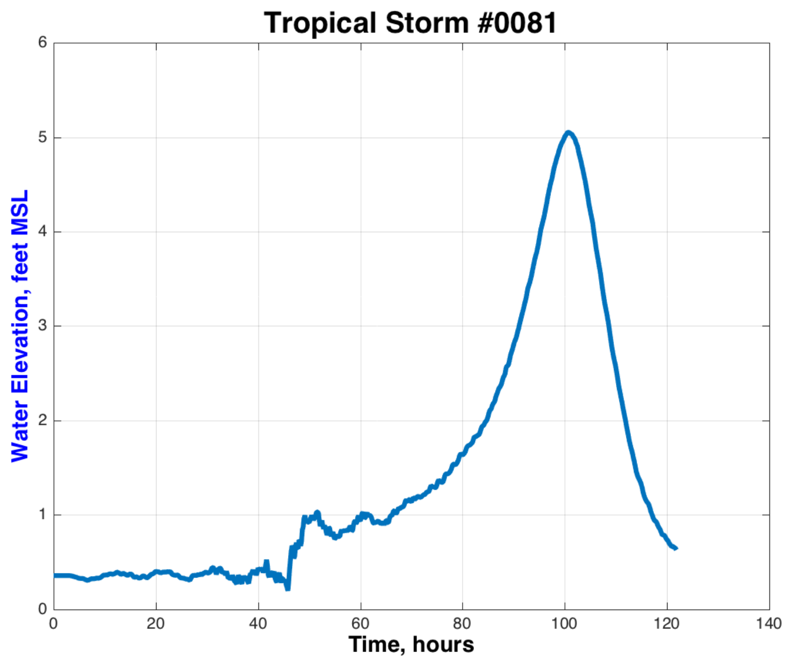


Figure 44 - Idealized Profile for Prime Hook

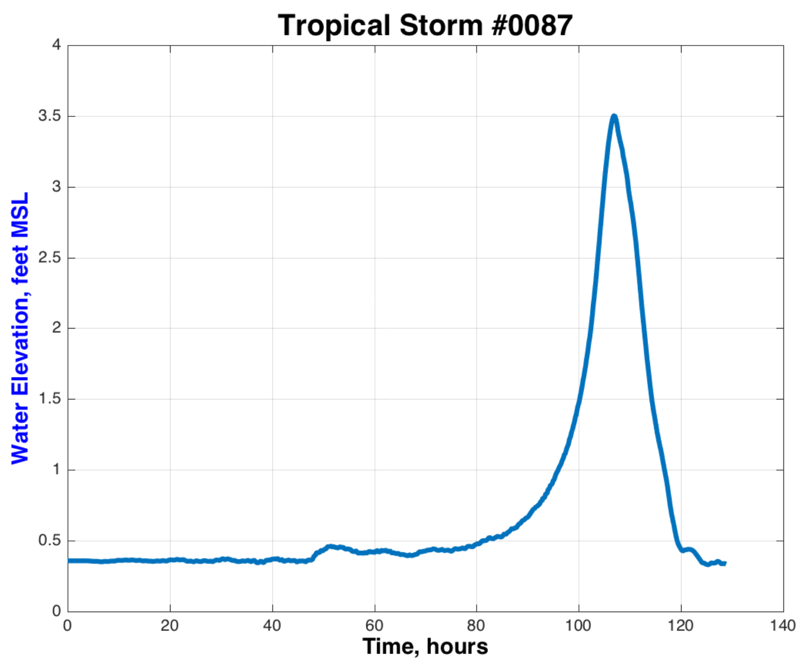
Figures 45 through 63: Selected Storm Hydrographs



