Croatan Beach Shoreline Protection Assessment

Presented to:

City of Virginia Beach, Department of Public Works

April 13, 2017 (Revised)

Prepared by:

moffatt & nichol

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1. Introduction

1.1. Study Purpose and Scope

Moffatt & Nichol (M&N) was retained by the City of Virginia Beach (City) to conduct a coastal engineering study of Croatan Beach shoreline and beach profile behavior in the context of historical and present sand bypassing and dredging practices at Rudee Inlet. Croatan Beach is a three-quarter mile section of shoreline located south of Rudee Inlet along the Atlantic Ocean in the City of Virginia Beach (Figure 1). It is bounded by Rudee Inlet in the north and by Camp Pendleton (Virginia National Guard) in the south.

The primary objective of the project is to determine whether the current level of protection provided by the beach and dune to upland structures and infrastructure meets adopted criteria. Related objectives are to determine whether inlet, dune, and beach management practices have affected the level of protection, and to determine if any changes may be needed to these practices to maintain a sufficient level of protection.

The present study includes documentation of Croatan Beach shoreline, beach and dune change patterns over time, estimation of the level of protection currently provided by the beach and dune system to upland structures and infrastructure, recommendations on the purpose, need, and conceptual plan for a beach and/or dune nourishment project. The study also addresses the issue of whether a U.S. Army Corps of Engineers (USACE) “Section 408” review and permit may be required for construction of certain conceptual plan elements, for example if the conceptual plan involves alterations to Rudee Inlet jetties, sand bypassing or dredging practices.

A separate report (in preparation) documents additional evaluations requested by the City in support of a Joint Permit Application (JPA) and potential Section 408 review relative to using approximately 20,000 cubic yards of sand annually, borrowed from the Rudee Inlet sand trap, to nourish the beach and dune in the northern segment of Croatan Beach.

1.2. General Description of the Project Site

Croatan Beach is a residential community beach, with several public access points including a large public parking area, restrooms and changing facilities at the south end of the beach. Aerial photos and digitized shoreline positions included in a shoreline evolution study by the Virginia Institute of Marine Science (VIMS, 2012) provide an informative visual overview of the history of Croatan Beach from 1937 to 2011. In the 1937 photo, Rudee Inlet does not exist as a significant open-water feature, and no habitable structures are apparent along Croatan Beach. The next photo in the VIMS data set is from 1970. By that time, Rudee Inlet was opened and was managed by dredging and by structures on the north and south sides. A system of residential streets and habitable structures are apparent on the 1970 photo; a few of these structures were built seaward of what is now South

Atlantic Avenue. Development of Croatan Beach as a residential area increased in the 1980s and 1990s, such that most of the residential parcels appear to be occupied by habitable structures by the 2002 photo.

Coastal processes affecting Croatan Beach are the longshore transport of sand by waves throughout the year, storm surge and waves affecting the beach intermittently, and winds that can move sand from the dry beach into the dunes. The net movement of sand by longshore transport is from south to north. Transport from north to south does occur, mainly during winter nor'easters. As reported by prior studies and confirmed by independent calculations in the present study, the typical annual rate of northerly-directed transport is more than twice the rate of southerly-directed longshore transport.

There are no coastal structures affecting the supply of sand to Croatan Beach from the south. Rudee Inlet and its associated dredged navigation channel, north jetty, and the south jetty with weir and sand trap are the primary manmade coastal engineering features influencing Croatan Beach. Northerly-transported sand either enters the sand trap (over the weir), becomes impounded by the weir and south jetty, or bypasses the south jetty to enter the navigation channel. The sand trap and the navigation channel are dredged regularly by a combination of City and USACE dredging efforts. The annual rate of dredging has varied throughout the history of Rudee Inlet. At present, between 175,000 and 250,000 cubic yards per year (cy/yr) are dredged from the Rudee Inlet system, and this sand is placed to the north of the inlet. Additional details on dredging rates and placement areas is provided in Section 3.2 of this report.

Figure 1: Location Map of Croatan Beach

2. Engineering Study Approach

2.1. Historical Shoreline Change Assessment

The Croatan Beach shoreline protection assessment started with a comprehensive analysis of available data. Data collected for the City and other publicly-available data sets relative to beach morphology and shoreline change at Croatan Beach were compiled and reviewed. Available data sets include historical beach profile and shoreline position survey data; aerial photography; publicly available wave; current, tide, and wind data; sediment data; and prior coastal engineering studies by others. These data sets were used to evaluate historical shoreline and beach volume change trends. Historical data sources utilized include:

- Historical shoreline data – Report and GIS data (polylines) from VIMS (2012) *Shoreline Evolution: City of Virginia Beach, Virginia, Chesapeake Bay, Lynnhaven River, Broad Bay and Atlantic Ocean Shorelines*

- Historical beach profile data – Reports, maps and ASCII text survey station-elevation data files from the City of Virginia Beach completed in April 2003, June 2003, August 2003, September 2003, January 2006, May 2006, October 2006, April 2015 and November 2015

- Prior studies of the project vicinity by Dr. David Basco (Beach Consultants, Inc. of Norfolk, Virginia, and Professor Emeritus of Old Dominion University Dept. of Civil Engineering) – *Chesapeake Bay Shoreline Study, City of Virginia Beach* (August 2003) and *Beach Profile Data: Archives and Analysis* (April 1994, Report No. 94-2)

- Study – Waterway Surveys & Engineering, Ltd. Virginia Beach, Virginia (2001) *Rudee Inlet Management Study*

- Study – USACE (2008) *Wave Climate and Littoral Sediment Study for Virginia Beach, VA – Rudee Inlet to Cape Henry*

- Hindcast wave and wind data from USACE WIS Atlantic Hindcast Station #63199

- Measured wave data from NOAA data buoy #44099 in the Atlantic Ocean immediately just outside the Chesapeake Bay entrance

- Observed water surface elevation data from NOAA tide gauging Station #8638863 at the Chesapeake Bay Bridge-Tunnel

2.2. Level of Protection Analysis

Croatan Beach has an established beach and dune system, and the purpose of this task is to quantify the level of protection from storm surge and waves that this feature is currently providing for the upland structures. M&N employed the computer model Storm-induced Beach Change Model (SBEACH) for this analysis. SBEACH simulates cross-shore beach, berm, and dune erosion produced by storm waves and water levels. Beach profile survey data are periodically collected by the City. From the survey data, eight typical profile cross-sections of the shoreline were selected for the beach response analysis in SBEACH.

SBEACH requires time series of storm waves as input to compute storm erosion of the beach profile. M&N utilized wave data from the U.S. Army Corps of Engineers (USACE) Wave Information Studies (WIS) hindcast to run the SBEACH model. The SBEACH model was calibrated utilizing the City profile survey data. The calibrated SBEACH model was used to run different levels of design storm scenarios. The results of the SBEACH model runs were used to determine the level of protection provided by the present existing beach and dune systems to the upland residential area.

VIMS (2013) has recommended the consideration of 1.5 feet of relative sea level rise over the next 30 to 50 years. M&N estimated the sensitivity of the level of protection determination to an indicative rate of sea level rise by running the SBEACH simulations for the selected storms with the storms' water levels increased by 1.5 feet.

2.3. Purpose & Need to Enhance the Beach Profile

Following completion of historical shoreline change assessment and level of protection analysis, M&N collaborated with the City and others as invited by the City to establish criteria to judge whether the existing beach profile (beach width and elevation, dune height and volume) and current inlet sand management practices are sufficient to provide an adequate level of protection to the upland buildings and infrastructure in the project area.

Using these criteria and findings of this report, M&N made recommendations regarding the necessity of actions to promote and maintain an increased beach width, increased beach elevation, and/or increased dune height and volume in the project area.

2.4. Outline of Conceptual Plan to Enhance the Beach Profile

In the event that such actions were found to be necessary, M&N developed conceptual plans for beach nourishment, dune enhancement, and/or changes to inlet management practices to achieve and sustain a beach and dune profile that meets the criteria. M&N investigated the technical regulatory issues associated with planning, permitting and implementing such recommended actions, and M&N recommended next steps for pursuing such actions.

3. Rudee Inlet Management History

Figure 2 presents a timeline of selected events in the history of Rudee Inlet. Much of the information on Rudee Inlet history is taken from a 2001 study report by Waterways Surveying & Engineering (WS&E); a table from that report is reproduced in Figure 3: History of structural changes and maintenance dredging practices at Rudee Inlet (reproduced from Table 1-1 in WS&E, 2001). The inlet was initially opened in 1927 when the Virginia Department of Highways installed a small concrete flume across a drainage ditch to support the existing road system. The flume was damaged and the inlet mostly closed during a hurricane in 1933, and for the next twenty years the inlet functioned as a small drainage channel. The inlet was reopened in the 1950s when mining for beach sand was initiated in Lake Wesley and Lake Rudee. A fixed sand bypassing plant was installed, but this plant was damaged during the Ash Wednesday storm of March 1963. Rudee Inlet was enlarged in 1968 to create additional waterfront property with a direct ocean access; the jetties were extended, and the original weir and sand trap were constructed. Significant changes to the weir and jetties were constructed in 2004; these changes are discussed in more detail below.

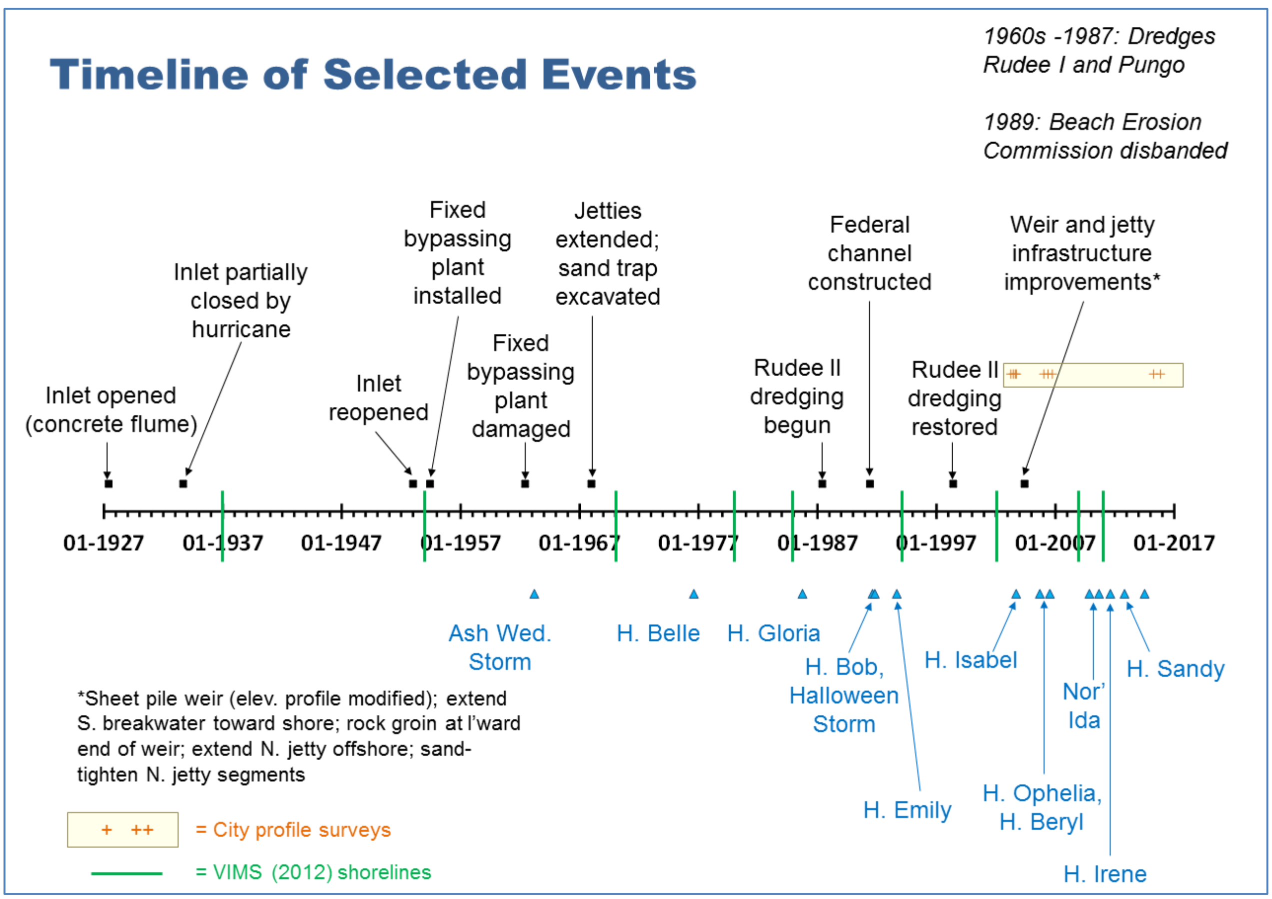


Figure 2: Timeline of Selected Events

DATE	ACTION
1927	Rudee Inlet opened by a concrete flume. A road system was constructed over the flume.
1933	Major hurricane partially closes the Inlet and damaged the flume.
1952/53	Inlet was re-opened with 2 short jetties spaced about 150-ft apart. An estimated 1.3 mcy of sand was dredged and placed on the beach.
1954	Fixed bypassing plant installed on south jetty.
1962	Fixed bypassing plant destroyed by Ash Wednesday Storm.
1967/68	Jetties were extended to current length and weir system was constructed. Sand trap was excavated between the weir and the channel.
1975	Jet pump eductor system was installed in the sand trap. Subsequently it failed and was later removed.
1986	Rudee Inlet channel was authorized.
1987	Rudee II, the municipal dredge was purchased. Typical reported bypassing between 1991 and 1996 was 160,000 cy/yr.
1991	Federal channel was first constructed.
1996	Authorization was changed to include participation for 50 years after initial project construction.
1998	Municipal dredging practices were improved and additional shifts were added. Typical reported bypassing since then is estimated at 270,000 cy/yr.

(Modified from USACE, 1983.)

Figure 3: History of structural changes and maintenance dredging practices at Rudee Inlet (reproduced from Table 1-1 in WS&E, 2001)

3.1. 2004 Weir and Jetty Modifications

The design of the 2004 weir and jetty modifications is documented in a design study report (WS&E, 2001) and drawings (WS&E, 2004). Figure 4 shows a plan view of the 2004 project elements, including extension of the north jetty and sand-tightening of that structure, extension of the south jetty breakwater on its landward end, construction of a rock groin on the landward end of the weir, and replacement of the prior existing timber weir with a sheet pile weir. The weir elevation profile was modified as shown in Figure 5. The most landward 50 feet of the weir was raised to elevation +8.8 feet MLW, and the adjacent weir crest was raised significantly over the next 60 feet before tying into the prior weir elevation at +1.8 feet MLW. The weir crest was lowered by 1.0 foot along approximately 180 feet of the weir profile connecting to the south breakwater.

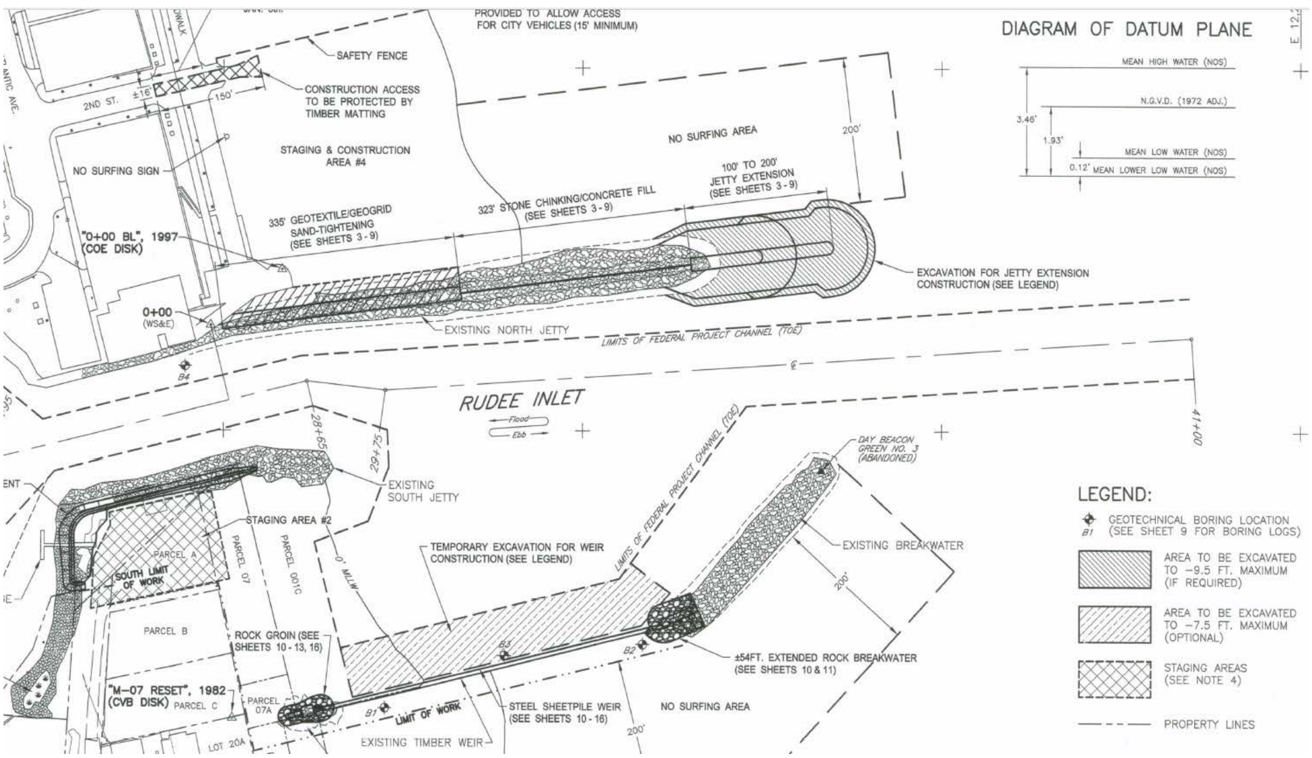


Figure 4: Plan Extents of 2004 Weir and Jetty Modifications (reproduced from WS&E, 2004 construction plans)

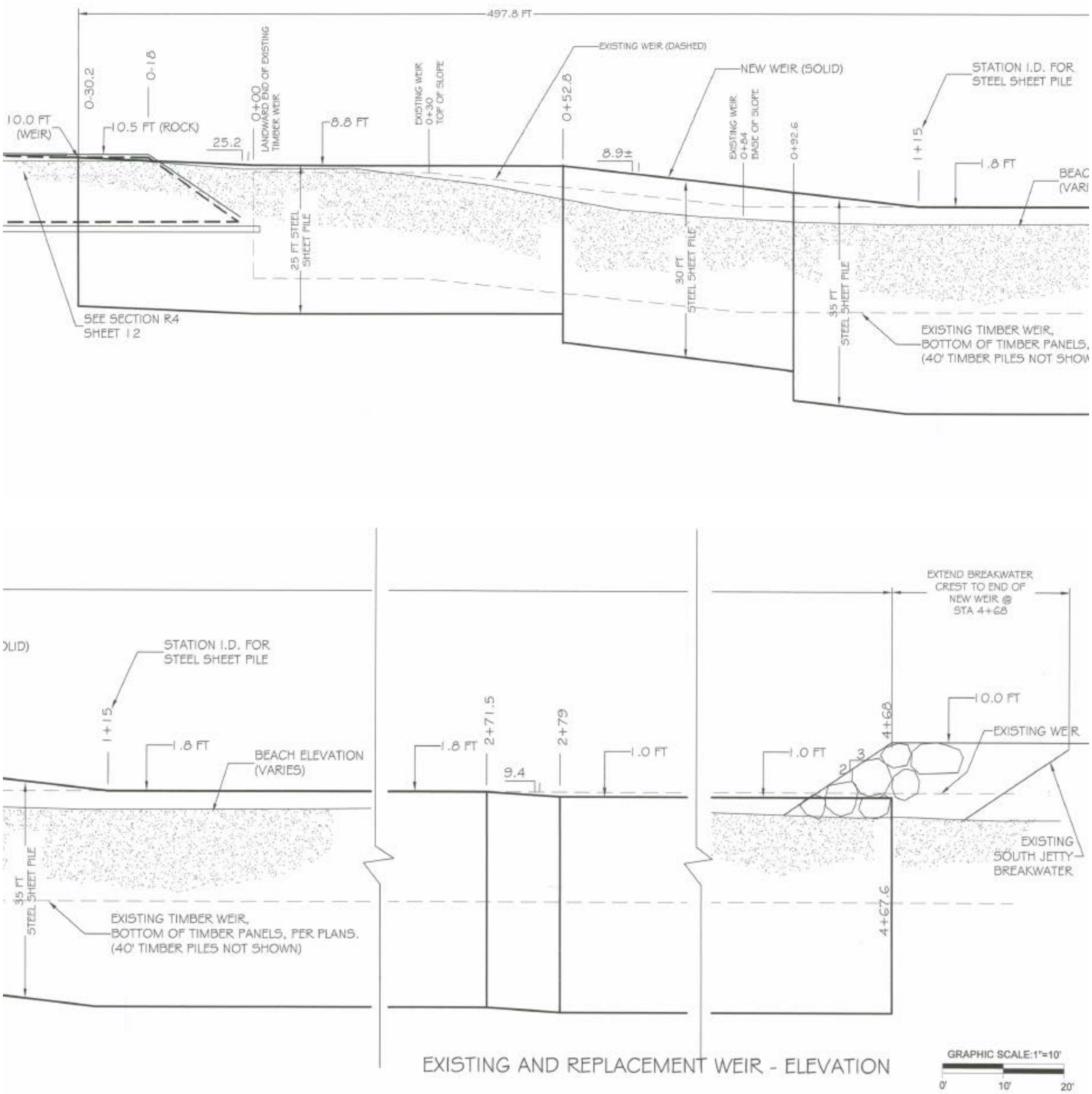


Figure 5: 2004 Weir Profile Modifications (looking north; reproduced from WS&E, 2004 construction plans)

3.2. Rudee Inlet Dredging History and Recent Croatan Beach Nourishment

Sand bypassing (generally from south to north) has been conducted at Rudee Inlet since the 1950s, first by a fixed plan using an eductor pump and then by dredging. Dredging methods and annual volumes have changed over the decades. Since the early 1990s, when the Federal navigation channel project was first constructed, the Rudee Inlet channel segments have been dredged by a combination of work by the City-owned dredge Rudee II and USACE-owned dredges, or contracted dredges.

Average annual sand bypassing between 1991 and 1996 is reported by WS&E (2001) to have been approximately 160,000 cubic yards per year (cy/yr). Rudee II dredging rates were increased in 1998, such that WS&E (2001) reported an increase in average annual dredging volume, to approximately 290,000 to 315,000 cy/yr for years 1998 and 1999. Based on the additional information below, this dredging volume is interpreted by M&N to refer to total dredging from combined City, USACE, and contractor efforts.

USACE provided volumes dredged by USACE plant or contracted dredges for the years 2000 to 2016. These values are shown as monthly totals in Figure 6. The dates and volumes for initial and maintenance dredging of the Deposition Area (shown in Figure 9) are labeled; Deposition Area dredging volumes are between 100,000 and 110,000 cy per event.

Rudee II dredging records from 2006 to 2015 were compiled into spreadsheets and made available by the City. These monthly totals are shown in Figure 7, where it is seen that the Rudee II compiled records are not available for all months, and significant variation exists in the monthly dredging rates. The bars in Figure 7 are “stacked” such that each bar shows the total of Rudee II, USACE, and contracted dredging with each component as a different color.

Figure 8 displays the same data summarized by year instead of as monthly totals. The bars are shown as totals for the preceding year, such that the year 2007 total bar appears immediately left of the January 2008 position on the date axis.

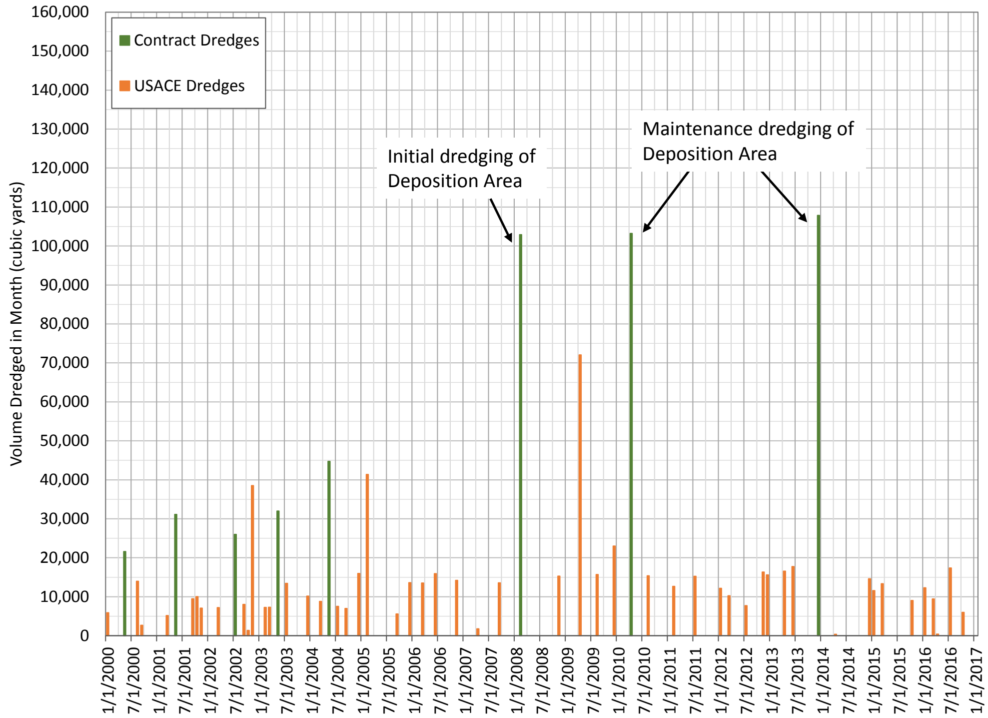


Figure 6: USACE Plant and Contract Dredging Monthly Volumes from Available Records

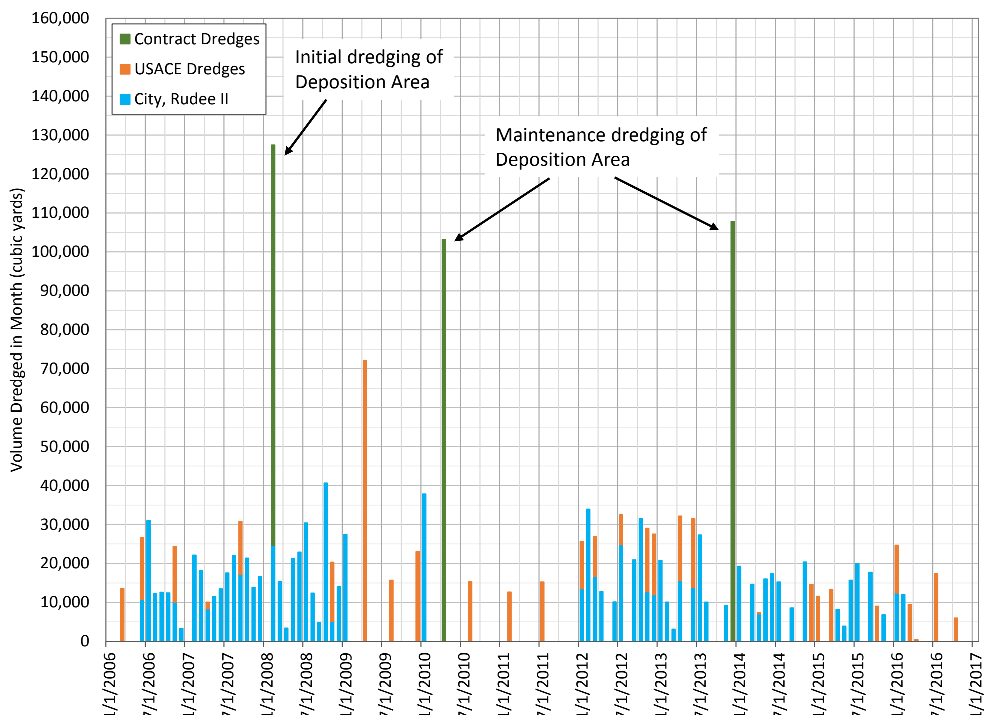


Figure 7: Rudee II (City), USACE, and Contract Dredging Monthly Volumes from Available Records

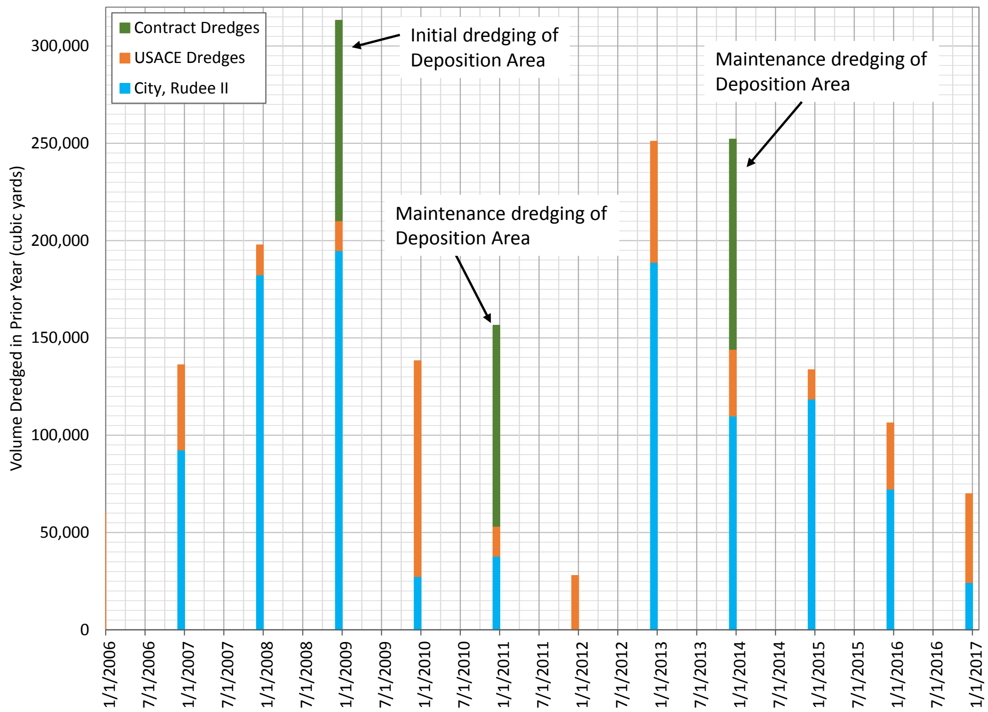


Figure 8: Rudee II (City), USACE, and Contract Yearly Dredging Volumes from Available Records

Since 2010, Federal dredging of the navigation channel has primarily been conducted by USACE-owned dredge *Currituck* a shallow-draft hopper dredge. USACE dredge *Merritt*, a sidecasting dredge, was used twice in 2013, and USACE hopper dredge *Murden* was used once in 2014. Dredging by USACE plant was approximately 374,000 cubic yards from 2006 – 2015. However, Federal dredging of Rudee Inlet takes place when needed for maintaining the navigation channel and when funding is available, and there is a large variation in Federal dredging volumes year to year.

Table 1 lists the dredging volumes by USACE from 2006 – 2015 along with the Rudee II dredging volumes for years with eight months or more of Rudee II records available. In these years, the Rudee II values were extrapolated from the number of months available to a 12-month equivalent value, and summed with the USACE and contract dredging to develop estimated annual combined dredging volumes. It is seen that the total dredging volumes in these years, from the records available, ranges between 178,610 and 330,876 cubic yards. A significant portion of the Federal dredging in 2013 was completed in January of that year, and it is associated with navigation maintenance efforts following the passage of Hurricane Sandy in November 2012.

Recognizing that the Rudee II dredging reports were not available for all months in any of the years in Table 1, it is reasonable to conclude that total dredging volumes may have been greater than indicated in the table. A working assumption, based on the available data and professional judgment, is that total annual dredging volume from both City and USACE efforts ranges between 200,000 and 330,000 cy/yr.

The City's dredging of the inlet using the Rudee II is subject to permits from USACE and VMRC. Currently, the City is operating under two sets of permits to dredge in the Federal channel and in the outer deposition area between and adjacent to the seaward ends of the jetties. The areas identified in the dredging permits are shown in Figure 9, a graphic that is extracted from a recent USACE hydrographic survey map for Rudee Inlet.

Table 1: Dredging Volumes in Rudee Inlet by USACE Plant, Rudee II, and Contract Dredge Plant

Year	USACE Dredging (cy)	Rudee II Dredging Records Availability	Rudee II Dredging from Available Records (cy)	Rudee II Extrapolated to 12 Months (cy)	Contract Dredging (cy)	Combined Dredging (cy)
2007	15,320	11 months	182,444	199,030		214,350
2008	15,295	11 months	194,968	212,692	102,889	330,876
2012	62,135	10 months	188,860	226,632		288,767
2013	34,355	8 months	109,888	164,832	107,878	307,065
2014	15,015	8 months	118,600	177,900		192,915
Average:	**28,400 cy/yr**			**196,200 cy/yr**	**42,200 cy/yr**	**267,000 cy/yr**

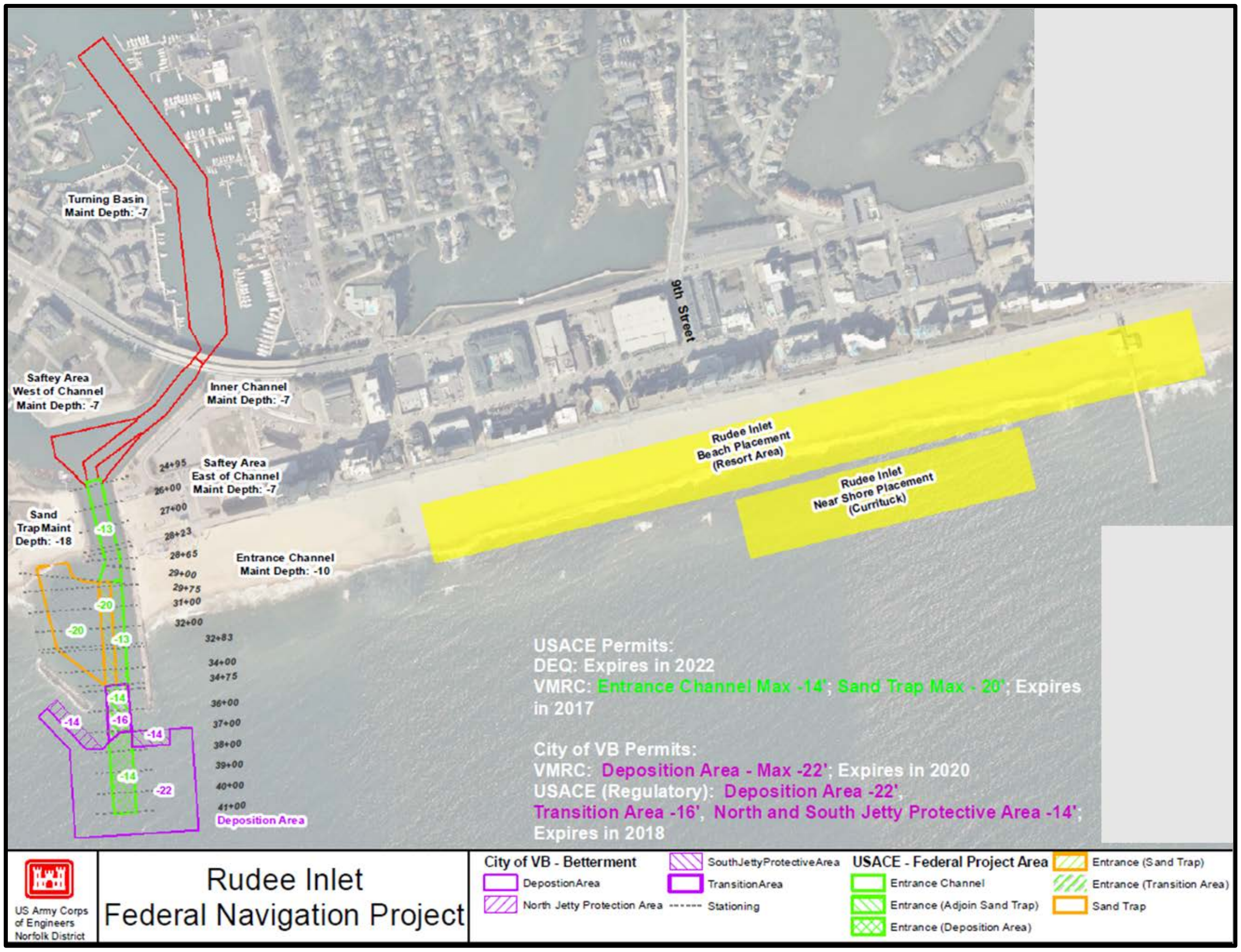


Figure 9: Rudee Inlet Dredging Areas

Under the first set of permits, the City is permitted by USACE[1] to dredge sandy material from the entrance channel, turning basin, safety area, and sand trap using a hydraulic cutterhead dredge and to place the material on the oceanfront north of Rudee Inlet as beach nourishment. The City is further permitted, during emergency shoaling events, to use sidecast dredging to remove hazardous shoals and to place the material "approximately 100-120 feet down drift of the channel." The current VMRC permit associated with the USACE permit further specifies that approximately 350,000 cubic yards per cycle of sandy material may be placed north of Rudee Inlet on the resort beach (i.e. for hydraulic pipeline dredging) or in the nearshore beach area (i.e. for hopper dredging). The USACE permit expires in August 2018, and the VMRC permit expires in September 2017.

The prior USACE permit 92-5673-02 (signed August 2003 and expired December 2012) specified that the material from station 24+95 seaward would be placed in the Virginia Beach Placement Area;

[1] Current permit numbers NAO-2006-08087 and VMRC 12-0967.

this is assumed to refer approximately to the present placement area north of Rudee Inlet. The associated Virginia DEQ permit 92-1530 (signed February 1998 and expired November 2007) allowed dredging of up to 120,000 cubic yards per year with placement north of Rudee Inlet.

The second set of permits[2] governs the City's dredging in the outer channel deposition area, north and south jetty protective areas, and the transition area. The USACE and VMRC permits allow an estimated 150,000 cubic yards of material per cycle to be dredged and placed in the above-referenced areas on the beach or nearshore north of Rudee Inlet.

The prior VMRC permit 04-1181 (with extensions to 2011) and the associated USACE permit allowed construction and maintenance of the outer deposition area with annual dredging volume of approximately 100,000 cubic yards. The USACE permit specified that the material would be placed to the north of Rudee Inlet as beach nourishment between Rudee Inlet and 14th Street and/or between Camp Pendleton and Rudee Inlet along Croatan Beach. The VMRC permit also contained this provision for placement south of Rudee Inlet, but only during the initial dredging of the deposition area.

<u>Summary of Rudee Inlet Dredging</u>

In summary, the present USACE and VMRC permits allow the dredging of up to 350,000 cy/yr from the entrance channel, turning basin, safety area, and sand trap and up to 150,000 cy/yr from the outer channel deposition area, north and south jetty protective areas, and the transition area. It is noted that the permits primarily specify the permitted channel width and bottom elevations to which the dredged areas can be maintained. Additional dredging to greater depths or widths, or outside of the permitted areas, in order to achieve the maximum permitted dredging volumes would not be in compliance with the permits.

According to the permits, the material must be placed to the north of Rudee Inlet in the yellow-shaded beach and nearshore placement areas shown in Figure 9. The City is permitted to use sidecast dredging in emergency shoaling hazard conditions, with that material sidecast approximately 100 feet downdrift. Placement of any of the dredged material on Croatan Beach would require new or modified permits from USACE and VMRC.

A working estimate of the volume of sandy material actually dredged from Rudee Inlet is between 200,000 and 330,000 cy/yr. This material is placed to the north of Rudee Inlet, as specified in the permits.

[2] Current permit numbers NAO-2004-04041 and VMRC 15-0068.

3.3. Croatan Beach Sand Placement

During initial dredging of the deposition area in 2008, approximately 50,000 cubic yards of sediment was placed on Croatan Beach, as allowed by the permit. In more recent years, sand has been borrowed from the sand trap – by land-based excavator equipment – and placed on Croatan Beach as emergency measures in response to single storms or particularly intense winter nor'easter seasons. A total volume of approximately 87,000 cy has been placed on Croatan Beach since the beginning of 2008, as summarized in Table 2.

Table 2: Historical Beach Nourishments

Date	Beach Nourishment Volume (cy)
2008	50,000
May 2013	15,000
April 2015	20,000
April 2016	1,917

4. Wave Conditions Utilized in the Study

Sand transport in the project area is primarily driven by waves transforming and breaking across the subaerial and submerged beach profile. Waves occurring throughout the year contribute to littoral drift, generally quantified as alongshore transport rates of cubic yards per year (cy/yr). Though the changes are usually small from week to week, over a period of months and years the littoral drift patterns drive the mid- and long-term stability of the shoreline position.

Waves associated with tropical and extratropical storms (e.g. nor'easters) can generate dramatic, visually-obvious changes in the beach and dune profile. Even without a significant storm surge, the increased wave heights during storms will run further up the beach, impacting the upper beach and dune toe. Storm surges associated with tropical storms and moderate to severe nor'easters have the added effect of allowing waves to break directly on the upper beach or the dune face; these storms do the most lasting damage to the dunes. The shoreline position can recover from storm effects over a period of weeks to a few months, if the normal supply of littoral drift is not interrupted by updrift structures. The dune crest and dune toe positions take longer to recover naturally, as dune building depends on a sufficient dry beach width to supply sand transportable by winds.

The scope of the present study did not include wave transformation modeling or detailed statistical analysis of historical wave conditions correlated with shoreline and dune changes. However, wave conditions are an important input for the SBEACH model used in the level of protection analysis. This section of the report discusses the wave data sources and calculations utilized to generate wave time series inputs to the SBEACH simulations.

4.1. Waves

The most relevant data sources for offshore waves in project area are the USACE's Wave Information Studies (WIS) Atlantic hindcast station #63199 and data from NOAA's National Data Buoy Center (NDBC) station #44099. The positions of these data stations are illustrated in Figure 10.

WIS Atlantic station #63199 contains hindcast (model simulated) wave conditions from January 1980 to December 2012. It has a water depth similar to NDBC #44099.

NDBC station #44099 is a waverider buoy operated by Scripps Institute of Oceanography. Water depth at the buoy location is approximately 60 feet. This study utilized data from this buoy between July 2008 and April 2016. Figure 11 shows a rose plot of the frequency of occurrence of wave heights by direction. Wave heights are significant wave height ($H_{1/3}$) in meters, and the directional bands represent the 16 compass sectors using the system northeast, east-northeast, east, east-southeast, southeast, etc. A table at the bottom of the figure provides a quantitative description of the percent occurrences of wave height categories by directional bands. The NDBC data indicate that offshore waves are mainly from east and east-southeast, with lesser but important contributions from east-northeast and southeast directions. Wave heights are less than 1.9 meters (6 feet) for 94% of the time, and wave heights greater than 3.3 meters (11 feet) occur only 0.4% of the time.

Figure 12 shows wave height roses of the same data set broken down by seasons. The spring season wave rose (top left) is very similar to the annual rose in Figure 11. The fall season rose (bottom left) is also similar to the annual rose but with a greater percentage of wave heights greater than 6 feet. The summer season rose (top right) is noticeably different from the annual, spring, and fall roses. Summer waves approach more from the southeasterly directions, with little occurrence of waves north of east, and the summer wave heights are the lowest of any of the seasons. Winter waves (bottom right) have strong east-northeast, east, and east-southeast occurrence – like the annual, spring, and fall roses – but waves also approach at meaningful frequencies from more northerly and southerly directions. The fall and winter seasons generally account for the largest wave heights in the record, and the summer season has the lowest wave heights.

Appendix B contains rose plots of the NDBC #44099 broken down by year from 2009 to 2015. It is observed that the wave roses for 2013 through 2015 each show a more equal spread of wave directions from northeast through southeast, compared to a stronger east and east-southeast distribution in 2009, 2010, and 2011. This may be responsible for changes in shoreline position trend since 2012, discussed in Section 5.3 of this report.

The directional distribution of greater and smaller wave heights has bearing mainly on the northerly, southerly, gross, and net alongshore transport rates. The calculation of those rates and discussion of implications is provided in detail in the companion report on the Rudee Inlet sediment budget.

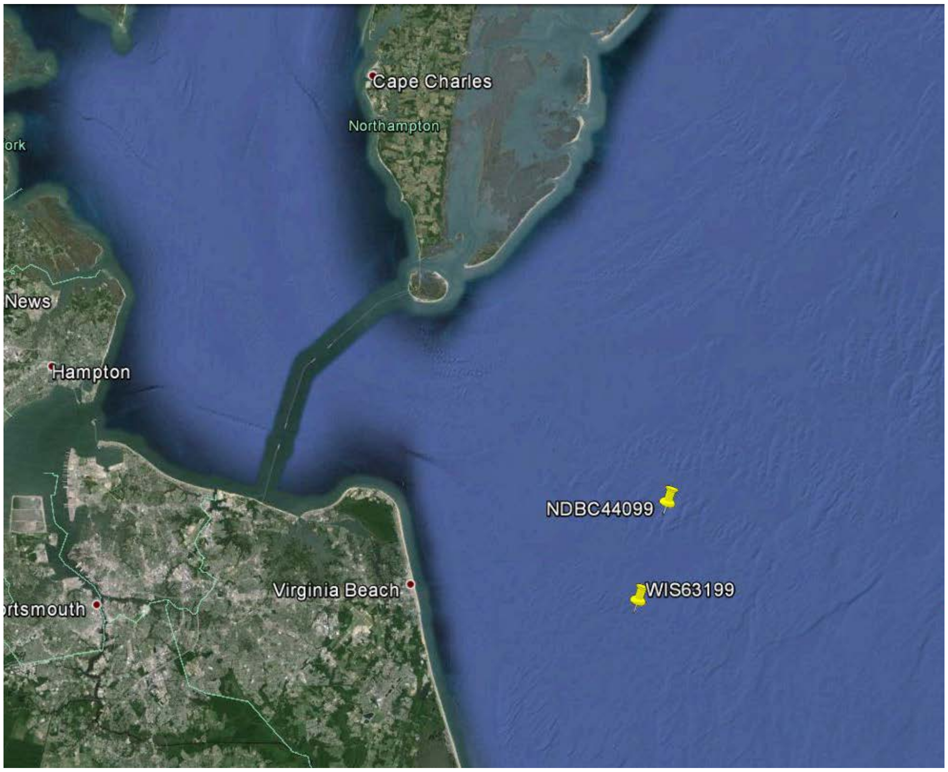
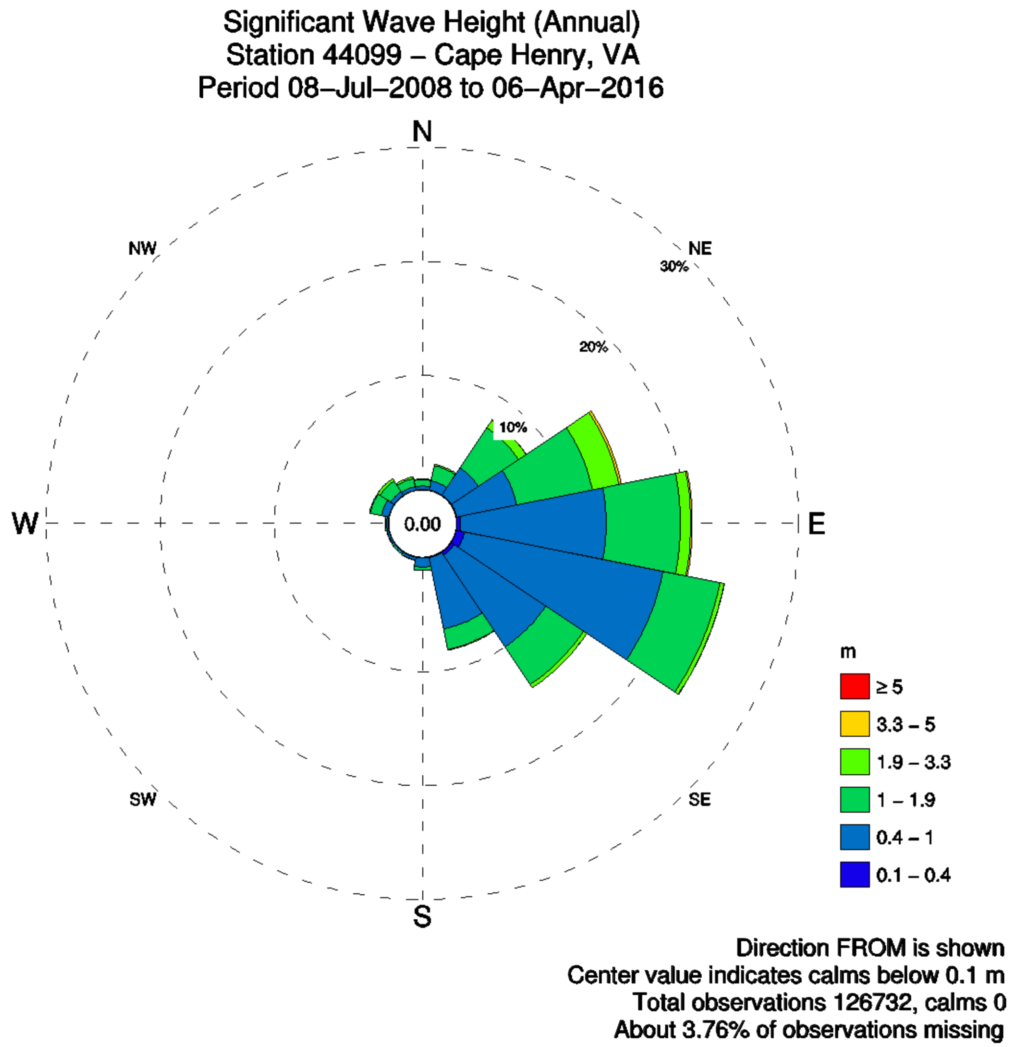


Figure 10: Wave Data Locations



Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	0.91	2.29	7.93	14.76	20.66	23.98	14.33	8.32	1.13	0.30	0.22	0.21	0.28	1.74	1.75	1.20	100.00
5																	
3.3 – 5				0.22	0.12												0.40
1.9 – 3.3		0.12	0.80	2.38	0.92	0.37	0.35								0.25	0.17	5.59
1 – 1.9	0.53	1.35	4.23	6.77	6.51	5.08	3.97	1.84	0.30				0.11	1.00	1.13	0.73	33.65
0.4 – 1	0.30	0.81	2.87	5.35	12.75	17.75	9.69	6.38	0.81	0.24	0.20	0.16	0.16	0.67	0.36	0.30	58.81
0.1 – 0.4					0.35	0.75	0.32										1.55

Figure 11: Wave Data Locations

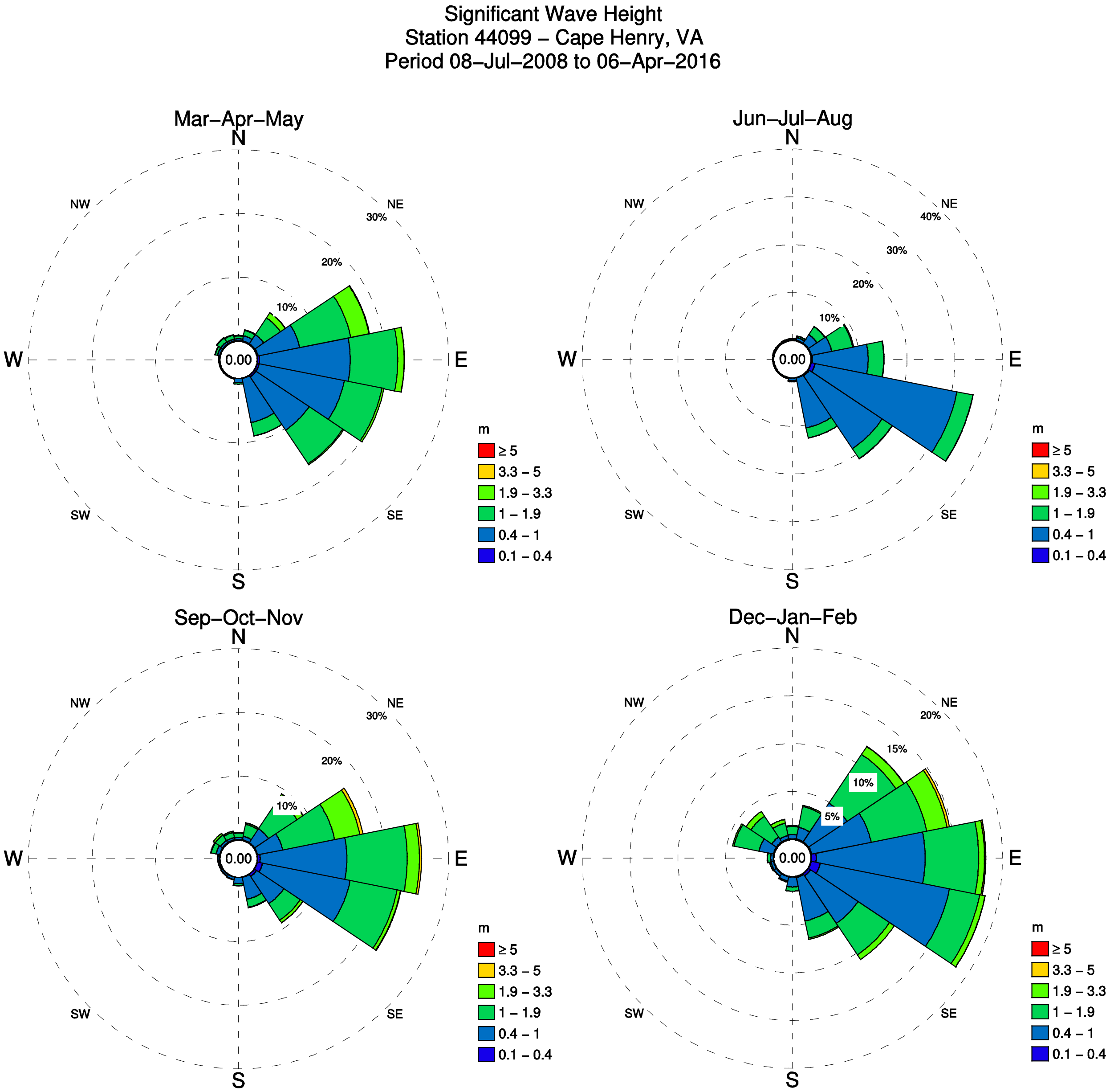


Figure 12: Wave Data Locations

Wave data were required for this study and the companion sediment budget study (in progress) for the time period from 2003 to 2015. A single complete time series of offshore wave conditions was developed by using the WIS data from 2003 to mid-2008 to supplement the NDBC measured data from mid-2008 to 2015. Analysis of statistics from the two data sets for overlapping time periods indicated that wave heights from the WIS data generally overpredicted the NDBC wave heights, and the WIS wave heights were reduced to account for this difference when creating the combined series.

Using a threshold of significant wave height greater than 11.5 feet (3.5 m), a total of 21 historical storms were extracted from the combined offshore wave data set from 2003 to January 2016. Time series plots of these storms are included as Appendix C. Table 3 summarizes these storms by date, peak offshore significant wave height ($H_{1/3}$), with an indication of the peak water level elevation at the closest operating NOAA tide station number 8638863 at the Chesapeake Bay Bridge Tunnel. Over the 12 years represented in Table 3, seventeen of the 21 storms (81%) occurred in winter, and four storms (19%) occurred in summer. This is based on defining wave climate in two seasons instead of four, with “winter” including November through April and “summer” including May through October. Winter storms are shaded blue in the table, and summer storms are shaded yellow.

Table 3 also includes an indication of the likely predominant sand transport direction induced by each storm. Likely South-to-north transport storm events are shaded green, and likely north-to-south transport storm events are shaded purple. All four of the summer storms indicated south-to-north transport, while a mix of potential transport direction is indicated for winter storms. Storms from 2013 to 2016 indicate north-to-south transport more frequently than storms from 2003 to 2012. This is consistent with the differences in annual wave roses discussed above, and may be further indication of reasons behind the shoreline retreat noted from aerial photos since 2012 (see Section 5.3). It is noted that waves would transform in direction as they approach nearshore, so this is an approximate indication only. The actual direction of transport in each storm would depend on the specific duration and intensity of nearshore transformed waves from various directions. This is beyond the scope of the present study but is addressed in the companion sediment budget study (in progress).

As an example of the effects of storm waves at Croatan Beach, Figure 13 illustrates the winter storm occurred in January 2016. The peak significant wave height offshore was approximately 17 feet, occurring from east-northeast. As noted during the March 2016 site inspection, the dune in the north segment of Croatan Beach was approximately 10 feet landward of the dune position visible in the November 2015 aerial image, implying significant beach and dune erosion due to the January 2016 storm.

Table 3: Storm Wave Height and Potential Sediment Transport Direction

No.	date	Max. Significant Wave Height Hs (ft)	Max. Water Elevation (ft, MLW)	Potential Sediment Transport Direction
1	Sep 2003	17.2	7.4	South to North
2	Feb 2005	12.2	3.7	North to South
3	Apr 2005	14.0	4.1	South to North
4	Sep 2006	12.6	5.4	South to North
5	Nov 2006	14.8	6.7	South to North
6	May 2007	14.5	3.8	South to North
7	Nov 2007	13.8	4.8	South to North
8	Nov 2008	11.6	3.9	South to North
9	Nov 2009	14.6	7.3	North to South
10	Dec 2009	15.3	6.1	South to North
11	Feb 2010	13.9	5.3	South to North
12	Nov 2011	12.4	4.8	North to South
13	Nov 2012	15.9	6.9	South to North
14	Feb 2013	11.7	4.5	South to North
15	Mar 2013	13.7	4.8	North to South
16	Jan 2014	12.0	5.3	North to South
17	Mar 2014	12.6	4.3	North to South
18	Nov 2014	12.8	4.8	North to South
19	Dec 2014	11.9	4.9	North to South
20	Oct 2015	13.4	5.7	South to North
21	Jan 2016	17.0	5.5	North to South

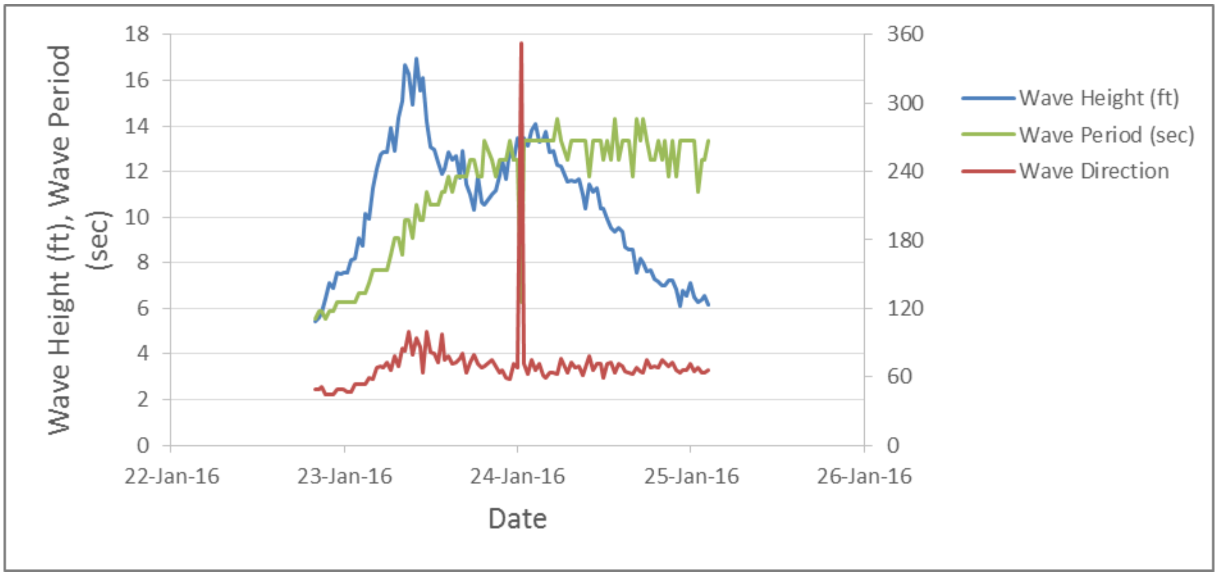


Figure 13: Winter Storm of January 2016

5. Historical Shoreline Change Assessment

Historical Croatan Beach shoreline and dune line positions were evaluated to assess long-term and recent short-term trends relative to subaerial beach width from Rudee Inlet south to the northern beach boundary of Camp Pendleton.

M&N obtained GIS shapefiles of the shoreline positions from the latest VIMS shoreline evaluation for the area (VIMS, 2012); this data set included shorelines from 1937, 1954, 1970, 1980, 1994, 2002, 2009, and 2011. The VIMS data set was supplemented with shoreline positions digitized by M&N from high-resolution satellite images at various dates between 2007 and 2014; the images were obtained by M&N through a registered installation of Google Earth Pro. The shoreline positions in each data set represent the approximate shoreline position apparent from aerial or satellite images, with uncertainties in shoreline position deriving from inherent image source limitations such as image quality and resolution, tidal excursions, image rectification and georeferencing.

Dune line positions were digitized by M&N from the Google Earth Pro satellite images, and they represent the apparent seaward edge of vegetation or, with less visual certainty, an apparent break between the seaward dune slope and the beach berm.

Shoreline and dune feature positions are also derived from the available City beach profile surveys from dates in 2003, 2006, and 2015. Though data are available for only a few dates, and these dates are widely spaced in time, the survey profiles allow the extraction of the position of specific elevation contours from survey to survey. Thus, the change in position of the MHW contour can represent shoreline change, and the change in the typical dune toe contour can represent dune advance or retreat.

This section of the report documents the apparent shoreline and dune line positions and summarizes calculations of shoreline change, dune position change, and beach width change over time.

5.1. Historical Shoreline and Dune Toe Positions Digitized from Imagery

Table 4 summarizes the dates for which shoreline positions were digitized by either VIMS or M&N from aerial or satellite images. Blue shaded cells indicate shorelines from the winter / mid-spring seasons, when a more northeasterly and stormy wave climate is typically experienced in the project area. The yellow shaded cells indicate shorelines from summer / mid-fall seasons, typically associated with a milder and more southeasterly wave climate in the project area.

Table 4: Dates of Shoreline Positions Digitized from Aerial or Satellite Images

Digitized By	Year	Month
VIMS (2012)	1937	April
	1954	October
	1970	February
	1980	March
	1994	month unknown
	2002	February
	2009	February
	2011	February
M&N (2016)	2006	January
	2007	January
	2008	May
	2009	November
	2010	April
	2011	June
	2012	April
	2012	July
	2013	February
	2014	April
	2015	November

Figure 14 and Figure 15 illustrate the VIMS (2012) shoreline positions for the northern and southern segments (respectively) of Croatan Beach. These historical shorelines spanning decades from 1937 to 2011 do not indicate a consistent long-term or short-term trend of shoreline erosion or accretion. In general, the most landward shoreline position is from February 2002, though the March 1980 shoreline is shown to be landward of the 2002 shoreline in the block south of Twilight Lane. Over most of Croatan Beach's length, the 1994 shoreline was further seaward than any of the other years' shorelines except for the effectively pre-inlet 1937 position. Very little variance in shoreline position is seen, except for the 2002 position, immediately south of the weir and sand trap. This indicates that the weir has a strong influence on shoreline position over a short distance southward. However, it does not appear that the weir has a strong direct influence on shoreline position as far south as Twilight Lane.

Figure 16 and Figure 17 show the shoreline positions from 2011 to 2014 digitized by M&N for the northern and southern segments of Croatan Beach. The dune toe position apparent from the Google Earth Pro images is also shown, including additional years of 2007, 2009, and 2016 dune positions. These shoreline positions indicate that the shoreline has retreated from 2011 to 2014, though it has not retreated as far landward as the VIMS-digitized 2002 position. The magnitude of the retreat between 2011 and 2014 is greater in the north, between the weir and Twilight Lane, than it is in the southern segment of Croatan Beach. In the blocks north and south of Twilight Lane, the dune position advanced seaward during 2011 to 2014, though at a slower rate than the shoreline retreated.

Figure 14: Historical Shoreline Positions by VIMS (north)

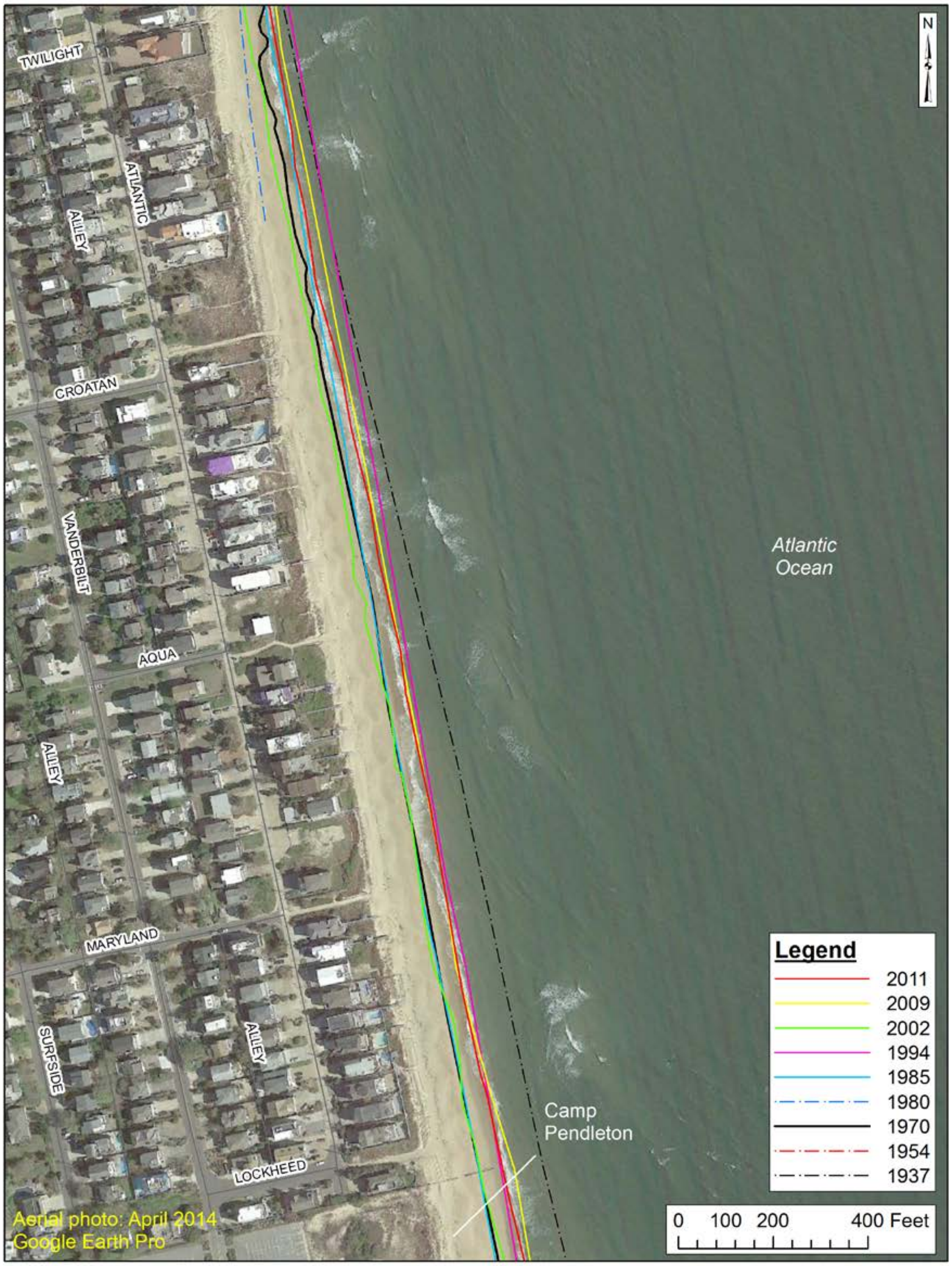


Figure 15: Historical Shoreline Positions by VIMS (south)

Figure 16: Historical Shoreline and Dune Toe Positions by M&N (north)

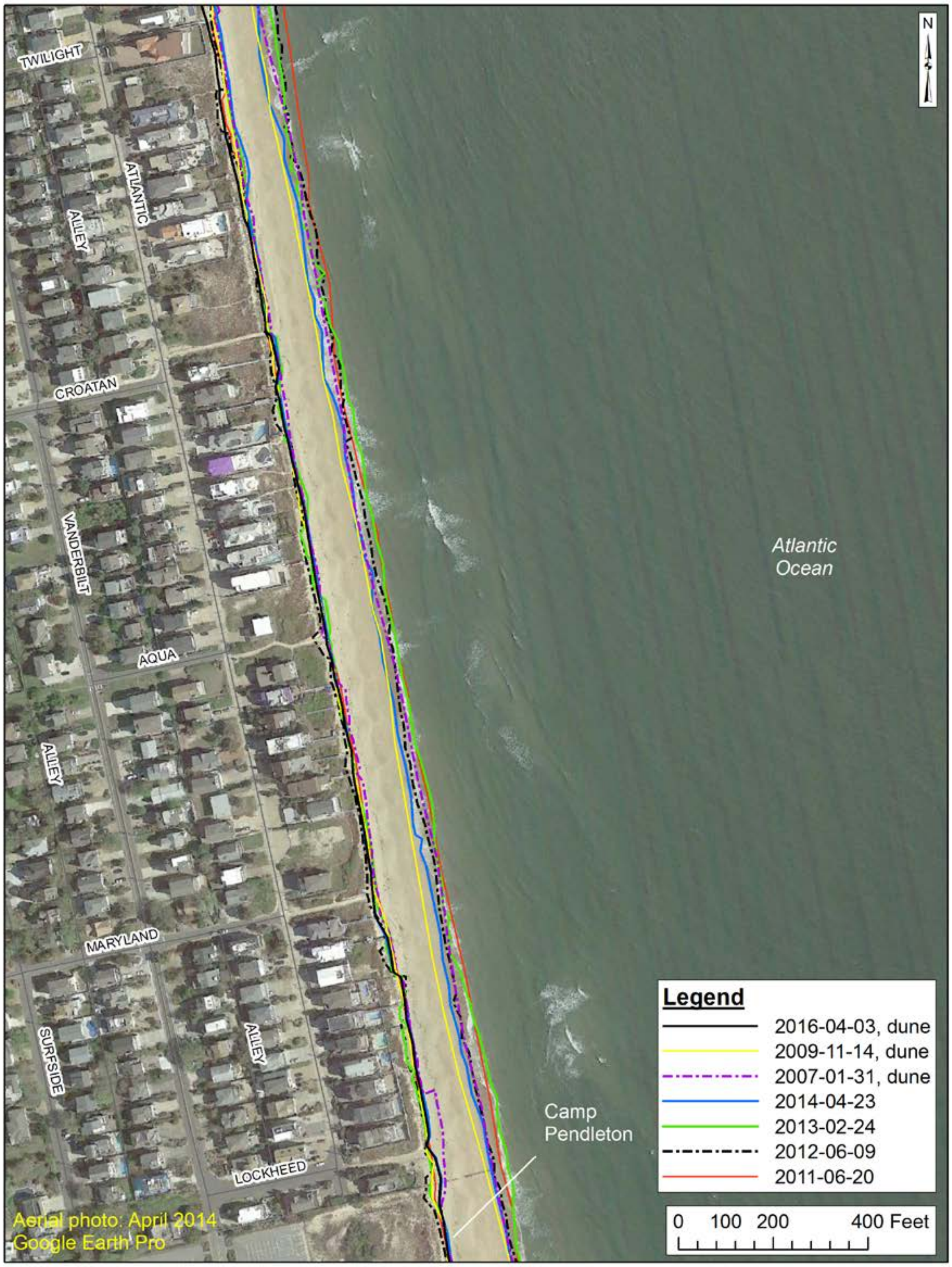


Figure 17: Historical Shoreline and Dune Toe Positions by M&N (south)

Detailed graphs and tabulations of shoreline change from both the VIMS and M&N digitized shorelines are presented later this report, following a discussion of the City profile survey data.

5.2. Historical Beach Profiles

5.2.1. City of Virginia Beach Survey Profiles

The surveying group of the City's Public Works Department provided beach profile surveys collected on various dates in 2003, 2006 and 2015. The survey data were collected along transects spaced approximately 500 feet apart as shown in Figure 18, beginning south of the weir (Station 0+00) and extending south towards Lockheed Ave (Station 35+00).

The data were provided to M&N in AutoCAD files. M&N extracted the elevation data points and referenced them to a common baseline, also shown in Figure 18. Stations along this baseline will be referenced throughout this report to describe historical and existing conditions and to discuss beach profile model simulations.

The City survey profiles included portions of the dune, the subaerial beach, intertidal zone, and in some cases the nearshore submerged profile to distances exceeding 2,500 feet seaward of the baseline. Table 5 summarizes the dates of the City's beach profile surveys provided to M&N for this study. The cross-shore extent of coverage is not the same between each of the survey dates. Plots of the historical beach profile surveys at all eight survey stations are included in Appendix D report.

Table 5: Dates of City Surveyors' Beach Profile Surveys

Year	Date	Extent
2003	April 4	Submerged profile
2003	June 23	Dune toe, beach and submerged profile
2003	August 21	Dune toe, beach and submerged profile
Hurricane Isabel		
2003	September 27	Dune and beach above MLW
2006	January 13	Dune toe, beach and submerged profile
2006	May 19	Dune toe, beach and submerged profile
2006	October 4	Dune toe, beach and submerged profile
2015	April 6	Submerged profile
Hurricane Joaquin and nor'easter		
2015	November 6	Dune, beach, and submerged profile
Winter Storm Jonas		
2016	August 30	Dune and beach above approx. +2 ft MLW

As Table 5 indicates, Hurricane Isabel passed Virginia Beach in mid-September, 2003. The survey profiles in Figure 19 through Figure 26 show the effects of the elevated water levels and storm waves on the beach. In these figures, the blue and green lines represent the pre- and post-Hurricane Isabel profiles, respectively. The red line indicates the most recent available survey data from November 2015, a few weeks after Hurricane Joaquin and multiple nor'easter events impacted the area. Though the pre-Isabel profiles did not reach as high as the dune crest, and the post-Isabel profiles did not extend into the nearshore submerged area, it can be seen that Hurricane Isabel caused erosion of the subaerial beach and retreat of the dune face at all of the stations.

In November 2015, the subaerial beach profile up to the toe of the dune (elevation approximately +10 feet MLW) was landward of both the pre- and post-Isabel profile.

Figure 18: Baseline and Station Location

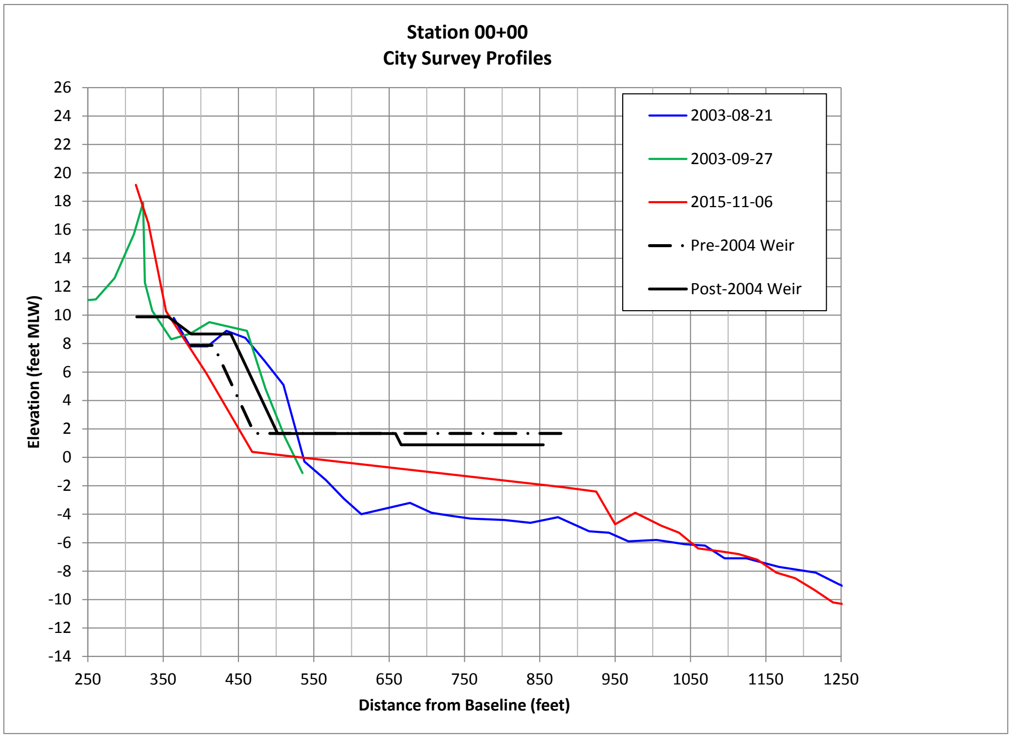


Figure 19: Selected City Survey Profiles, Station 00+00

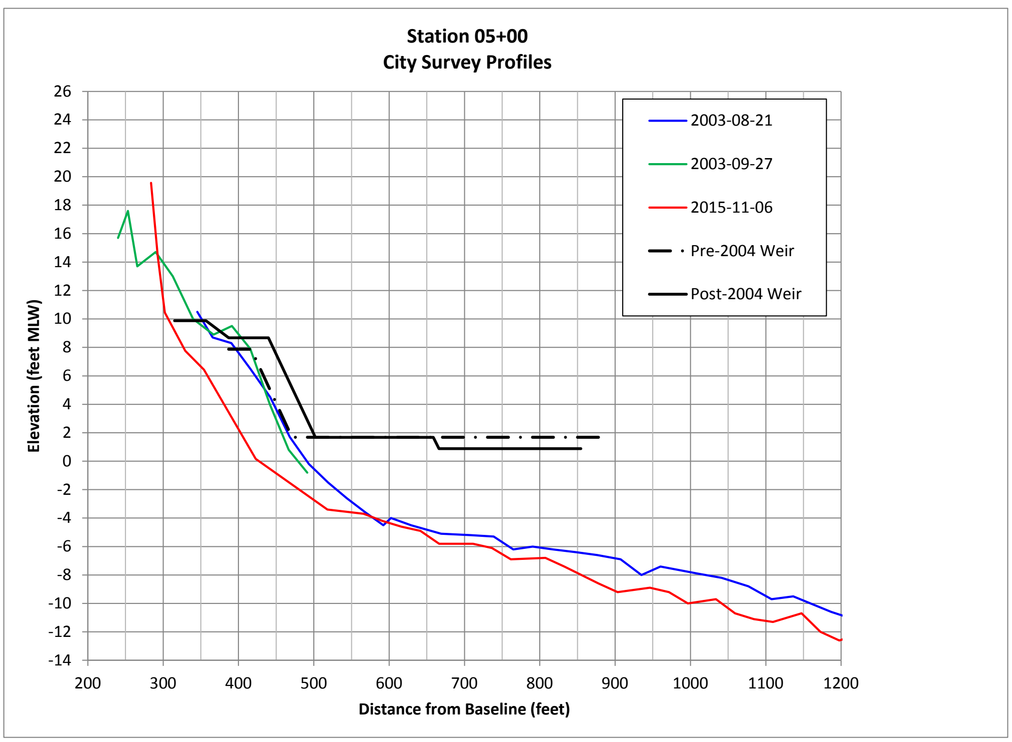


Figure 20: Selected City Survey Profiles, Station 05+00

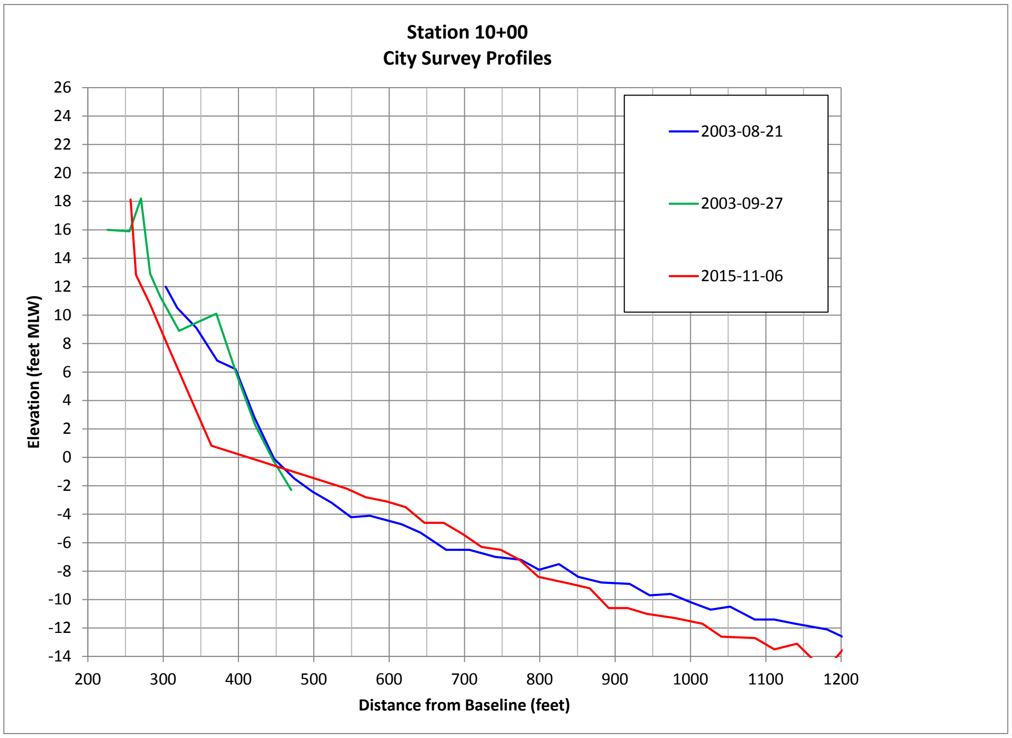


Figure 21: Selected City Survey Profiles, Station 10+00

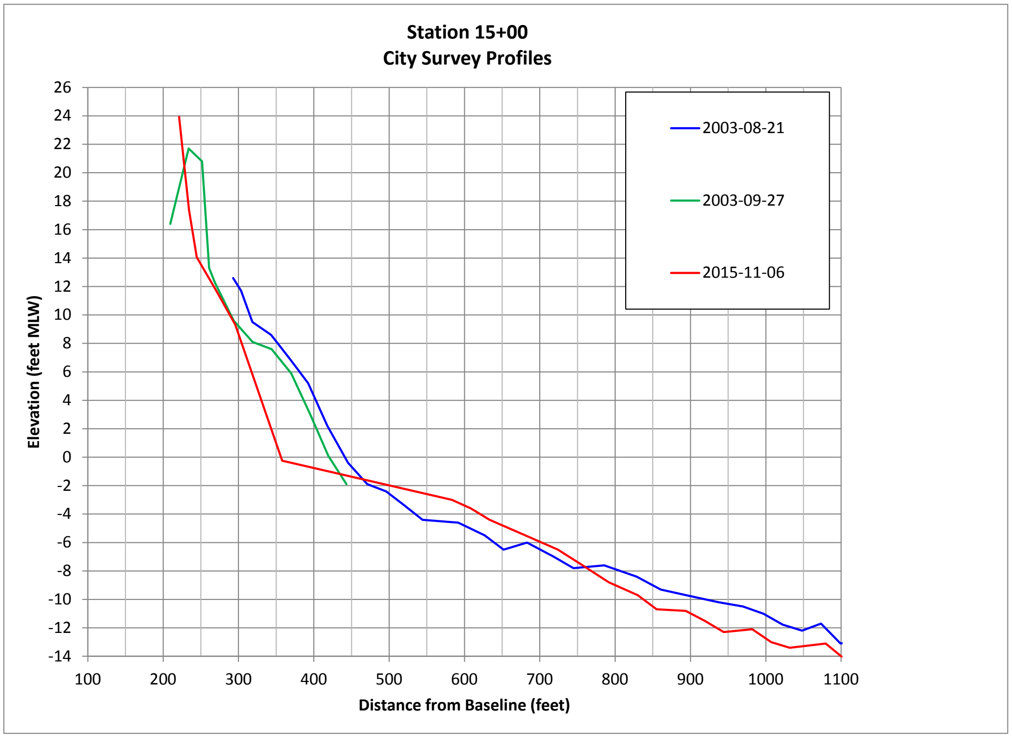


Figure 22: Selected City Survey Profiles, Station 15+00

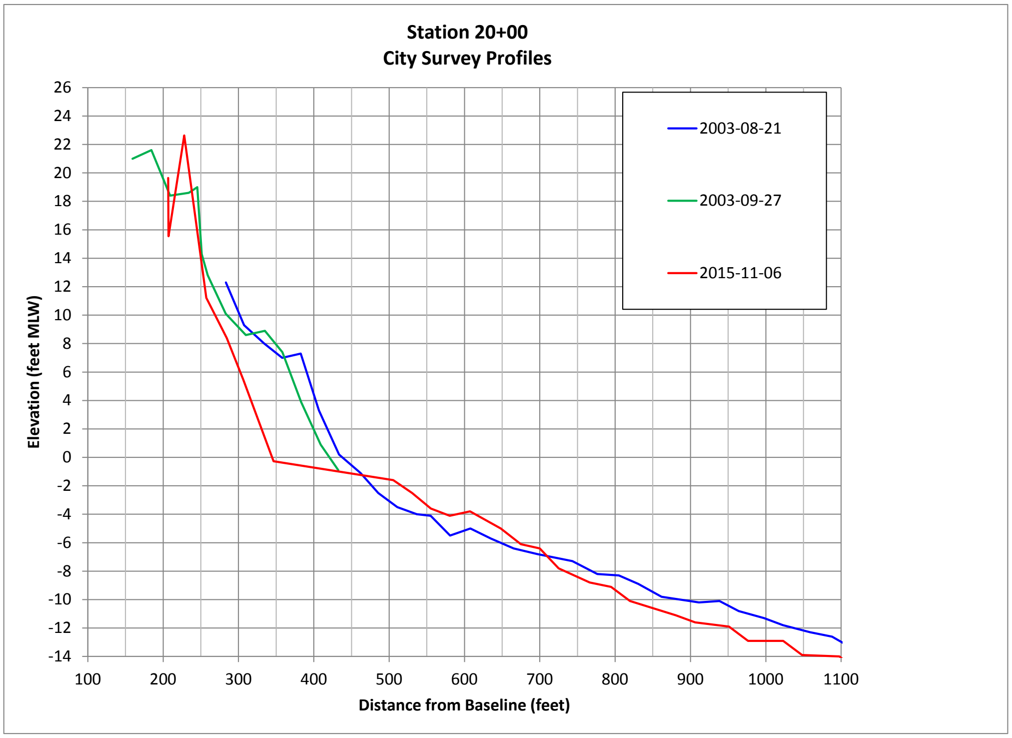


Figure 23: Selected City Survey Profiles, Station 20+00

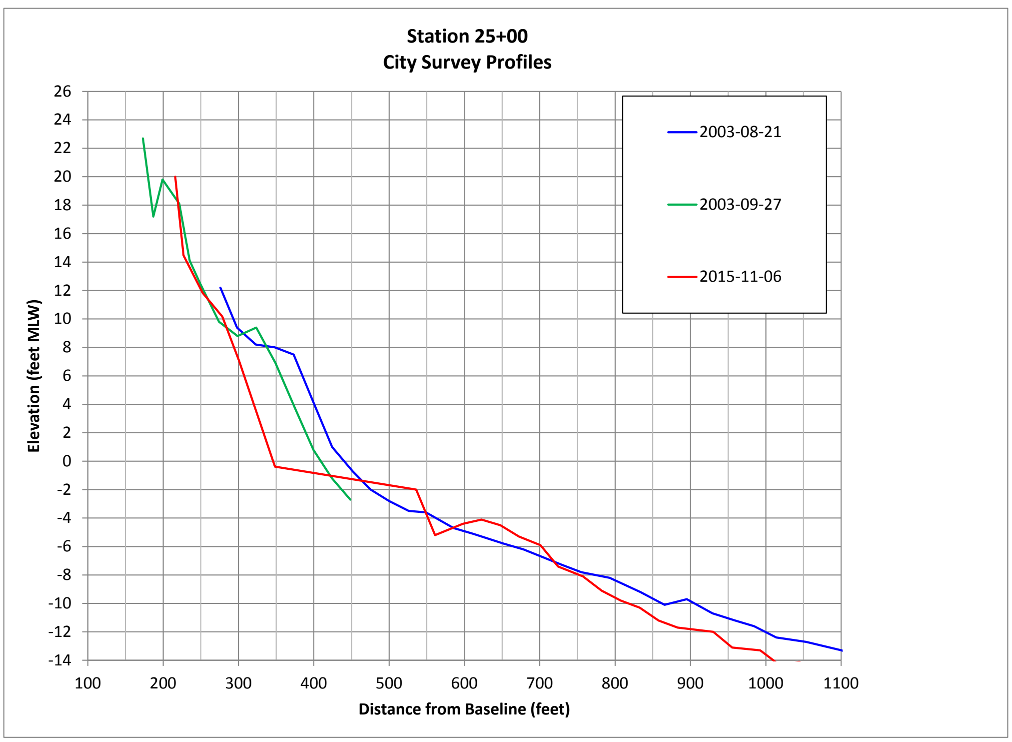


Figure 24: Selected City Survey Profiles, Station 25+00

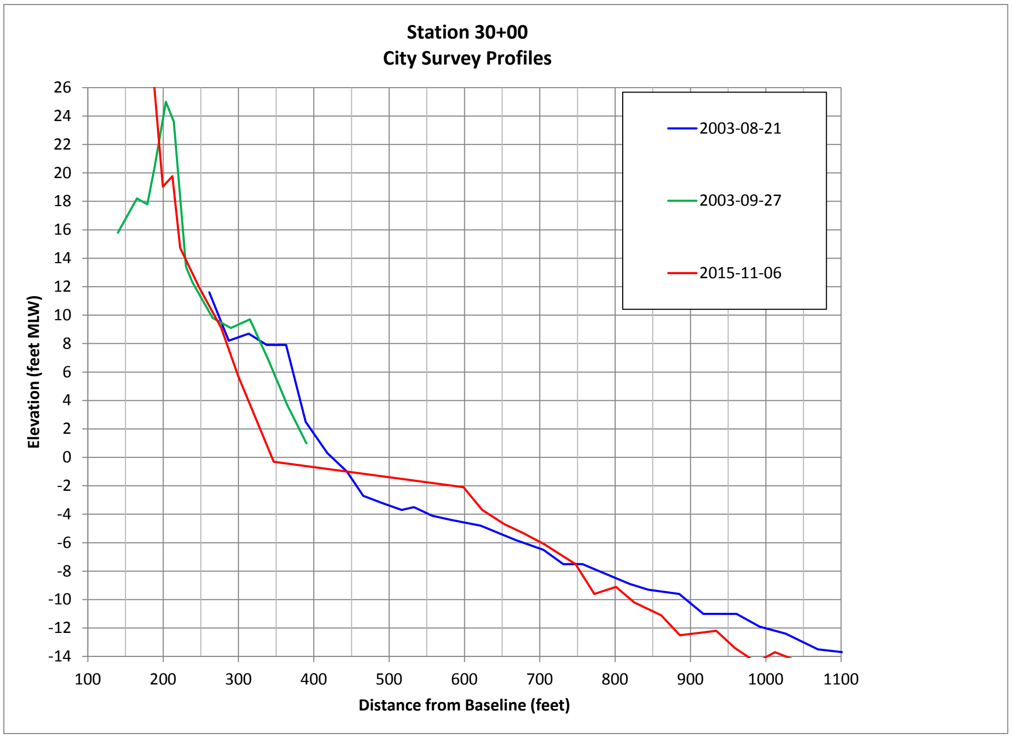


Figure 25: Selected City Survey Profiles, Station 30+00

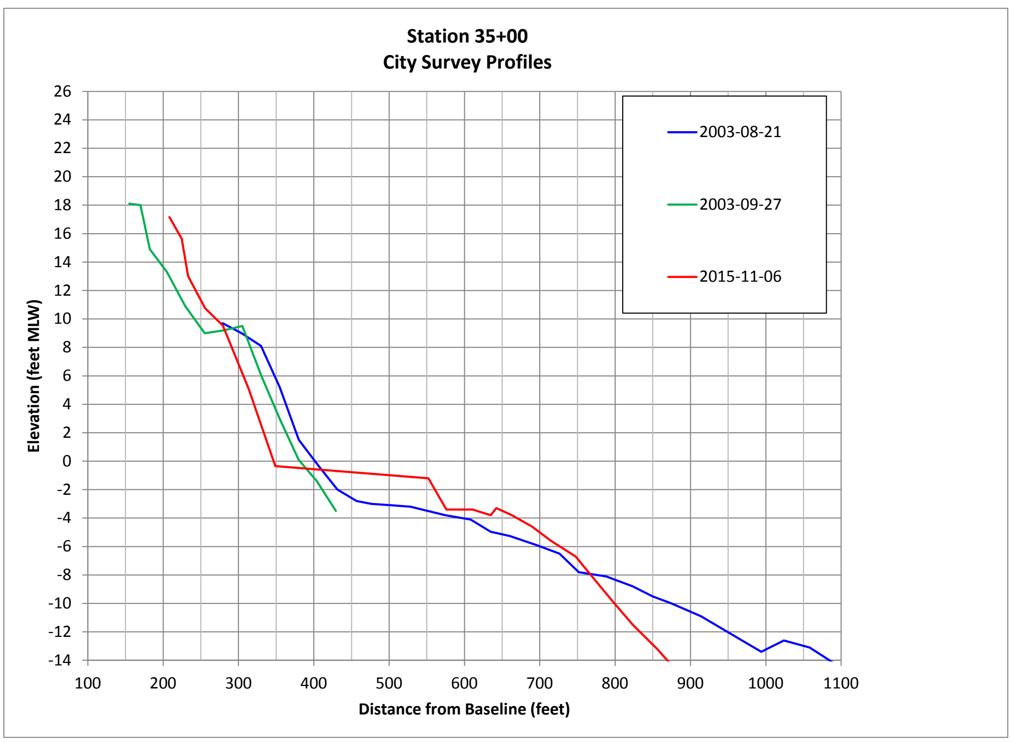


Figure 26: Selected City Survey Profiles, Station 35+00

5.2.2. ODU Beach Profile Data Analysis

Dr. David Basco and associates from Old Dominion University's Coastal Engineering Institute (Basco, 1994) evaluated historical survey profiles along various segments of the Virginia Beach shoreline. Profile data from several dates between October 1980 and July 1993 were evaluated at two transects on Croatan Beach. The transect locations are shown in Figure 27, excerpted from (Basco, 1994). Figure 28 and Figure 29 show Dr. Basco's plots of shoreline position and shoreline change trends at both of the Croatan Beach transects. At both locations, the shoreline advanced seaward from 1980 to 1993. The rate of shoreline advance was greater at the north end of the beach than at the south end near the boundary with NAS Oceana Dam Neck Annex. Taking the two transects together and computing a weighted average of all the profile dates, Dr. Basco estimated a shoreline position change rate of +6.1 feet per year (ft/yr) and a volume change rate of +1.8 cubic yards per foot per year (cy/ft/yr) for Croatan Beach from October 1980 to June 1993.