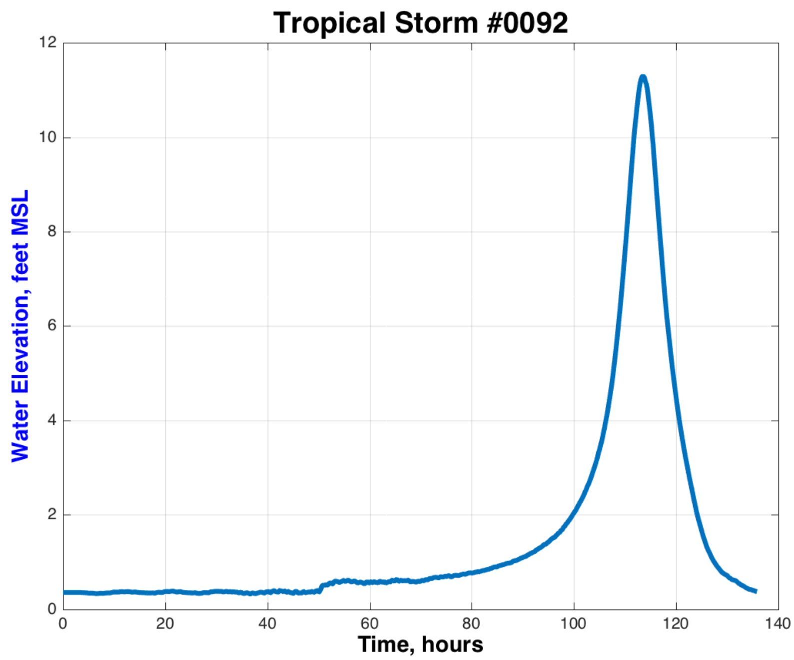


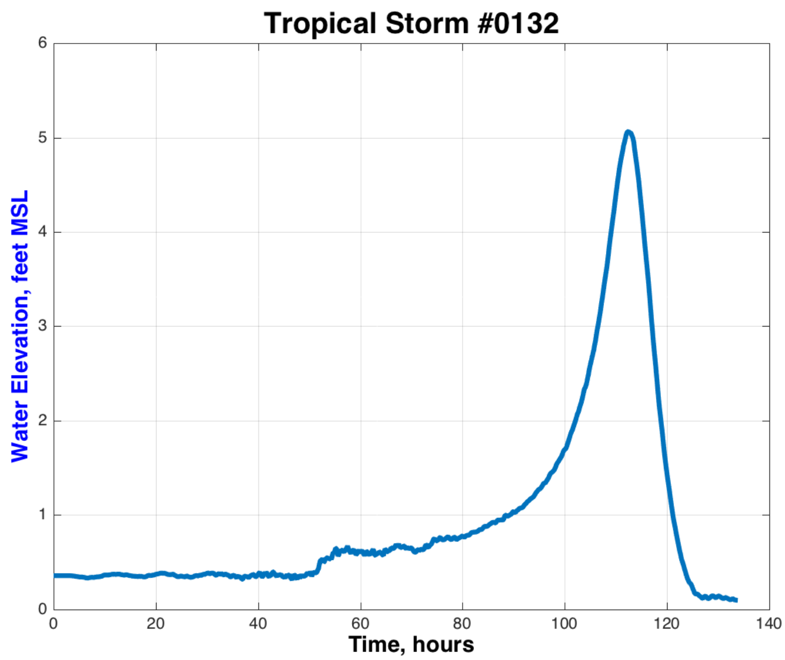


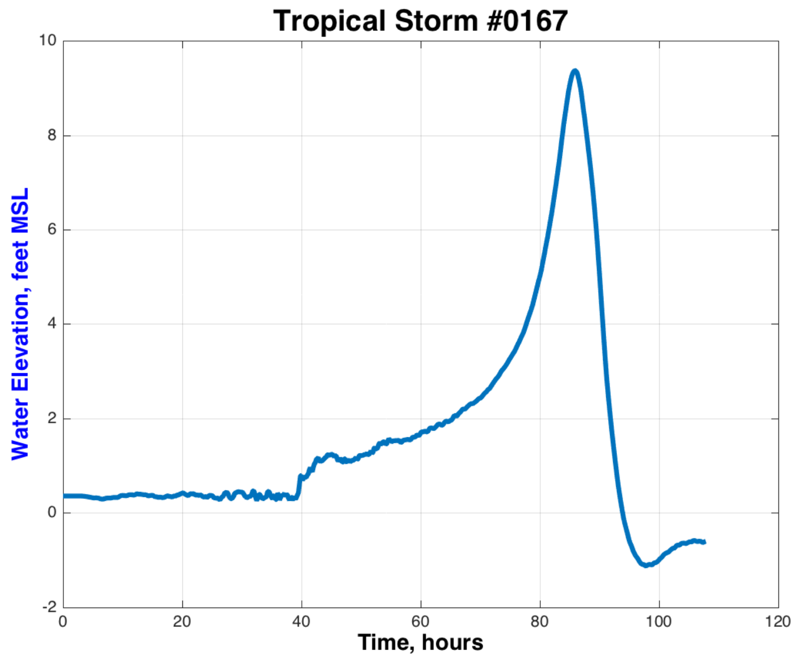
Tropical Storm #0081
Water Elevation, feet MSL
Time, hours
0
1
2
3
4
5
6
20
40
60
80
100
120
140