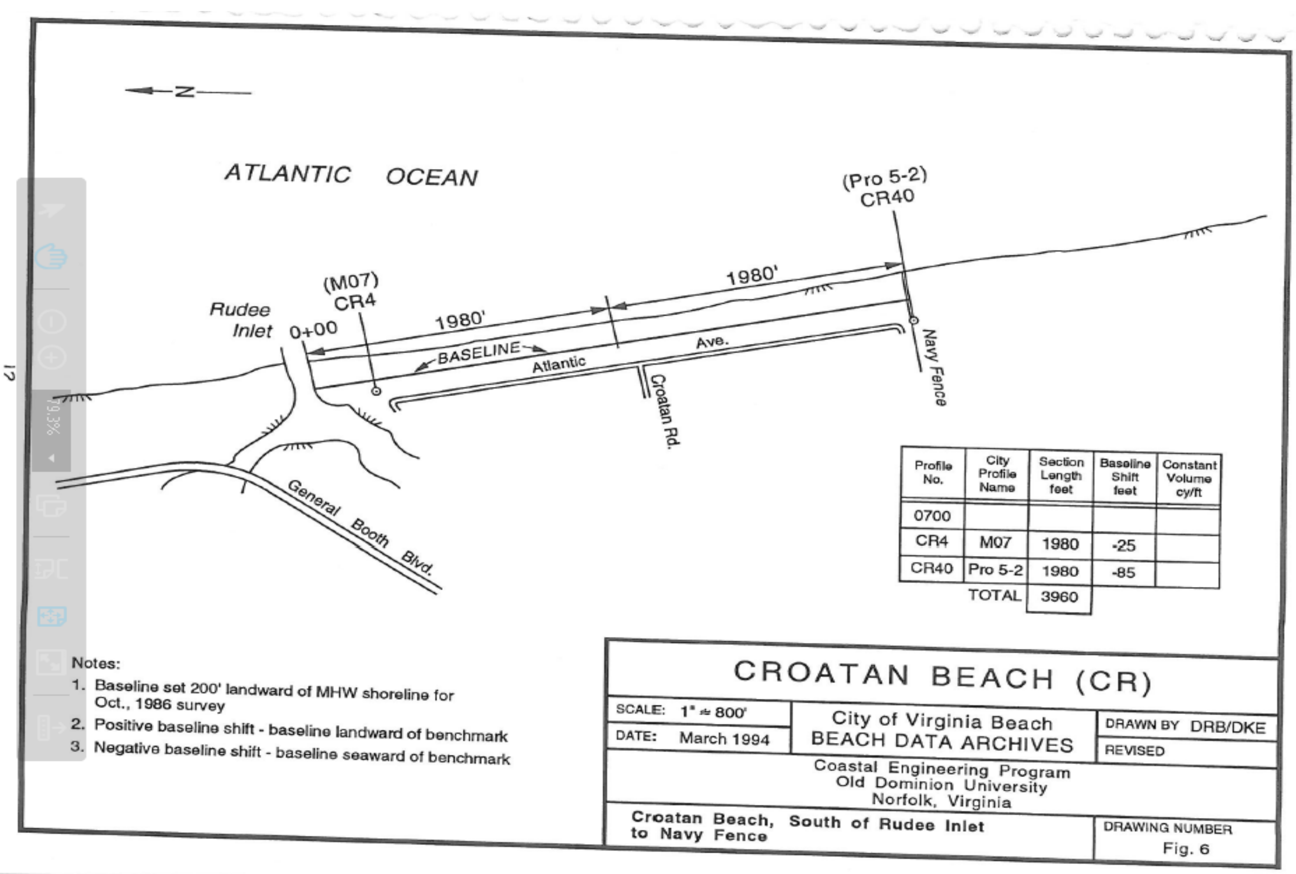


Figure 27: Croatan Beach Transects Studied in (Basco, 1994)

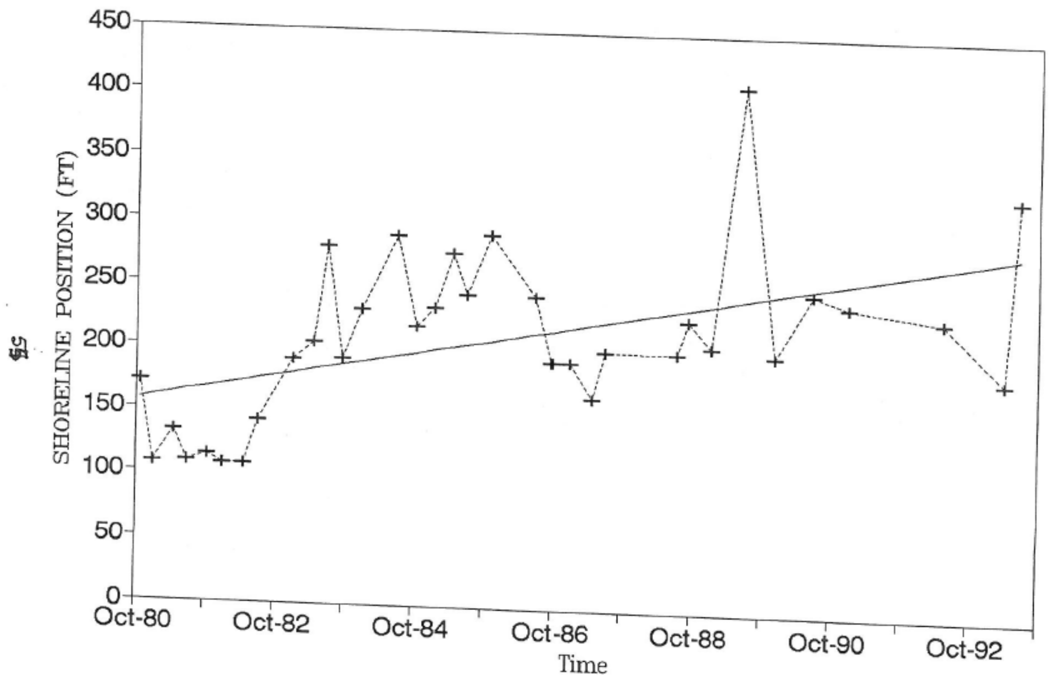


Fig. 39 Shoreline Position Change in Time at Croatan Beach Profile CR40 (MO7)

Figure 28: Shoreline Change 1980-1993 at Northern Croatan Beach (from Basco, 1994)

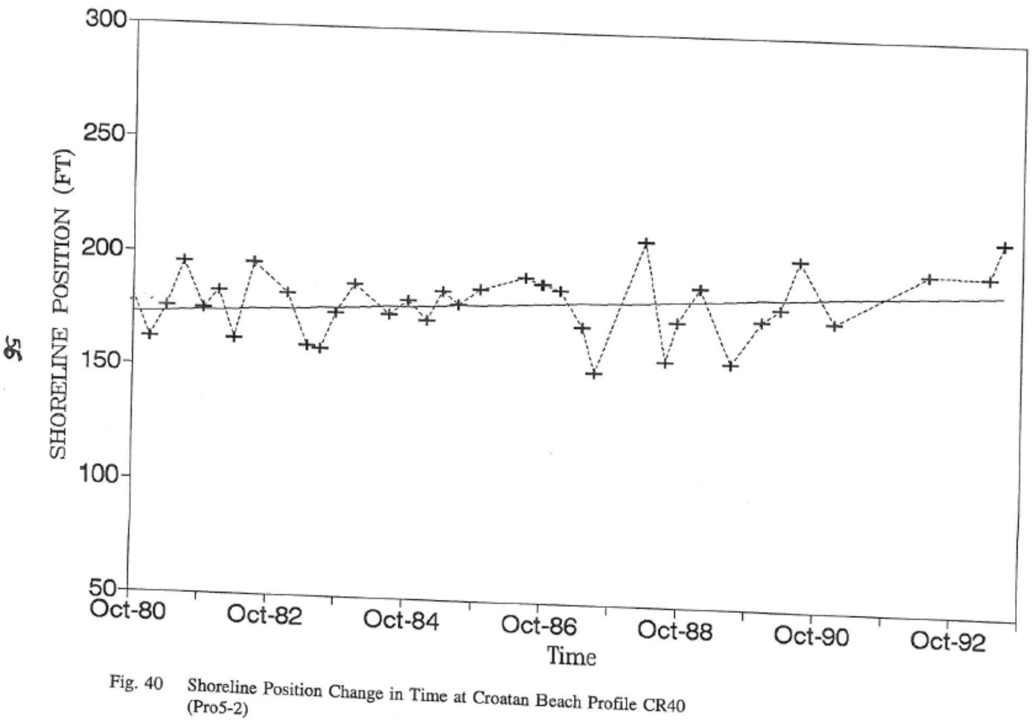


Figure 29: Shoreline Change 1980-1993 at Southern Croatan Beach (from Basco, 1994)

5.3. Shoreline and Dune Toe Position Change

Shoreline changes and the volumetric changes were computed from the VIMS- and M&N-digitized shorelines and from the City survey profiles at the eight City survey transects locations (stations 00+00 through 35+00). The changes were evaluated separately between winter season and summer season data points. As discussed above, for the purposes of this shoreline and dune change study, the winter season is defined as the months of November through April, and the summer season consists of May through October.

Figure 30 shows a time series progression of VIMS- and M&N-digitized shoreline position (distance from baseline) at each of the eight survey transect stations, from 1970 to 2014. Shorelines from 1970 to 2011 are by VIMS (2012), and shorelines from 2012 through 2014 are by M&N. The May, June, and July 2012 shorelines digitized by M&N are excluded from the chart, as all of the other shoreline positions were from imagery captured in winter season months. Vertical dashed lines indicate the dates of known beach fill projects undertaken by the City; these were generally small dune or dry beach restoration projects. The chart in Figure 30 shows that the Croatan Beach shoreline has not simply advanced or retreated consistently over the past several decades. The figure confirms that the shoreline was furthest landward in 2002. End-point shoreline change calculations reveal the changes at each station summarized in Table 6. The data indicate that the shoreline position between the weir and Twilight Lane (station 10+00) has retreated in the long-term, from 1970 – 2014. This calculation is largely due to the significantly greater retreat – compared to the other stations – that occurred between 1970 and 2002. From 2002 to 2014, which includes the 10 years after the weir was modified in 2004, the shoreline advanced seaward at all stations, with some of the greatest advance seen between the weir and Twilight Lane. Finally, from April 2014 to November 2015 the shoreline retreated along the entire length of Croatan Beach; the most retreat occurred between Twilight Lane and Croatan Road.

The more frequent data points from 2009 to present may give a sense that the shoreline has been less stable in recent years; however, it is more likely that the shoreline went through periods of advance and retreat in prior decades that is not captured by the widely-spaced data point prior to 2009.

The content of Figure 31 is identical to Figure 30, with a shorter time axis focusing on the time period since the 1994 shoreline position from VIMS (2012). Subsequent figures illustrating shoreline positions and dune toe positions from City surveys utilize the same time axis as Figure 31 for convenience in comparing data sets.

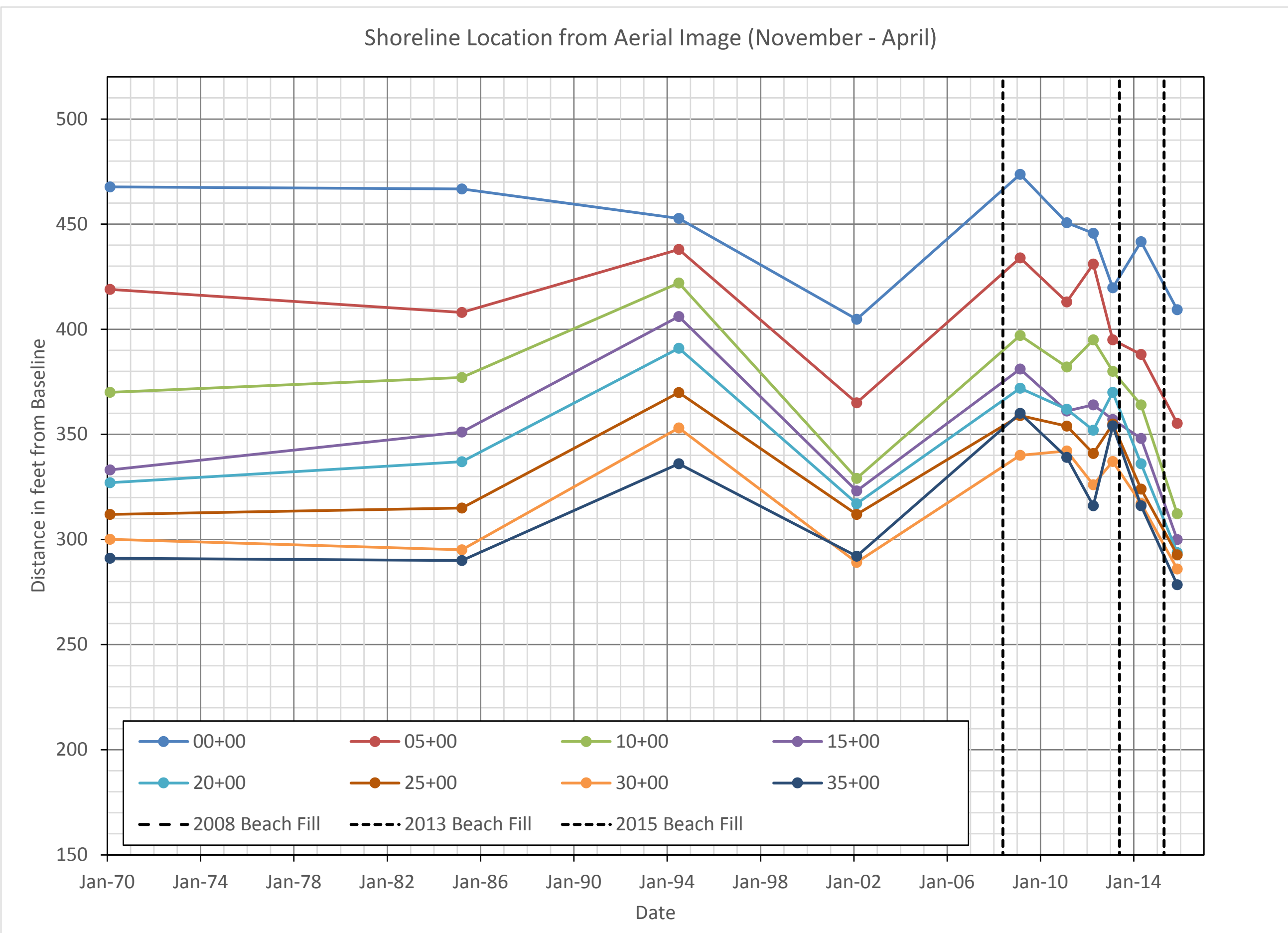


Figure 30: Shoreline Location from Aerial Image, 1970-2015 (Winter Season)

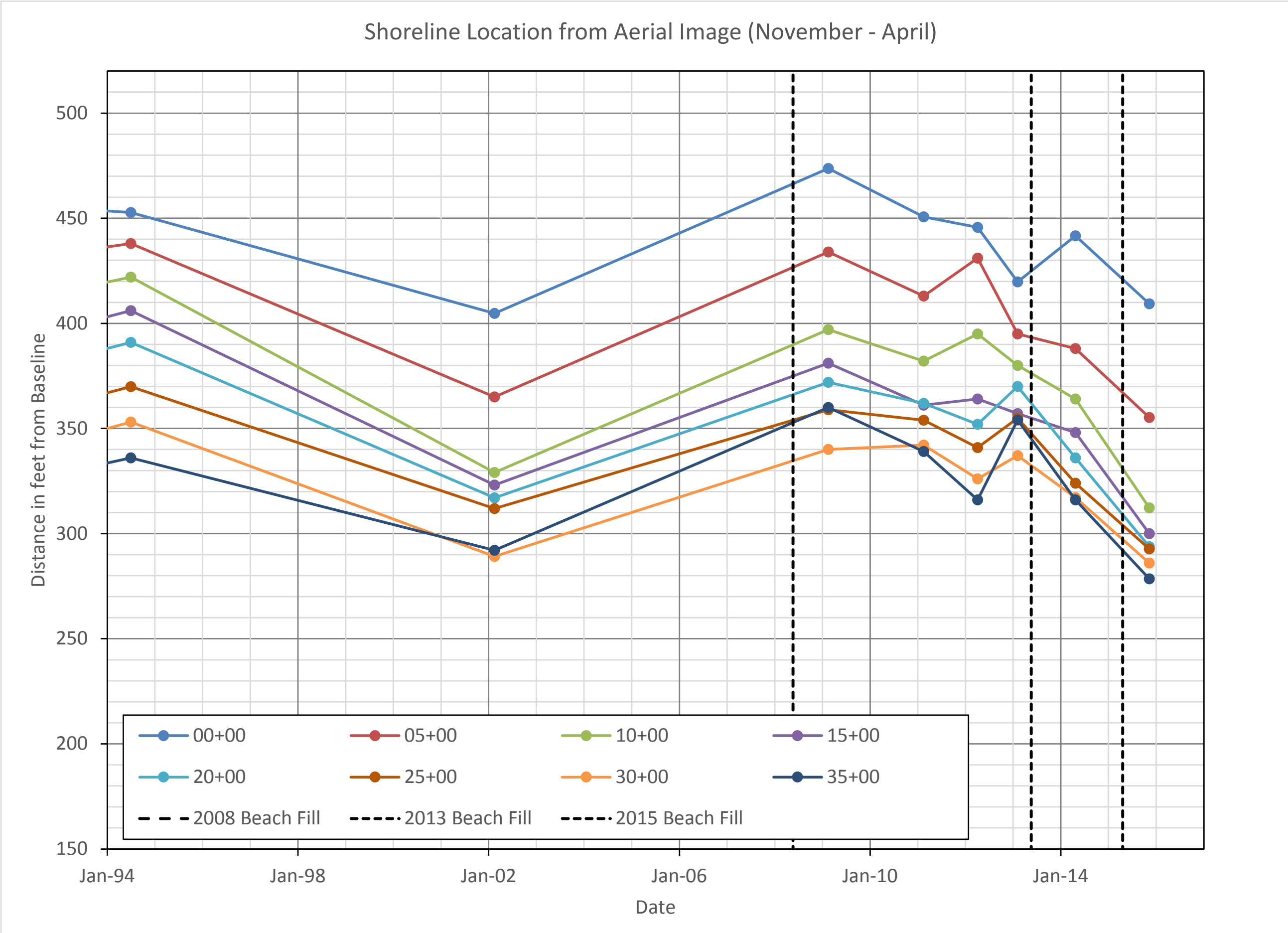


Figure 31: Shoreline Location from Aerial Image, 1994-2015 (Winter Season)

Table 6: Historical Shoreline Changes from Digitization of Aerial and Satellite Imagery

Transect Station	Shoreline Change 1970-2002, feet	Shoreline Change 2002-2014, feet	Shoreline Change 1970-2014, feet	Shoreline Change 2014-2015, feet
00+00 Virginia Dare Dr.	-63	37	-26	-32
05+00	-54	23	-31	-33
10+00 Twilight Lane	-41	35	-6	-52
15+00 North of Croatan Rd.	-10	25	15	-48
20+00 South of Croatan Rd.	-10	19	9	-42
25+00 North of Aqua Ln.	0	12	12	-31
30+00 Maryland Ave.	-11	28	17	-31
35+00 Lockheed Ave.	1	24	25	-38

Figure 32 and Figure 33 plot the shoreline position, represented by the position of the MHW elevation contour, derived from the City survey profile data at each of the eight transect stations. Figure 32 shows the summer season profiles, consisting of three survey dates in 2003 (June, August, and September) plus two dates in 2006 (May and October). From June 2003, two months prior to Hurricane Isabel, to October 2006, the Croatan Beach shoreline advanced an average of 16 feet.

Figure 33 shows the winter season profiles, consisting of the January 2006 and November 2015 dates. During that approximate 9.5 year span, the shoreline retreated at all of the survey transects. However, it is noted that the November 2015 survey was taken less than one month after Hurricane Joaquin and multiple nor'easter storms impacted the project area. Thus, the reader is cautioned against using just these two widely-spaced data points to estimate a representative shoreline change rate for general application at Croatan Beach. It is recommended that a more regular program of beach surveys be undertaken at Croatan Beach, which will provide valuable data for a more accurate estimation of representative shoreline and volume change rates.

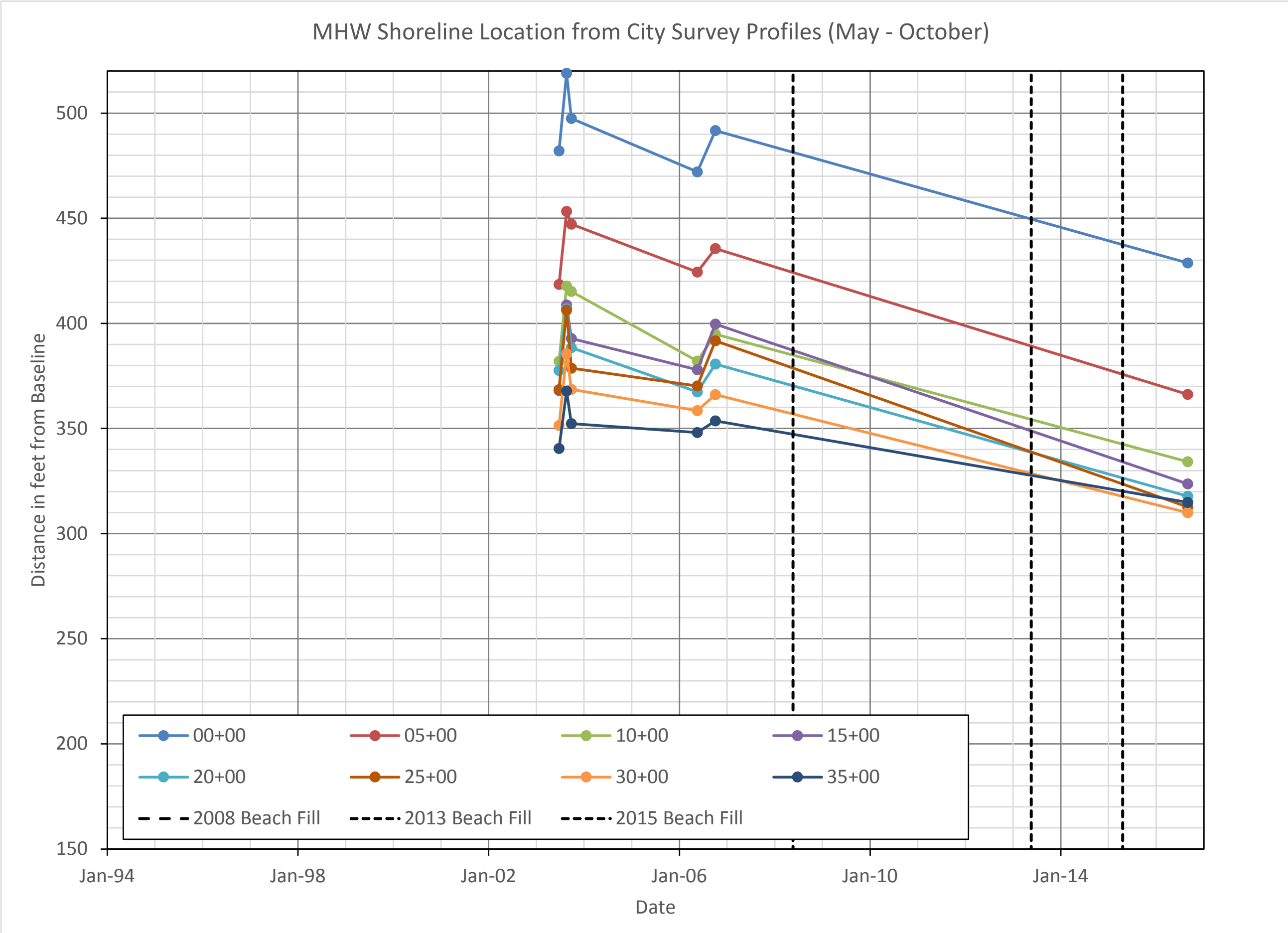


Figure 32: MHW Shoreline Location from City Profile Data (Summer Season)

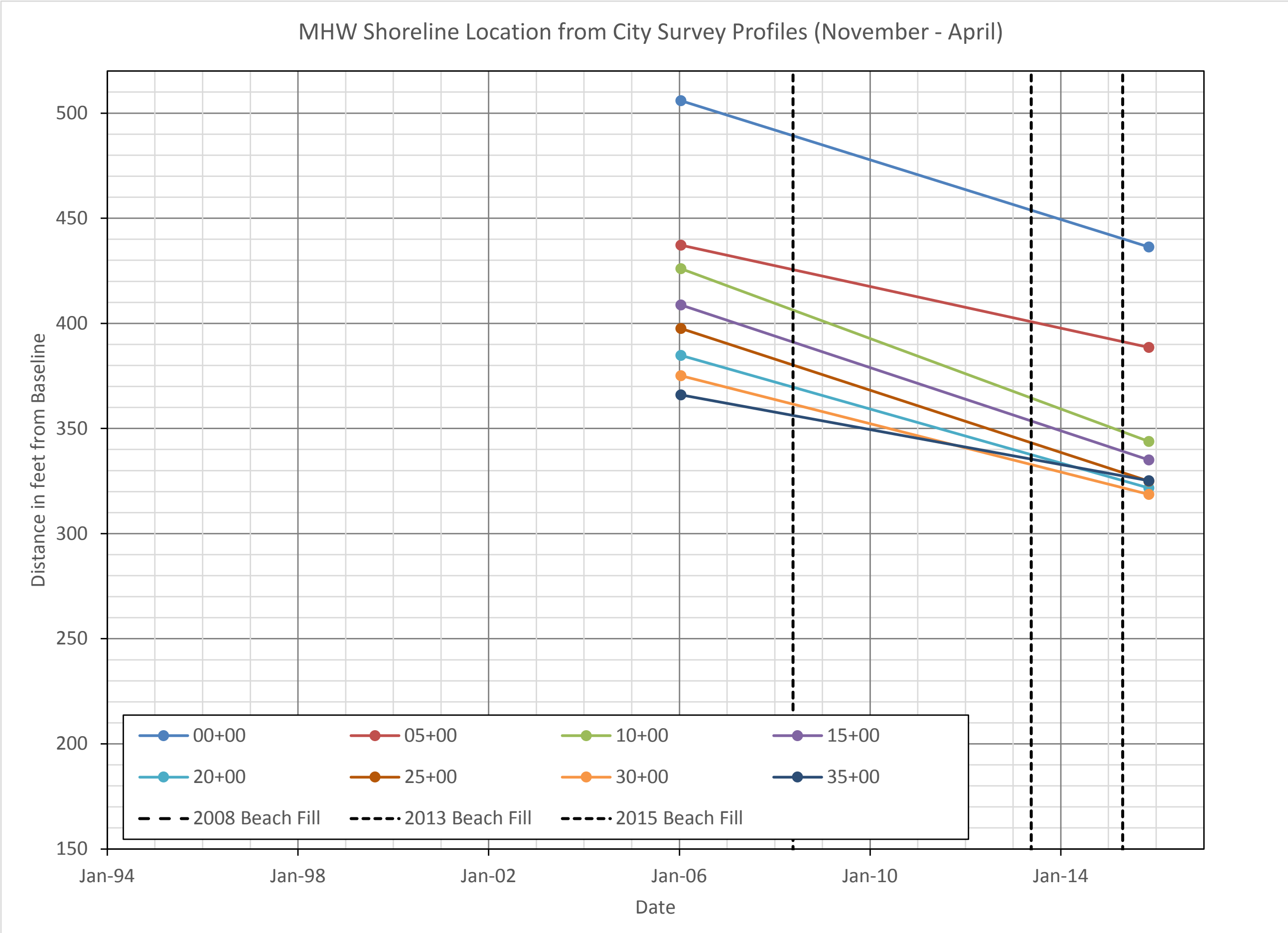


Figure 33: MHW Shoreline Location from City Profile Data (Winter Season)

For documenting changes in dry beach width over time, changes in the dune position – most readily digitized from aerial and satellite imagery as change in the apparent seaward edge of dune vegetation or apparent seaward dune toe – are important to consider in combination with changes in the shoreline position. Figure 34 shows the dune toe positions for both winter and summer seasons, as digitized by M&N from Google Earth Pro satellite images. Figure 34 shows that the dune toe in April 2014 was approximately the same as, or slightly seaward of, the January 2007 position. North of Twilight Lane (stations 00+00 and 05+00), the progression of the dune toe position shows less variability than at the remaining stations from Twilight Lane to the southern end of Croatan Beach. At all stations, the most landward dune toe position occurs in November 2009 and is associated with the impacts of the nor'easter storm (also known as Nor'Ida) that occurred in that month. Varying magnitudes of dune retreat are noted between the July 2012 and February 2013 data points, and it is believed that this dune retreat is associated with passage of Hurricane Sandy in late October 2012.

Between April 2014 and November 2015, the dune toe advanced seaward at the weir (station 00+00) and at all five stations south of Twilight Lane (stations 15+00 through 35+00). The dune toe remained approximately the same at Twilight Lane (station 10+00), and it retreated by approximately 12 feet at station 05+00.

Figure 35 shows the dune toe location extracted from the City survey profile data, taking the location of the +10 ft MLW contour as the dune toe. In contrast to the aerial image-based dune toe movement seen in Figure 34, between January 2006 and November 2015 the position of the +10 ft MLW contour retreated at all stations. The lack of survey data between these two points makes it difficult to put this observation in context. One explanation may be that the dune face in early November 2015 was very steep, reflecting the impacts from the prior month's storms. The dune toe position apparent form the aerial images may be further seaward than the +10 ft MLW contour, while the City survey would have captured the true position of that contour. The most that can be concluded is that the aerial images show a long-term trend of dune toe stability to moderate advance, and the City surveys establish that the +10 ft MLW contour in November 2015 was 20 to 50 feet landward of its position in October 2006. An exception is at station 05+00 north Twilight Lane, where the +10 ft MLW contour is 70 feet landward of its October 2006 position.

The dry beach widths between the shoreline positions and dune toe positions apparent from the aerial images are illustrated in Figure 36. The City survey data indicate different values for beach widths than those apparent from the aerial photos, as indicated in Table 7.

Table 7: Beach Widths from City Survey Data since October 2006

Transect Station	Oct 2006 Beach Width (feet)	Nov 2015 Beach Width (feet)	Aug 2016 Beach Width (feet)
00+00 Virginia Dare Dr.	111.4	79.1	-
05+00	59.4	81.9	61.46
10+00 Twilight Lane	75.1	54.9	54.28
15+00 North of Croatan Rd.	62.8	46.6	59.39
20+00 South of Croatan Rd.	67.9	52.8	60.49
25+00 North of Aqua Ln.	86.4	45.4	60.27
30+00 Maryland Ave.	79.1	50.9	62.5
35+00 Lockheed Ave.	52.9	54.9	69.86

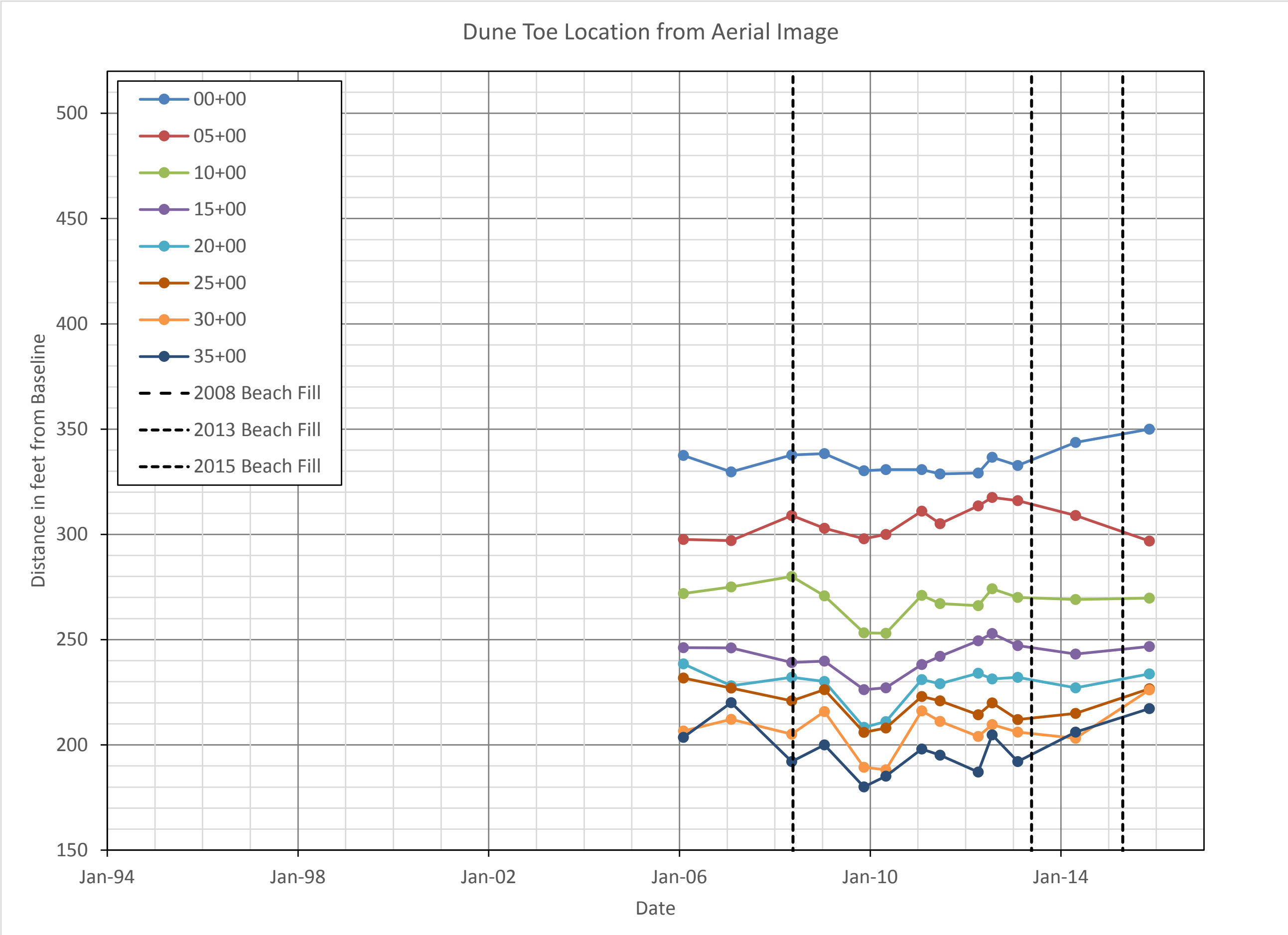


Figure 34: Toe of Dune Location from Aerial Image (All Seasons)

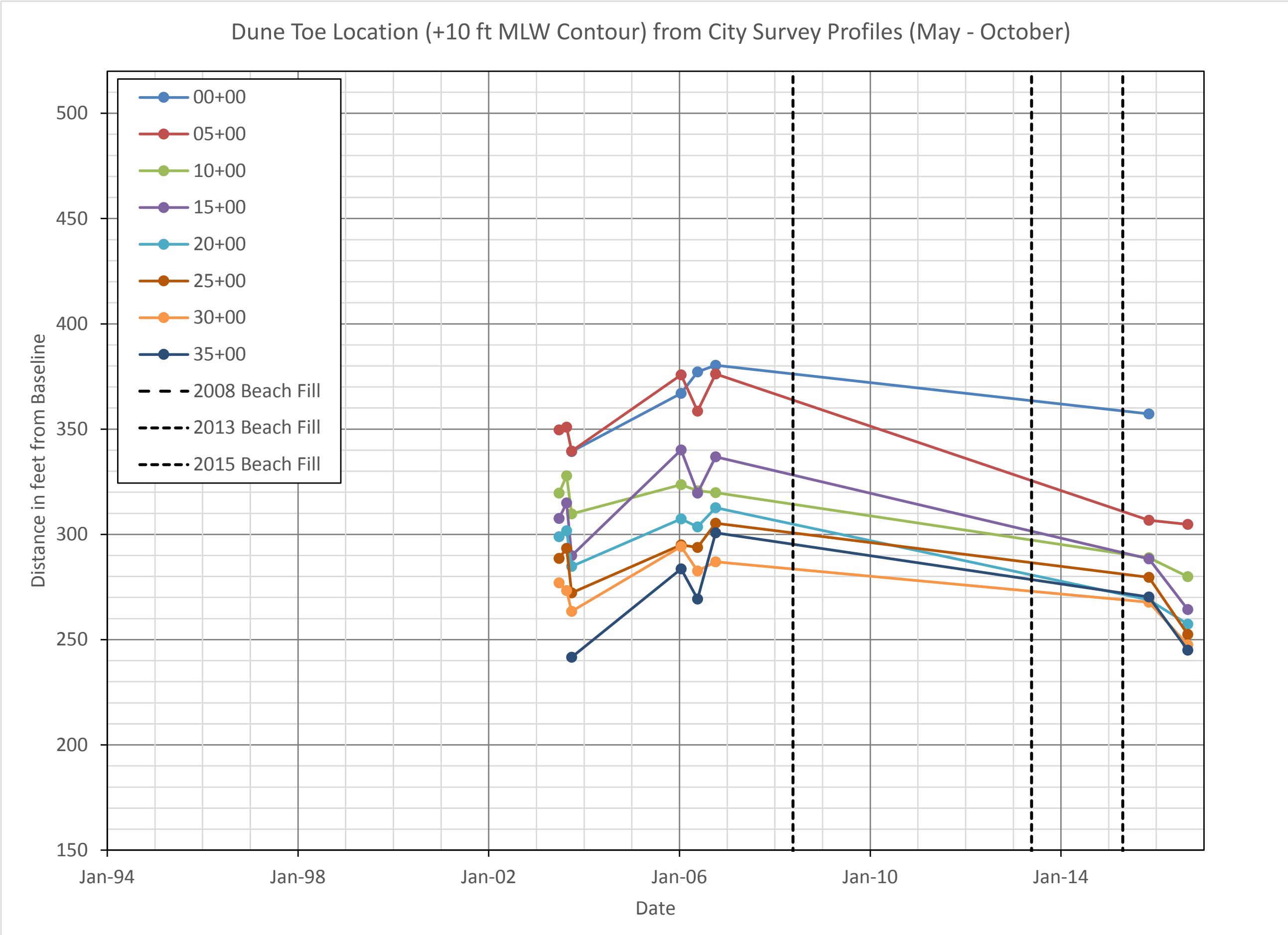


Figure 35: Toe of Dune Location from City Profile Data (All Seasons)

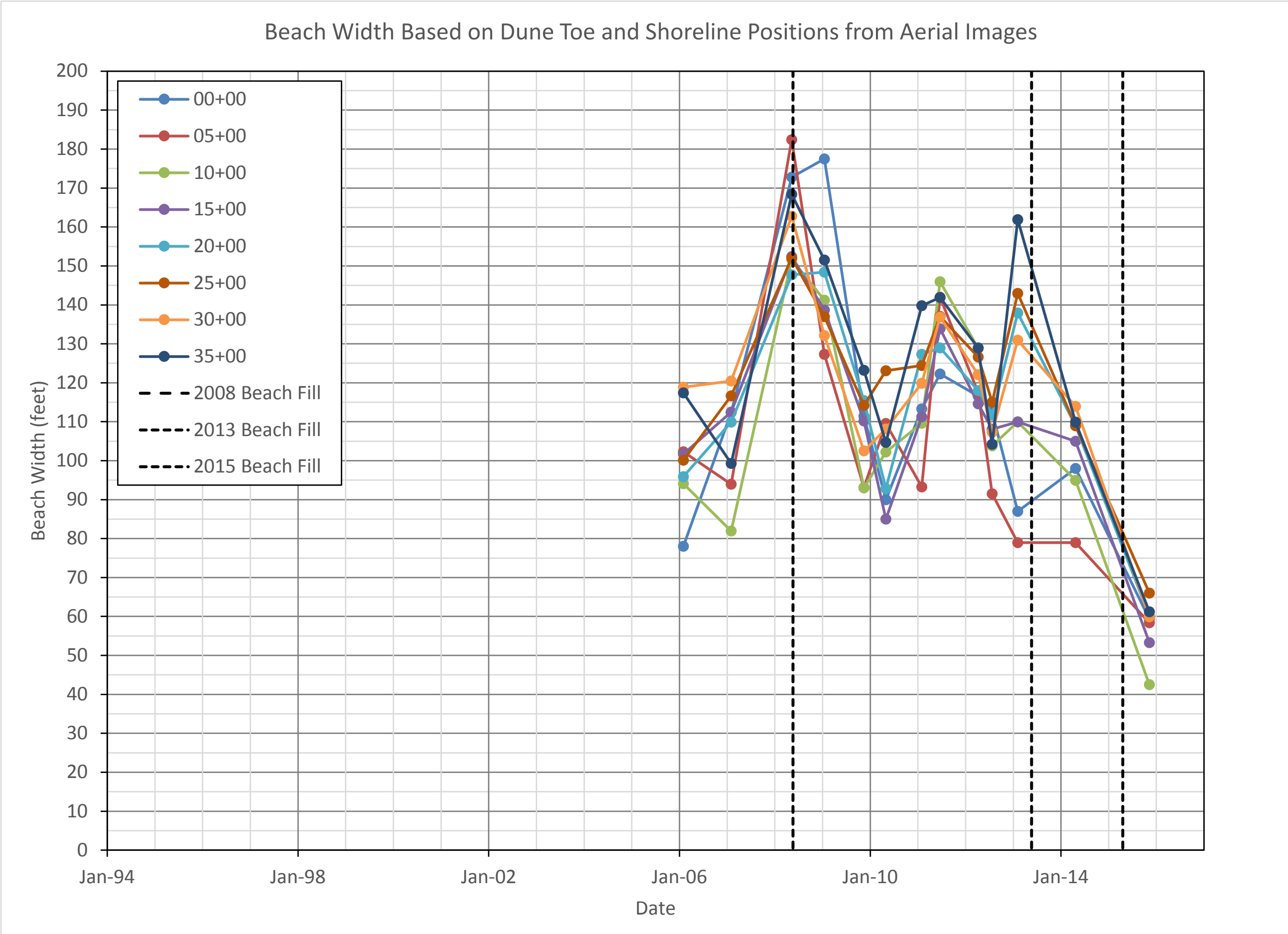


Figure 36: Beach Width Between Dune Toe and Shoreline Apparent from Aerial / Satellite Images

Table 8 summarizes the shoreline changes from the various data sets evaluated in this study, presented in terms of end-point change rates (feet per year, ft/yr) between various years. The rates are shown over various short and long time periods to illustrate that there is not a consistent signal of slow or fast shoreline advance or retreat. Dr. Basco found a rate of +6.1 ft/yr over 13 years, while the City survey data indicate a rate of -3.0 ft/yr over a different, more recent 12-year period. There is also not a consistent difference in shoreline change from the pre- and post-2004 period when the weir modifications were constructed. From digitization of the aerial images, the shoreline advanced at a rate of more than +8 ft/yr from 2002 – 2009, and then it retreated at a rate of -7 ft/yr from 2009 – 2014. Thus, over the combined period of 2002 – 2014, the shoreline advanced at a rate of approximately +2 ft/yr (average of +2.5 and +1.7 in the table). The trend over the longest applicable term from the available imagery indicates that from 1970 – 2014 the northern segment shoreline retreated at -0.3 ft/yr while the southern shoreline advanced at +0.4 ft/yr. The end-point signal of erosion from 2002 – 2015 and from 1970 – 2015 is dominated by the erosion due to storms prior to the November 2015 survey.

Table 8: Shoreline Change Rates

		Shoreline Change Rate (ft/yr)	
Source	**Time Period**	**Entire Length (Sta. 00+00 to 35+00)**	
Basco, 1994 (MHW shoreline)	1980 - 1993	+6.1	
VIMS, 2012 (visible shoreline)	1937 - 2009	-1.2	
		North Reach Sta. 00+00 to 15+00	**South Reach Sta. 20+00 to 35+00**
Aerial Image (visible shoreline)	Feb 1970 – Jul 1994	+1.3	+2.3
	Jul 1994 – Feb 2002	-9.8	-7.9
	Feb 2002 – Feb 2009	+9.4	+7.9
	Feb 2009 – Apr 2014	-6.9	-6.6
	Apr 2014 – Nov 2015	-27.5	-23.7
	Feb 2002 – Apr 2014	**+2.5**	**+1.7**
	Feb 2002 – Nov 2015	**-0.8**	**-1.1**
	Feb 1970 – Apr 2014	**-0.3**	**+0.4**
	Feb 1970 – Nov 2015	**-1.2**	**-0.4**
City Survey Data (MHW shoreline)	Jun 2003 – Oct 2006	+5.4	+4.1
	Oct 2006 – Nov 2015	-6.0	-5.5
	Jun 2003 – Nov 2015	**-3.0**	**-3.0**
	Jun 2003 – Aug 2016	**-3.7**	**-3.5**

Table 9 shows the dune toe position change rates (ft/yr) for the available time periods. Dune toes digitized from aerials indicate long-term advance less than 1 ft/yr from 2006 - 2015. The survey data show long-term retreat over a similar time period. It is noted that while the survey data is a more consistent indicator of the toe of the dune, the most recent two survey data sets reflect the erosion effects of storms with no assisted recovery, and that dunes take significantly longer to recover post-storm than shoreline positions. Regardless, from the survey data the dune toe in November 2015 and in August 2016 is significantly landward of its position in 2006.

Table 9: Toe of Dune Position Change Rates

		Dune Toe Position Change Rate (ft/yr)	
Source	**Time Period**	**North Reach Sta. 00+00 to 15+00**	**South Reach Sta. 20+00 to 35+00**
Aerial Image (visible dune toe)	Jan 2006 – Jan 2009	-0.1	-0.7
	Jan 2009 – Nov 2009	-13.9	-27.6
	Nov 2009 – Jul 2012	+6.8	+7.6
	Jul 2012 – Apr 2014	-2.4	-2.1
	Apr 2014 – Nov 2015	-0.3	+8.8
	Jan 2006 – Nov 2015	**+0.3**	**+0.6**
		North Reach Sta. 05+00 to 15+00	**South Reach Sta. 20+00 to 30+00**
City Survey Data (+10 ft MLW)	Jun 2003 – Jan 2006	+8.2	+4.2
	Jan 2006 – Nov 2015	**-5.3**	**-2.7**
	Jun 2003 – Nov 2015	**-2.5**	**-1.3**
	Jun 2003- Aug 2016	**-3.2**	**-2.7**

5.4. Site Conditions in March 2016

On March 30, 2016, M&N coastal engineers conducted a site visit at Croatan Beach. The team observed the position of the shoreline, apparent elevation and slope of the beach, and position and condition of the dune face and dune toe with respect to dune walkover structures. Appendix A presents site visit photos taken at 12 locations that are representative of the conditions observed along the beach. Based on the site visit and historical data (see representative March 30 site visit photos 1 through 3), it is apparent that Croatan Beach can be divided into two representative segments as illustrated in Figure 37. In the northern Segment I, the dune was obviously eroded, with evidence from its position at several dune walkovers (along with damage seen to some of the walkovers). The northern segment beach appeared to be both lower in elevation and flatter in slope than the beach to the south. Segment II starts approximately mid-way between Twilight Lane and Croatan Road. Less recent dune erosion was observed, and the dry beach appeared to have higher elevations and a steeper slope, with an obvious slope break between the beach berm and the high tide / wrack line.

Figure 37: Two Segments at Croatan Beach

Photo 1: Damaged dune walkover structure (left) and dune erosion (right) approximately 650 feet north of Twilight Lane (March 30, 2016)

Photo 2: Planted dune with sand fence and back beach slope adjacent to walkover structure approximately 400 feet south of Twilight Lane (March 30, 2016)

Photo 3: Dry beach and dune with sand covering seaward end of dune walkover structure approximately 150 feet south of Aqua Lane (March 30, 2016)

6. Level of Protection Analysis

The beach profile response and the benefits provided by the beach and dune during coastal storms were evaluated utilizing the USACE SBEACH model. All of the beach profile response simulations used the November 2015 survey data for the pre-storm starting profile. The SBEACH model parameters were calibrated using pre- and post-Hurricane Isabel (2003) survey profiles. The calibrated SBEACH parameters were then used to simulate beach profile response in a series of design storms representing storm surge and wave action ranging from 10-year return period (10% annual chance) to 100-year return period (1% annual chance) levels of intensity.

The purpose of the beach profile response simulations is to estimate the level of protection that the profile can provide to landward structures and infrastructure, as defined below:

- Habitable structure – In the context of the present analysis, habitable structures are enclosed buildings that may be, or appear to be, used as dwellings. This is an expanded definition compared to the FEMA definition of a habitable area[3] as "an enclosed area having more than 20 linear feet of finished interior walls (paneling, etc.) or used for any purpose other than solely for parking of vehicles, building access or storage."

- Structure – In the present analysis, a structure is any built, permanent facility, other than a habitable structure, infrastructure or beach access facility. At Croatan Beach, these structures typically include in-ground or above-ground pools, decks, sheds and similar structures. It is important to note that private beach accesses such as dune overwalks and stairways, and gazebos or other facilities integrated into these accesses, were not included in the evaluation of storm surge and wave impacts on structures. Since beach accesses of necessity protrude through and seaward of the dune, it is expected that they will be impacted in moderate to severe storm events. Playsets and other similarly small features were also excluded.

- Infrastructure – Facilities such as streets, parking areas, public beach accesses, restrooms and changing facilities and utilities. These facilities are typically owned and maintained by the City or by community organizations such as Home Owner Associations (HOAs). Except for the Rudee Inlet jetties, weir and dredging plant, no infrastructure appears to be present along Croatan Beach in an area expected to be impacted by storm surge and/or waves in the range of design storms evaluated.

Table 10 presents the dune crest elevation, location of the most seaward habitable structures, and the most seaward location of other considered structures at each of the survey transect stations. The positions of the habitable structures were determined by measuring the distance from baseline to the most seaward habitable building's seaward face, as apparent from the April 2014 satellite image at (or applicable to) each of the eight survey transects. The location of the most seaward other structure at each station was determined in a similar manner.

[3] https://www.fema.gov/national-flood-insurance-program/definitions

Table 10: Dune and Structures Information at Each Survey Transect

Location	Dune Elevation[1] (ft, NAVD)	Dune Elevation[1] (ft, MLW)	Seaward Habitable Structure (ft, Baseline)	Grade Elevation at Habitable Structure (ft, MLW)	Seaward Other Structure (ft, Baseline)
00+00 Virginia Dare Dr.	16.6	19.0	190	13.9	225
05+00	19.5	21.9	190	15.4	222
10+00 Twilight Lane	17.0	19.4	200	16.4	226
15+00 North of Croatan Rd.	20.1	22.5	165	13.9	195
20+00 South of Croatan Rd.	19.5	21.9	165	16.4	185
25+00 North of Aqua Ln.	17.3	19.7	175	18.4	175
30+00 Maryland Ave.	24.0	26.4	140	17.4	160
35+00 Lockheed Ave.	18.4	20.8	155	16.4	170

[1]From November 2015 City profile survey.

6.1. SBEACH Model Calibration

The SBEACH model was calibrated by simulating the effects of storm surge and waves associated with Hurricane Isabel, a storm that passed the project area on September 18, 2003. Pre- and post-storm surveys were available from the City survey data captured on August 21, 2003 and September 27, 2003, respectively. Water levels for the model were taken from the CBBT tide data, and wave conditions were developed from the WIS Atlantic hindcast station 63199, as described in Section 4. Wave and water level inputs to the SBEACH simulation are shown in Figure 38. Calibrated model results at station 15+00 are shown in Figure 39; the dashed black line is the measured pre-storm August 21 profile, the red line is the measured post-storm September 27 profile, and the SBEACH simulated post-storm profile is the blue line.

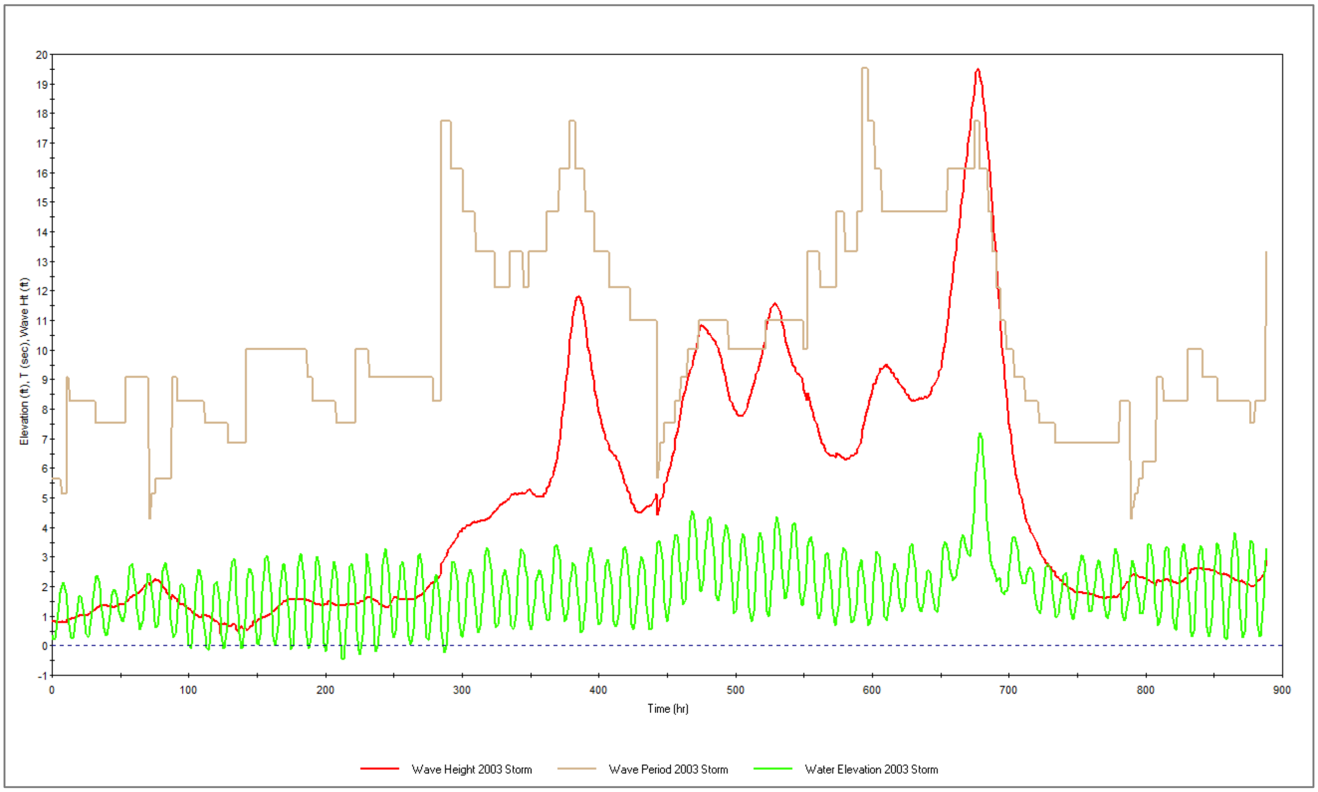


Figure 38: Storms used for the SBEACH model calibration

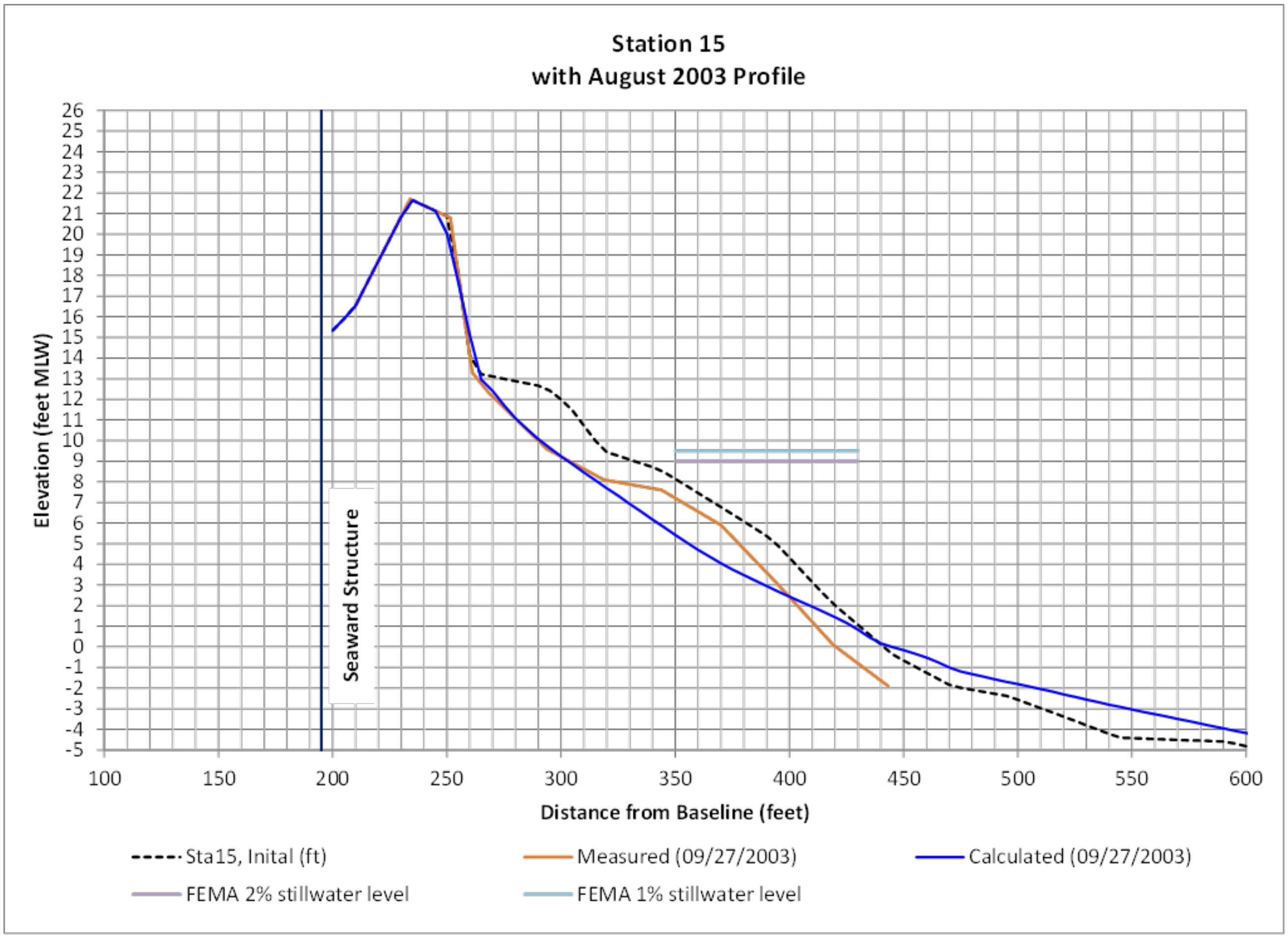


Figure 39: Comparisons between Measured Profile and Calculated Profile

The calibrated SBEACH model represents the erosion of the upper beach and the toe of the dune very well. The discrepancy between the model (blue line) and the measured (red line) post-storm profiles is likely due to the inability of SBEACH to represent the deposition of sand on the intertidal beach and seaward berm that typically occurs in the days to weeks following a storm's passage, as waves bring material eroded to the storm bar back onto the beach. The SBEACH model sufficiently represents the impacts of surge and waves on the dune and landward of it to fulfill the purpose of this level of protection analysis.

The calibrated model parameters are presented in Table 11. SBEACH calibration results at all of the transects are provided in Appendix E.

Table 11: Parameters for the SBEACH Model

Parameter name	Value
Effective Grain Size (mm)	0.40
Landward Surf Zone Depth (ft)	1.6
Max Slope prior to Avalanching	35
Overwash Parameter	0.005
Transport Rate Coefficient (m^4/N)	5e-7
Coefficient for Slope-dependent Term (m^2/s)	0.001
Transport Rate Decay Coefficient Multiplier	0.3
Water Temp (^{O}C)	15

6.2. Design Storms for Level of Protection Analysis

Design storm water levels were developed by scaling the storm surge associated with Hurricane Isabel up to achieve peak water levels associated with each return period evaluated, as shown in Table 12. Stillwater storm surge elevations at Croatan Beach for the 10-year, 50-year, and 100-year return periods were derived from the January 2015 effective FEMA Flood Insurance Study (FIS) for the City of Virginia Beach. The FIS stillwater elevations at all return periods included contributions from wave setup. Since SBEACH introduces wave setup across the profile as the simulation is running, the FIS stillwater elevations were adjusted to remove wave setup before they were applied as boundary conditions to the SBEACH simulations. The amount of wave setup to remove was calculated according to methods outlined in the USACE Coastal Engineering Manual. The peak storm surge stillwater values applied in the SBEACH simulations is given in the yellow-shaded column of Table 12.

Design storm wave time series were developed by applying the wave conditions from Hurricane Isabel, as transformed from the WIS hindcast station as described previously. These wave conditions provide depth-limited wave heights on the beach for all of the design storm water levels simulated.

Figure 40 shows the storm surge stillwater level time series, including wave setup, for the design storms in Table 12. Figure 41 shows the stillwater level time series (with wave setup removed), significant wave height, and wave period applied to the SBEACH model boundary for the 25-year return period (4% a.c.) design storm.

Table 12: Design Storm Surge Elevations for SBEACH Simulations

Source	Return Period (year)	Annual chance, or AEP (%)	Stillwater Elevation incl. Wave Setup (ft, NAVD)	Stillwater Elevation Without Wave Setup (ft, NAVD)	Stillwater Elevation Without Wave Setup (ft, MLW)
FEMA	10	10%	5.2	3.5	5.9
Interpolation	20	5%	5.7	4.0	6.4
Interpolation	25	4%	5.9	4.2	6.6
FEMA	50	2%	6.6	4.9	7.3
FEMA	100	1%	7.1	5.4	7.8

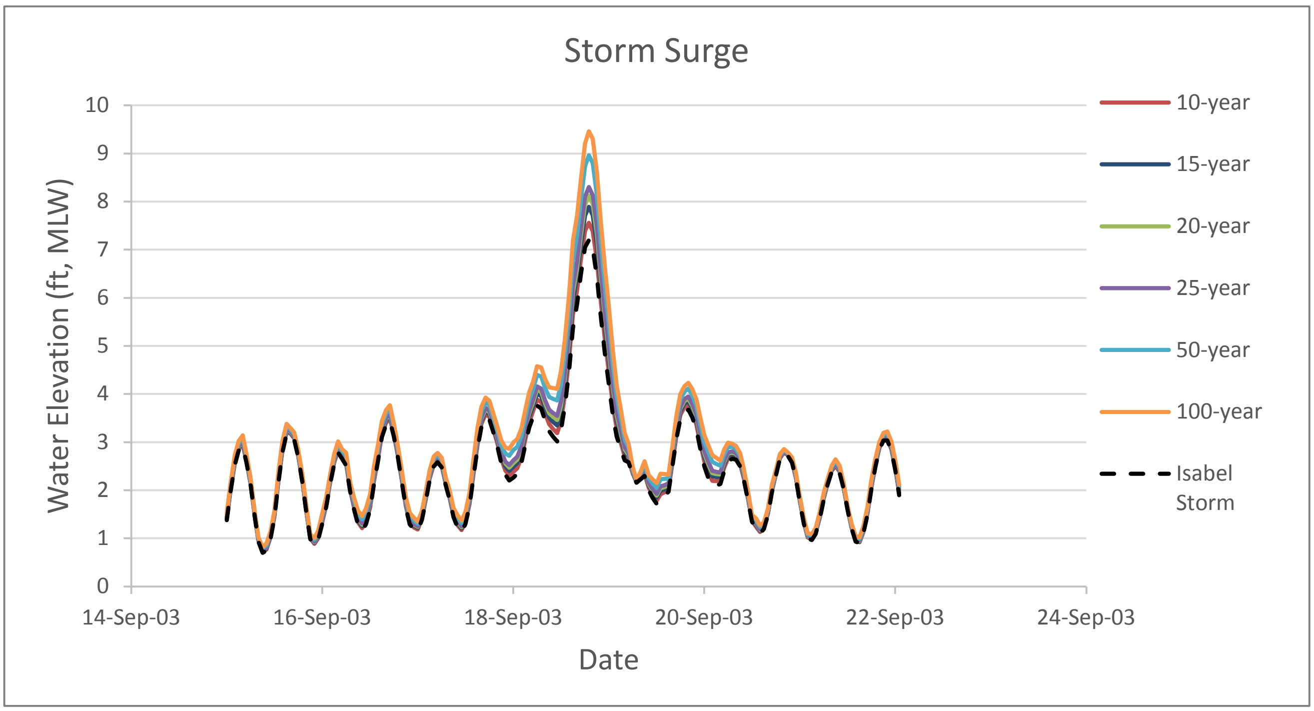


Figure 40: Design Storm Surges (Include Wave Setup)

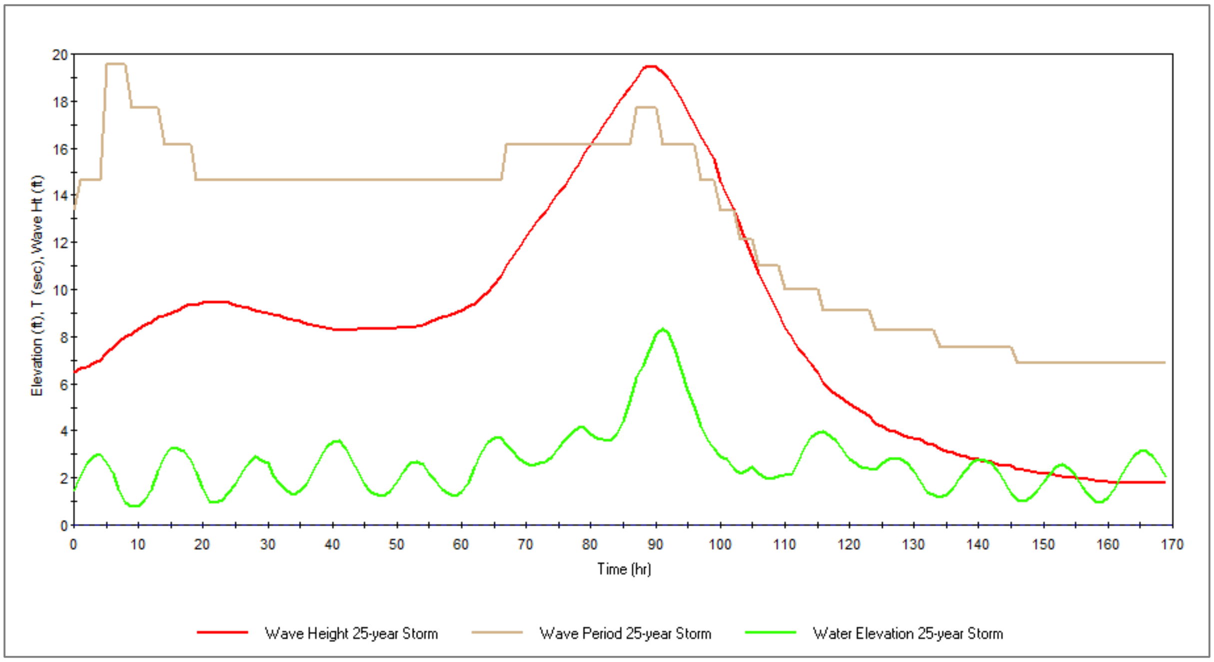


Figure 41: Design Storm Conditions for 25-year Return Period (4% AEP)

6.3. Beach Profile Storm Response: Present Sea Levels

The beach profile response and the benefits provided by the beach and dune system during coastal storms were evaluated utilizing the calibrated SBEACH model for the design storm events described in Table 12 and Figure 40. SBEACH simulations were run at each of the eight transects at stations 00+00 through 35+00. The November 2015 City survey profiles were taken as representative of existing conditions, and this data was used to create the initial (pre-design storm) profiles in SBEACH.

Figure 42 charts the beach and dune profile erosion in the five design storms at station 00+00. The November 2015 initial beach profile is shown as a dashed black line, and the SBEACH post-storm eroded profiles for the design storms are shown with solid lines as indicated in the legend. The vertical line labeled “Seaward Structure” indicates the approximate position of the most seaward structures in the reach represented by transect 00+00; a separate vertical line is labeled to indicate the seaward position of habitable structures associated with this transect. The Mean High Water (MHW) elevation at Rudee Inlet of +3.3 ft MLW is indicated by the dashed blue horizontal line. Additional horizontal lines show the elevations of the FEMA (2015) 1% annual chance (100-year return period) and 0.2% annual chance (500-year return period) storm surge stillwater elevations, including wave setup. Figure 43 through Figure 49 show SBEACH results for stations 05+00 through 35+00. These plots are shown at a larger scale in Appendix F.

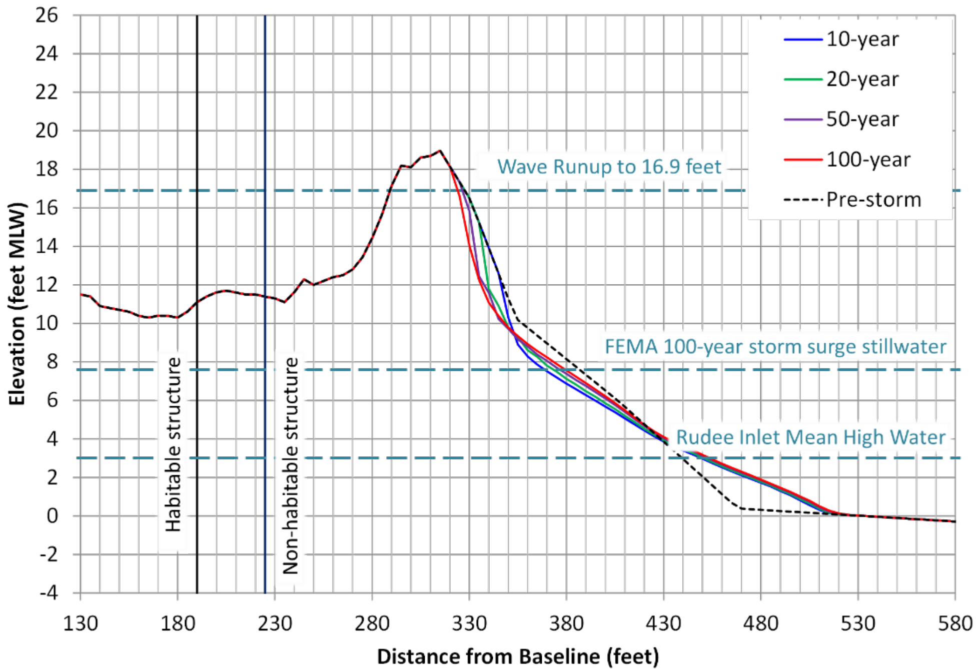


Figure 42: Existing Condition SBEACH Simulation Results for Station 00+00

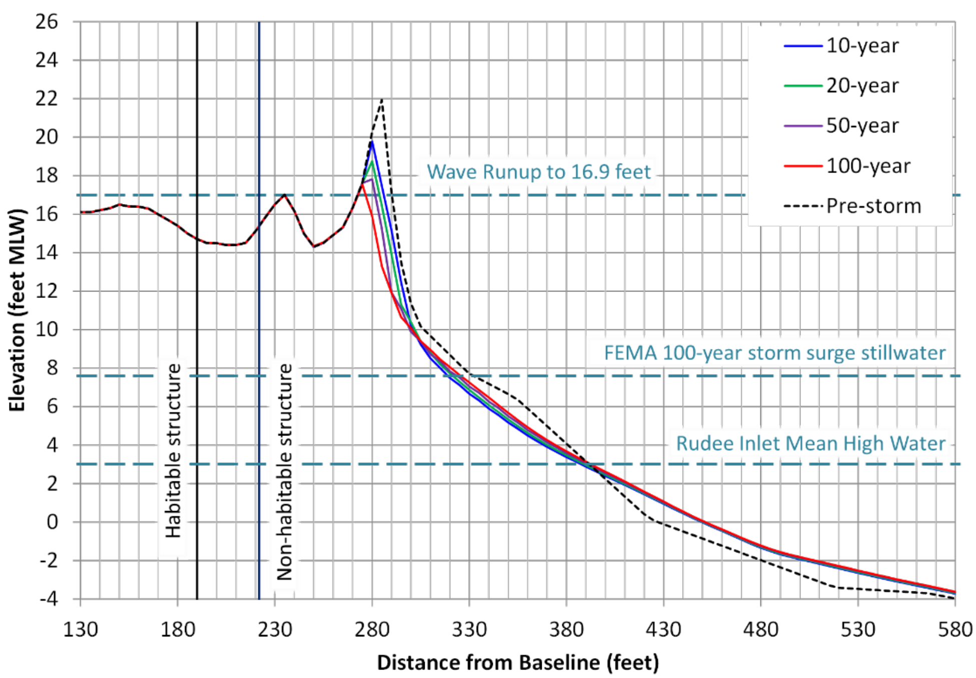


Figure 43: Existing Condition SBEACH Simulation Results for Station 05+00

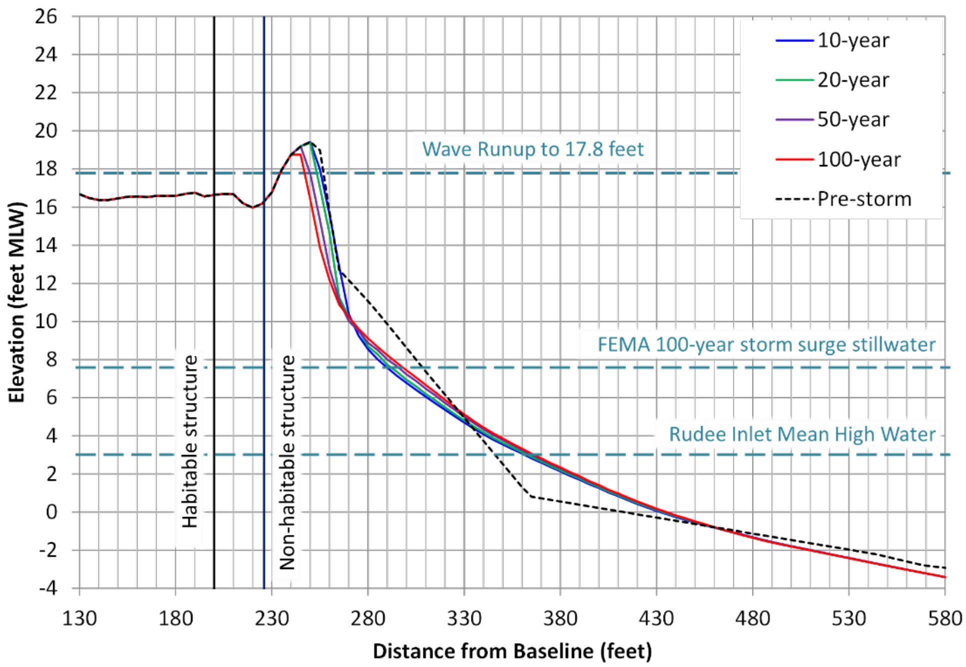


Figure 44: Existing Condition SBEACH Simulation Results for Station 10+00

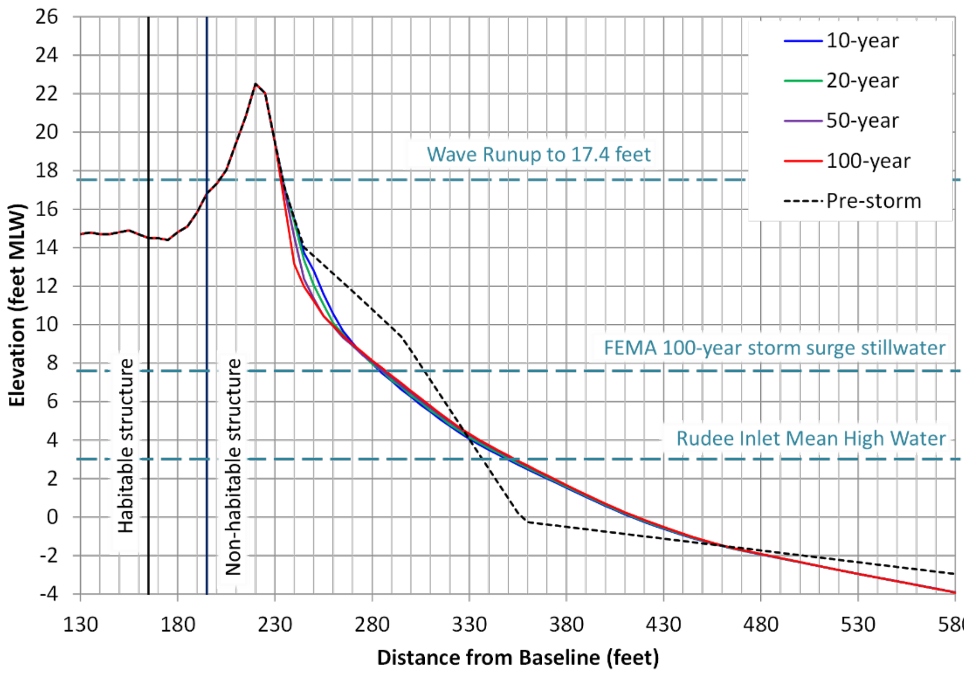


Figure 45: Existing Condition SBEACH Simulation Results for Station 15+00

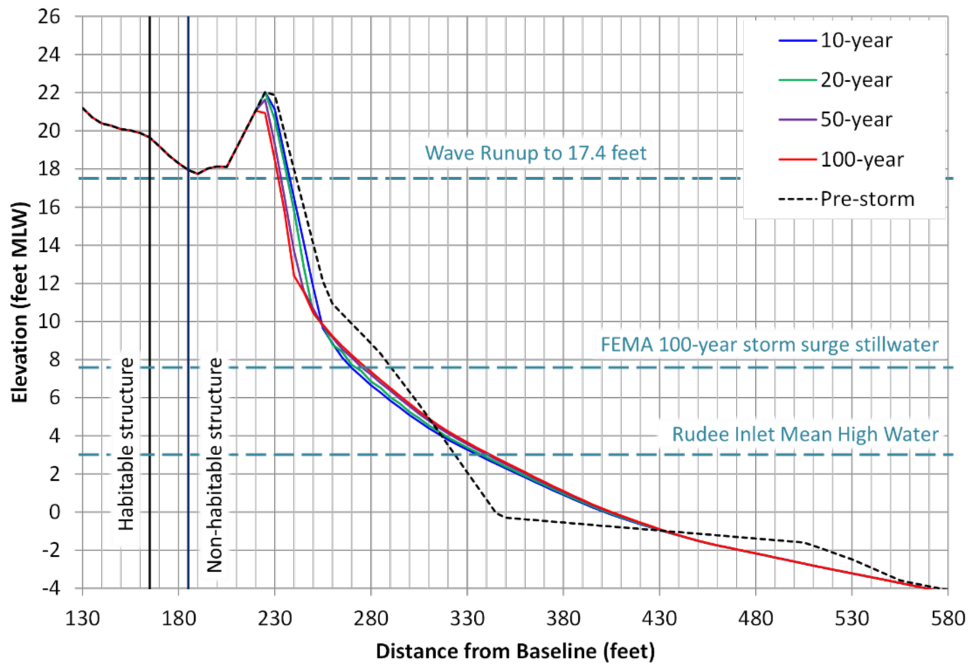


Figure 46: Existing Condition SBEACH Simulation Results for Station 20+00

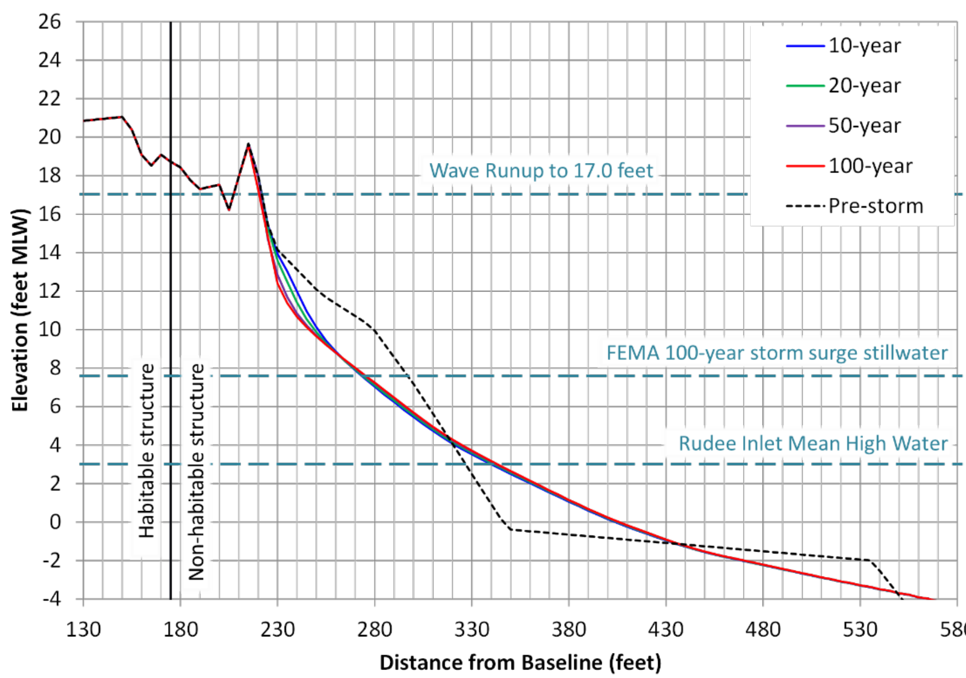


Figure 47: Existing Condition SBEACH Simulation Results for Station 25+00

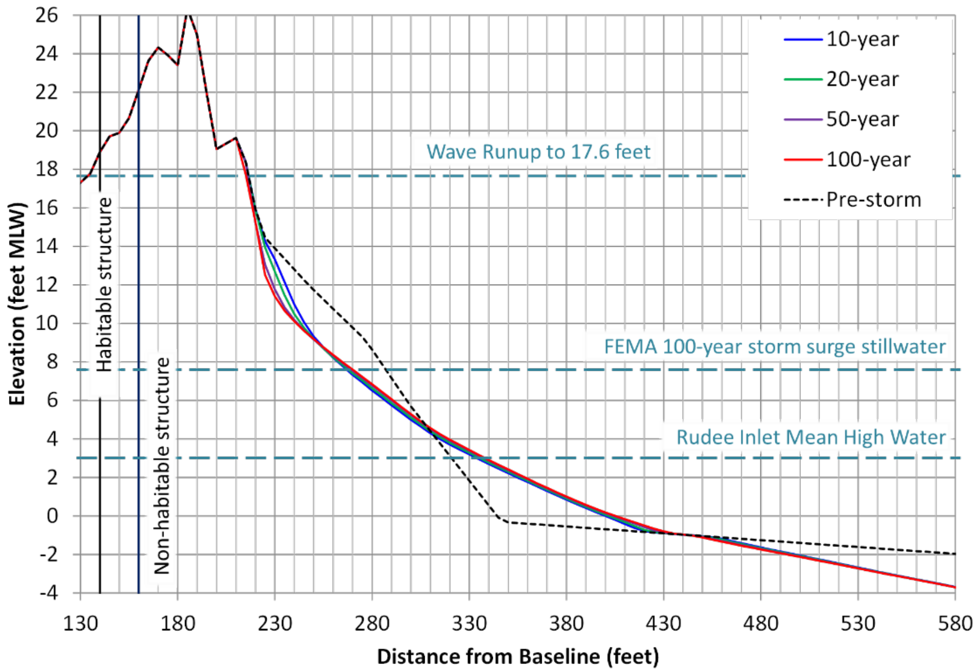


Figure 48: Existing Condition SBEACH Simulation Results for Station 30+00

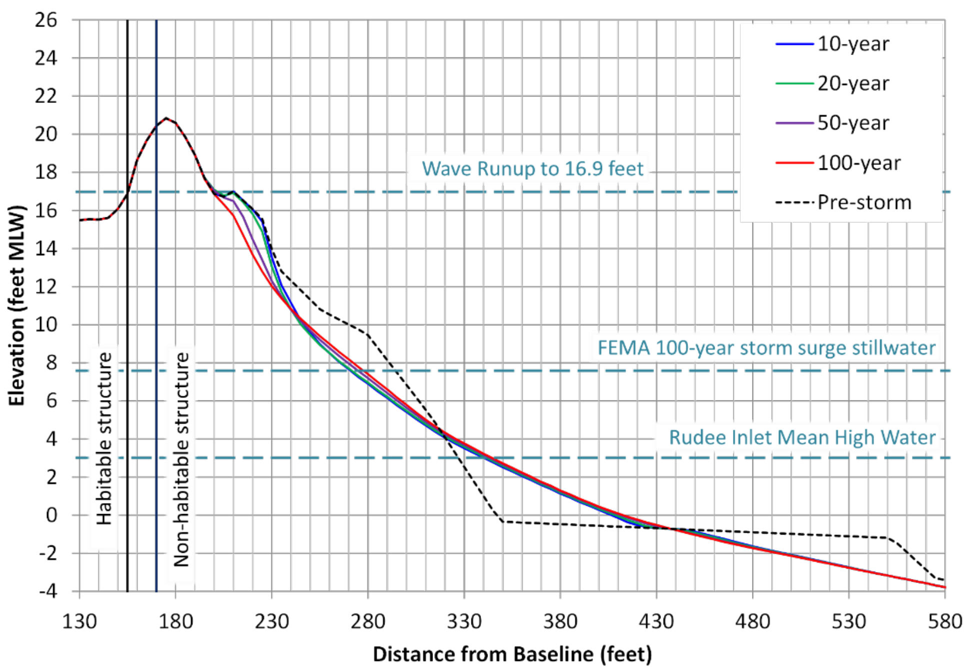


Figure 49: Existing Condition SBEACH Simulation Results for Station 35+00

Table 13 summarizes the key points regarding the beach and dune erosion for each of the SBEACH simulations. The results indicate that the existing-condition beach and dune profile is sufficient to provide protection to structures in design storms through the 1% annual chance (100-year return period) storm surge, for present sea levels, at all of the transects except for station 05+00. The existing condition dune at station 05+00 is narrow and thus has less volume above the storm surge stillwater elevations than the other transects have. The SBEACH simulations show that the dune at station 05+00 would be significantly eroded in all of the design storms. Through the 4% annual chance (25-year return period) design storm, the eroded dune crest elevation and volume would be sufficient to prevent impacts on structures in the lee of the dune. In the 2% and 1% annual chance design storms, the dune is sufficiently lowered and eroded that there is a potential for the most seaward non-habitable structures to be affected by wave overtopping due to wave runup on the eroded dune face. Table 14 illustrates the relationship between the grade elevation at seaward-most habitable structure, the eroded dune crest elevation, and the estimated peak wave runup elevation associated with the 1% a.c. design storm. Wave runup was calculated using a method by Hughes (2005) for estimating irregular wave runup on rough, impermeable slopes, as documented in the Coastal Engineering Manual.

Table 15 summarizes the level of protection provided by the dune for the design storms at present sea levels. It is noted that no impacts to habitable structures are indicated at any of the transects, even at station 05+00, in any of the design storms simulated.

Table 13: SBEACH Storm Erosion Results for Existing Conditions Profile at Present Sea Levels

Station	**Storm Return Period (% annual chance[4])**				
	10-year (10% a.c.)	**20-year (5% a.c.)**	**25-year (4% a.c.)**	**50-year (2% a.c.)**	**100-year (1% a.c.)**
00+00 Virginia Dare Dr.	Dune face erosion; dune crest not eroded or lowered; no wave or surge impacts to structures or infrastructure.				
05+00	Dune crest erosion with significant lowering of dune crest. No wave or surge impacts to structures or infrastructure.			Dune crest significantly lowered; potential wave overwash impacts to structures.	
10+00 Twilight Lane	Dune face and dune crest erosion with minor lowering of dune crest. No wave or surge impacts to structures or infrastructure.			Dune crest significantly lowered; potential wave overwash impacts to structures.	
15+00 North of Croatan Rd.	Dune face erosion; dune crest not eroded or lowered; no wave or surge impacts to structures or infrastructure.				
20+00 South of Croatan Rd.	Dune face and dune crest erosion with minor lowering of dune crest. No wave or surge impacts to structures or infrastructure.				Dune crest lowered; no wave or surge impacts to structures or infrastructure.
25+00 North of Aqua Ln.	Dune face erosion; dune crest not eroded or lowered; no wave or surge impacts to structures or infrastructure.				
30+00 Maryland Ave.	Dune face erosion; dune crest not eroded or lowered; no wave or surge impacts to structures or infrastructure.				
35+00 Lockheed Ave.	Dune face erosion; dune crest not eroded or lowered; no wave or surge impacts to structures or infrastructure.				

[4] Annual exceedance probabilities, AEP (annual chance) follow a Poisson distribution such that the probability of an event with return period (RP, years) being equaled or exceeded exactly once in any given year is: AEP = 1 – exp(-1/RP)

Table 14: Eroded Dune Crest and Wave Runup Elevations in Present Sea Level

Station	Grade at Seaward Habitable Struct. (ft, MLW)	Eroded Dune Crest Elevation in 1% a.c. Design Storm (ft, MLW)	Assoc. Wave Runup Elevation (ft, MLW)	Wave Overtopping
00+00 Virginia Dare Dr.	13.9	18.9	16.8	No
05+00	15.4	17.5	16.9	No
10+00 Twilight Lane	16.4	18.7	17.8	No
15+00 North of Croatan Rd.	13.9	22.5	17.4	No
20+00 South of Croatan Rd	16.4	21.0	17.4	No
25+00 North of Aqua Ln.	18.4	19.6	17.0	No
30+00 Maryland Ave.	17.4	26.4	17.6	No
35+00 Lockheed Ave.	16.4	20.8	16.9	No

Table 15: Existing Condition Profiles' Levels of Protection in Present Sea Level

Station	Level of Protection at Habitable Structures (Return Period)	Level of Protection at Other Structures (Return Period)
00+00 Virginia Dare Dr.	100-year (1% a.c.)	100-year (1% a.c.)
05+00	25-year (4% a.c.)	20-year (5% a.c.) to 25-year (4% a.c.)
10+00 Twilight Lane	25-year (4% a.c.) to 50-year (2% a.c.)	25-year (4% a.c.) to 50-year (2% a.c.)
15+00 North of Croatan Rd.	100-year (1% a.c.)	100-year (1% a.c.)
20+00 South of Croatan Rd.	100-year (1% a.c.)	100-year (1% a.c.)
25+00 North of Aqua Ln.	100-year (1% a.c.)	100-year (1% a.c.)
30+00 Maryland Ave.	100-year (1% a.c.)	100-year (1% a.c.)
35+00 Lockheed Ave.	100-year (1% a.c.)	100-year (1% a.c.)

6.4. Beach Profile Storm Response: With 1.5 Feet of Sea Level Rise

This study's scope included an evaluation of the effects of progressive mean sea level rise (i.e. relative sea level rise) on the level of protection afforded by the current beach profiles. In keeping with recommendations by VIMS (2013), this study considered the sensitivity of the beach profile performance to an assumed 1.5 feet of relative sea level rise over the next 30 to 50 years. The SBEACH model simulations were repeated with all of the water levels in each storm increased by 1.5 feet. The SBEACH results are presented in Appendix G, and key points are summarized in Table 16 for comparison with Table 13.

The higher storm surge stillwater elevations that would occur in this future SLR scenario, with associated increased water depth over the beach allowing larger depth-limited wave heights, would be expected to result in significantly greater erosion of the dune at multiple stations along Croatan Beach. Table 18 summarizes the level of protection provided by the dune for the design storms with 1.5 feet of future SLR. Between stations 20+00 and 25+00 (Croatan Road to Aqua Lane), the level of protection for non-habitable structures would be reduced to approximately the 25-year return period (4% annual chance).

At stations 10+00 (Twilight Lane), the non-habitable structures would potentially be impacted in an event between the 10-year and 25-year return period.

North of Twilight Lane at station 05+00, the level of protection to non-habitable structures would be reduced to less than the 10-year return period. Put another way, there would be greater than a 10% probability in any given year of surge, wave, or erosion impacts on the most seaward non-habitable structures adjacent to station 05+00.

This analysis of the effects of a projected future 1.5 feet of SLR is provided for information and for future planning purposes. Projection of future SLR values has significant uncertainty, and sea level rise occurs slowly relative to the rate of the beach and dune processes.

Table 16: SBEACH Storm Erosion Results for Existing Conditions Profiles with 1.5 ft of SLR

<table>
<tr><th rowspan="2">Station</th><th colspan="5">Storm Return Period (% annual chance)</th></tr>
<tr><th>10-year
(10% a.c.)</th><th>20-year
(5% a.c.)</th><th>25-year
(4% a.c.)</th><th>50-year
(2% a.c.)</th><th>100-year
(1% a.c.)</th></tr>
<tr><td>00+00
Virginia
Dare Dr.</td><td colspan="5">Dune face and dune crest erosion; dune crest not lowered; no wave or surge impacts to structures or infrastructure.</td></tr>
<tr><td>05+00</td><td>Dune crest significantly lowered; potential wave overwash impacts to non-habitable structures (e.g. pools).</td><td colspan="2">Dune breached; potential for wave runup impacts to habitable structures.</td><td colspan="2">Dune breached; likely wave runup and/or erosion impacts to habitable structures.</td></tr>
<tr><td>10+00
Twilight
Lane</td><td colspan="3">Dune crest significantly lowered; potential wave overwash impacts to non-habitable structures (e.g. pools).</td><td colspan="2">Dune breached; likely wave runup and/or erosion impacts to habitable structures.</td></tr>
<tr><td>15+00
North of
Croatan
Rd.</td><td colspan="3">Dune face and dune crest erosion; dune crest not lowered; no wave or surge impacts to structures or infrastructure.</td><td colspan="2">Dune crest lowered; no wave or surge impacts to structures or infrastructure.</td></tr>
<tr><td>20+00
South of
Croatan
Rd.</td><td colspan="3">Dune crest lowered; no wave or surge impacts to structures or infrastructure.</td><td>Dune lowered; potential impacts to structures.</td><td>Dune breached; likely wave runup impacts to habitable structures.</td></tr>
<tr><td>25+00
North of
Aqua Ln.</td><td colspan="3">Dune face and dune crest erosion; dune crest not lowered; no wave or surge impacts to structures or infrastructure.</td><td colspan="2">Dune breached; likely wave runup and/or erosion impacts to habitable structures.</td></tr>
<tr><td>30+00
Maryland
Ave.</td><td colspan="5">Dune face erosion; dune crest not eroded or lowered; no wave or surge impacts to structures or infrastructure.</td></tr>
<tr><td>35+00
Lockheed
Ave.</td><td colspan="4">Dune face erosion; dune crest not eroded or lowered; no wave or surge impacts to structures or infrastructure.</td><td>Minor dune crest lowering; potential erosion impacts to non-habitable structures.</td></tr>
</table>

Table 17: Eroded Dune Crest and Wave Runup Elevations with 1.5 Feet of SLR

Station	Grade at Seaward Habitable Struct. (ft, MLW)	Eroded Dune Crest Elevation in 1% a.c. Design Storm (ft, MLW)	Wave Runup Elevation (ft, MLW)	Wave Impacts to Habitable Structures
00+00 Virginia Dare Dr.	13.9	18.6	18.8	Unlikely
05+00	15.4	15.0	18.7	Yes
10+00 Twilight Lane	16.4	16.0	18.5	Yes
15+00 North of Croatan Rd.	13.9	20.6	20.5	Potential
20+00 South of Croatan Rd	16.4	18.0	19.7	Yes
25+00 North of Aqua Ln.	18.4	17.9	19.0	Yes
30+00 Maryland Ave.	17.4	26.4	20.0	No
35+00 Lockheed Ave.	16.4	20.4	19.1	No

Table 18: Existing Condition Profiles' Levels of Protection with 1.5 Feet of SLR

Station	Level of Protection at Habitable Structures (Return Period)	Level of Protection at Other Structures (Return Period)
00+00 Virginia Dare Dr.	100-year (1% a.c.)	100-year (1% a.c.)
05+00	10-year (10% a.c.)	Less than 10-year (> 10% a.c.)
10+00 Twilight Lane	25-year (4% a.c.)	Less than 25-year (> 4% a.c.)
15+00 North of Croatan Rd.	50-year (2% a.c.) to 100-year (1% a.c.)	100-year (1% a.c.)
20+00 South of Croatan Rd.	50-year (2% a.c.)	25-year (4% a.c.)
25+00 North of Aqua Ln.	25-year (4% a.c.)	25-year (4% a.c.)
30+00 Maryland Ave.	100-year (1% a.c.)	100-year (1% a.c.)
35+00 Lockheed Ave.	100-year (1% a.c.)	50-year (2% a.c.)

7. Purpose & Need to Enhance the Beach and Dune Profile

The purpose of this section of the report is to discuss need for and purpose of courses of action that may be taken to enhance the beach and dune along Croatan Beach. In the most general description, such courses of action could include adding height and/or volume to the dune, increasing the elevation and/or width of the dry beach between the toe of the dune and the shoreline, or a combination of those two approaches.

Part of the purpose and need analysis is the establishment of criteria for evaluating the performance of the existing conditions beach and dune system at present-day sea levels. During collaborative discussions with City engineering staff and representatives from the Croatan Beach community, several potential criteria regarding levels of protection were discussed, including the following:

- Avoid impacts to habitable structures at the 1% annual chance (a.c.) (100-year return period) level of protection (LoP), while providing a lower level of protection for non-habitable structures.

- Avoid impacts to both habitable and non-habitable structures at the 100-year return period (1% annual chance) level of protection.

- Avoid dune breaching in storm events up to and including the 1% annual chance storm surge and associated waves at all locations along Croatan Beach.

Additional criteria not directly related to the level of protection have also been discussed. These are generally related to maintaining sufficient beach width for recreational usage and accessibility for maintenance and emergency response vehicles. In general, this would provide for a beach berm width of approximately 50 feet between the toe of the dune and the MHW shoreline position. This allows 15 feet for vehicles to traverse the back of the beach, 10 feet for lifeguard stands, and 25 feet seaward of the lifeguard stands for beachgoers.

The paragraphs below describe the performance of the existing conditions beach and dune, as represented by the November 2015 survey profiles, with respect to the candidate level of protection criteria above.

1% a.c. LoP for habitable and non-habitable structures

The results of the level of protection analysis indicated that no habitable or non-habitable structures are currently at risk from storm surge, wave action, or erosion by waves in coastal storm events up to and including the 100-year return period event (1% annual chance) along most of Croatan Beach. The level of protection criteria were not met at stations 05+00 and station 10+00 near Twilight Lane. Modification to the existing beach and dune profiles would be required in this segment of the beach to meet the level of protection criteria.

No dune breaching in the 1% a.c. design storm

For the purposes of this discussion, dune breaching is defined as a reduction in the dune crest elevation over the entire width of dune crest. The existing condition SBEACH simulations and indicate that such dune breaching is likely in the 1% a.c. design storm at stations 05+00, 10+00, and 20+00. Achieving the criterion of no such dune breaching in the 1% a.c. design storm would require the placement and maintenance of additional dune volume at these three stations, with tie-in to adjacent beach and dune profile. Maintaining this dune volume expansion would be most effectively achieved by raising and widening the dry beach between the berm and the shoreline.

Beach width for recreational usage and vehicle access

The March and August 2016 site visits and the August 30, 2016 City survey data indicate that the existing beach profile does not meet the proposed criteria for beach berm width relative to vehicular access and recreational beach usage. It also noted that the March 2016 site visit indicated that segments of the dune may have, at that time, been eroded landward of the November 2015 condition[5] due to an intense winter and early spring wave climate (including Winter Storm Jonas in late January 2016). It is prudent to establish a conceptual plan for restoring sufficient dune height and volume and for increasing beach width. The outline of such a plan is the focus of the next section of this report.

[5] City surveyors captured dune face and dry beach elevation profiles on August 30, 2016. That survey data, received during the completion of this draft report, also indicates that segments of the dune face may continue to be landward of the November 2015 conditions. Additional analysis of the August 2016 data is required before this can be confirmed.

8. Beach Nourishment Conceptual Plan

A conceptual plan to maintain sufficient beach width and dune volume to meet the working group's adopted criteria would generally include courses of action such as increasing dune height and/or volume, increasing the dry beach elevation and/or width, or a combination of those features. Within the present study scope, one conceptual plan was developed for enhancing the beach and dune system at Croatan Beach. The conceptual plan includes a combination of dune fill and beach fill toward the goal of meeting the criteria discussed in Section 7.