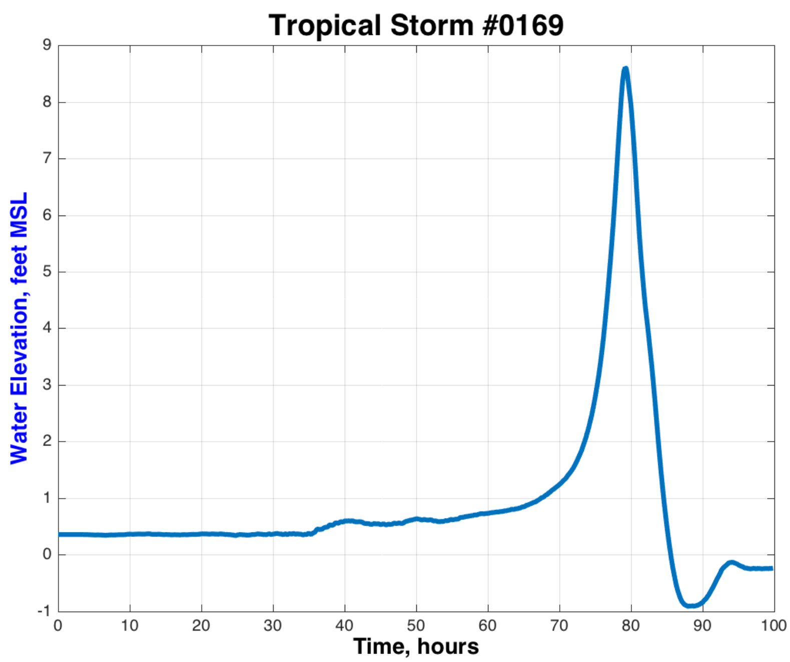


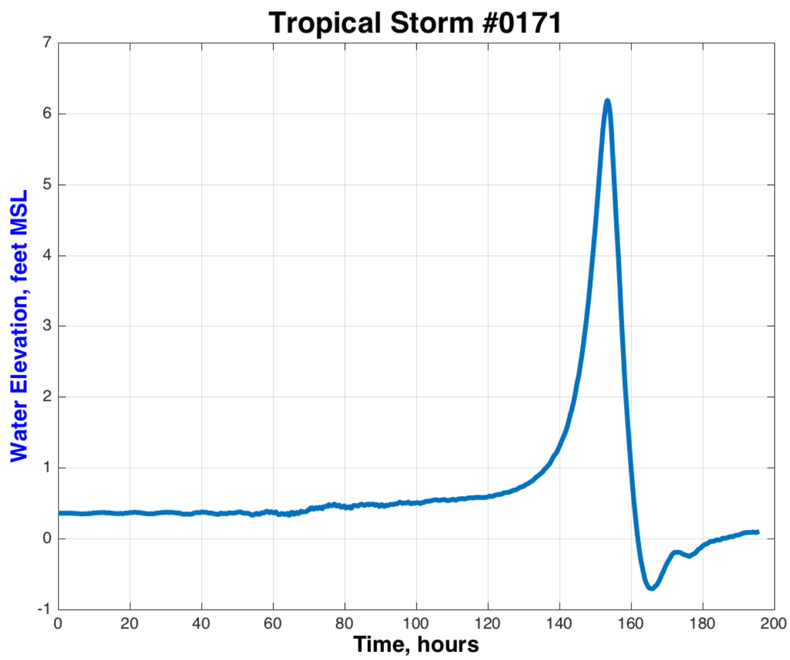
Tropical Storm #0087
Water Elevation, feet MSL
Time, hours
0
0.5
1
1.5
2
2.5
3
3.5
4
20
40
60
80
100
120
140