8.1. Conceptual Plan Beach and Dune Profile

It was concluded from the level of protection analysis that the November 2015 existing condition along Croatan Beach would be sufficient to avoid impacts to both habitable and non-habitable structures at the 100-year return period (1% annual chance) level of protection along most of Croatan Beach, for storms occurring in present sea levels. The level of protection analysis indicated that the level of protection criteria would not be met adjacent to station 05+00 and station 10+00 (near Twilight Lane). Additionally, the proposed beach width criteria is not met along a majority of Croatan Beach. Thus, the conceptual design is proposed as a representative way to increase the dune crest elevation and dune volume where necessary and to increase the usable beach width along the entire length of Croatan Beach.

The conceptual dune fill concept includes establishing and maintaining a dune width of approximately 15 feet at an elevation of 21 feet MLW, with the dune face sloping seaward at 5:1 (horizontal:vertical) to tie in to a beach berm at elevation 8 feet MLW. A berm width of 50 feet would be established seaward of the dune toe, with a seaward beach face slope of 12:1 to connect with the existing submerged beach profile. Figure 50 through Figure 57 illustrate the conceptual beach and dune profiles at stations 00+00 through 35+00.

The conceptual plan presented above satisfies the requirement to provide and maintain a 1% a.c. level of protection for both habitable and non-habitable structures along Croatan Beach. It also satisfies the requirement to increase usable beach width as discussed in Section 7.

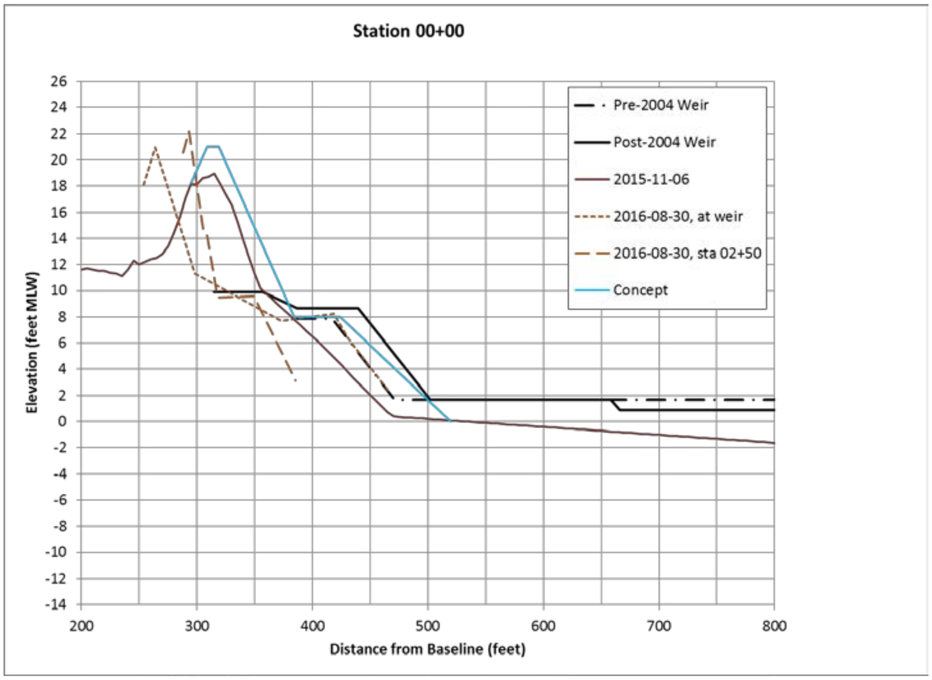


Figure 50: Conceptual Plan Profile at Station 00+00

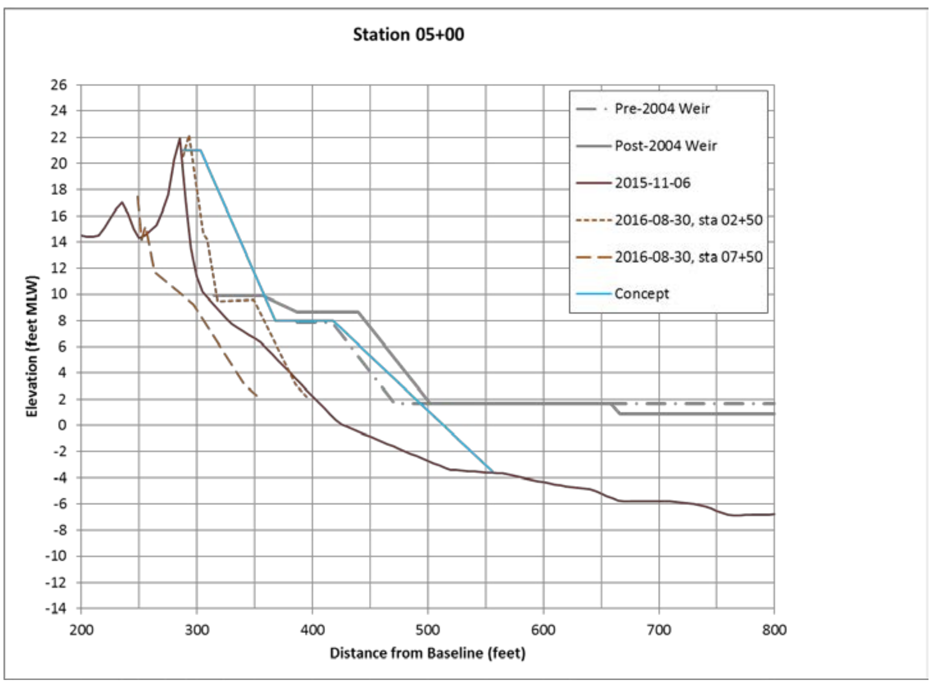


Figure 51: Conceptual Plan Profile at Station 05+00

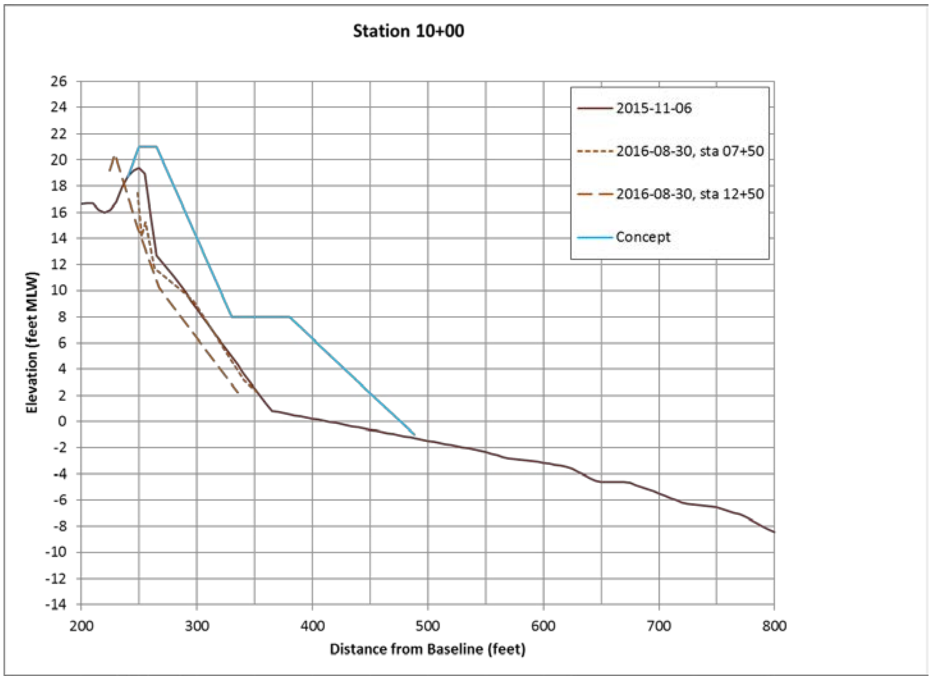


Figure 52: Conceptual Plan Profile at Station 10+00

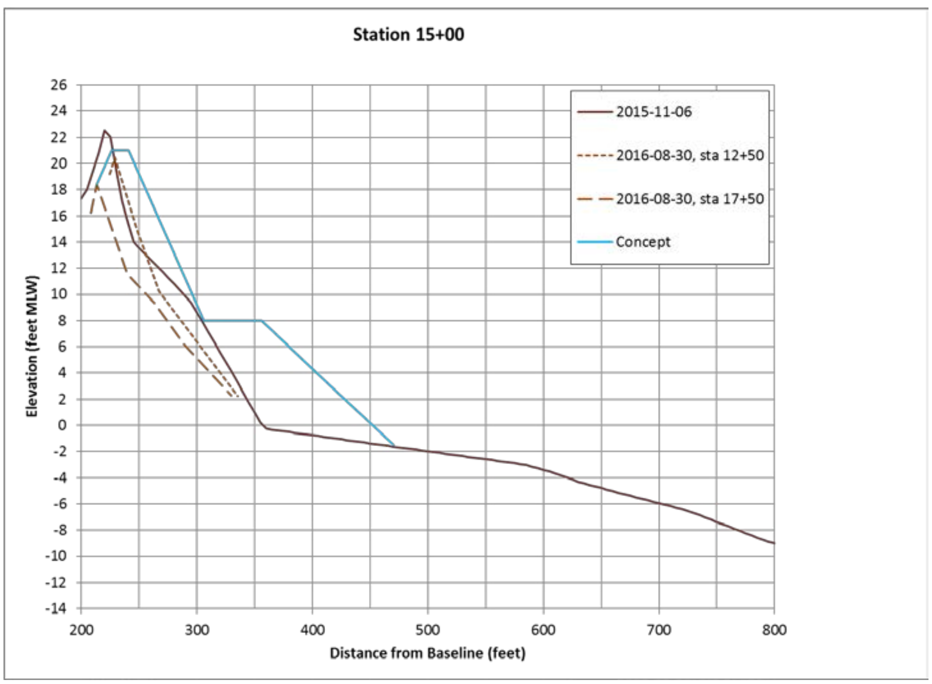


Figure 53: Conceptual Plan Profile at Station 15+00

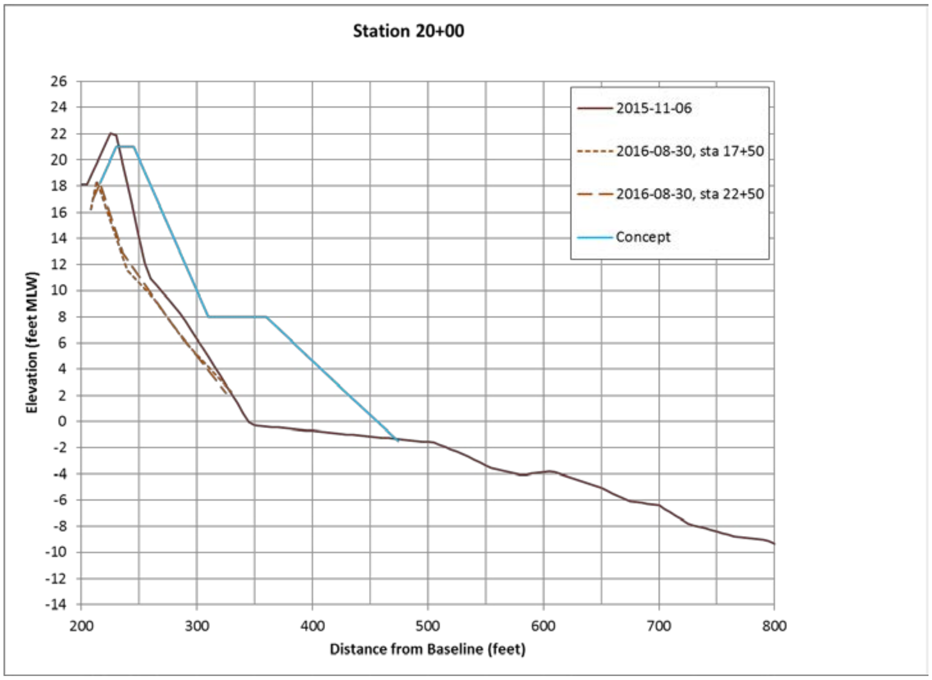


Figure 54: Conceptual Plan Profile at Station 20+00

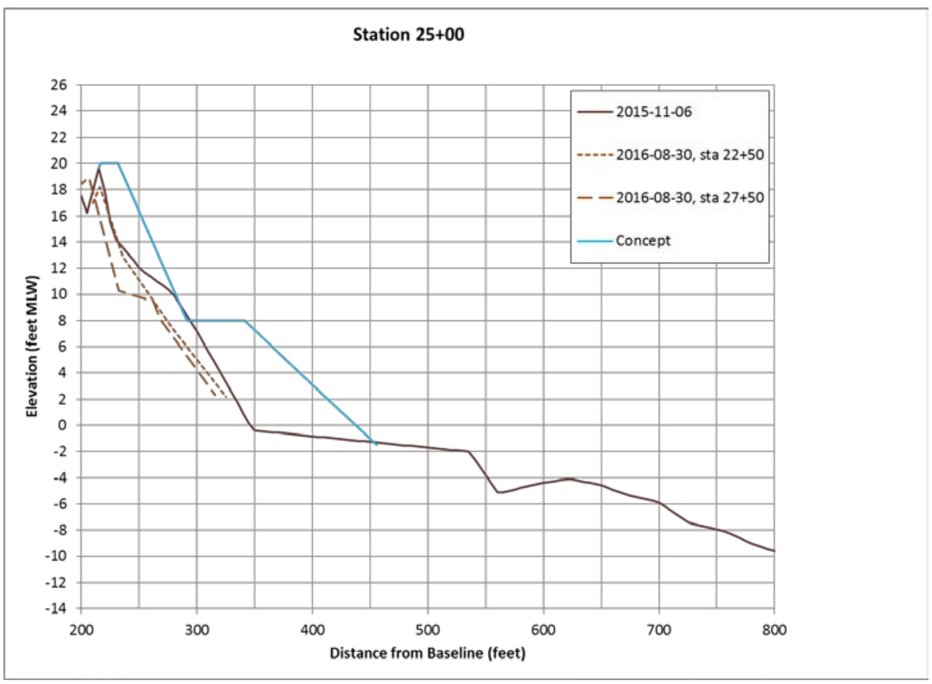


Figure 55: Conceptual Plan Profile at Station 25+00

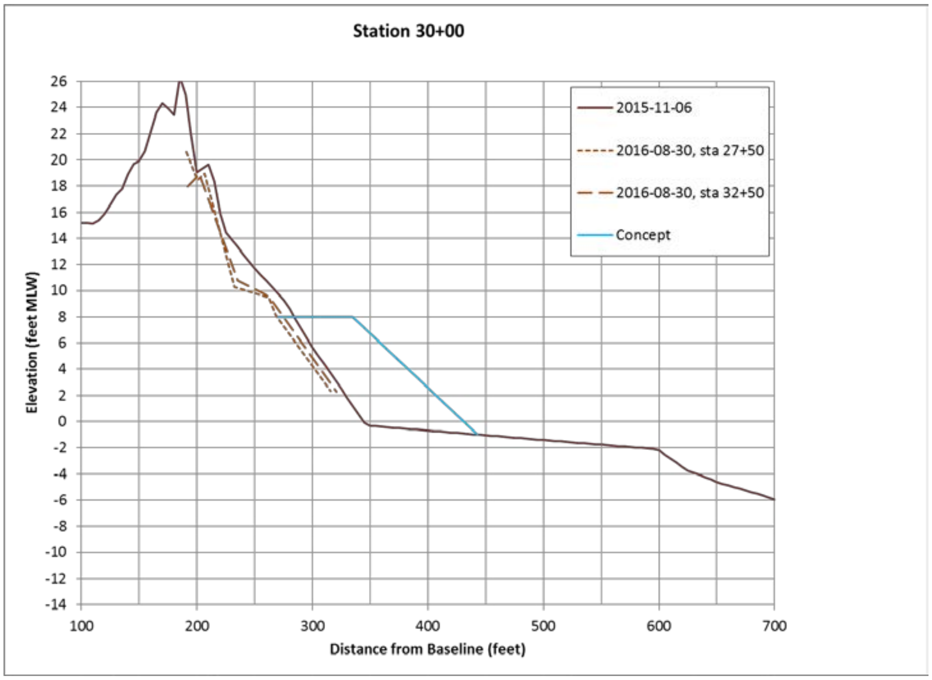


Figure 56: Conceptual Plan Profile at Station 30+00

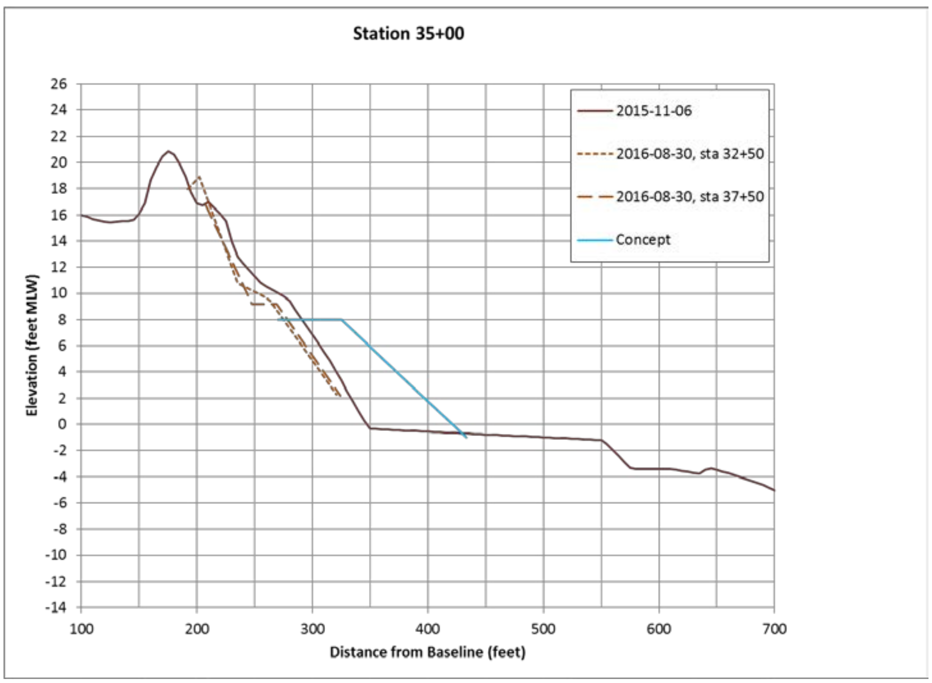


Figure 57: Conceptual Plan Profile at Station 35+00

8.2. Fill Volumes Required for Conceptual Plan

Table 19 lists the cross-section fill density, in cubic yards per linear foot (cy/ft), to construct the conceptual plan profile at each of the transect stations. The total volume required to construct the conceptual plan is approximately 130,000 cubic yards.

Table 19: Required Beach Fill Density (cy/ft) Conceptual Plan

Transect Station	Conceptual Plan for Dune Fill & Beach Widening
	Cross-section Fill Volume (cy/ft)
00+00	19.9
05+00	52.2
10+00	42.2
15+00	35.0
20+00	42.0
25+00	31.4
30+00	23.3
35+00	18.5

It is noted that this is the volume required to construct the conceptual plan beach and dune nourishment project. Maintaining this profile over several years (or several significant storms) post-construction would require additional sand to be added periodically. The maintenance interval and maintenance volumes would be determined during the detailed design of the project.

Volume changes between the August 2003 and November 2015 City surveys, including consideration of the 85,000 cubic yards of sand added by dune and beach fill since 2008, indicated an average annual volume loss of approximately 15,000 cy/yr along Croatan Beach from station 0+00 to station 35+00. As noted in prior sections of this report, the wave climate and shoreline changes since 2012 indicate that the past few years may have been a more erosive period at Croatan Beach, compared to prior time periods. Without additional profile surveys covering the dune, beach, and submerged profile more consistent, regular time intervals, it is difficult to establish an accurate medium to long-term volume change rate. Regular monitoring of the profile is recommended.

8.3. Requirement for Section 408 Review of Conceptual Plan

A Section 408 review can be required by USACE for permitting any project that has the potential to adversely impact an authorized Federal project. The navigation channel (and associated dredging) and the resort beach north of Rudee Inlet are both authorized Federal projects. Since adding significant volumes of sand to Croatan Beach – particularly in the northern sections close to the weir – could be seen as having the potential to increase dredging requirements to maintain safe navigation through the inlet, this may be a concern that USACE would raise. Therefore, it is considered likely that USACE would require a Section 408 review of such a project before granting a Federal permit for construction.

The MHW shoreline positions at station 05+00 and station 10+00 associated with the conceptual plan are within the envelope of shoreline positions that have existed at those stations in years since 2009, well after modification of the weir in 2004. It is considered unlikely that modifications to the weir would be required in order to construct and maintain the conceptual dune and beach profiles for maintaining acceptable levels of protection in present sea levels.

However, maintaining a 1% a.c. level of protection in the future 1.5 feet SLR condition would require much more dune volume and beach width than recommended for present-day conditions. Expanding the dune and beach profile to keep pace with 1.5 feet of SLR would likely require modifications to the weir and possibly to the south breakwater. These projects would be very likely to require a Section 408 review.

9. Conclusions and Recommendations

M&N conducted a study of the shoreline at Croatan Beach, between Rudee Inlet and Lockheed Avenue, to document historical shoreline and dune position changes. An objective of the study is to determine whether observed shoreline and dune changes can be correlated with dune and beach management practices, and if so whether those practices have decreased the level of protection provided by the beach and dune to the upland structures in the project area.

At the outset of the study, in March 2016, two M&N coastal engineers walked the length of Croatan Beach, making observations, taking photos of then-existing conditions of the inlet structures, beach, dune, and beach access structures, and recording waypoints with a handheld GPS device.

Historical data were evaluated to document shoreline and dune position changes. The data included data and findings from prior studies (e.g. Basco, 1994 and VIMS, 2012), City surveys, and digitization of more recent aerial images by M&N coastal engineers.

The level of protection currently provided by the beach and dune system to upland habitable and non-habitable structures was estimated through evaluation of SBEACH storm response model simulations at the eight City survey transect stations along Croatan Beach. The SBEACH model was calibrated utilizing the City profile survey data, and the calibrated model was used to simulated six design storms between a 10-year return period (10% annual chance) and a 100-year return period (1% annual chance). These simulations were conducted for storms occurring at present-day sea levels and for the same design storms if they occurred in a future scenario with 1.5 feet of SLR.

The purpose and need for adding dune volume and/or elevating and widening the dry beach profile were considered in light of the level of protection conclusions. Conceptual dune fill and beach fill profiles were evaluated. The potential for USACE Section 408 reviews for permitting of the conceptual options was considered.

<u>Site conditions post-November 2015 survey</u>

During the March 2016 site visit, the northern segment of Croatan Beach (north of Croatan Road) visually appeared more eroded by the recent winter storms compared to the southern segment. The northern beach had a lower, flatter dry beach profile, and more dune erosion and dune walkover damage appeared to exist in the northern segment.

During an August 2016 site visit, the beach profile in the northern segment appeared to have gained significant elevation and volume since the March 2016 visit.

Historical shoreline and dune position trends

There is not a consistent signal of shoreline advance or retreat or of dune accretion or erosion at Croatan Beach. Rather, the shoreline goes through cycles with multi-year periods of advance followed by periods of retreat. The shoreline has generally retreated since 2012. According to data from the nearest NDBC wave buoy (#44099), this retreat coincides with an apparent increase in frequency of northeasterly-approaching offshore wave heights. Estimated shoreline and dune toe position changes from the historical data are repeated from earlier tables in the report as Table 19 and Table 21 below.

Table 20: Shoreline Change Rates

		Shoreline Change Rate (ft/yr)	
Source	**Time Period**	**Entire Length (Sta. 00+00 to 35+00)**	
Basco, 1994 (MHW shoreline)	1980 - 1993	+6.1	
VIMS, 2012 (visible shoreline)	1937 - 2009	-1.2	
		North Reach Sta. 00+00 to 15+00	**South Reach Sta. 20+00 to 35+00**
Aerial Image (visible shoreline)	Feb 1970 – Jul 1994	+1.3	+2.3
	Jul 1994 – Feb 2002	-9.8	-7.9
	Feb 2002 – Feb 2009	+9.4	+7.9
	Feb 2009 – Apr 2014	-6.9	-6.6
	Apr 2014 – Nov 2015	-27.5	-23.7
	Feb 2002 – Apr 2014	**+2.5**	**+1.7**
	Feb 2002 – Nov 2015	**-0.8**	**-1.1**
	Feb 1970 – Apr 2014	**-0.3**	**+0.4**
	Feb 1970 – Nov 2015	**-1.2**	**-0.4**
City Survey Data (MHW shoreline)	Jun 2003 – Oct 2006	+5.4	+4.1
	Oct 2006 – Nov 2015	-6.0	-5.5
	Jun 2003 – Nov 2015	**-3.0**	**-3.0**
	Jun 2003 – Aug 2016	**-3.7**	**-3.5**

Table 21: Toe of Dune Position Change Rates

Source	Time Period	Dune Toe Position Change Rate (ft/yr) North Reach Sta. 00+00 to 15+00	South Reach Sta. 20+00 to 35+00
Aerial Image (visible dune toe)	Jan 2006 – Jan 2009	-0.1	-0.7
	Jan 2009 – Nov 2009	-13.9	-27.6
	Nov 2009 – Jul 2012	+6.8	+7.6
	Jul 2012 – Apr 2014	-2.4	-2.1
	Apr 2014 – Nov 2015	-0.3	+8.8
	Jan 2006 – Nov 2015	**+0.3**	**+0.6**
		North Reach Sta. 05+00 to 15+00	**South Reach Sta. 20+00 to 30+00**
City Survey Data (+10 ft MLW)	Jun 2003 – Jan 2006	+8.2	+4.2
	Jan 2006 – Nov 2015	**-5.3**	**-2.7**
	Jun 2003 – Nov 2015	**-2.5**	**-1.3**
	Jun 2003- Aug 2016	**-3.2**	**-2.7**

An average annual volume change of -15,000 cy/yr (between approximately +10 feet and -10 feet MLW) is estimated from end-point comparison of City profile surveys in August 2003 and November 2015. This includes consideration of the 85,000 cubic yards of sand added by dune and beach fill since 2008.

<u>Historical beach width trends</u>

Dune toe positions and shoreline positions digitizes from aerial imagery indicate that between 2006 and 2013 the dry beach width was greater than 75 feet at all stations along Croatan Beach (see Figure 36). Beach width was significantly larger in some years during that period. From 2013 to November 2015, the beach width consistently decreased.

The City survey data indicate different values for beach width than those apparent from the aerial images. According to the profile data, beach width between +10 ft MLW and the MHW shoreline decreased between October 2006 and November 2015, beach width decreased by 20 feet near the weir, increased by 20 feet at station 05+00, decreased by 20 feet at Twilight Lane, and decreased moderately from Twilight Lane to south of Croatan Road. From Aqua Lane to Maryland Ave., the beach width decreased by more than 20 feet, and the beach width increased near Lockheed Ave. The most recent City survey profiles indicate that the beach width decreased by 20 feet at station 05+00, but it was stable or increased at all other stations from 10+00 (Twilight Lane) south to the end of Croatan Beach. Most stations show a total beach width greater than 50 feet in August 2016.

Rudee Inlet dredging

From evaluation of the available City and Federal dredging records, it is estimated that an average of between 200,000 and 330,000 cubic yards of material has been dredged from inlet annually in the years since 2006. According to the USACE and VMRC permits for dredging in Rudee Inlet, the material dredged from Rudee Inlet is placed to the north of the inlet on the beach or nearshore submerged profile. In an emergency channel shoaling situation, material may be sidecast approximately 100 feet downdrift of the shoal instead of being placed on the northern beach.

Relationship of shoreline and beach width trends with management practices

The observed shoreline changes do not appear to be related to the 2004 modification of the north jetty and the weir in the south jetty. From the available shoreline position data, the shoreline retreated by approximately 50 to 75 feet from 1994 to 2002, before the weir and jetty modifications occurred. The shoreline advanced seaward between 2002 and 2009. The shoreline then retreated relatively slowly (at most locations along Croatan) from 2009 to 2012. From 2012 to the present, the shoreline generally retreated, though it is noted that in the southern segment (stations 20+00, 25+00, 30+00 and 35+00) the shoreline moved seaward in early 2013 as the northern segment retreated.

Additionally, no particular correlation is observed from the historical data between dredging volumes and shoreline position or beach width. Shoreline position is driven primarily by the annual wave climate, with both the intensity of wave climate (wave heights) and directionality of wave climate being important factors.

It is noted that the offshore wave climate represented by NDBC #44099 indicates directionality that would tend to result in shoreline retreat in the zone of inlet and jetty effects south of Rudee Inlet. As described in the main body of this report, the persistence of more northerly waves, creating a greater proportion of north-to-south littoral drift, would tend to cause the Croatan shoreline to retreat as sand is moved south without being resupplied naturally from the north at an equivalent rate.

The sand pushes that have historically occurred prior to storms typically cause short-term changes to the beach profile. This study is primarily concerned with longer-term trends and long-term beach and dune management actions. Thus, the short-term sand pushes were not explicitly considered in this study. In general, moving sand from the lower part of the beach to the upper beach and dune, sand pushes trade dry beach width (and shoreline position) for a gain in sand volume higher up on the beach. But sand pushes do not cause significant additional erosion of sand volume from the beach profile, beyond what would have occurred in the storm without the sand push.

Likewise, the relatively small volumes of sand borrowed from the inlet's sand trap and placed on Croatan periodically add sand to the Croatan beach and dune. While these projects may appear to erode or reshape quickly following placement, they do not increase the overall volume rate of erosion on the beach.

Finally, the beach nourishment projects at Dam Neck and Sandbridge do not reduce the supply of sand in the nearshore littoral system at Croatan. Sand for those projects is taken from a borrow area three to four miles offshore, and it is sand that would not have been transported to the beach without being dredged and placed on the beach as part of those projects.

Level of protection

The results of the level of protection analysis indicated that no habitable or non-habitable structures are currently at risk from storm surge, wave action, or erosion by waves in coastal storm events up to and including the 100-year return period event (1% annual chance) along most of Croatan Beach. The level of protection criteria were not met at stations 05+00 and station 10+00 near Twilight Lane. Modification to the existing beach and dune profiles would be required in this segment of the beach to meet the level of protection criteria.

Purpose and need for a project to enhance the beach and dune

The March and August 2016 site visits and the August 30, 2016 City survey data indicate that the existing beach profile does not meet the proposed criteria for beach berm width relative to vehicular access and recreational beach usage. It is prudent to establish a conceptual plan for restoring dune height and volume at selected transects and for increasing beach width along Croatan Beach.

Conceptual plan

A conceptual plan is recommended to include restoration a dune width of approximately 15 feet at elevation 21 feet MLW and creation of a beach berm width of approximately 50 feet at elevation 8 feet MLW. The total volume required for construction of the conceptual plan project is approximately 130,000 cubic yards. Maintaining this profile over several years (or several significant storms) post-construction would require addition of sand volumes periodically. The maintenance volumes and intervals would be determined during detailed design of the beach nourishment project.

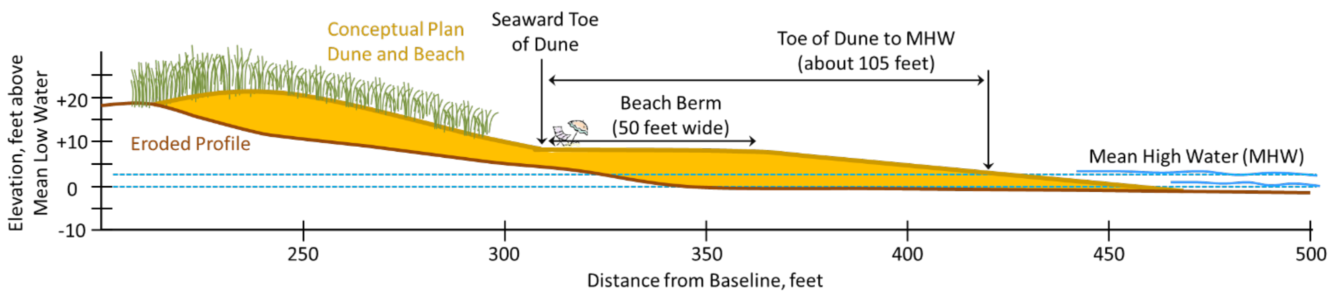


Figure 58: Conceptual Plan Typical Profile

Section 408 review

The navigation channel (and associated dredging) of Rudee Inlet is an authorized Federal project. Adding significant volumes of sand to Croatan Beach – particularly in the northern sections close to the weir – could be seen as having the potential to increase dredging requirements to maintain safe navigation through the inlet. It is likely that USACE would require a Section 408 review of such a project before granting a Federal permit for construction. The fill volumes proposed as part of the conceptual plans outlined above are similar to the volume of 20,000 cy/yr in a current Joint Permit Application currently being reviewed by USACE and VMRC.

Effects of 1.5 feet of sea level rise

With sea level rise, the level of protection by the existing beach and dune system will be reduced. The SBEACH model simulations indicated the levels of protection in Table 18, repeated from Section 6.4 regarding the effects of 1.5 feet of SLR. Providing acceptable levels of protection from storm surge and wave effects in such a future SLR condition would require addition of significant dune volume and beach width. Maintaining the increased beach volumes would likely require modifications to the existing weir and southern breakwater. At the same time, the weir profile would need to be modified to keep bypassing rates over the weir similar to present rates, when the tidal range were to rise by 1.5 feet due to SLR. Any changes to the weir and breakwater structures are likely to require a Section 408 review, along with modeling and coastal engineering analyses.

Table 22: Existing Condition Profiles' Levels of Protection with 1.5 Feet of SLR

Station	Level of Protection at Habitable Structures (Return Period)	Level of Protection at Other Structures (Return Period)
00+00 Virginia Dare Dr.	100-year (1% a.c.)	100-year (1% a.c.)
05+00	10-year (10% a.c.)	Less than 10-year (> 10% a.c.)
10+00 Twilight Lane	25-year (4% a.c.)	Less than 25-year (> 4% a.c.)
15+00 North of Croatan Rd.	50-year (2% a.c.) to 100-year (1% a.c.)	100-year (1% a.c.)
20+00 South of Croatan Rd.	50-year (2% a.c.)	25-year (4% a.c.)
25+00 North of Aqua Ln.	25-year (4% a.c.)	25-year (4% a.c.)
30+00 Maryland Ave.	100-year (1% a.c.)	100-year (1% a.c.)
35+00 Lockheed Ave.	100-year (1% a.c.)	50-year (2% a.c.)

10. References

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Appendix A: Photos of Project Site

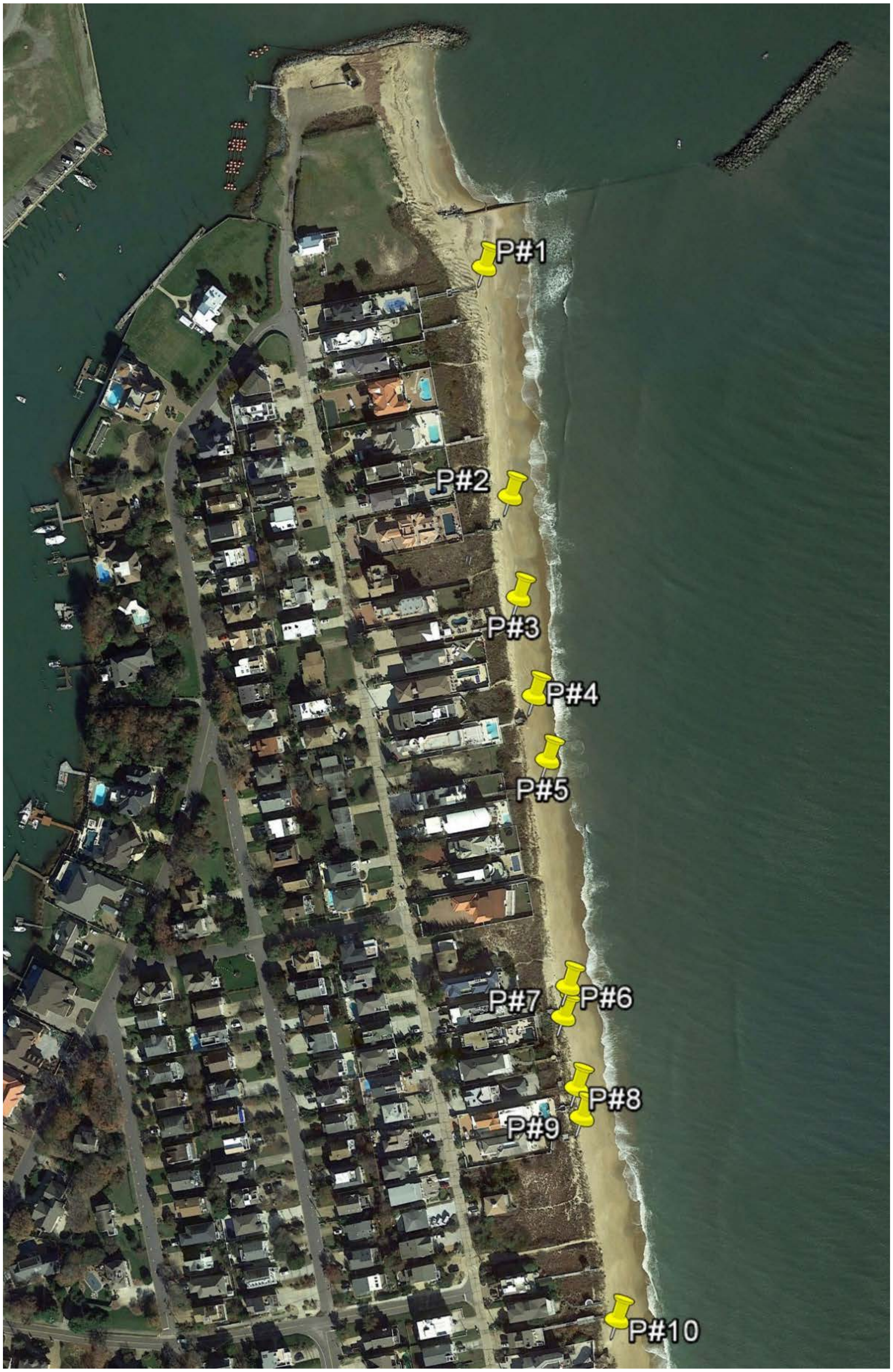


Photo Location

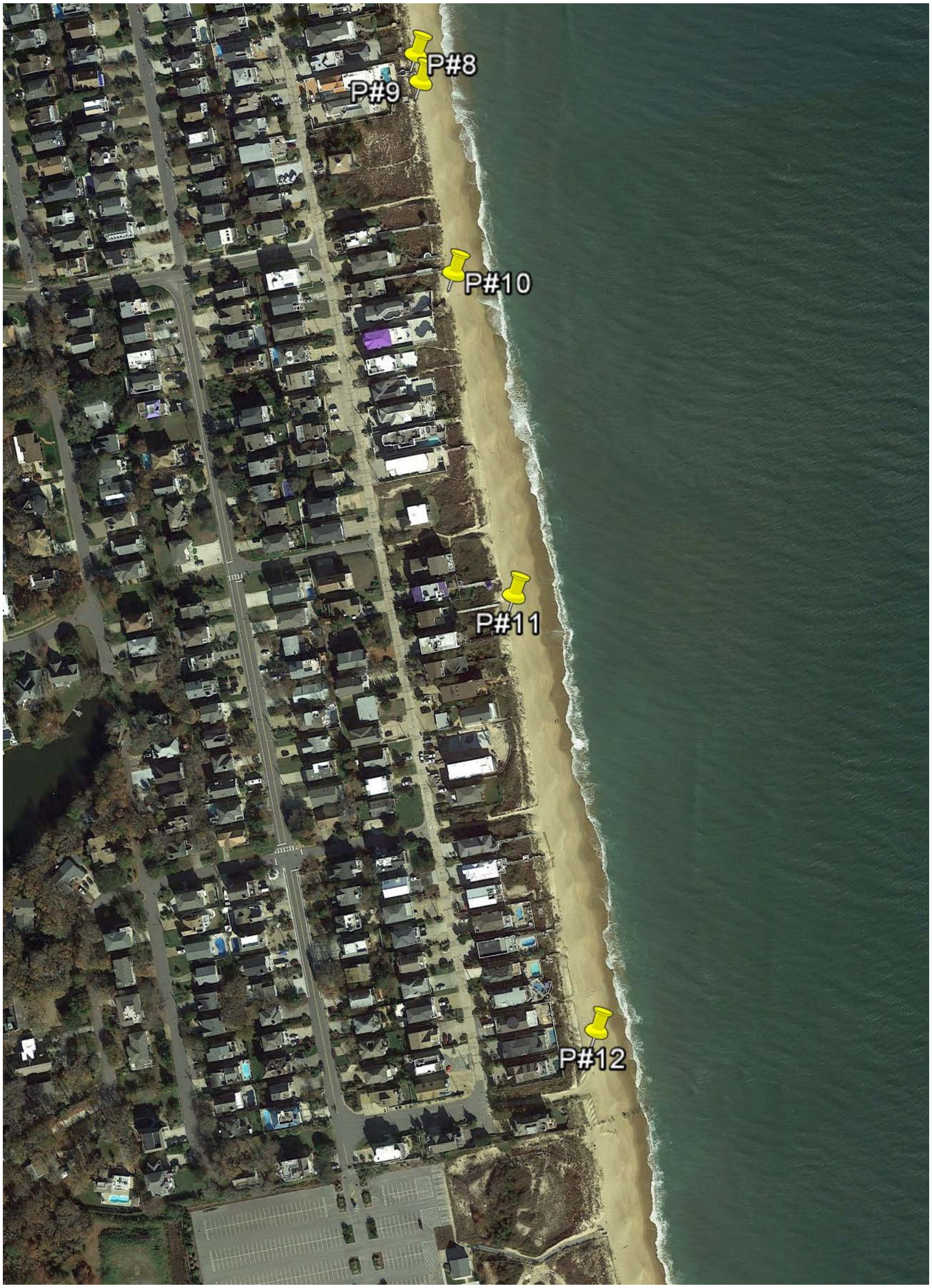


Photo Location

Photo 1

Photo 2

Photo 2-1

Photo 2-2

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

Photo 8

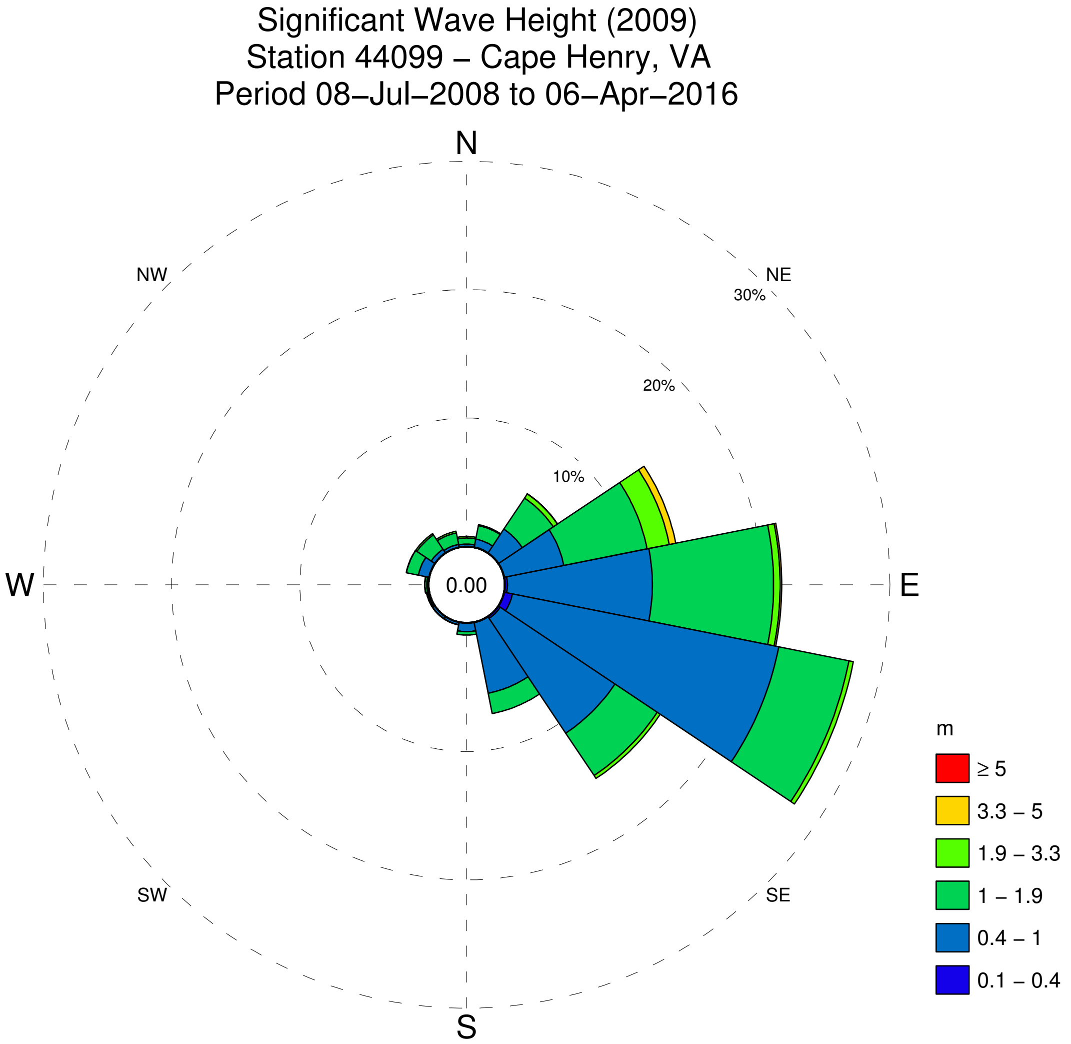
Photo 9

Photo 10

Photo 11

Photo 12

Appendix B: Annual Wave Roses

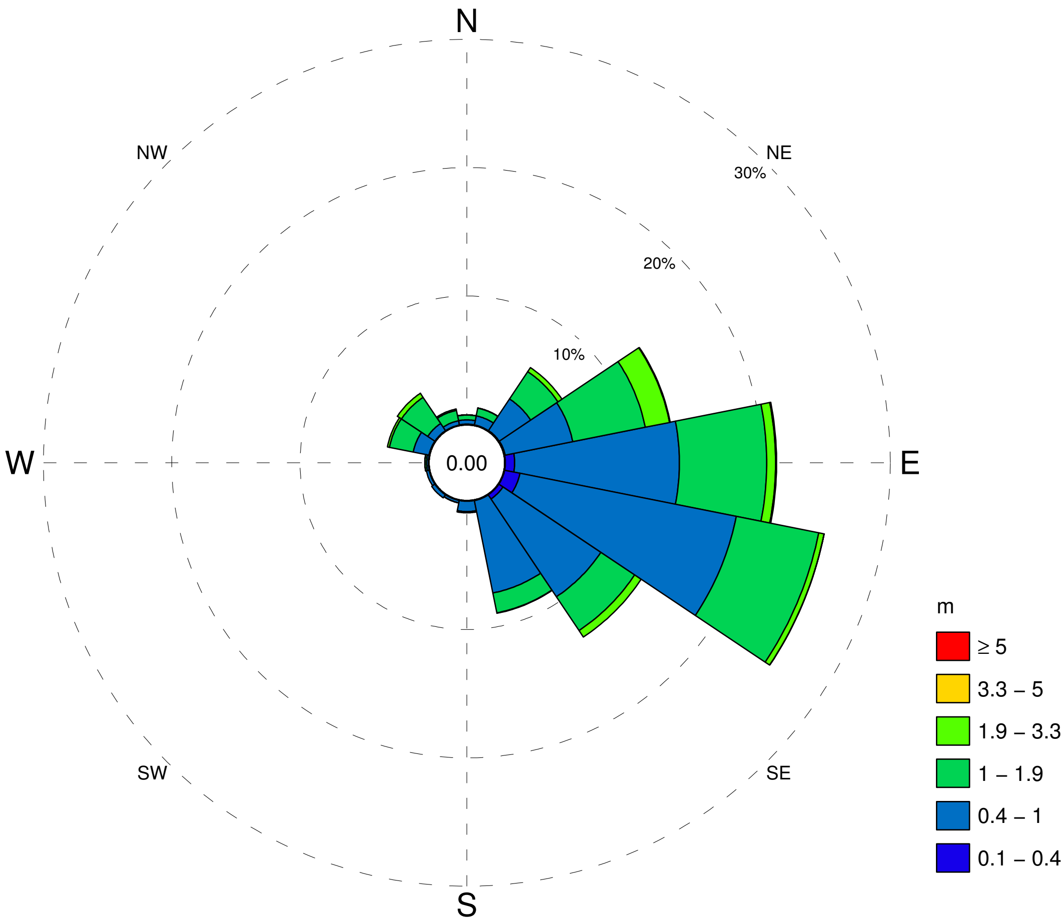


Direction FROM is shown
Center value indicates calms below 0.1 m
Total observations 16192, calms 0
About 4.7% of observations missing

Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	0.77	1.78	5.52	13.62	21.57	27.75	15.16	7.24	0.92	0.20	0.19	0.19	0.27	1.80	1.78	1.25	100.00
≥ 5																	
3.3 – 5				0.51	0.12												0.64
1.9 – 3.3	0.12		0.39	1.77	0.51	0.35	0.28								0.12	0.13	3.75
1 – 1.9	0.48	1.07	2.91	6.63	9.46	5.58	3.96	1.62	0.27				0.15	0.96	1.34	0.91	35.42
0.4 – 1	0.17	0.63	2.22	4.72	11.30	21.18	10.76	5.61	0.65	0.17	0.18	0.10	0.10	0.83	0.33	0.22	59.17
0.1 – 0.4					0.18	0.64	0.15										1.02

Significant Wave Height (2010)
Station 44099 – Cape Henry, VA
Period 08–Jul–2008 to 06–Apr–2016

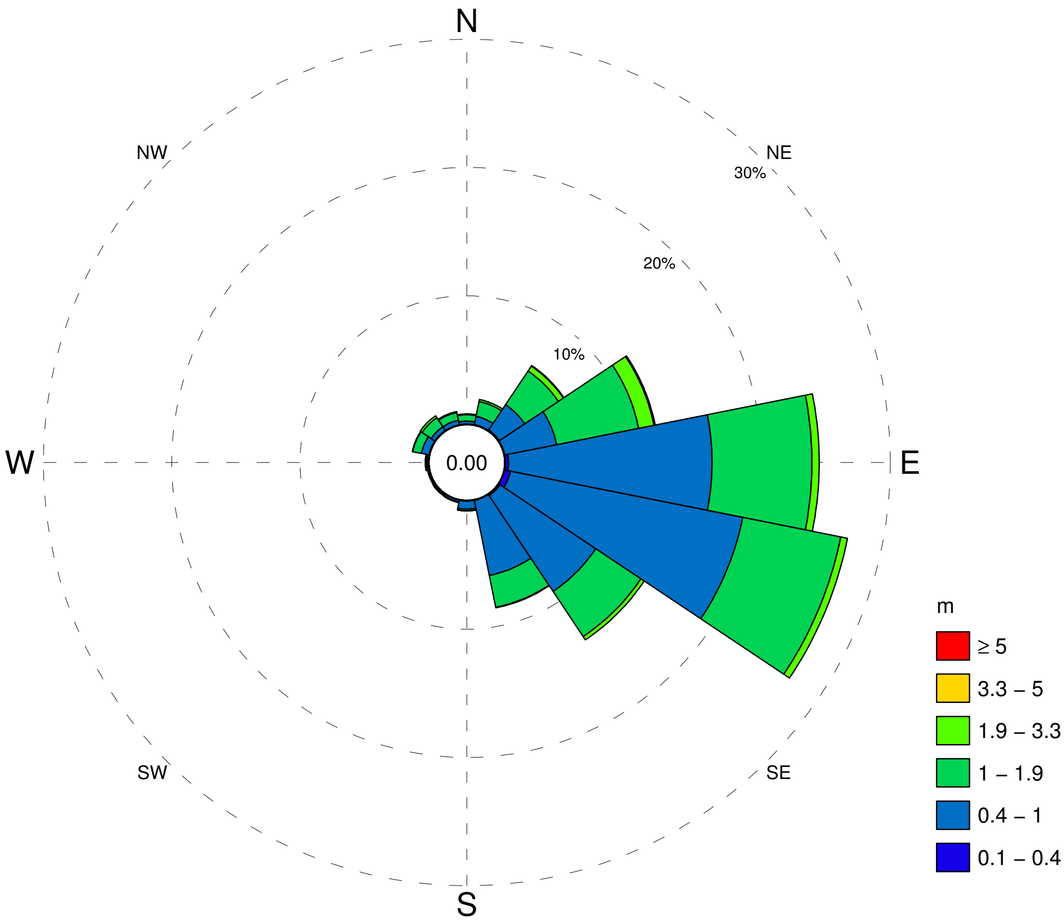


Direction FROM is shown
Center value indicates calms below 0.1 m
Total observations 16006, calms 0
About 4.63% of observations missing

Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	0.73	1.36	5.92	13.17	21.14	25.38	13.34	8.96	0.91	0.19	0.30	0.22	0.27	3.32	3.52	1.27	100.00
≥ 5																	
3.3 – 5																	0.14
1.9 – 3.3			0.37	1.94	0.69	0.42	0.61							0.16	0.38	0.11	4.74
1 – 1.9	0.38	0.62	2.56	5.76	6.80	6.55	3.17	1.57					0.13	1.89	2.46	0.82	32.82
0.4 – 1	0.33	0.72	2.96	5.37	12.85	17.19	9.17	7.34	0.81	0.19	0.30	0.22	0.14	1.25	0.67	0.34	59.84
0.1 – 0.4					0.72	1.22	0.39										2.46

Significant Wave Height (2011)
Station 44099 – Cape Henry, VA
Period 08–Jul–2008 to 06–Apr–2016

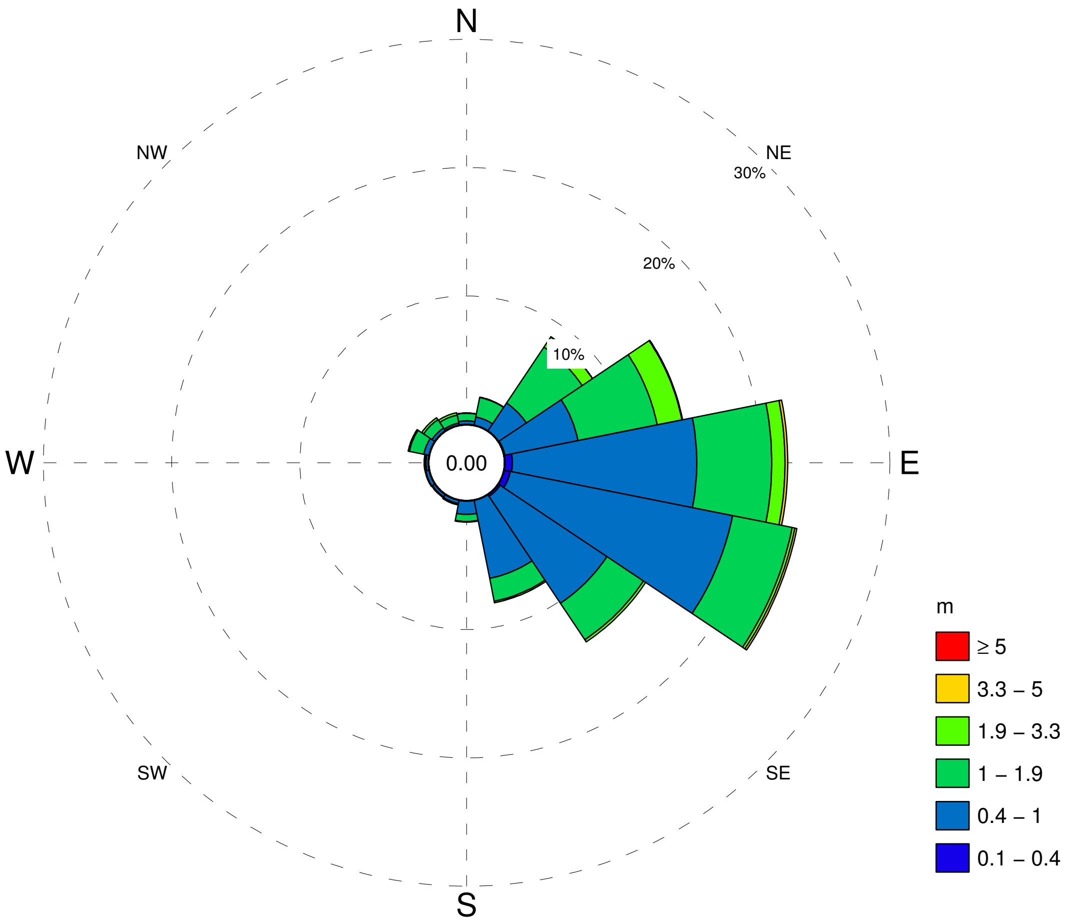


Direction FROM is shown
Center value indicates calms below 0.1 m
Total observations 14816, calms 0
About 11.7% of observations missing

Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	0.79	2.01	6.09	11.97	24.46	27.24	13.62	8.56	0.78	0.19	0.16	0.12	0.24	1.34	1.38	1.05	100.00
≥ 5																	
3.3 – 5																	0.15
1.9 – 3.3		0.16	0.47	1.22	0.56	0.53	0.30								0.18		3.66
1 – 1.9	0.51	1.18	3.15	6.51	7.79	7.78	4.23	2.53	0.13				0.11	0.69	0.84	0.61	36.16
0.4 – 1	0.22	0.65	2.38	4.13	15.86	18.46	8.98	5.97	0.62	0.14	0.11		0.12	0.61	0.35	0.36	59.04
0.1 – 0.4					0.25	0.47	0.11										0.99

Significant Wave Height (2012)
Station 44099 – Cape Henry, VA
Period 08–Jul–2008 to 06–Apr–2016

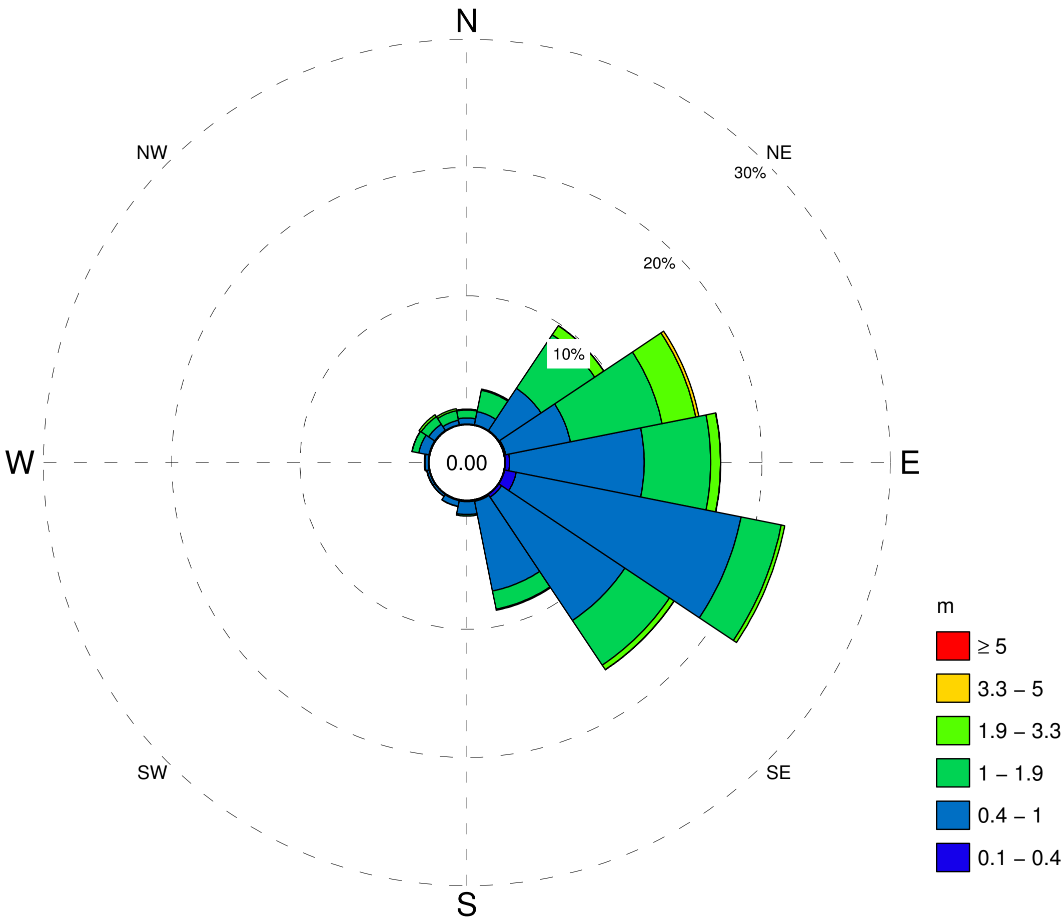


Direction FROM is shown
Center value indicates calms below 0.1 m
Total observations 16824, calms 0
About 0.519% of observations missing

Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	0.87	2.22	8.81	14.18	22.04	23.26	13.78	8.12	1.63	0.36	0.27	0.31	0.32	1.65	1.22	0.97	100.00
≥ 5																	
3.3 – 5					0.21	0.16											0.44
1.9 – 3.3			0.97	1.97	1.04	0.21	0.20	0.12							0.18	0.19	5.20
1 – 1.9	0.59	1.55	5.24	6.29	5.84	4.74	3.42	1.82	0.55				0.10	1.15	0.79	0.63	32.85
0.4 – 1	0.27	0.64	2.60	5.81	14.38	17.66	10.00	6.18	1.03	0.25	0.20	0.26	0.18	0.40	0.25	0.15	60.27
0.1 – 0.4					0.57	0.48	0.15										1.25

Significant Wave Height (2013)
Station 44099 – Cape Henry, VA
Period 08–Jul–2008 to 06–Apr–2016

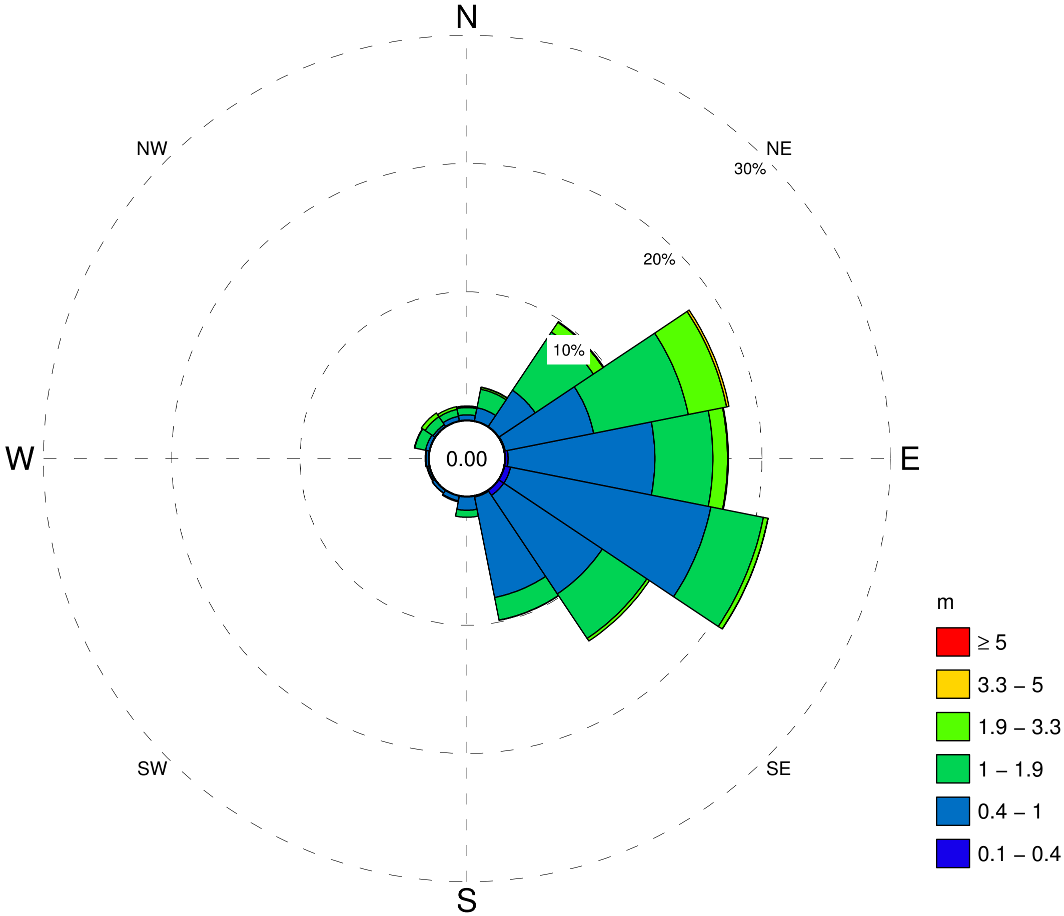


Direction FROM is shown
Center value indicates calms below 0.1 m
Total observations 16878, calms 0
About 1.59% of observations missing

Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	1.16	2.84	9.84	15.44	16.79	22.27	16.44	8.74	1.18	0.50	0.19	0.20	0.31	1.36	1.48	1.28	100.00
≥ 5																	
3.3 – 5				0.25													0.28
1.9 – 3.3			0.85	2.68	0.76	0.28	0.43								0.19	0.16	5.61
1 – 1.9	0.62	1.70	5.02	7.29	5.18	3.19	4.18	1.45	0.12					0.53	0.69	0.76	30.83
0.4 – 1	0.47	1.04	3.94	5.14	10.49	17.87	11.57	7.12	1.01	0.46	0.18	0.17	0.26	0.80	0.57	0.36	61.44
0.1 – 0.4					0.33	0.92	0.25										1.83

Significant Wave Height (2014)
Station 44099 – Cape Henry, VA
Period 08–Jul–2008 to 06–Apr–2016

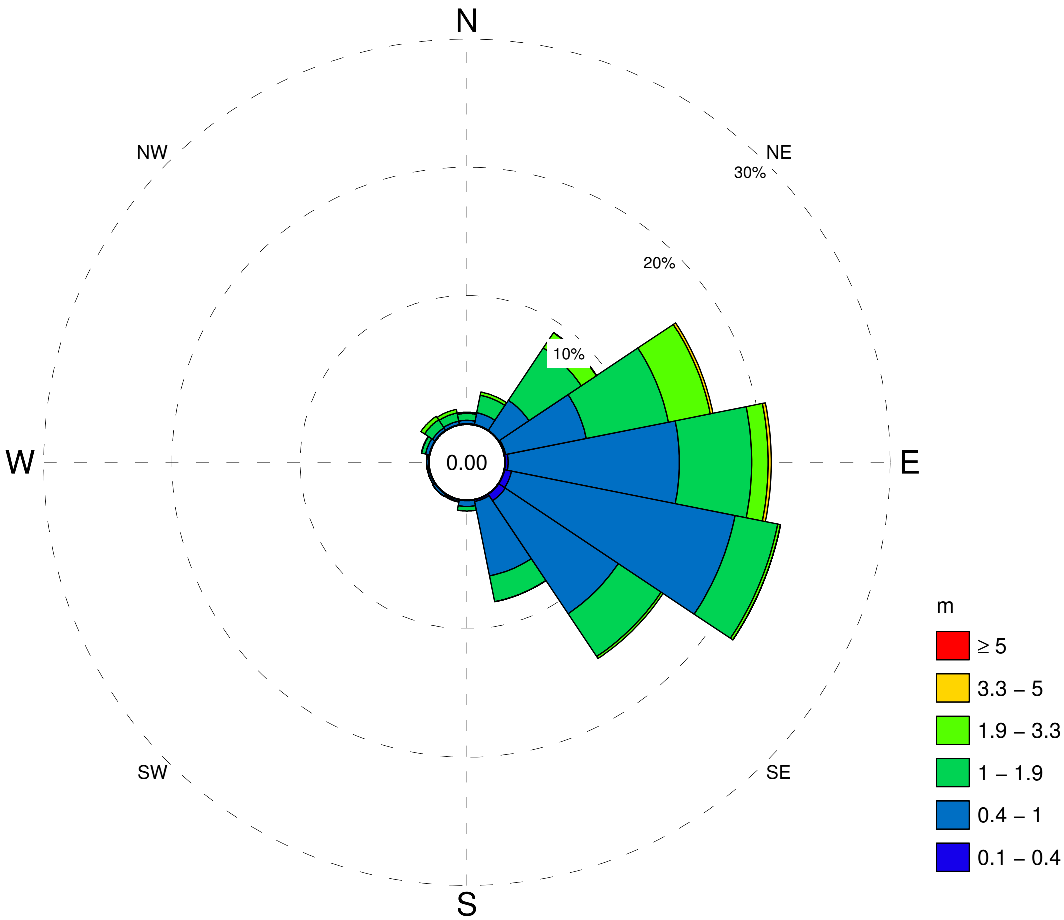


Direction FROM is shown
Center value indicates calms below 0.1 m
Total observations 17145, calms 0
About 0.58% of observations missing

Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	1.09	2.68	9.83	17.83	17.38	20.93	14.12	9.87	1.58	0.44	0.26	0.19	0.24	1.17	1.27	1.11	100.00
≥ 5																	
3.3 – 5				0.19													0.37
1.9 – 3.3		0.15	0.92	3.04	1.14	0.36	0.24								0.35	0.22	6.56
1 – 1.9	0.57	1.47	5.45	7.53	4.53	4.18	4.18	1.80	0.54					0.86	0.75	0.54	32.60
0.4 – 1	0.40	1.04	3.39	7.02	11.44	15.92	9.24	7.99	1.04	0.36	0.24	0.12	0.19	0.28	0.17	0.36	59.21
0.1 – 0.4					0.22	0.47	0.45										1.25

Significant Wave Height (2015)
Station 44099 – Cape Henry, VA
Period 08–Jul–2008 to 06–Apr–2016

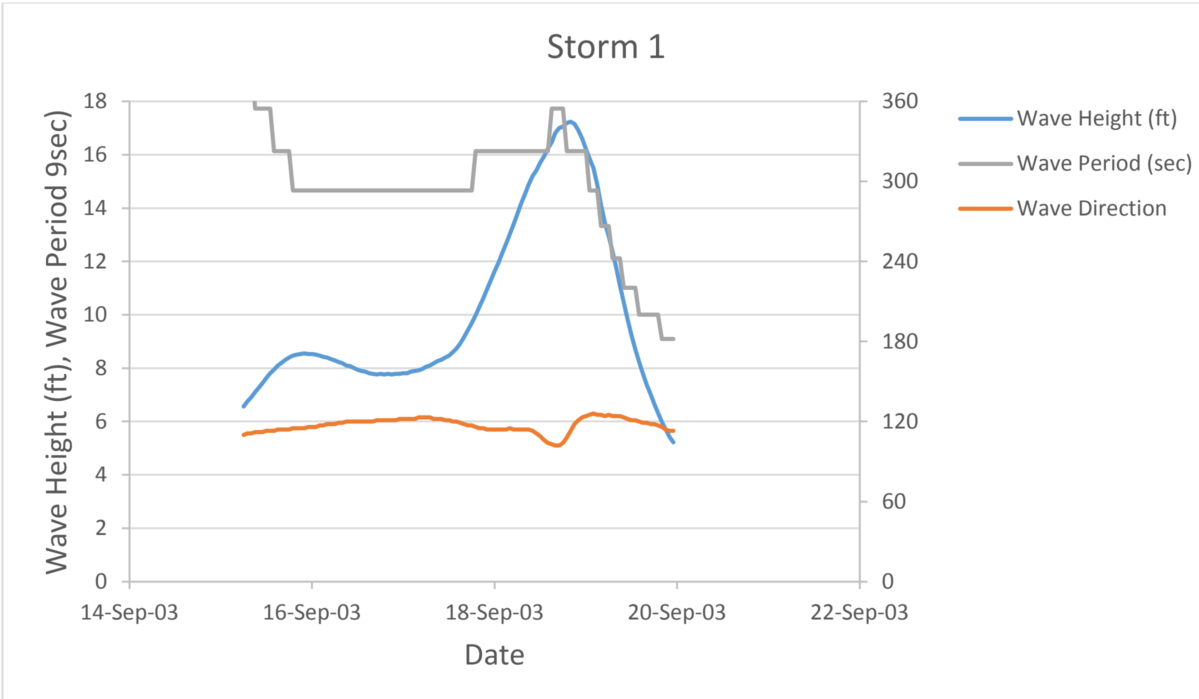


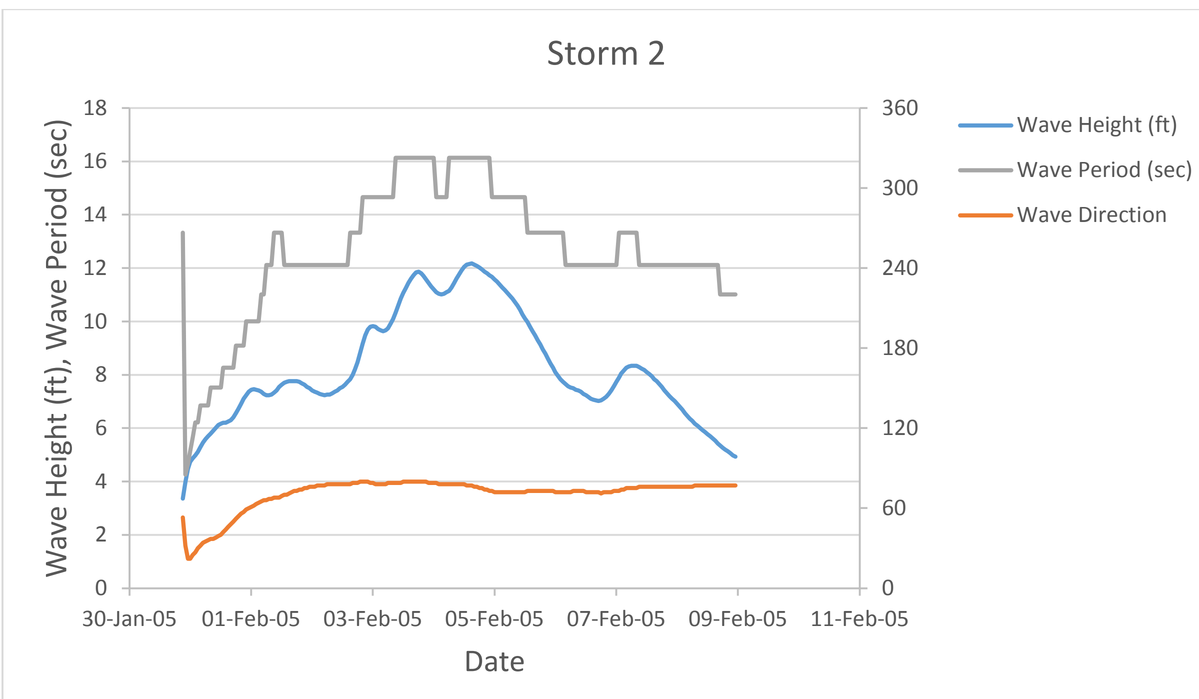
Direction FROM is shown
Center value indicates calms below 0.1 m
Total observations 16658, calms 0
About 1.19% of observations missing

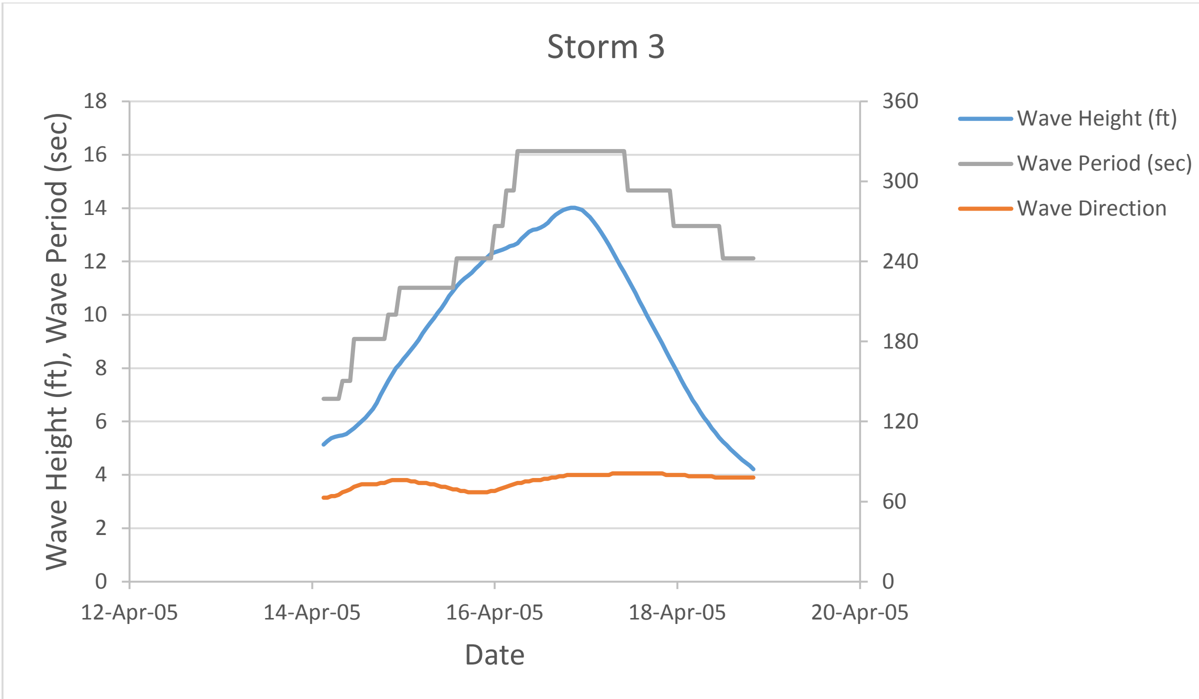
Percentage of Occurrence

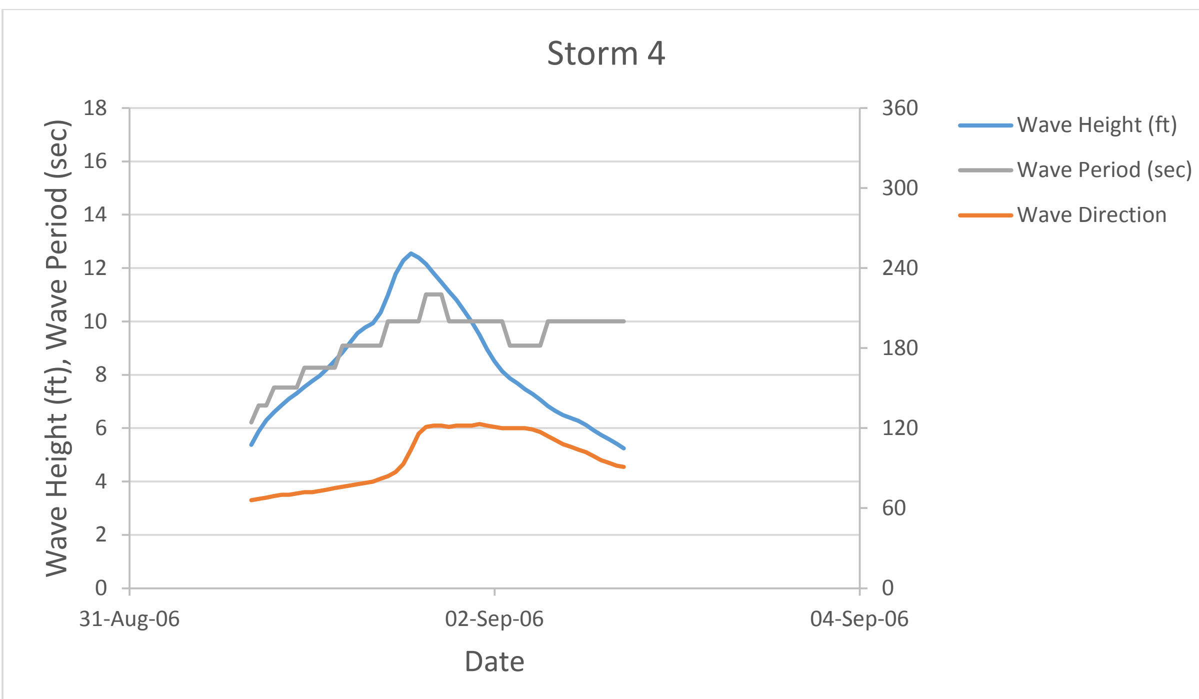
Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	0.90	2.58	9.17	16.55	20.73	21.94	15.41	8.10	0.80	0.17	0.20	0.14	0.14	0.63	1.31	1.20	100.00
≥ 5																	
3.3 – 5				0.21	0.24												0.48
1.9 – 3.3		0.25	1.42	3.33	1.28	0.22	0.19								0.33	0.28	7.44
1 – 1.9	0.54	1.39	4.90	6.54	5.64	3.39	4.02	2.05	0.35					0.31	0.75	0.65	30.63
0.4 – 1	0.26	0.93	2.82	6.39	13.35	17.78	10.60	5.91	0.45	0.11	0.19	0.13	0.13	0.29	0.22	0.26	59.83
0.1 – 0.4					0.22	0.55	0.61	0.13									1.62

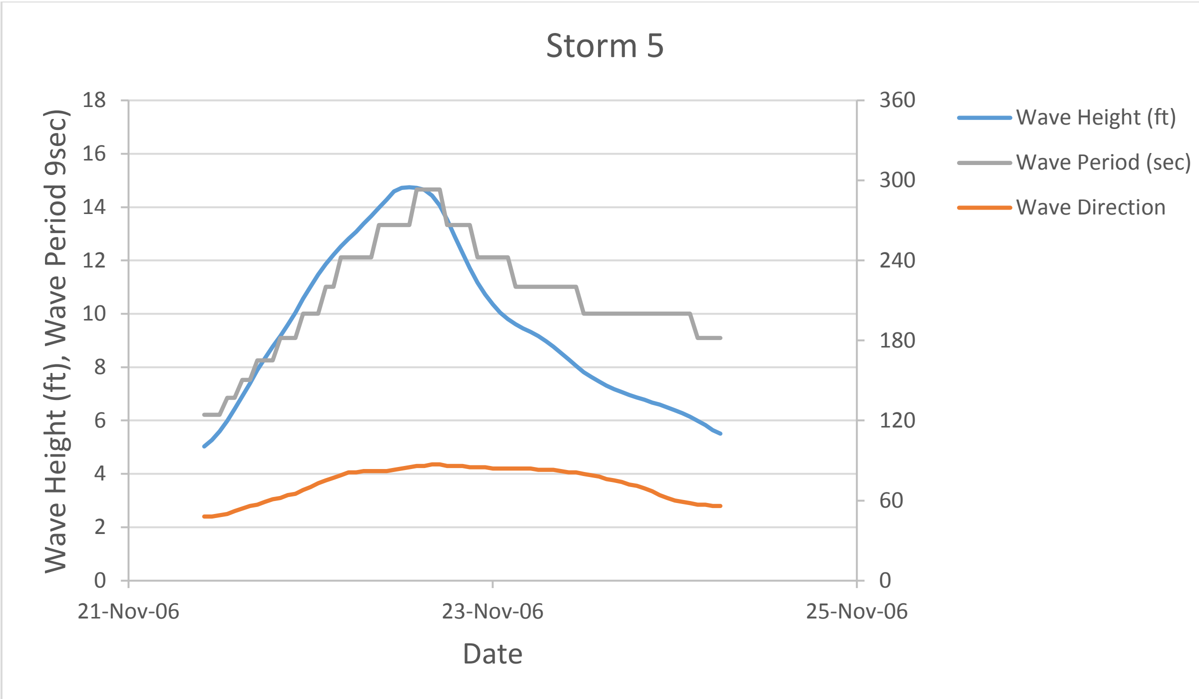
Appendix C: Historical Storms

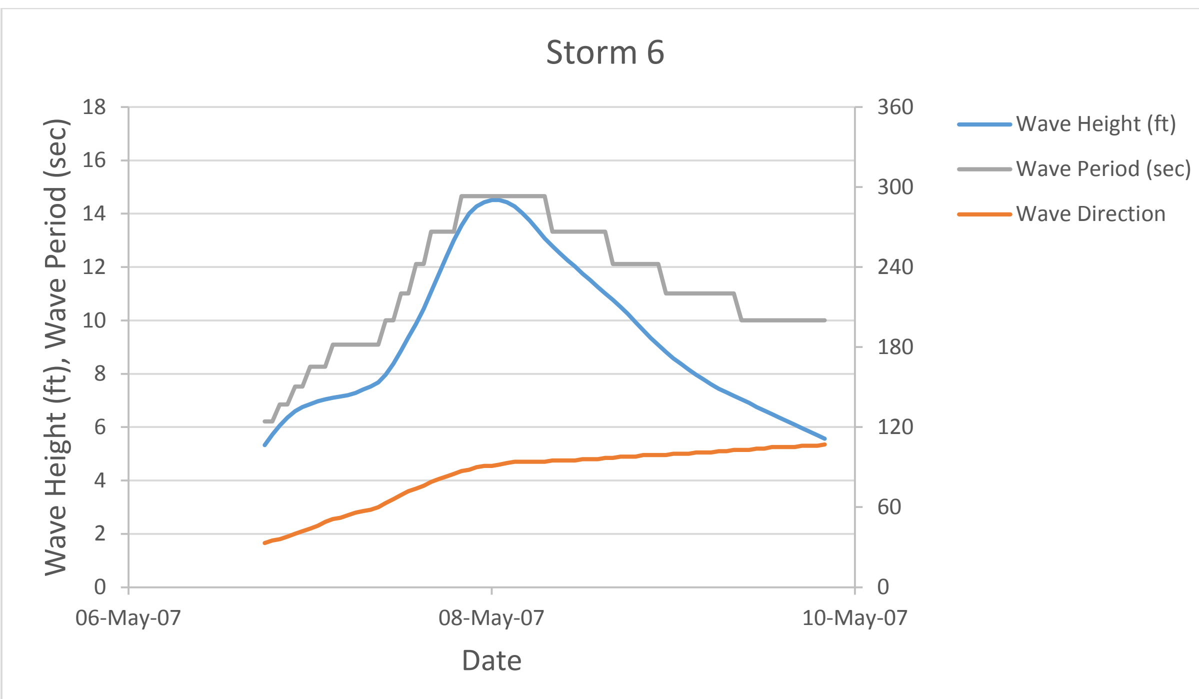

Storm 1
Wave Height (ft), Wave Period 9sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
14-Sep-03
16-Sep-03
18-Sep-03
20-Sep-03
22-Sep-03
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

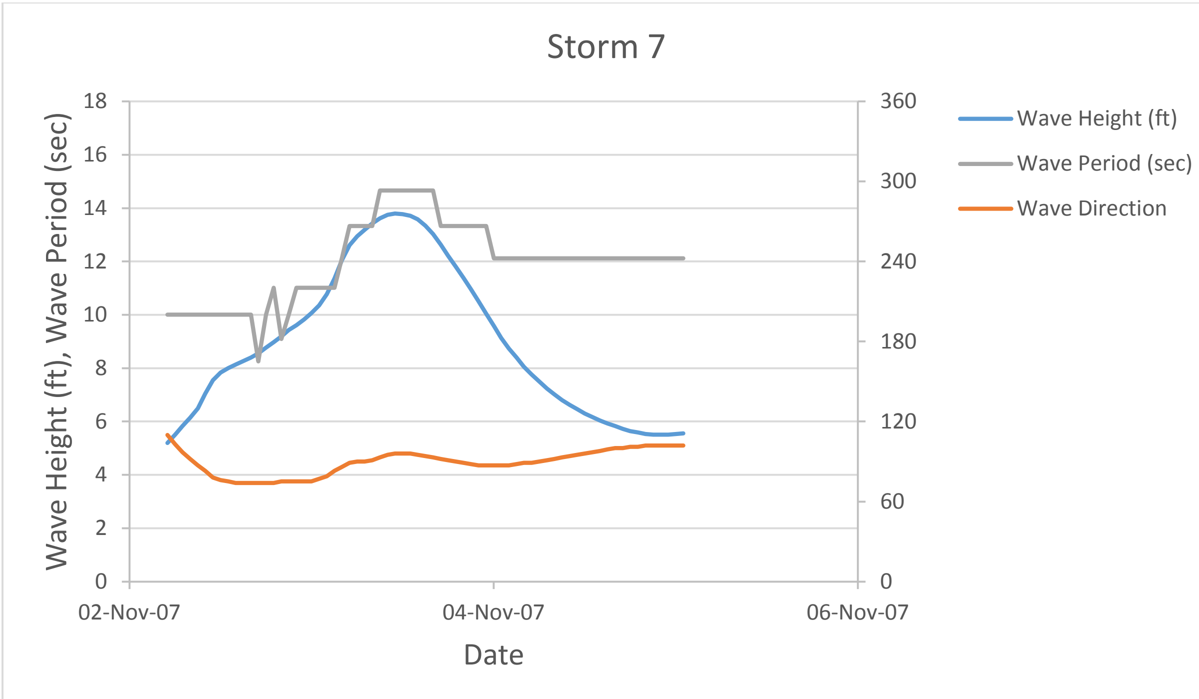

Storm 2
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
30-Jan-05
01-Feb-05
03-Feb-05
05-Feb-05
07-Feb-05
09-Feb-05
11-Feb-05
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

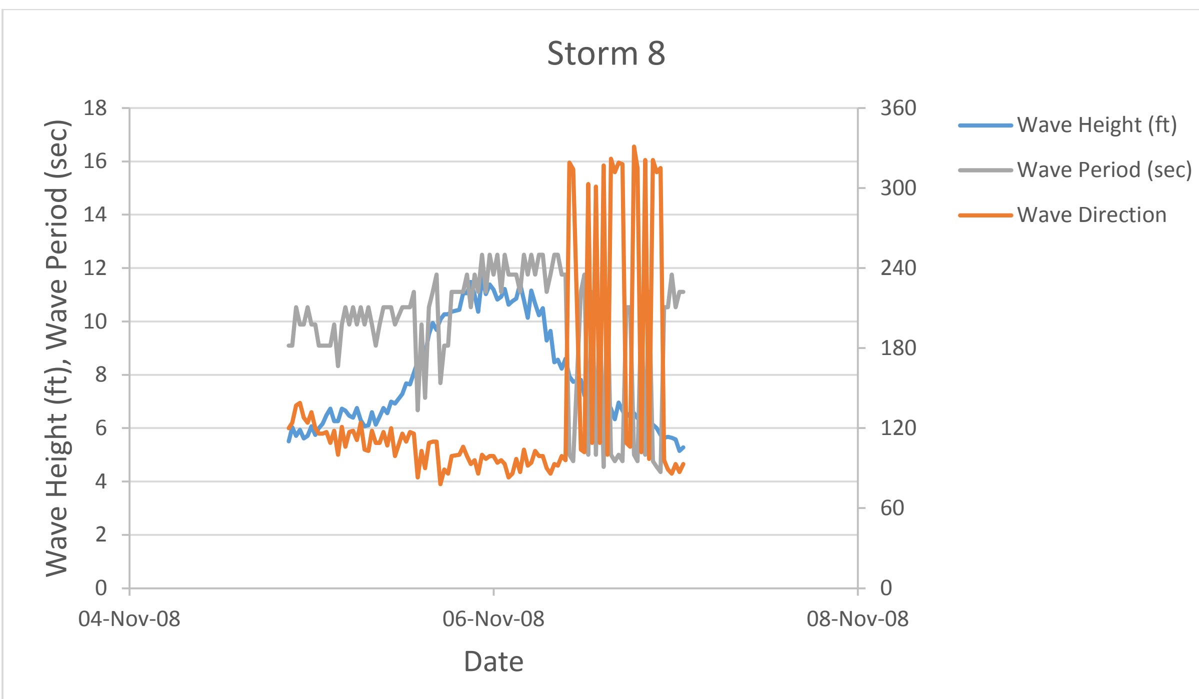

Storm 3
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
12-Apr-05
14-Apr-05
16-Apr-05
18-Apr-05
20-Apr-05
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

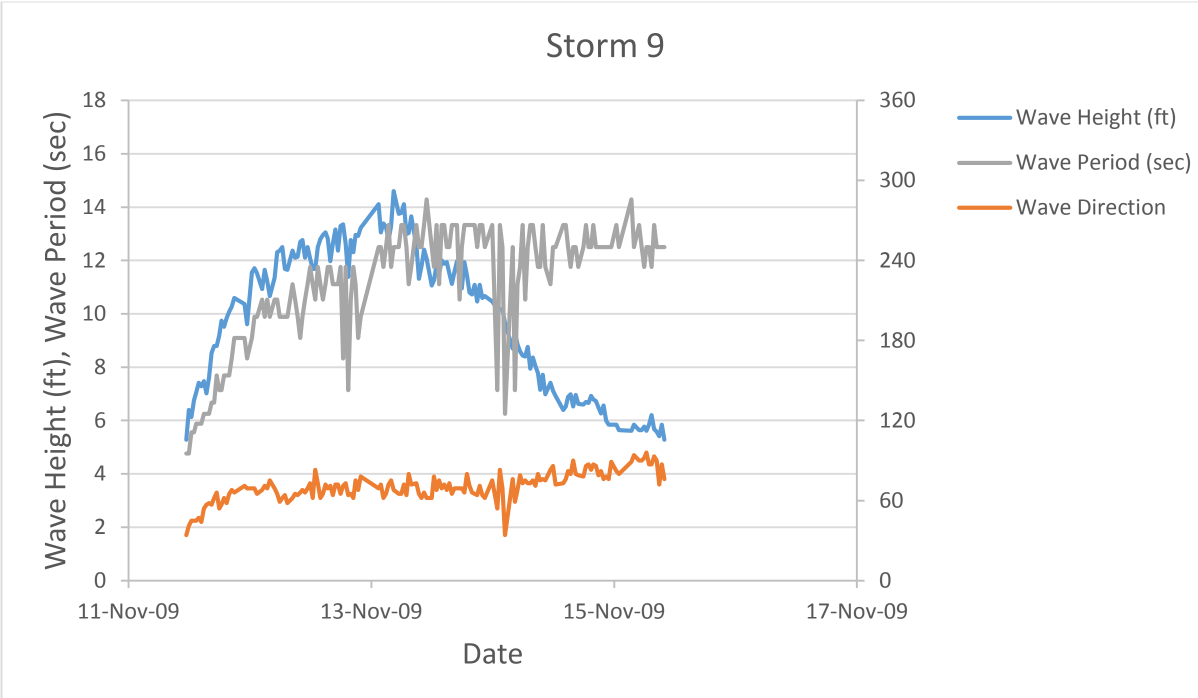

Storm 4
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
31-Aug-06
02-Sep-06
04-Sep-06
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction


Storm 5
Wave Height (ft), Wave Period 9sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
21-Nov-06
23-Nov-06
25-Nov-06
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

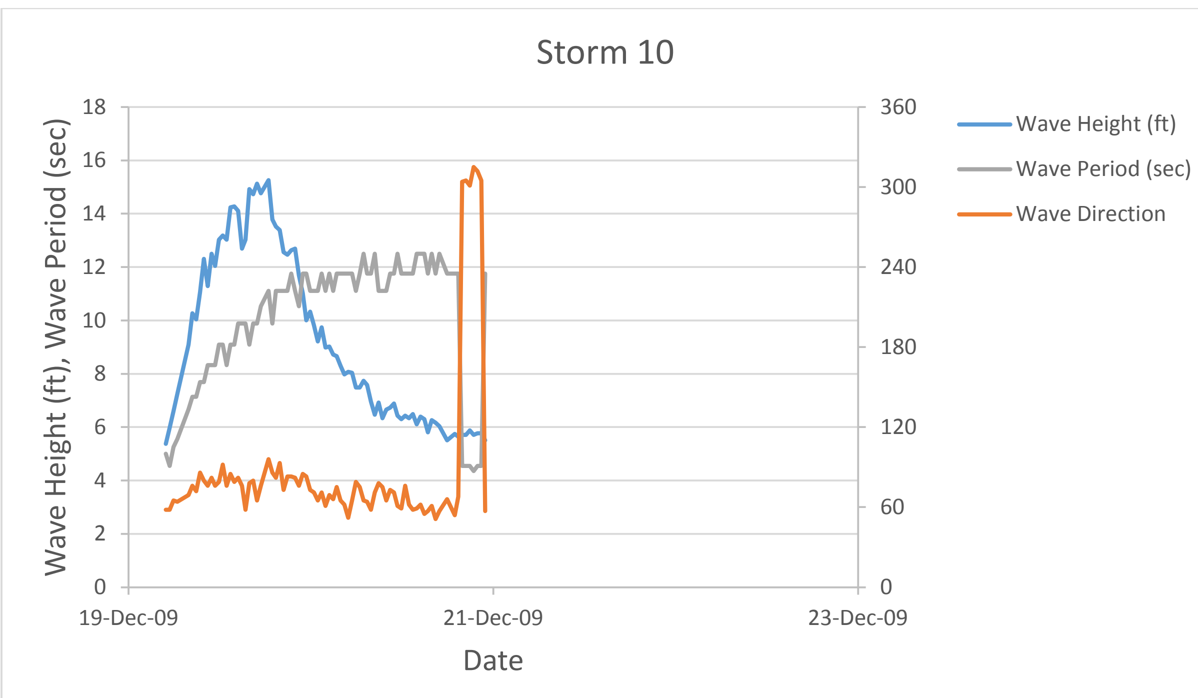

Storm 6
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
06-May-07
08-May-07
10-May-07
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction


Storm 7
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
02-Nov-07
04-Nov-07
06-Nov-07
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