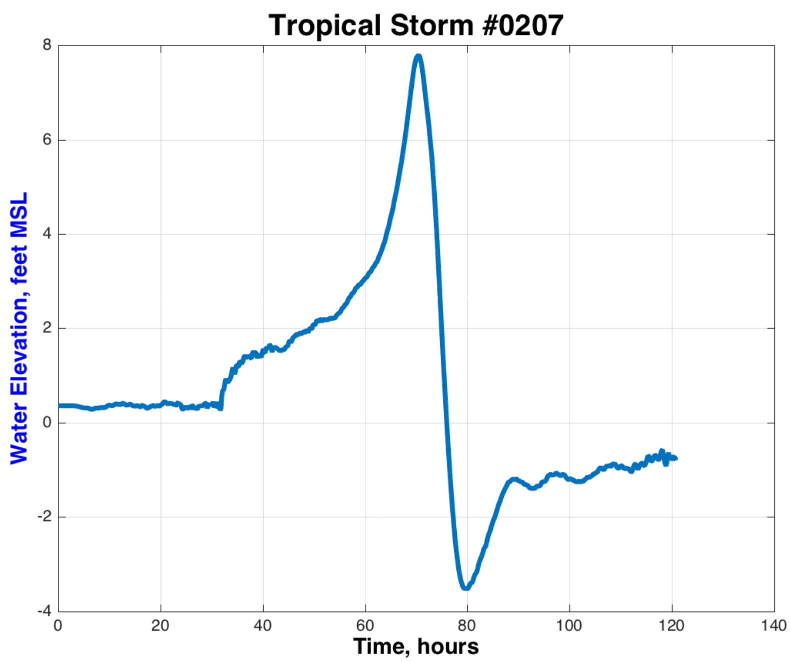

Tropical Storm #0092
Water Elevation, feet MSL
Time, hours
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140

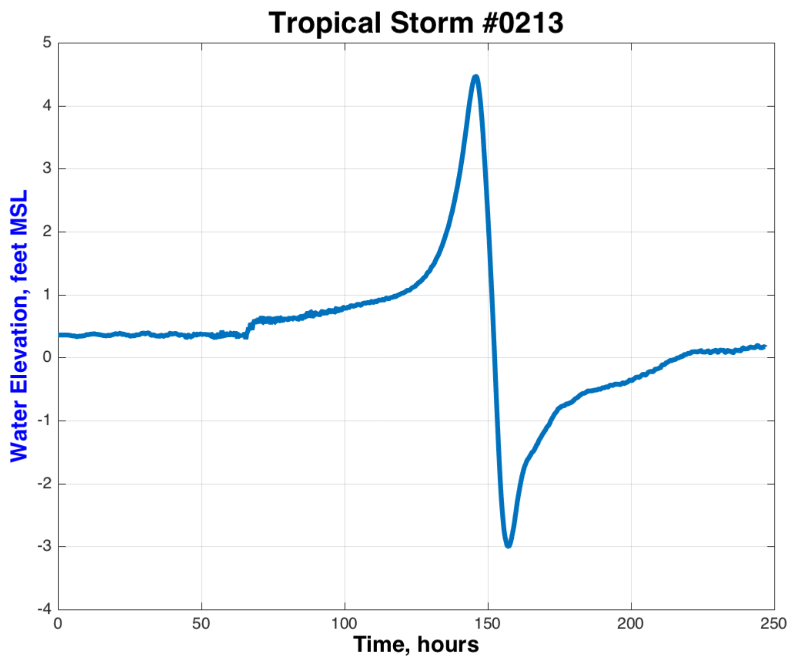

Tropical Storm #0132
Water Elevation, feet MSL
Time, hours
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140

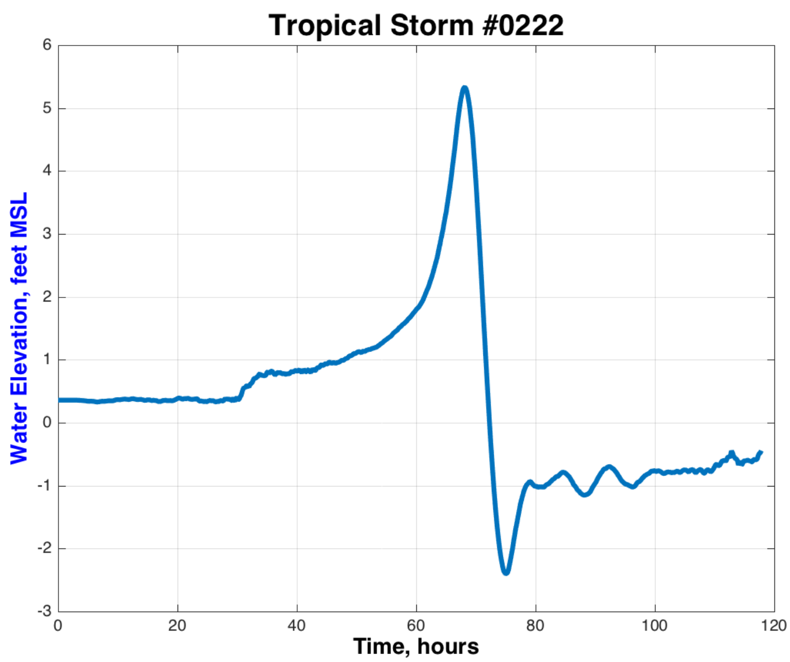

Tropical Storm #0167
Water Elevation, feet MSL
Time, hours
10
8
6
4
2
0
-2
0
20
40
60
80
100
120