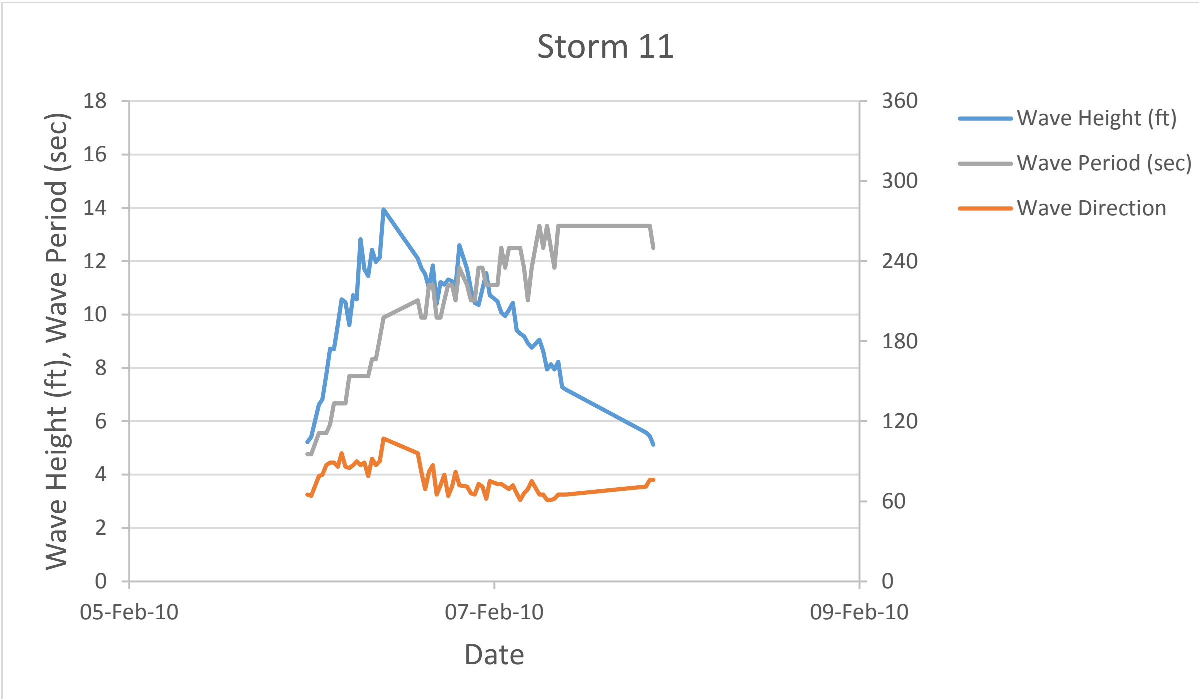

Storm 8
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
04-Nov-08
06-Nov-08
08-Nov-08
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

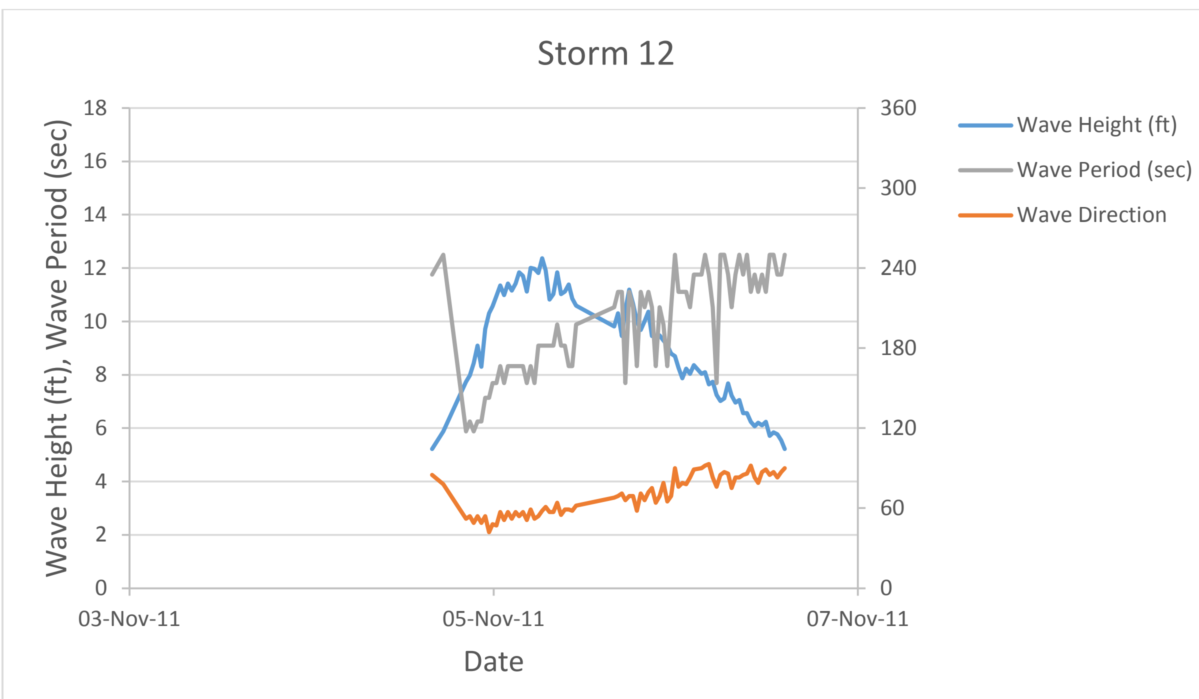


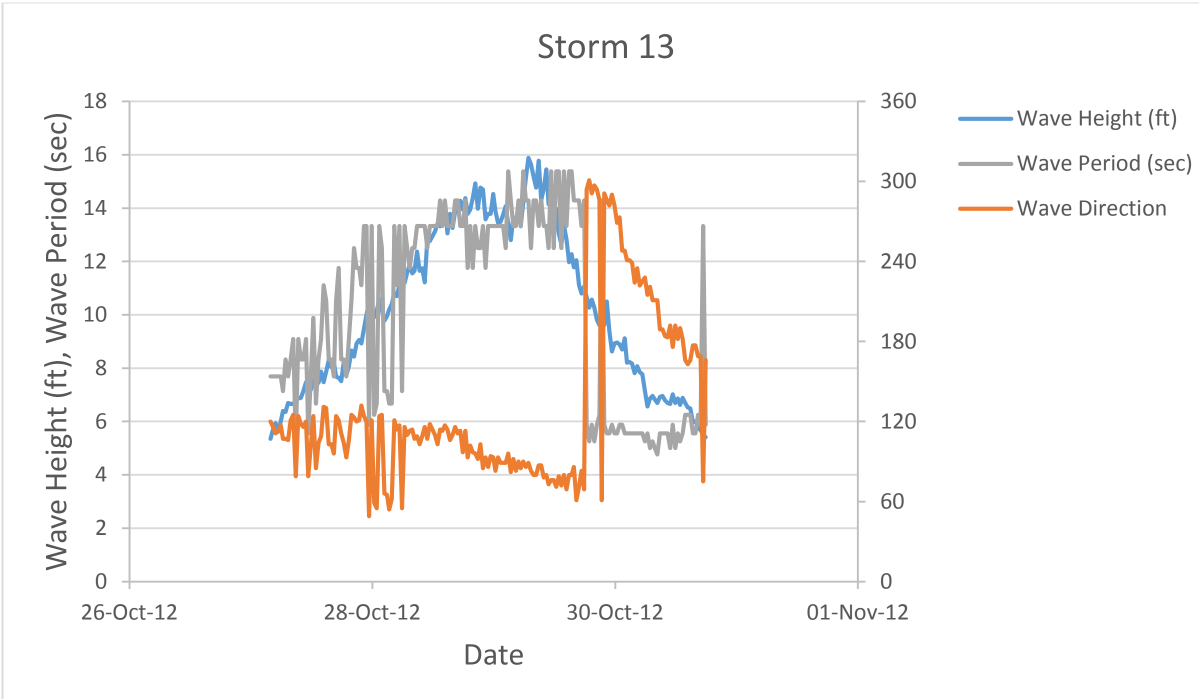
Storm 9
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
11-Nov-09
13-Nov-09
15-Nov-09
17-Nov-09
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

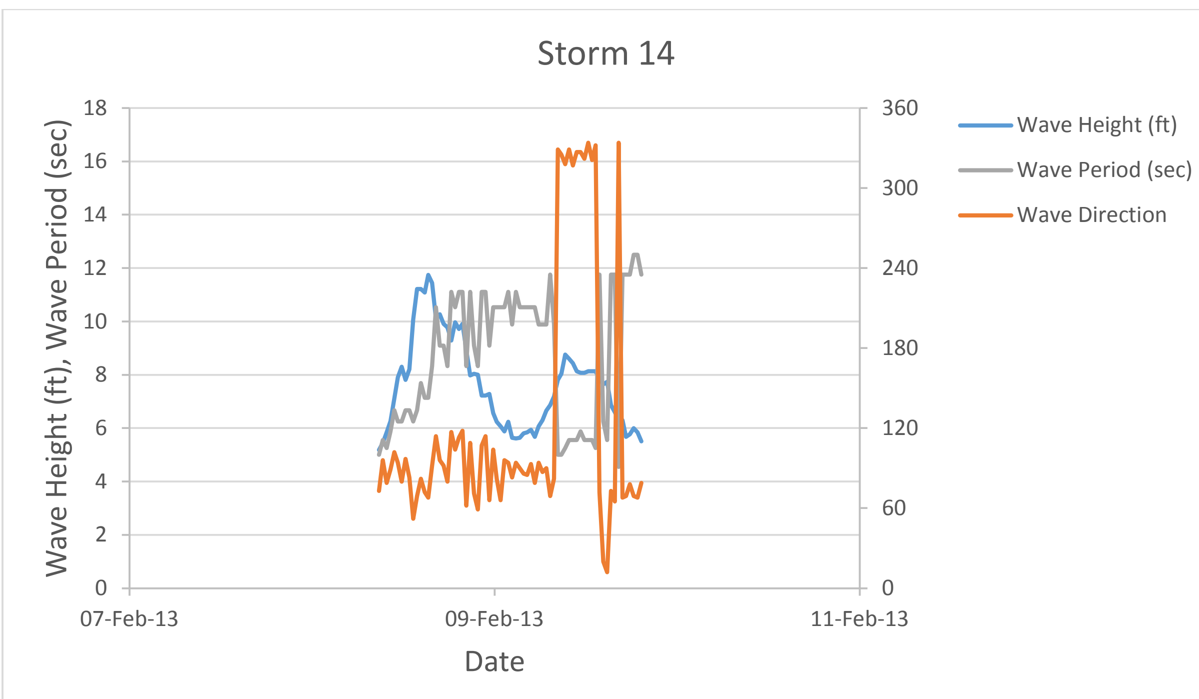


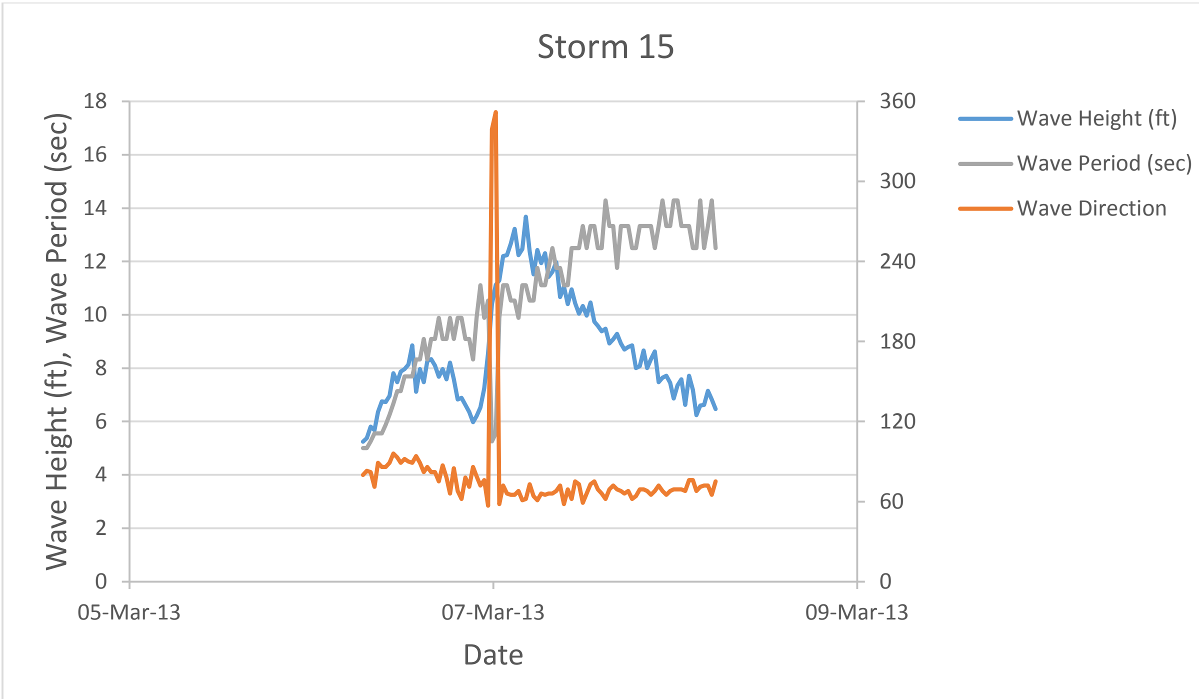
Storm 10
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
19-Dec-09
21-Dec-09
23-Dec-09
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction


Storm 11
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
05-Feb-10
07-Feb-10
09-Feb-10
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

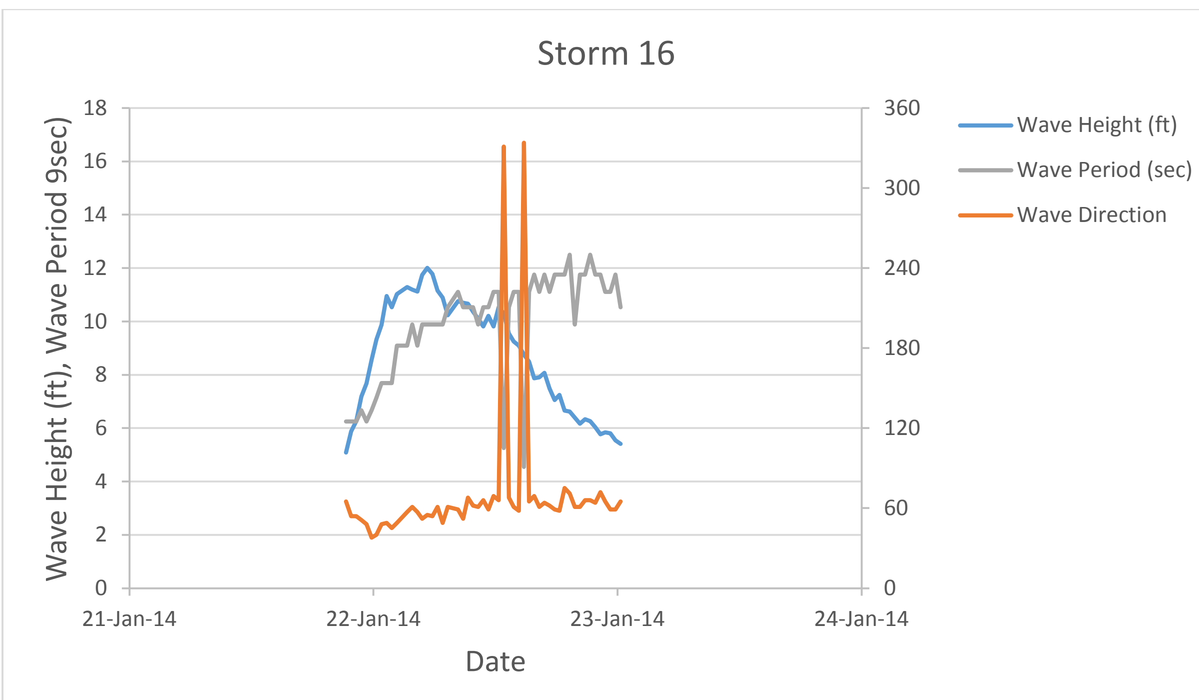

Storm 12
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
03-Nov-11
05-Nov-11
07-Nov-11
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction


Storm 13
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
26-Oct-12
28-Oct-12
30-Oct-12
01-Nov-12
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

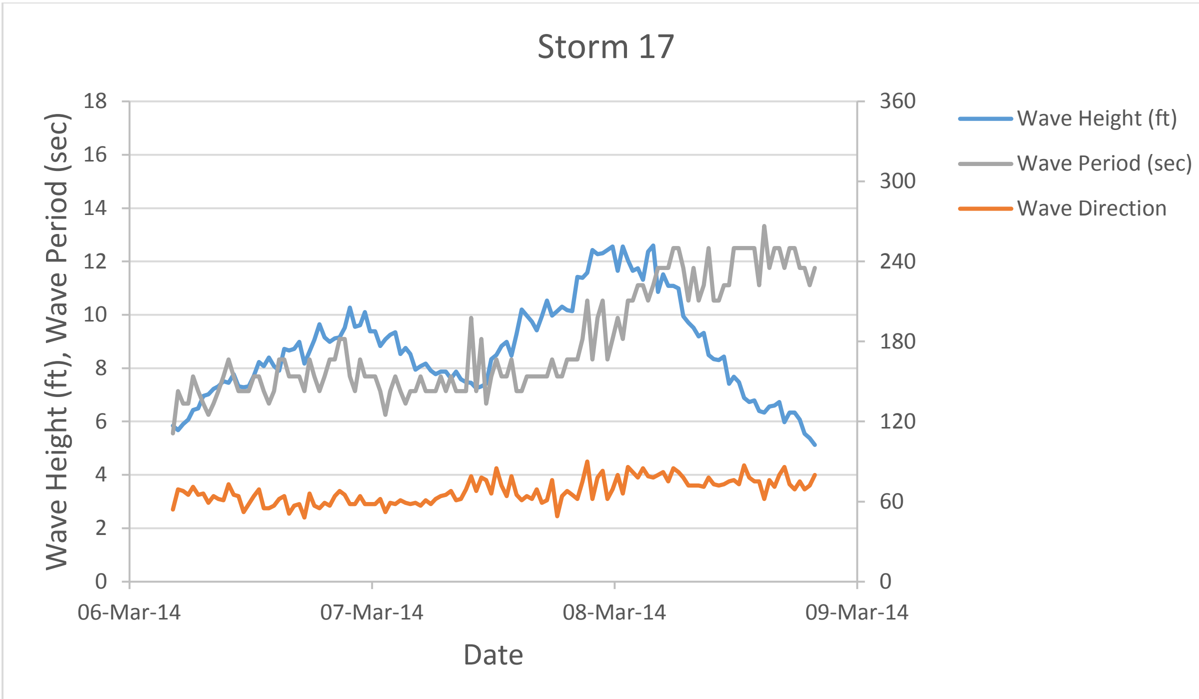

Storm 14
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
07-Feb-13
09-Feb-13
11-Feb-13
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

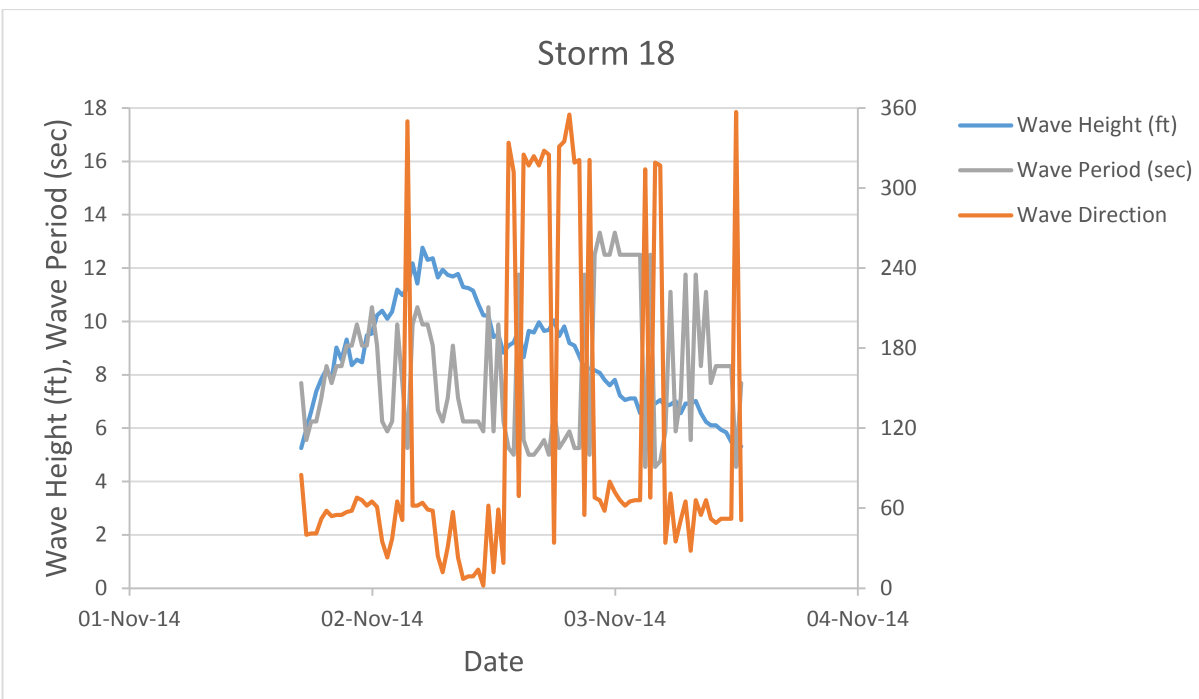


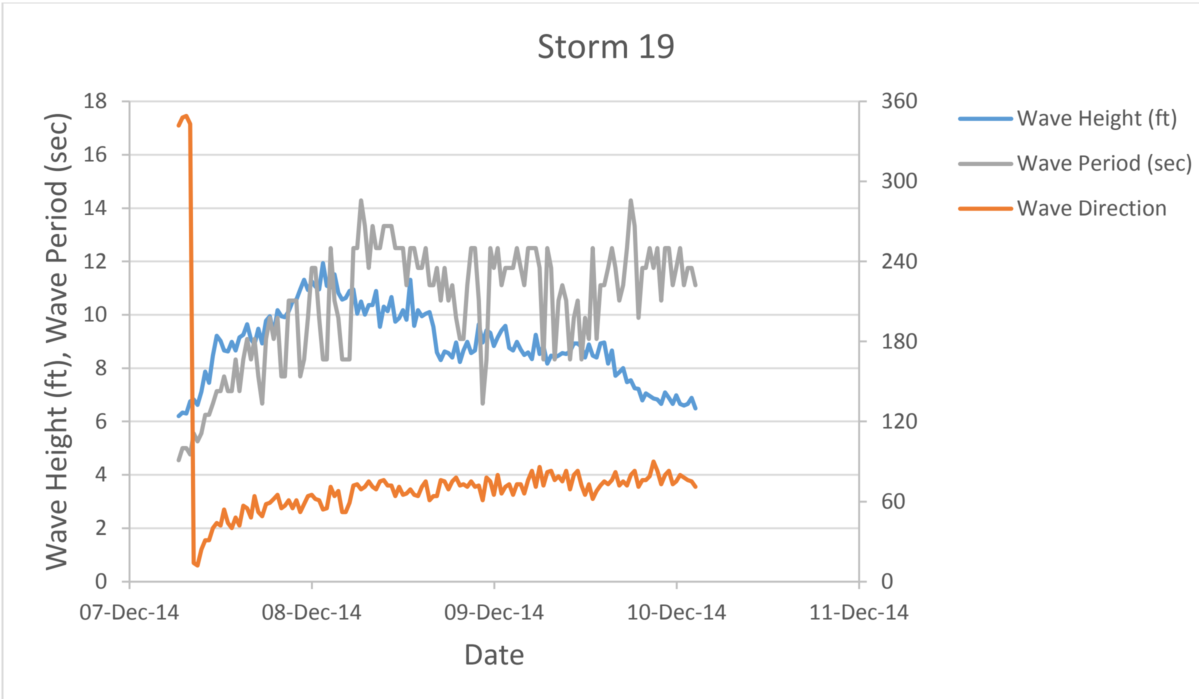
Storm 15
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
05-Mar-13
07-Mar-13
09-Mar-13
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction



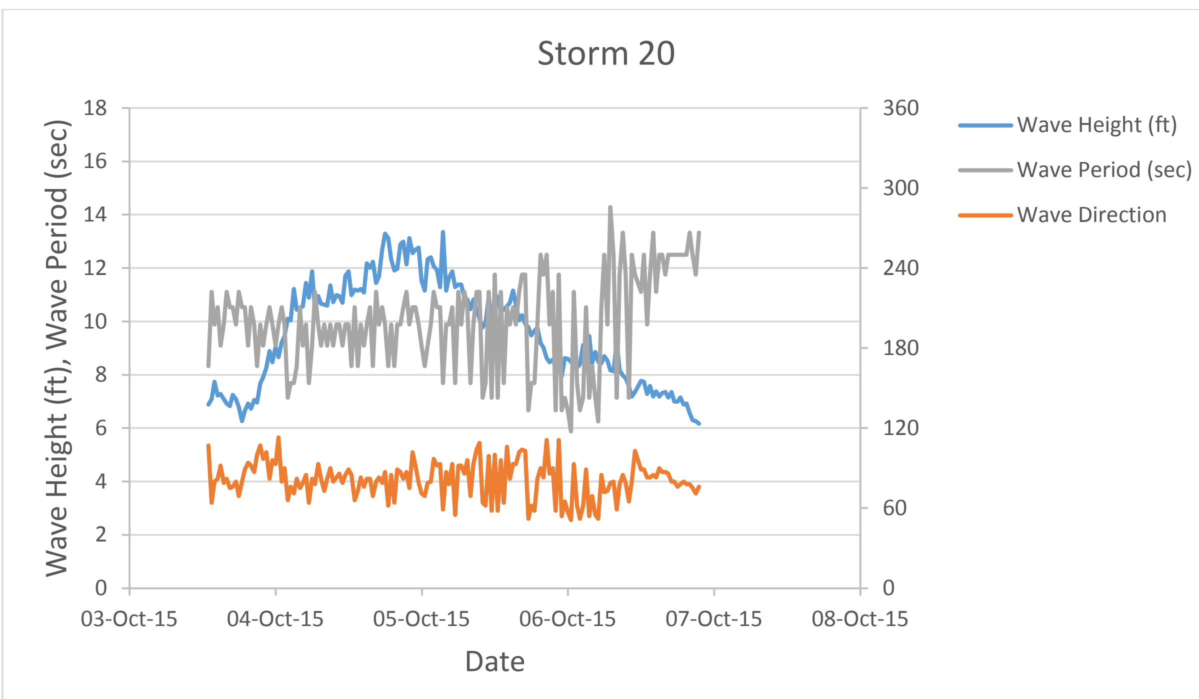
Storm 16
Wave Height (ft), Wave Period 9sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
21-Jan-14
22-Jan-14
23-Jan-14
24-Jan-14
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction


Storm 17
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
06-Mar-14
07-Mar-14
08-Mar-14
09-Mar-14
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

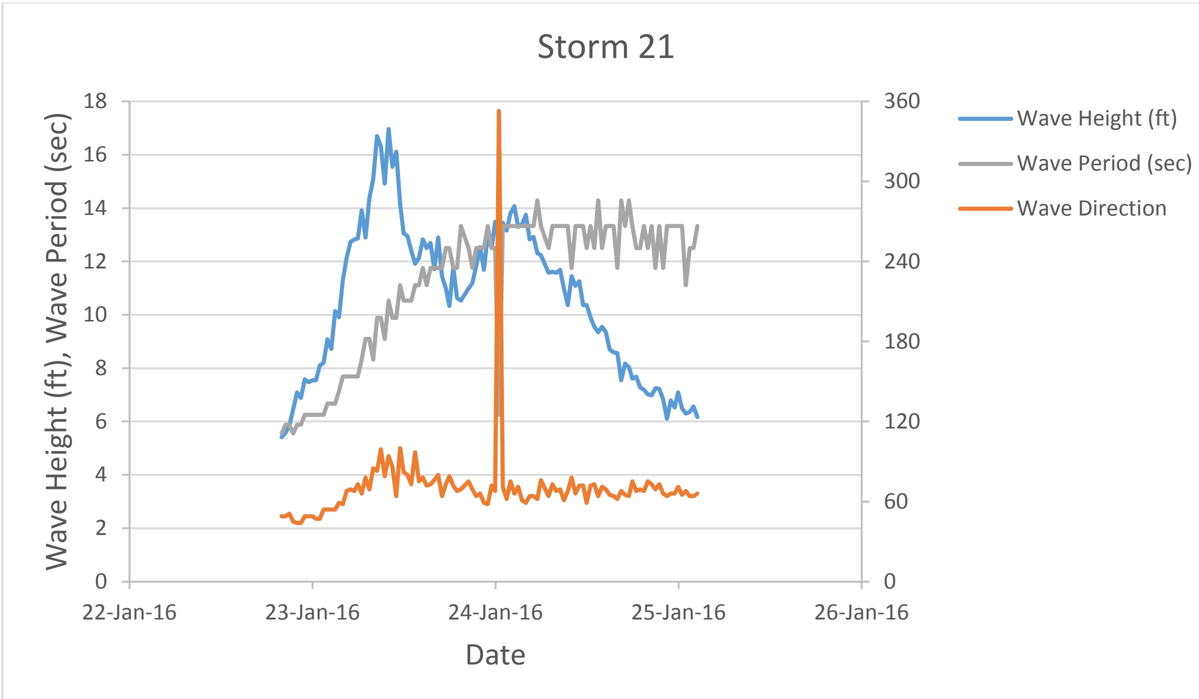

Storm 18
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
01-Nov-14
02-Nov-14
03-Nov-14
04-Nov-14
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction



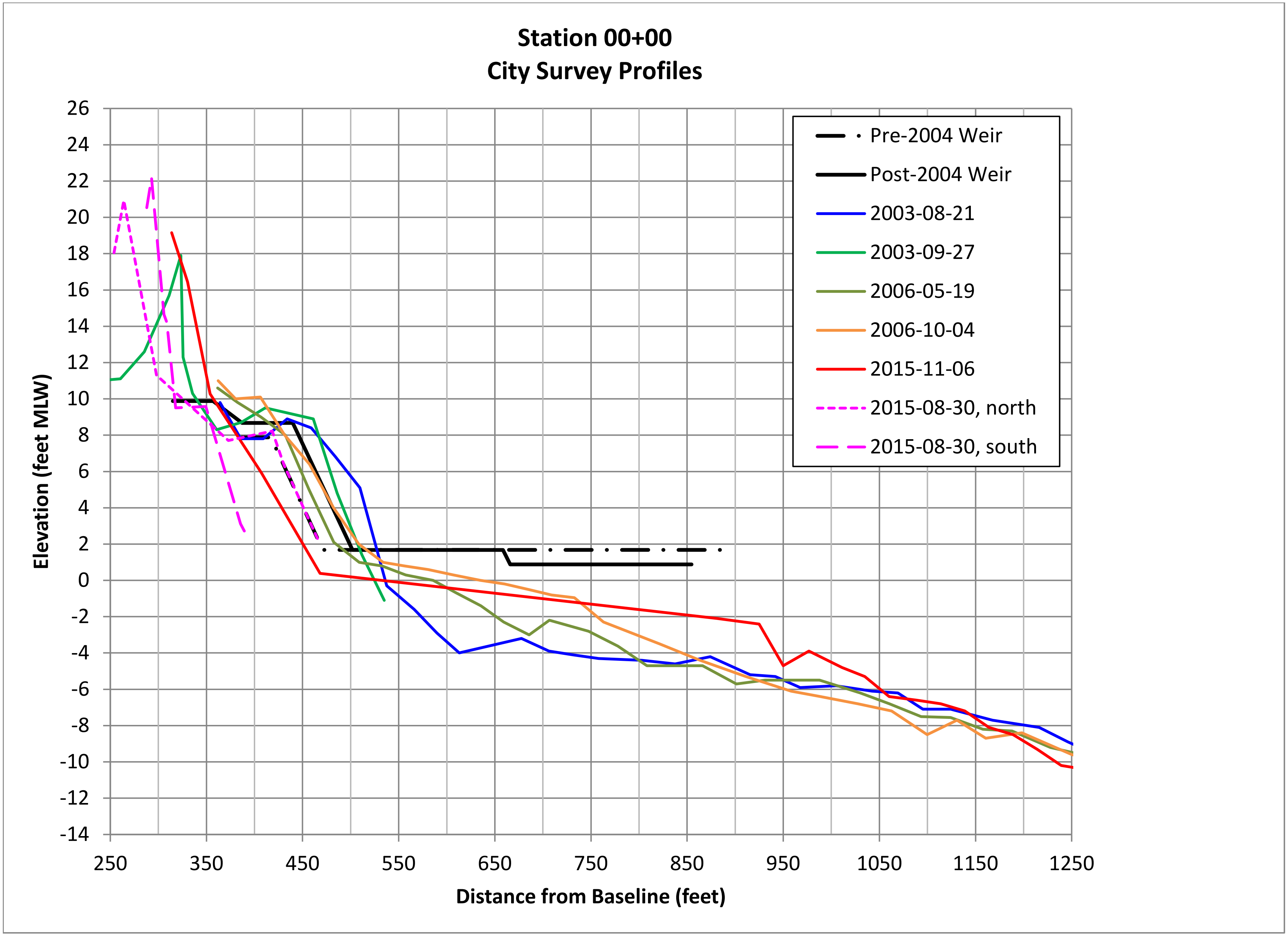
Storm 19
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
07-Dec-14
08-Dec-14
09-Dec-14
10-Dec-14
11-Dec-14
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

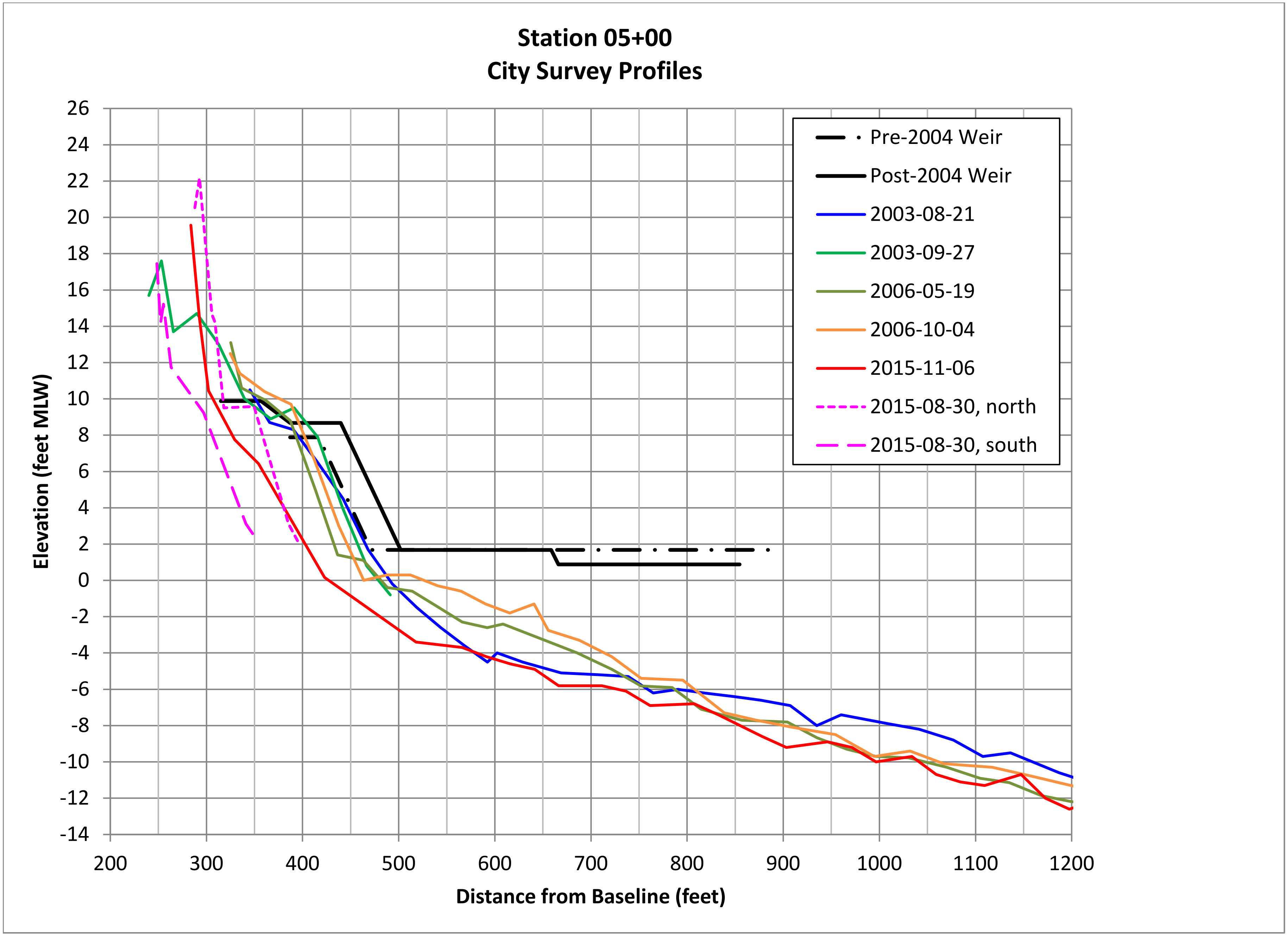


Storm 20
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
03-Oct-15
04-Oct-15
05-Oct-15
06-Oct-15
07-Oct-15
08-Oct-15
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

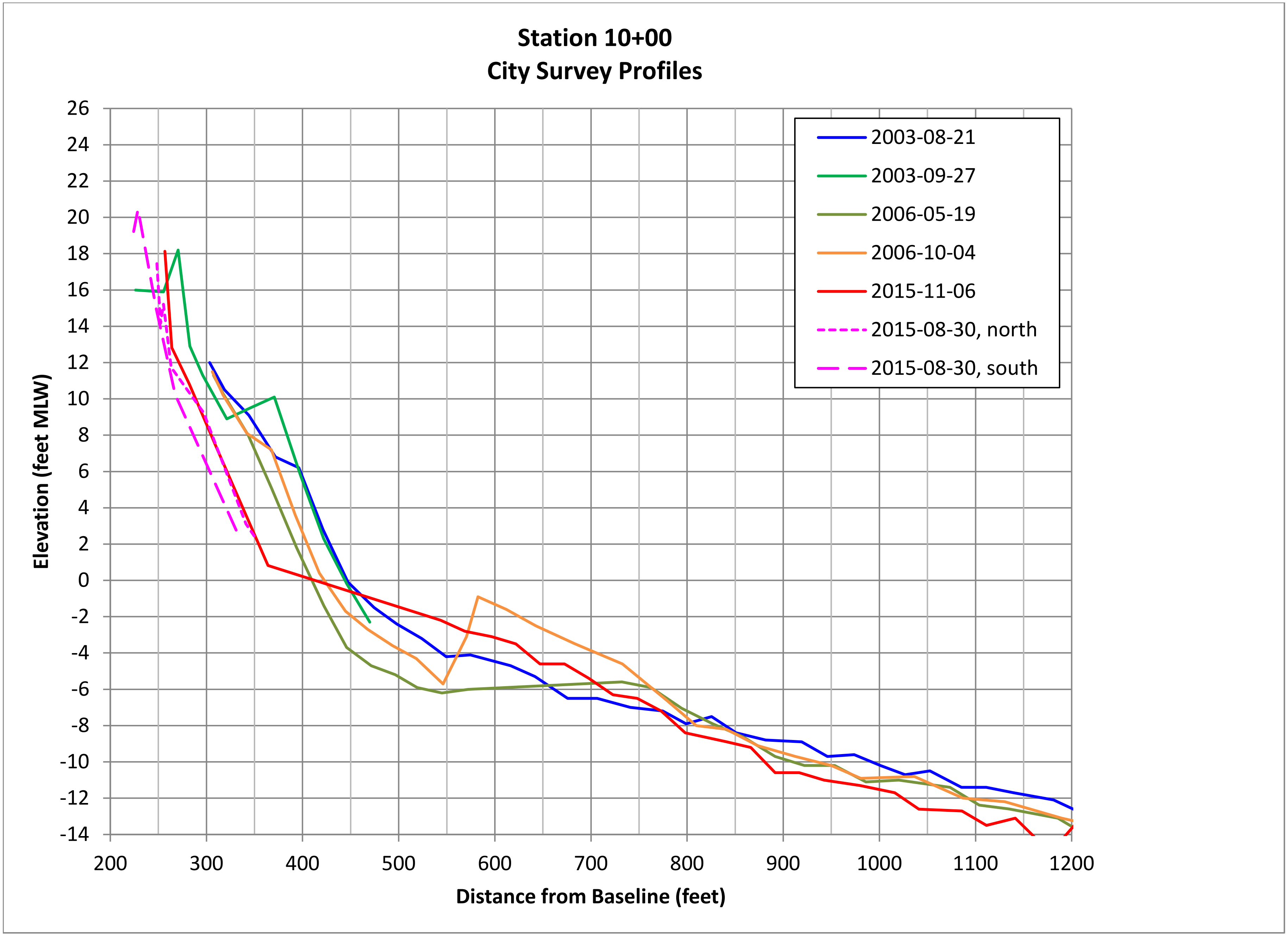

Storm 21
Wave Height (ft), Wave Period (sec)
18
16
14
12
10
8
6
4
2
0
360
300
240
180
120
60
0
22-Jan-16
23-Jan-16
24-Jan-16
25-Jan-16
26-Jan-16
Date
Wave Height (ft)
Wave Period (sec)
Wave Direction

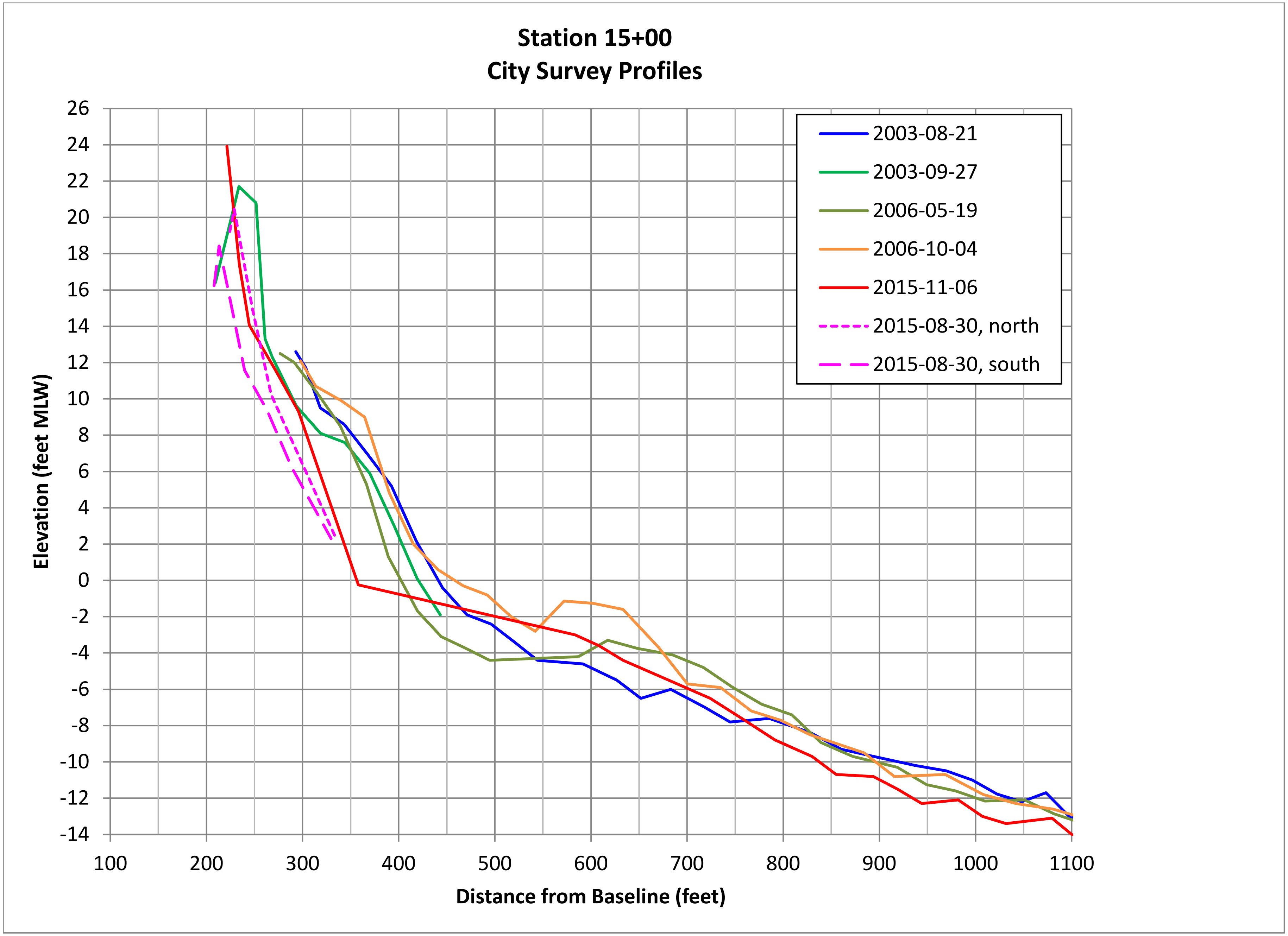
Appendix D: Historical Beach Profiles at Croatan Beach


Station 00+00
City Survey Profiles
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
Elevation (feet MLW)
250
350
450
550
650
750
850
950
1050
1150
1250
Distance from Baseline (feet)
Pre-2004 Weir
Post-2004 Weir
2003-08-21
2003-09-27
2006-05-19
2006-10-04
2015-11-06
2015-08-30, north
2015-08-30, south

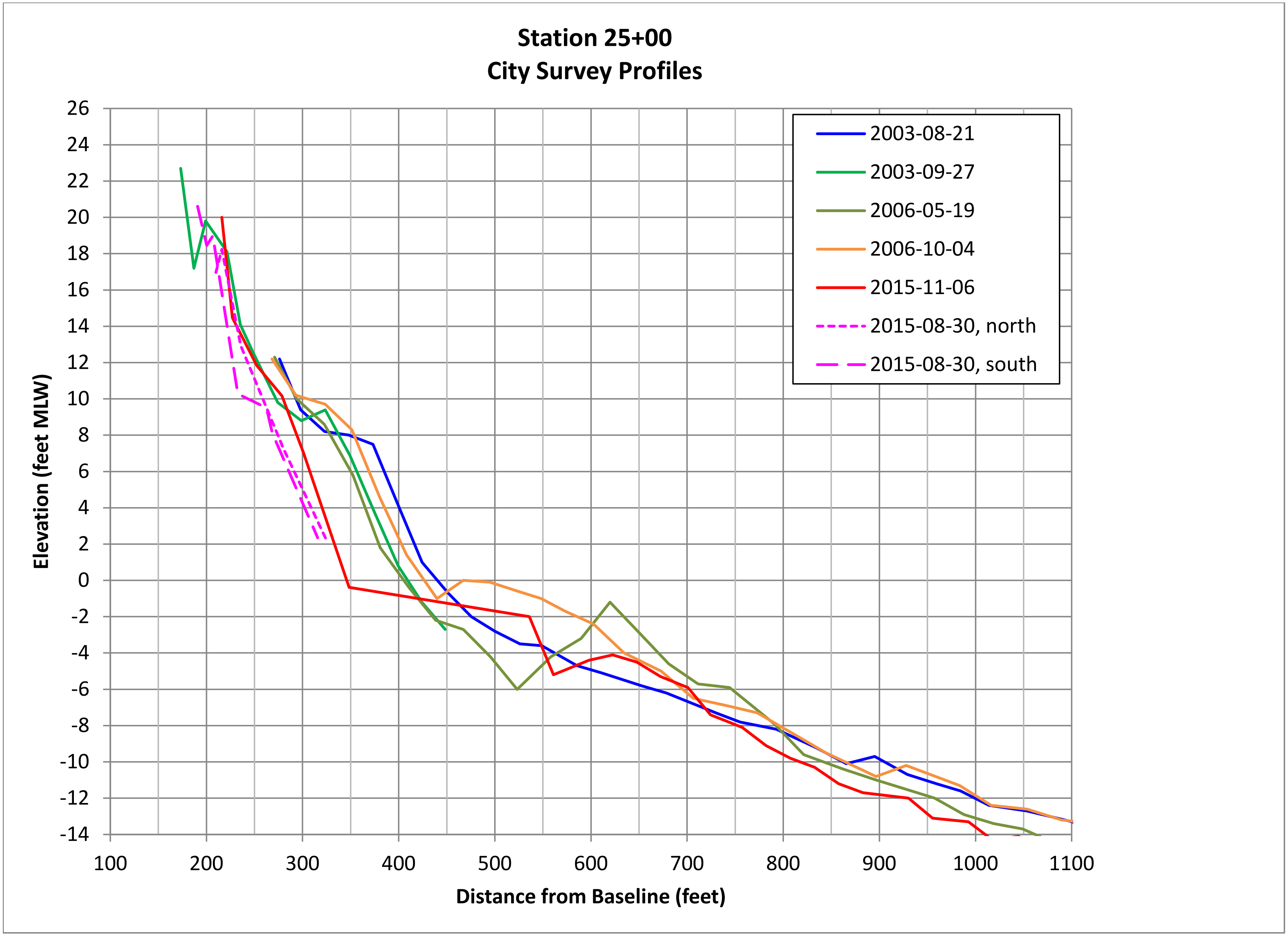


Station 05+00
City Survey Profiles
Elevation (feet MLW)
Distance from Baseline (feet)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
200
300
400
500
600
700
800
900
1000
1100
1200
Pre-2004 Weir
Post-2004 Weir
2003-08-21
2003-09-27
2006-05-19
2006-10-04
2015-11-06
2015-08-30, north
2015-08-30, south