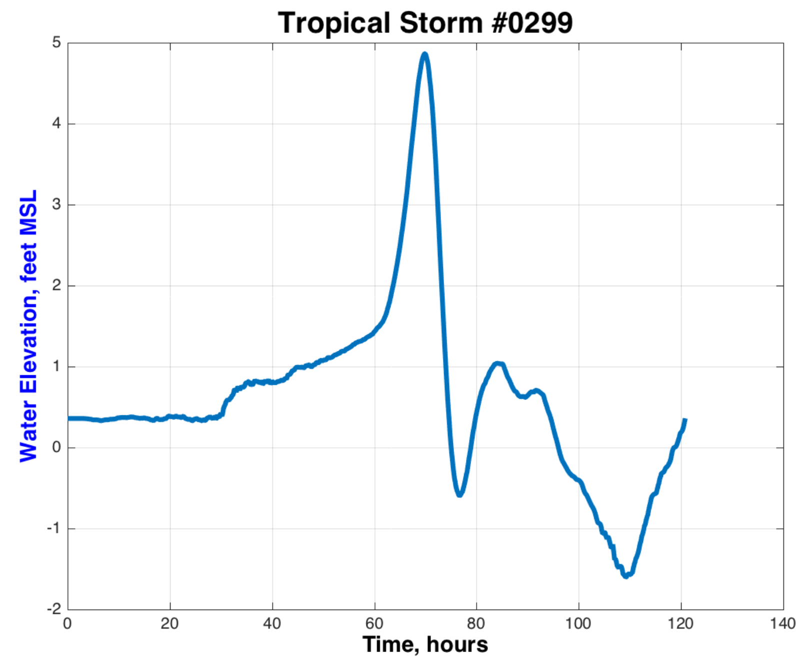

Tropical Storm #0169
Water Elevation, feet MSL
Time, hours
9
8
7
6
5
4
3
2
1
0
-1
0
10
20
30
40
50
60
70
80
90
100

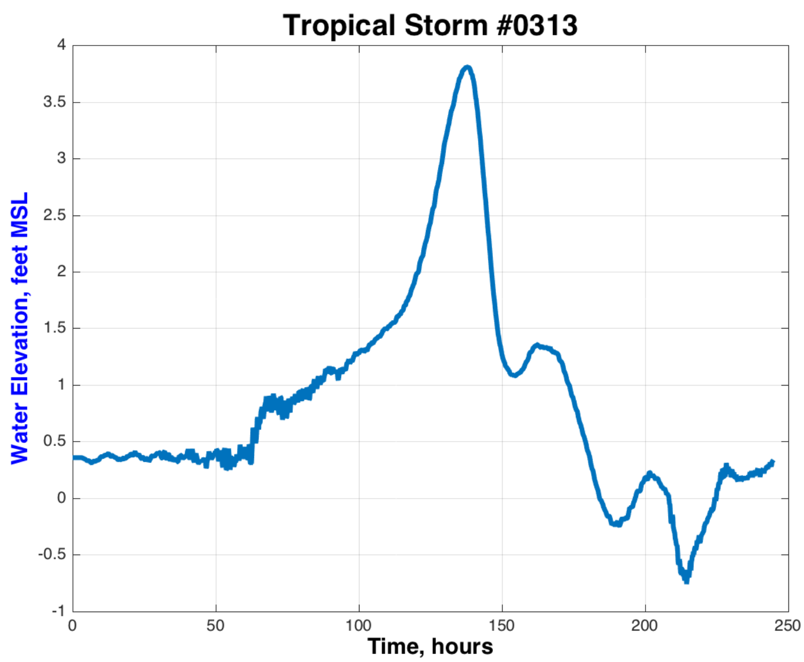

Tropical Storm #0171
Water Elevation, feet MSL
Time, hours
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200

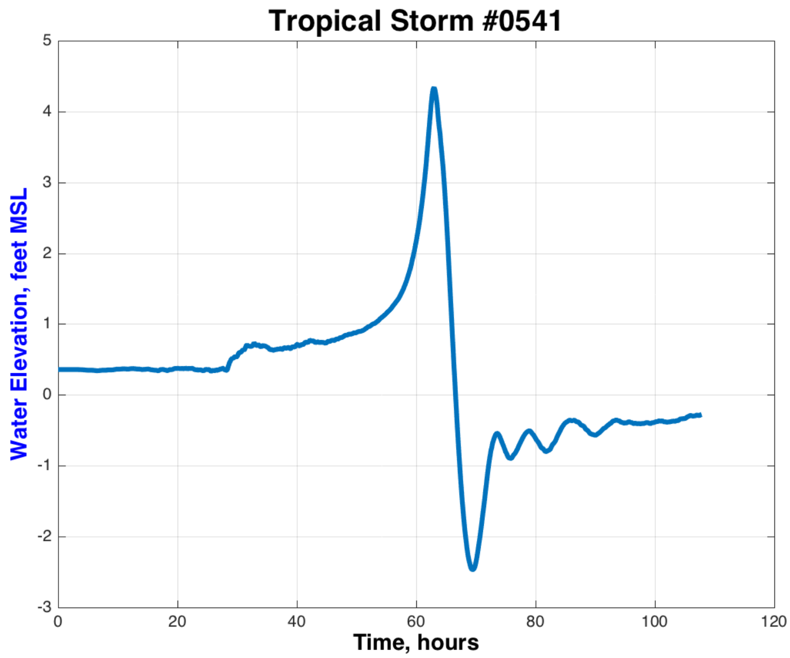

Tropical Storm #0207
Water Elevation, feet MSL
Time, hours
8
6
4
2
0
-2
-4
0
20
40
60
80
100
120
140

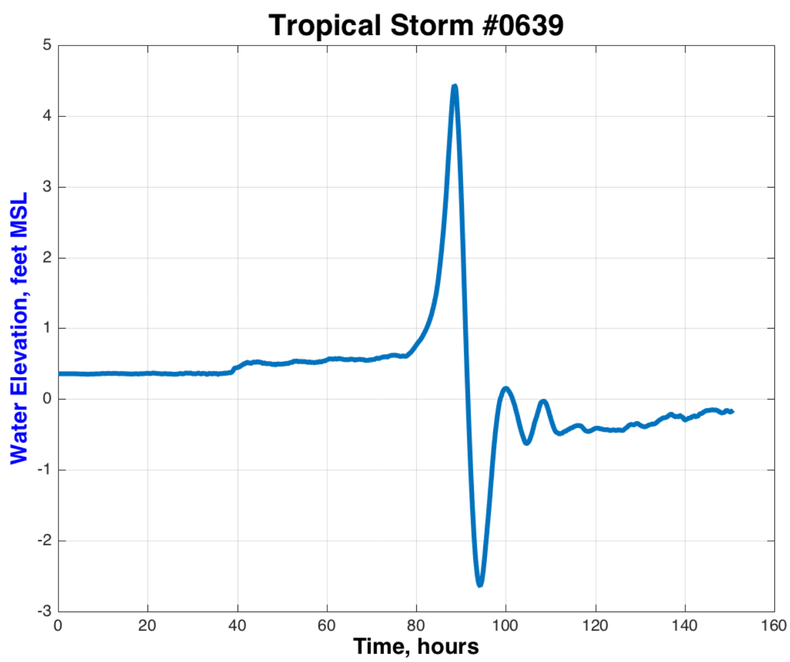

Tropical Storm #0213
Water Elevation, feet MSL
5
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
Time, hours

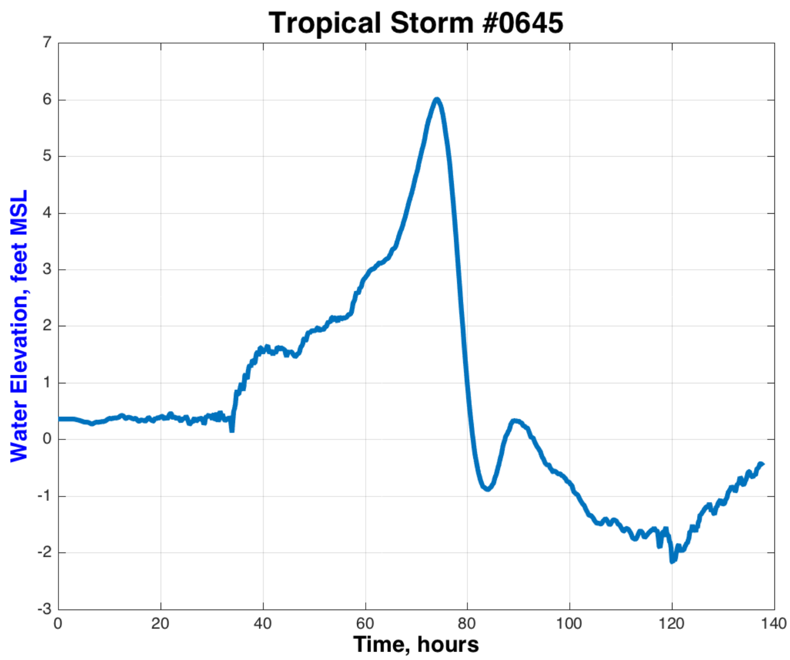

Tropical Storm #0222
Water Elevation, feet MSL
6
5
4
3
2
1
0
-1
-2
-3
0
20
40
60
80
100
120
Time, hours


Tropical Storm #0299
Water Elevation, feet MSL
5
4
3
2
1
0
-1
-2
0
20
40
60
80
100
120
140
Time, hours

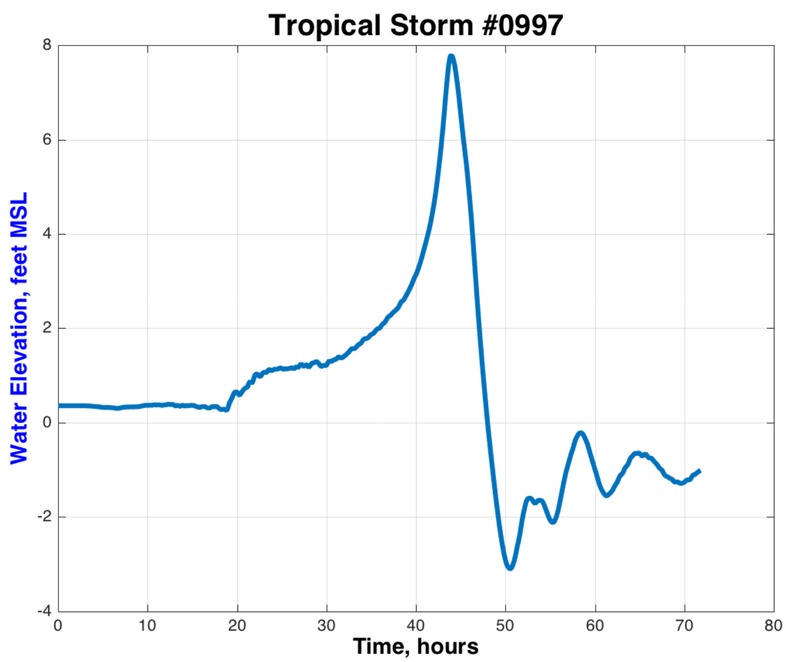

Tropical Storm #0313
Water Elevation, feet MSL
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
50
100
150
200
250
Time, hours


Tropical Storm #0541
Water Elevation, feet MSL
Time, hours
5
4
3
2
1
0
-1
-2
-3
0
20
40
60
80
100
120

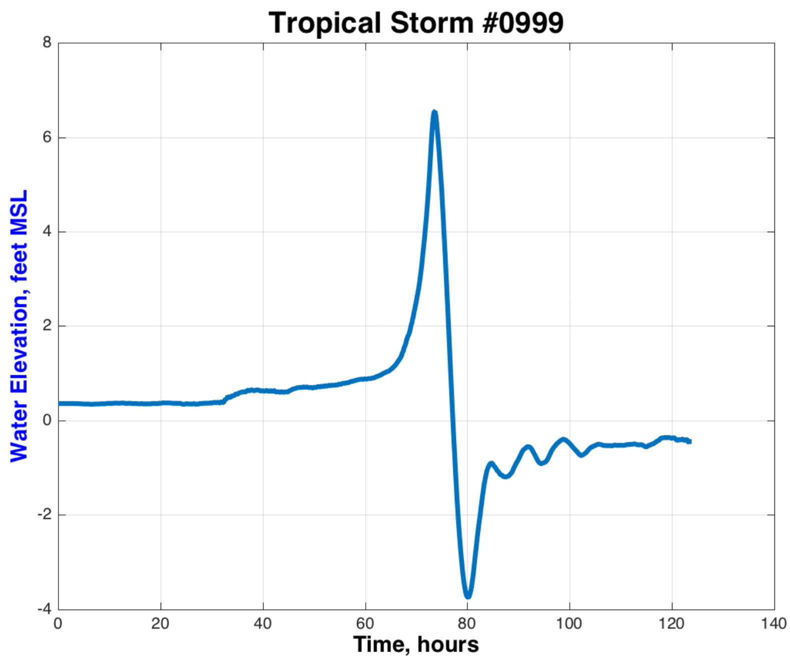

Tropical Storm #0639
Water Elevation, feet MSL
Time, hours
5
4
3
2
1
0
-1
-2
-3
0
20
40
60
80
100
120
140
160



Tropical Storm #0645
Water Elevation, feet MSL
Time, hours
7
6
5
4
3
2
1
0
-1
-2
-3
0
20
40
60
80
100
120
140



Tropical Storm #0997
Water Elevation, feet MSL
Time, hours
8
6
4
2
0
-2
-4
0
10
20
30
40
50
60
70
80



3.2.6 Future Sea Level Change (SLC)

In accordance with ER 1100-2-8162, the direct and indirect effects of future sea level change on the identified Tentatively Selected Plan (beach nourishment alternative) were evaluated using the Beach-fx model. Relative sea level change at all of the final locations along the Delaware Bay is one of rising sea levels. The historical rate of sea level rise was determined through the use of the online calculator provided by USACE at 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. Currently, the Beach-fx analysis utilizes only the historic curve rate of 0.0105 ft/yr, however Table 3 above provides a summary of the computed sea level rise that will ultimately be utilized in Beach-fx for each of the three sea level change scenarios across the simulation period (2020 to 2070) in later phases. While the economic analysis is limited to the 50-yr life cycle, SLC was also assessed on a 100-yr planning horizon, and used to qualitatively inform project performance (e.g. understanding future level of protection offered in 2100), and identify potential for adaptive management (e.g. increasing dune/berm height/width). SLC at 2100 will be used more quantitatively to guide optimization of proposed protections measures during later project phases.

3.3 Shoreline Change Rates

In August 1991, the Corps conducted a review of the Delaware Bay and its tributaries to determine the magnitude, location, and effect of the shoreline erosion problems under the scope of the Delaware Bay Coastline - New Jersey and Delaware Reconnaissance Study. The study focused on the Delaware shoreline extending from Woodland Beach to Lewes, DE. At the time of the study, there was little information available on shoreline change north of Woodland Beach, DE. Table 11 provides a summary of shoreline erosion trends from Woodland Beach to Lewes, DE.

Table 11 – Delaware Shoreline Erosion Rates

Site	Range of Shoreline Change Rates (ft/yr)	Average Shoreline Change Rate (ft/yr)
Woodland Beach	-2 to -7	-4.5
Port Mahon	-9 to -12	-10.5
Pickering Beach	-5	-5
Bowers Beach	-2	-2
South Bowers Beach	-8	-8
Big Stone Beach	-5 to -6	-5.5
Big Stone Beach to Mispillion Inlet	-10 to -13	-11.5
Mispillion Inlet	-9 to -11	-10
Slaughter Beach	-2	-2
Slaughter Beach to Fowler	-1 to -5	-3
Broadkill Beach	-3	-3
Lewes Beach (near Roosevelt Inlet)	-3	-3

The range of shoreline change rates listed on Table 11 were extracted from the 1991 Delaware Bay Coastline - New Jersey and Delaware Reconnaissance Study. The average shoreline change rates were then calculated by the PDT. Average shoreline change rates were utilized for both with- and without-project conditions within Beach-fx. While Beach-fx does allow for the specification of "project-induced" shoreline change to capture the beach fill diffusion, inputs are most commonly derived from GENESIS and GENCADE modeling, which was not part of the original scope of work. However, as there has been previous fill placement at the majority of the study locations, it was assumed that the historical shoreline changes rates inherently include dispersion of those fill activities. This assumption regarding dispersion will be considered further in the optimization effort. Also during optimization, effort will be made to calibrate Beach-fx modeling to historic change rates, as feasible where calibration data exists.

4. References

USACE, 2015. North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk

USACE, 2013. ER 1100-2-8162, Incorporating Sea Level Change in Civil Works Programs

DNREC, 2012. Preparing for Tomorrow's High Tide: Sea Level Rise Vulnerability Assessment for the State of Delaware. Delaware's Sea Level Rise Advisory Council.

NOAA, 2009. NOAA Tides & Currents, Sea Level Trends. http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml

USACE, 1991. Delaware Bay Coastline, DE & NJ Feasibility Study