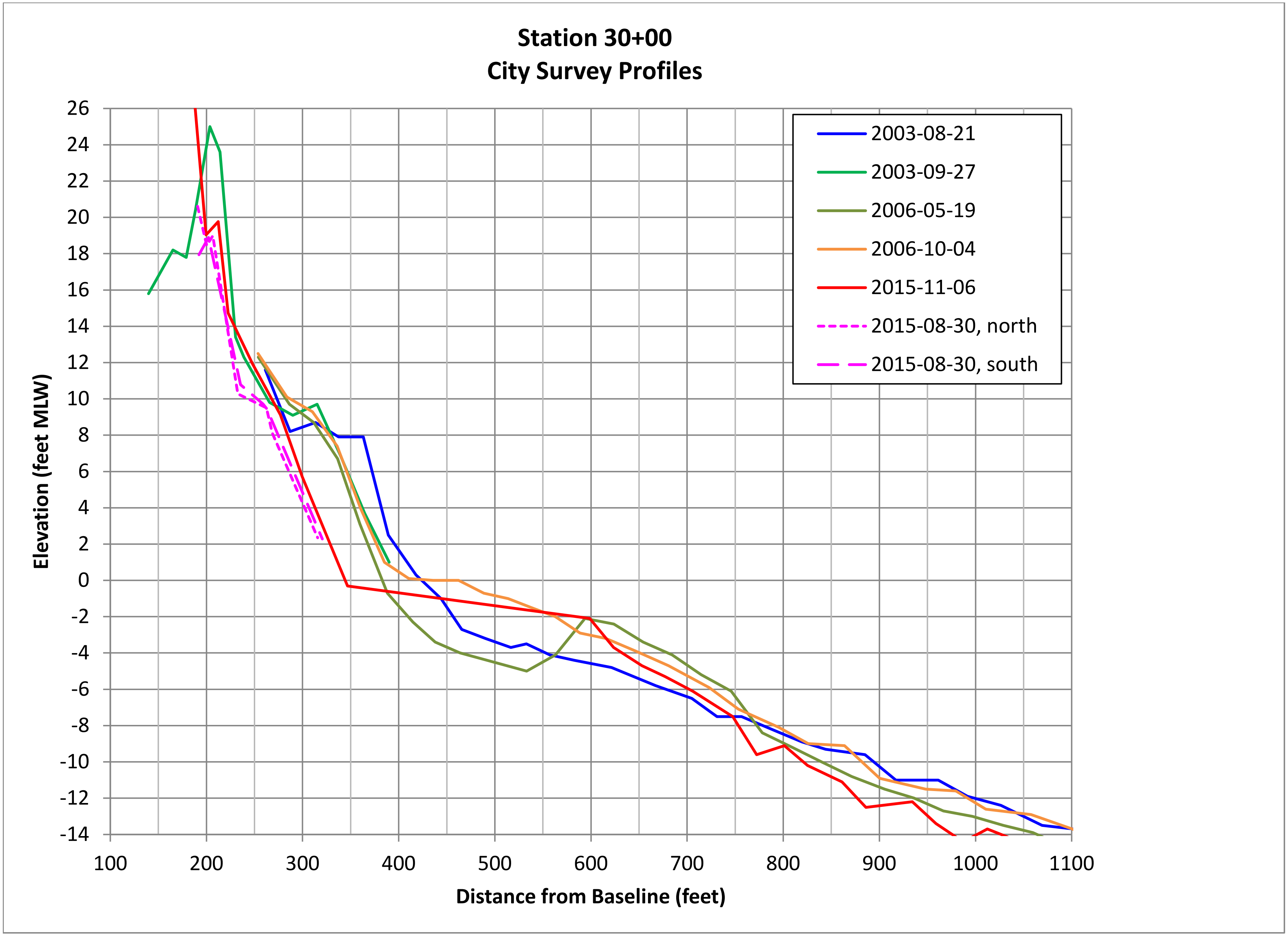

Station 10+00
City Survey Profiles
Elevation (feet MLW)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
200
300
400
500
600
700
800
900
1000
1100
1200
Distance from Baseline (feet)
2003-08-21
2003-09-27
2006-05-19
2006-10-04
2015-11-06
2015-08-30, north
2015-08-30, south


Station 15+00
City Survey Profiles
Elevation (feet MLW)
Distance from Baseline (feet)
2003-08-21
2003-09-27
2006-05-19
2006-10-04
2015-11-06
2015-08-30, north
2015-08-30, south
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
100
200
300
400
500
600
700
800
900
1000
1100


Station 20+00
City Survey Profiles
Elevation (feet MLW)
Distance from Baseline (feet)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
100
200
300
400
500
600
700
800
900
1000
1100
2003-08-21
2003-09-27
2006-05-19
2006-10-04
2015-11-06
2015-08-30, north
2015-08-30, south

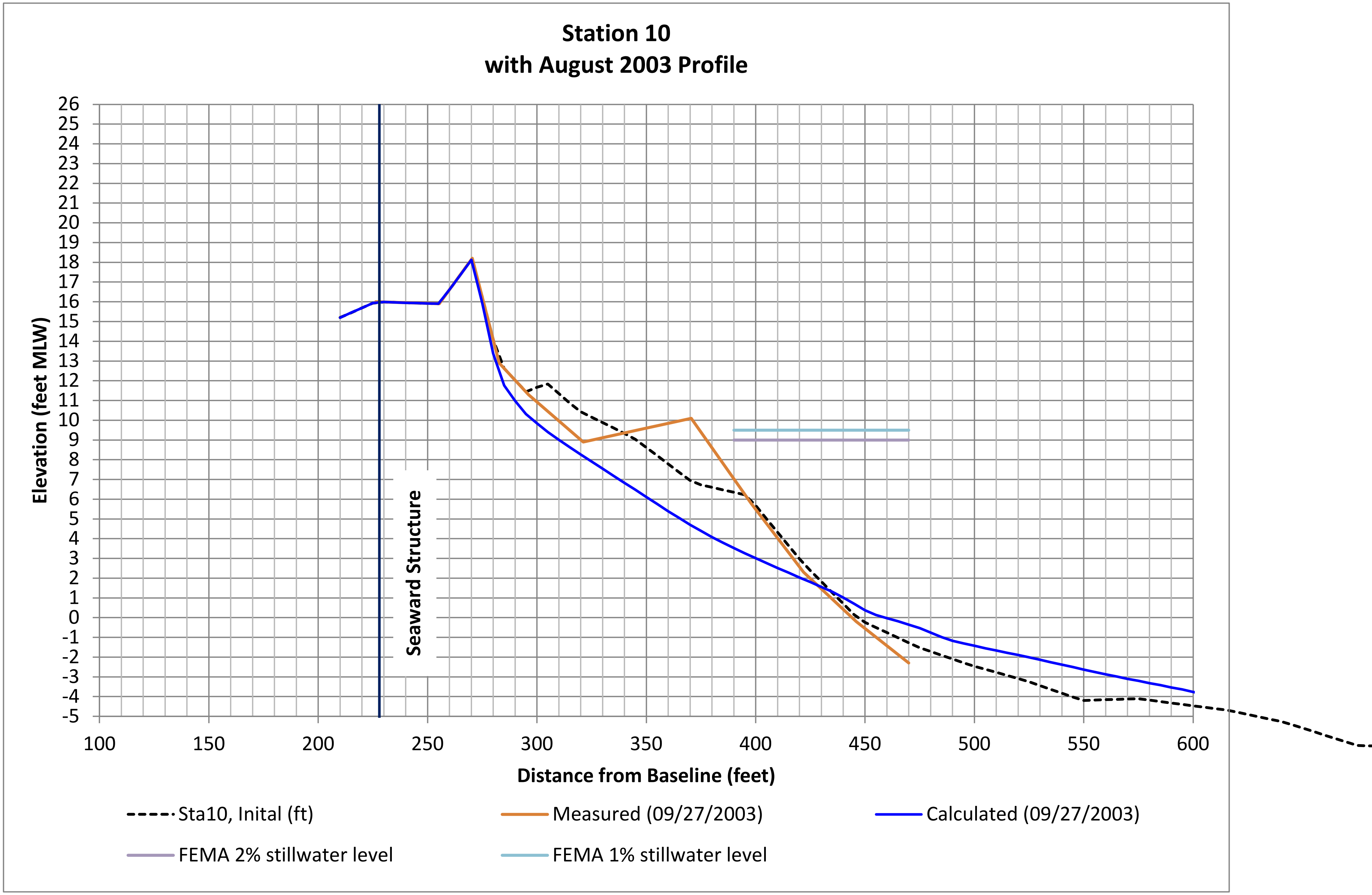


Station 25+00
City Survey Profiles
Elevation (feet MLW)
Distance from Baseline (feet)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
100
200
300
400
500
600
700
800
900
1000
1100
2003-08-21
2003-09-27
2006-05-19
2006-10-04
2015-11-06
2015-08-30, north
2015-08-30, south

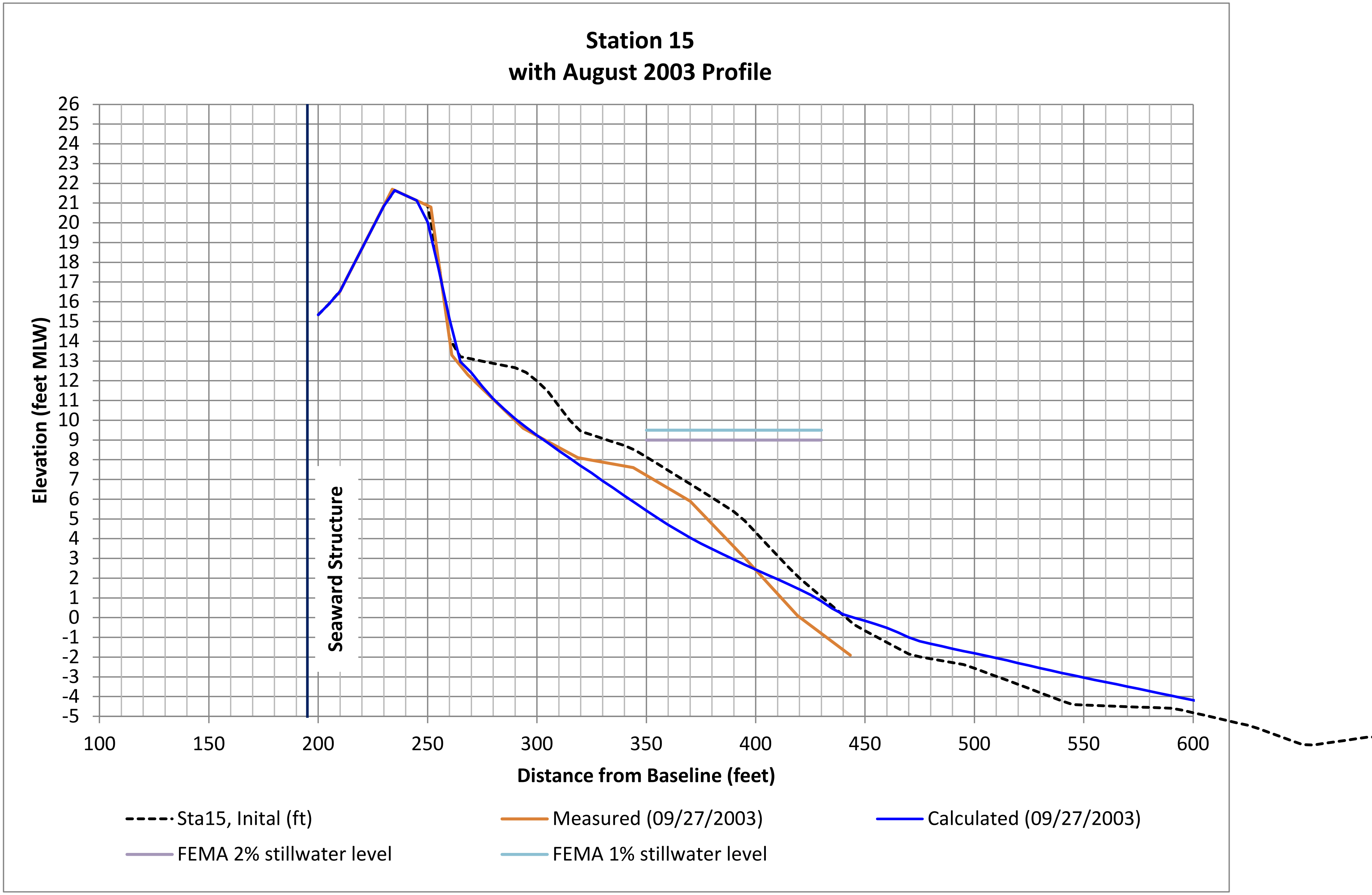

Station 30+00
City Survey Profiles
2003-08-21
2003-09-27
2006-05-19
2006-10-04
2015-11-06
2015-08-30, north
2015-08-30, south
Elevation (feet MLW)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
100
200
300
400
500
600
700
800
900
1000
1100
Distance from Baseline (feet)


Station 35+00
City Survey Profiles
2003-08-21
2003-09-27
2006-05-19
2006-10-04
2015-11-06
2015-08-30, north
2015-08-30, south
Elevation (feet MLW)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
100
200
300
400
500
600
700
800
900
1000
1100
Distance from Baseline (feet)

Appendix E: SBEACH Model Calibration

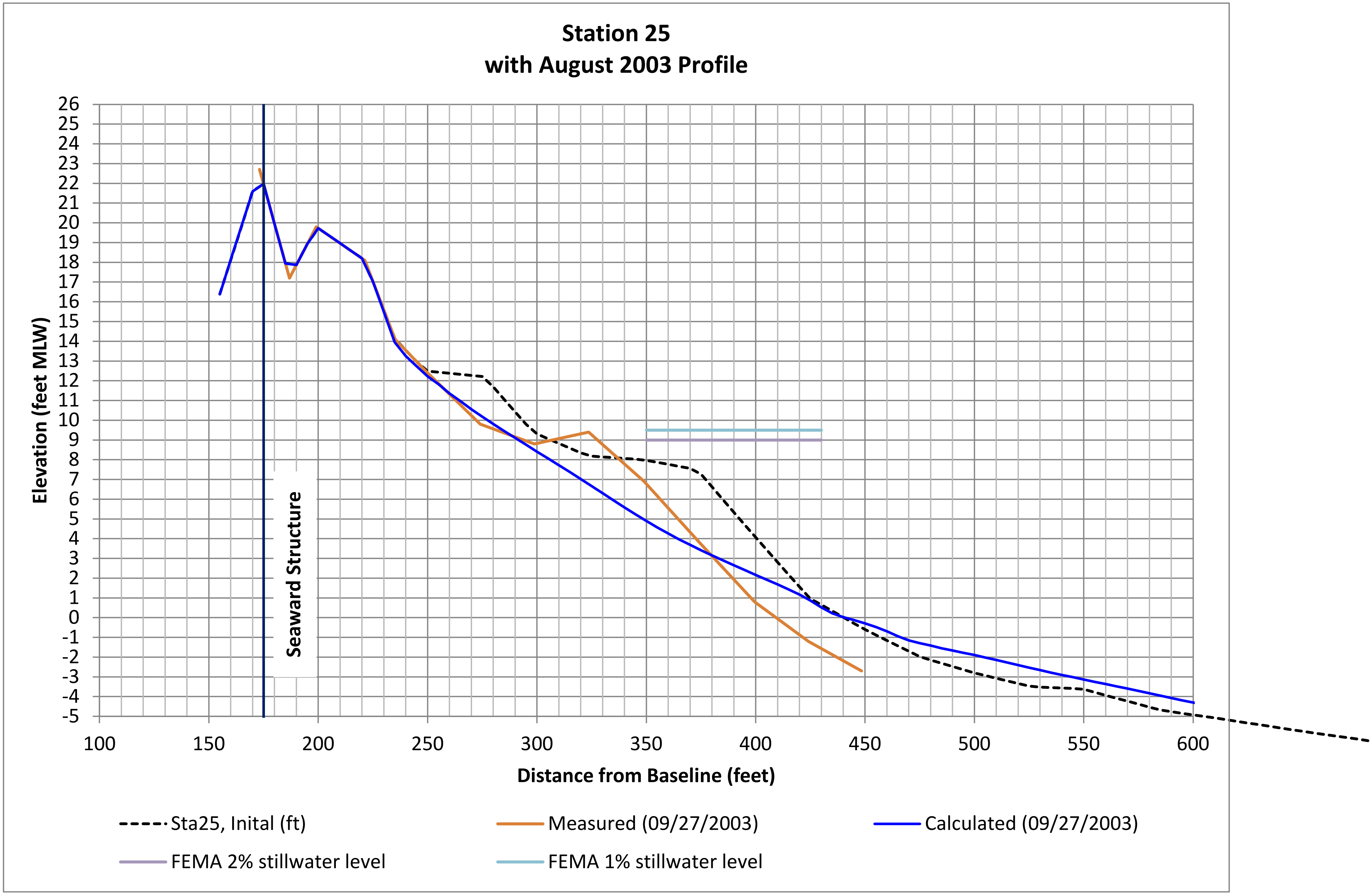


Station 10
with August 2003 Profile
Elevation (feet MLW)
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
Seaward Structure
100
150
200
250
300
350
400
450
500
550
600
Distance from Baseline (feet)
Sta10, Inital (ft)
Measured (09/27/2003)
Calculated (09/27/2003)
FEMA 2% stillwater level
FEMA 1% stillwater level

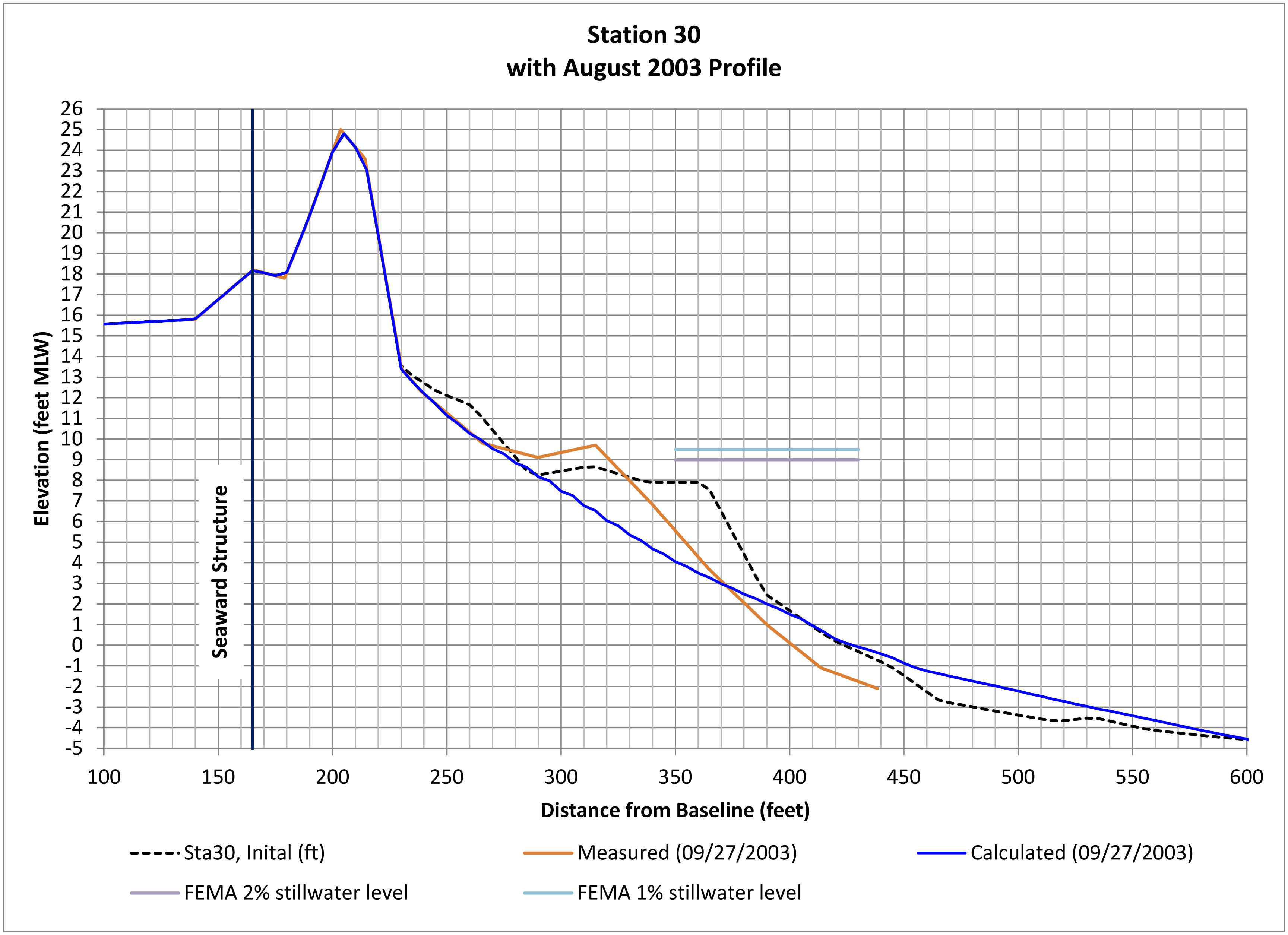


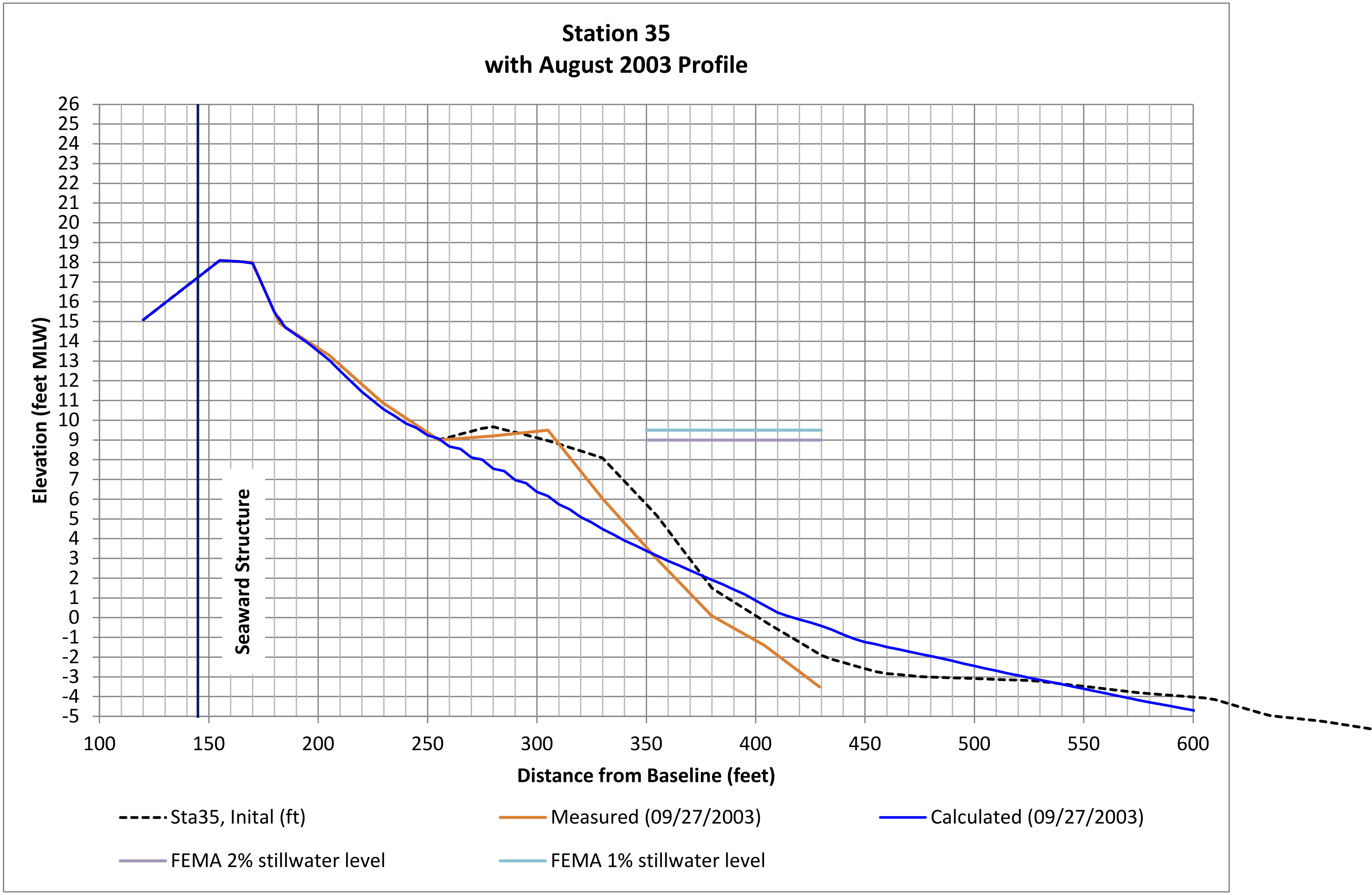
Station 15
with August 2003 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Structure
Sta15, Inital (ft)
Measured (09/27/2003)
Calculated (09/27/2003)
FEMA 2% stillwater level
FEMA 1% stillwater level

Station 20
with August 2003 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Structure
Sta20, Inital (ft)
Measured (09/27/2003)
Calculated (09/27/2003)
FEMA 2% stillwater level



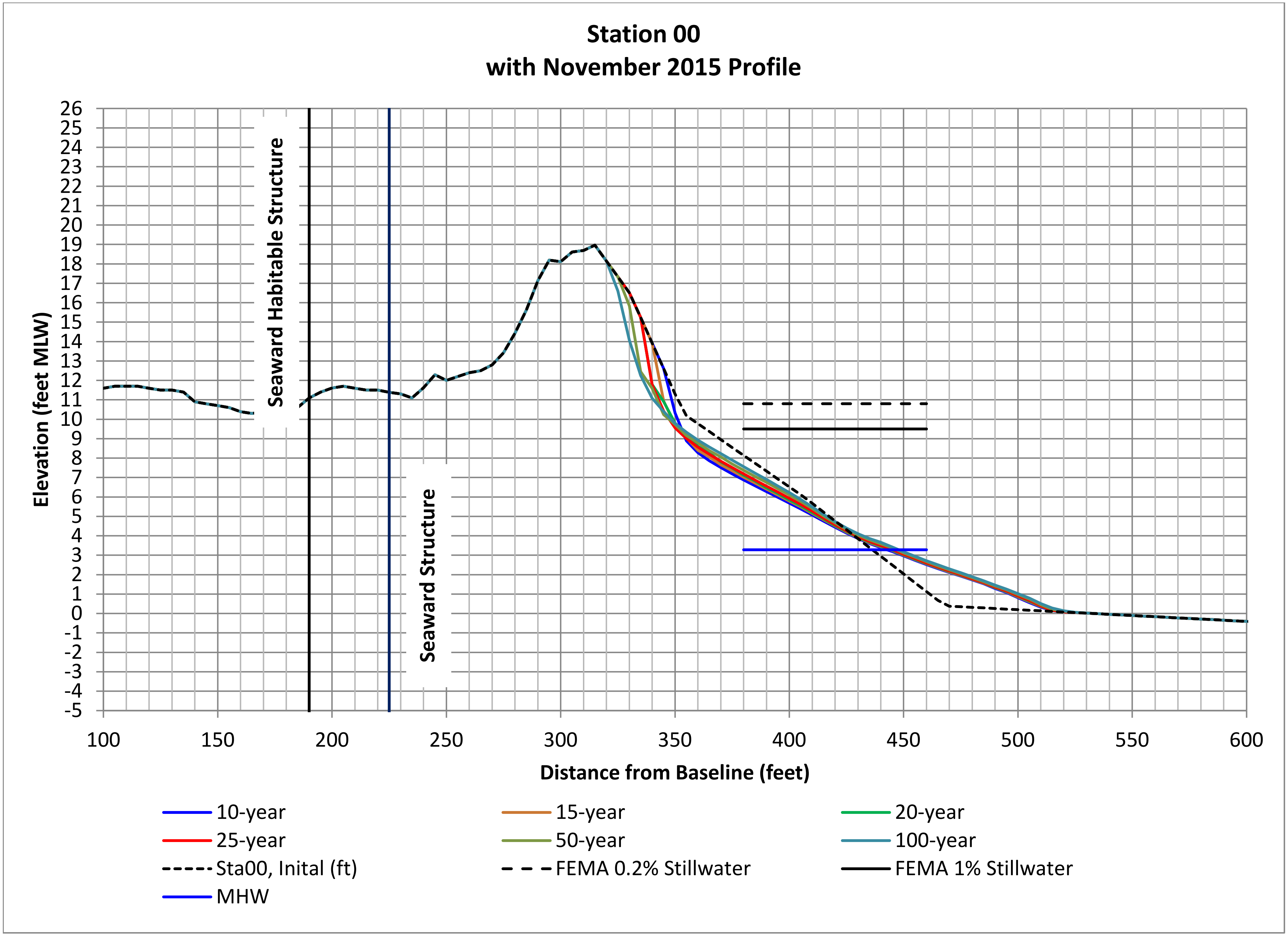
Station 25
with August 2003 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
Sta25, Inital (ft)
Measured (09/27/2003)
Calculated (09/27/2003)
FEMA 2% stillwater level
FEMA 1% stillwater level


Station 30
with August 2003 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
Sta30, Inital (ft)
Measured (09/27/2003)
Calculated (09/27/2003)
FEMA 2% stillwater level
FEMA 1% stillwater level

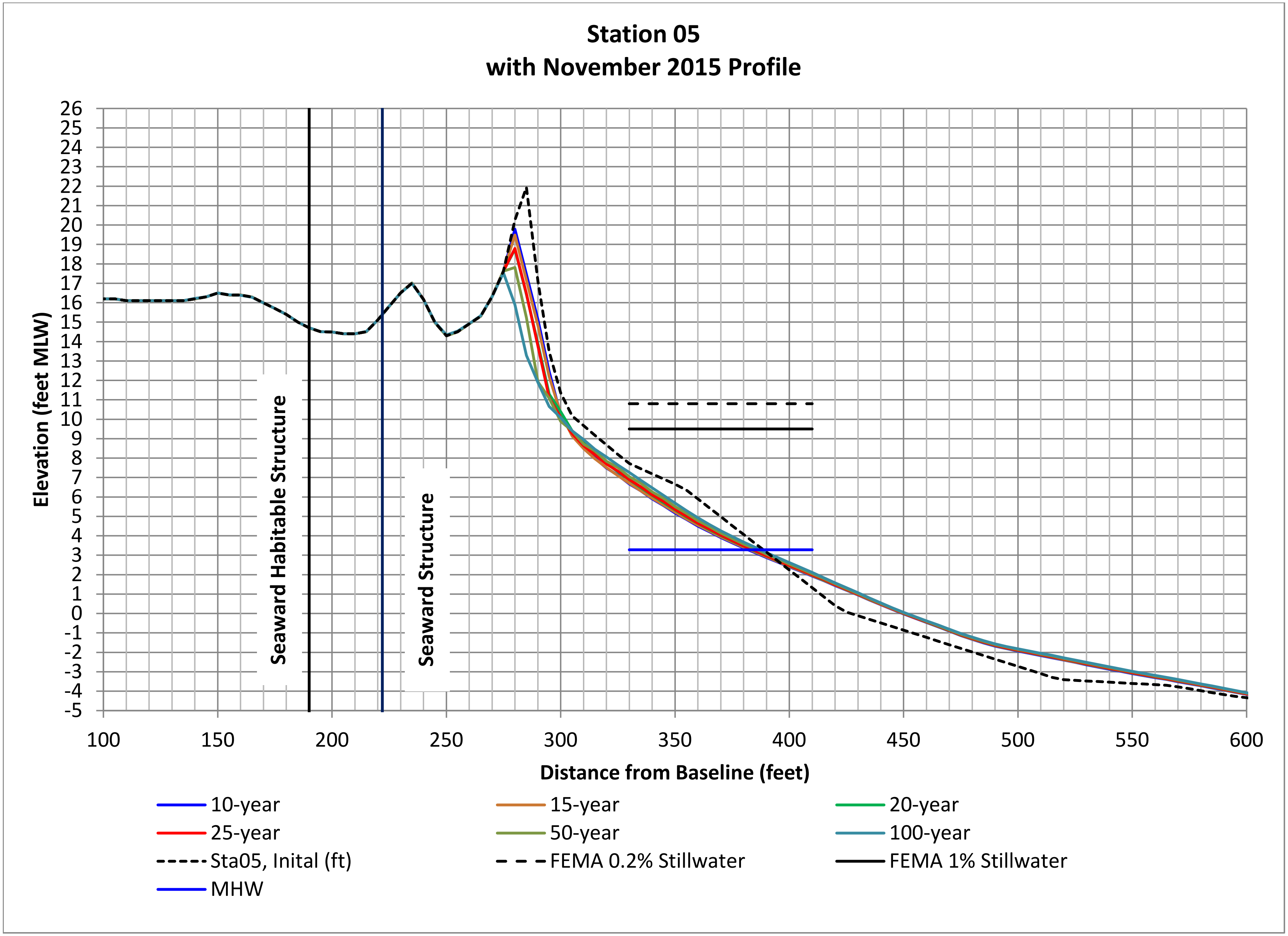


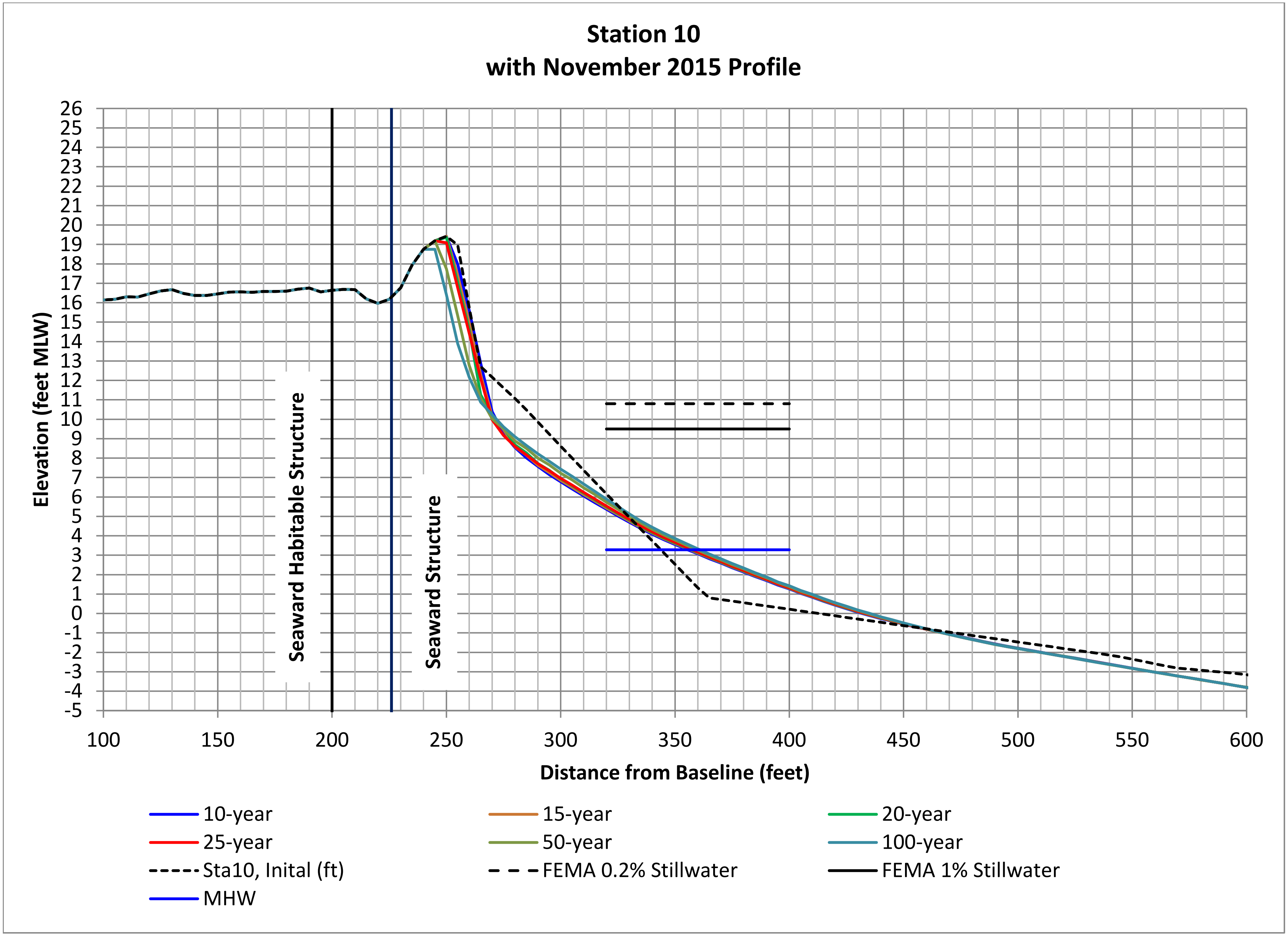
Station 35
with August 2003 Profile
Elevation (feet MLW)
Seaward Structure
Distance from Baseline (feet)
Sta35, Inital (ft)
Measured (09/27/2003)
Calculated (09/27/2003)
FEMA 2% stillwater level
FEMA 1% stillwater level

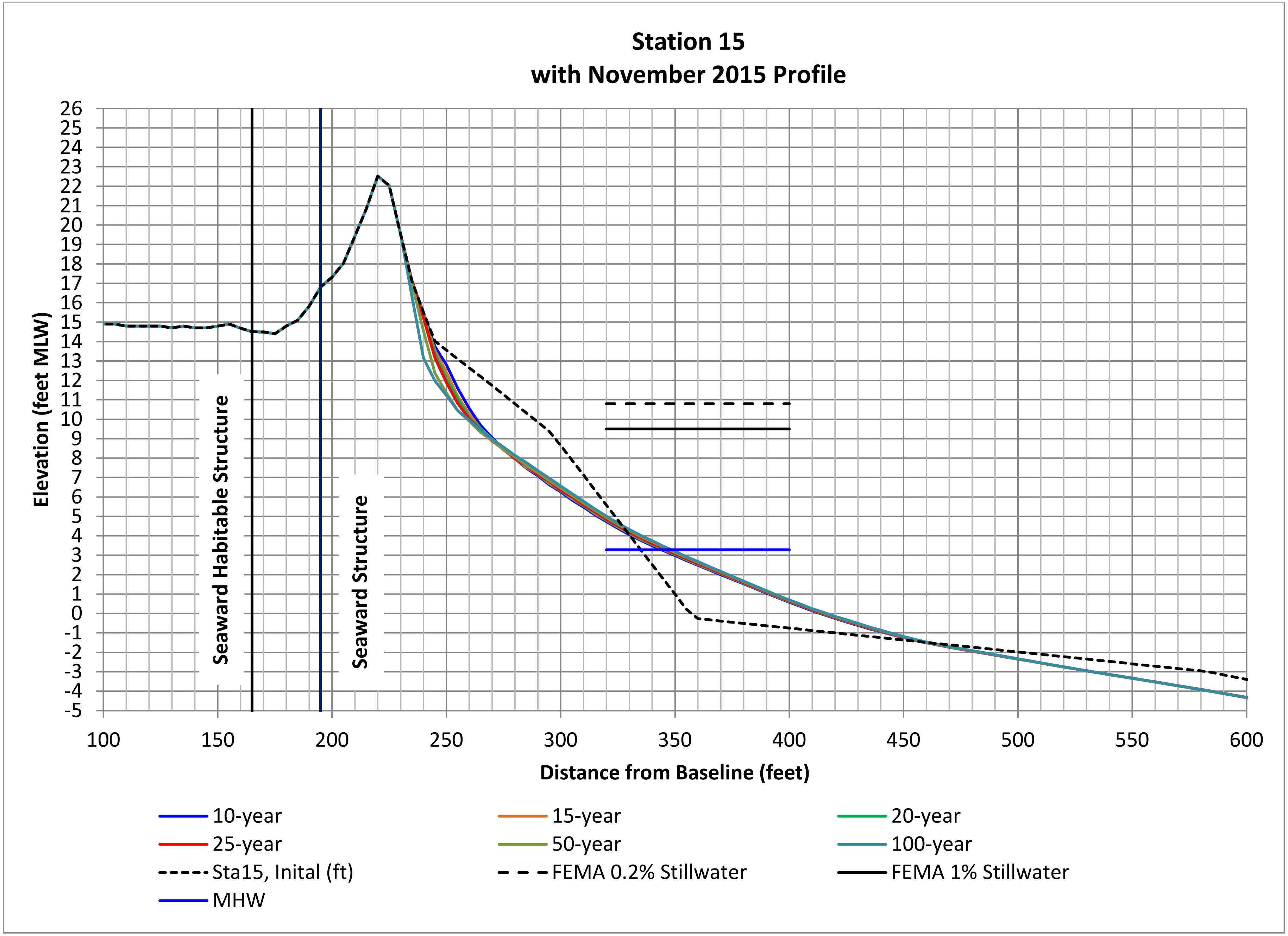
Appendix F: Beach Profile Storm Responses (Present Sea Levels)



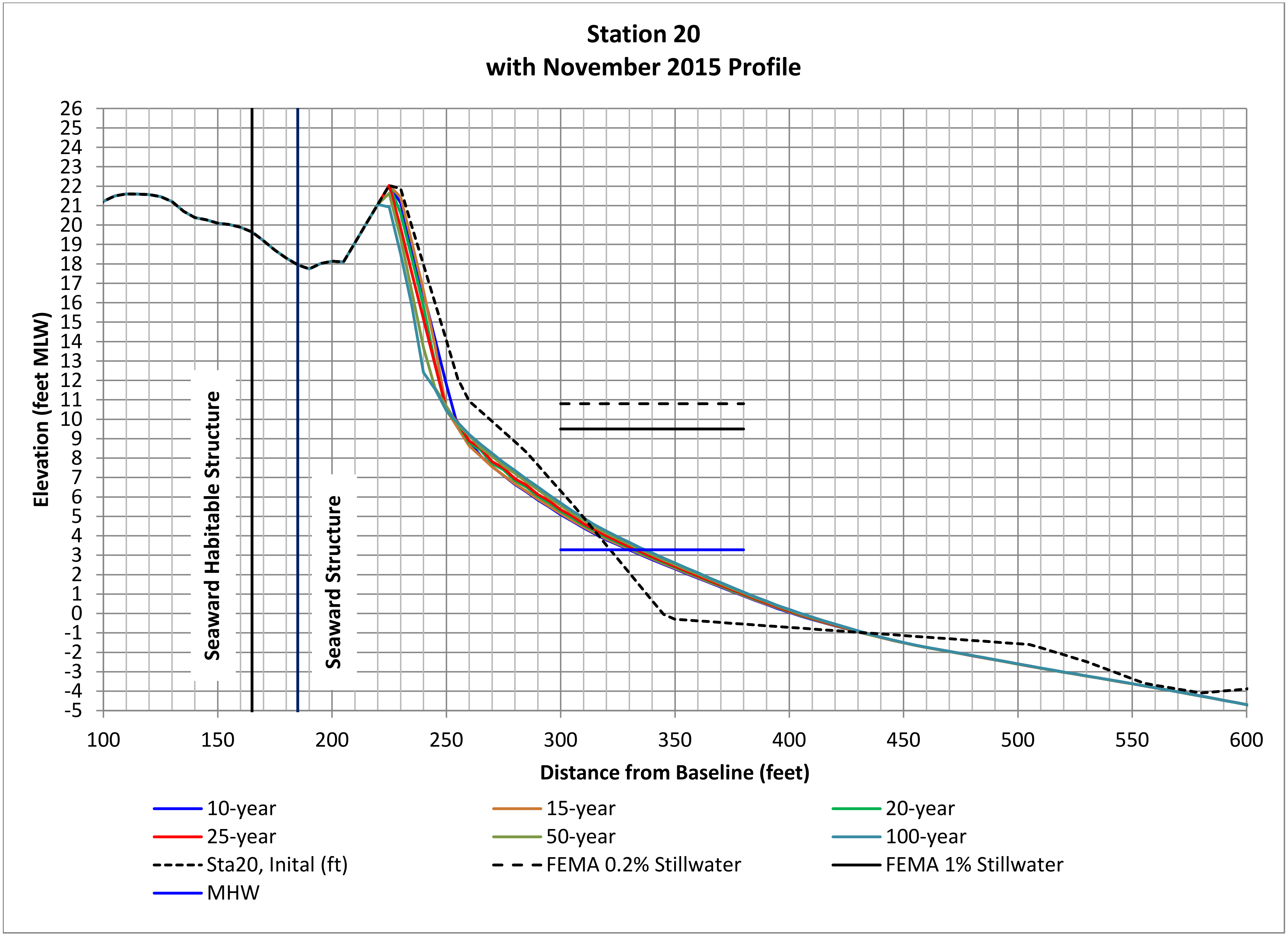
Station 00
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta00, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW

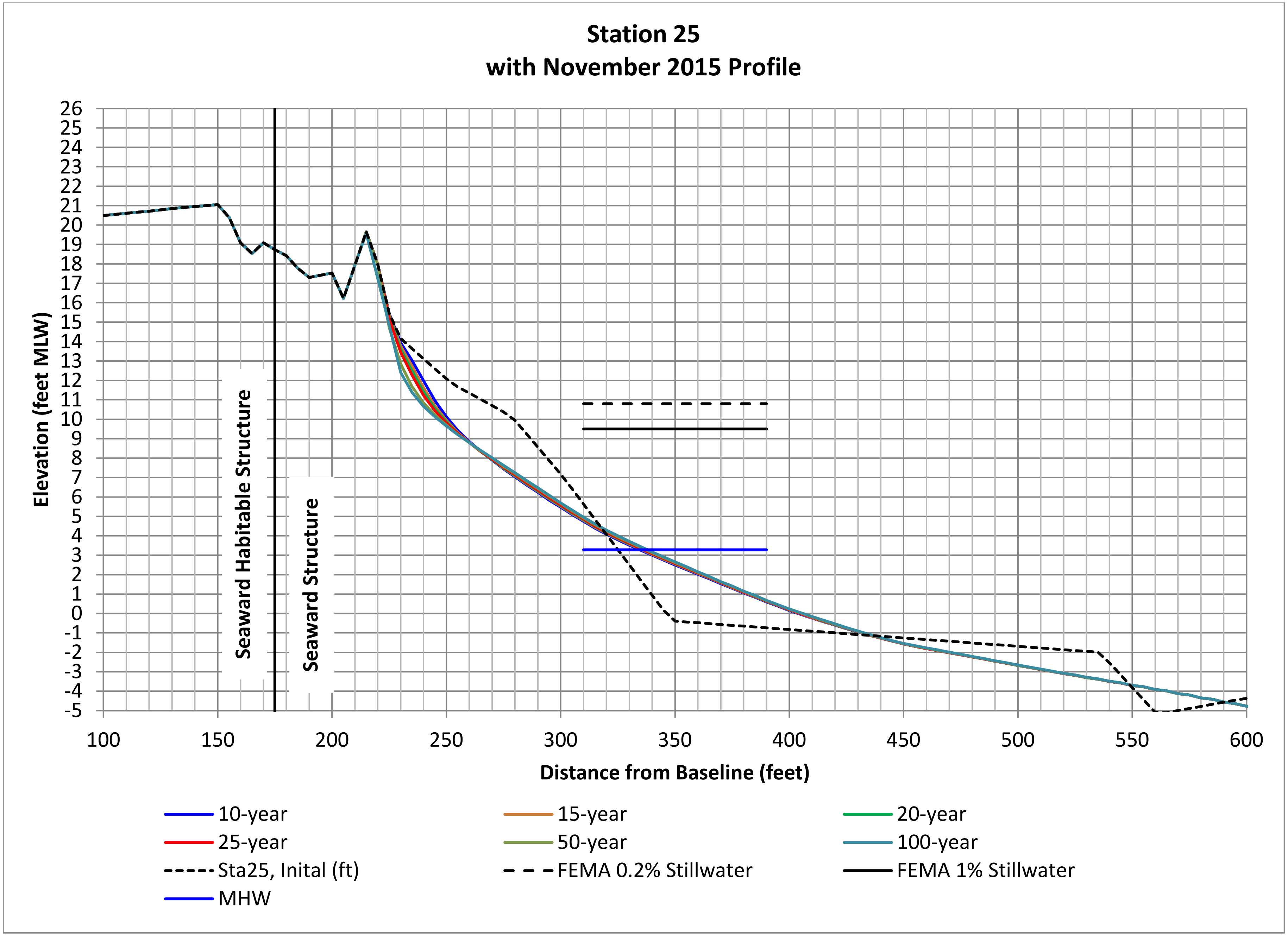

Station 05
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta05, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW

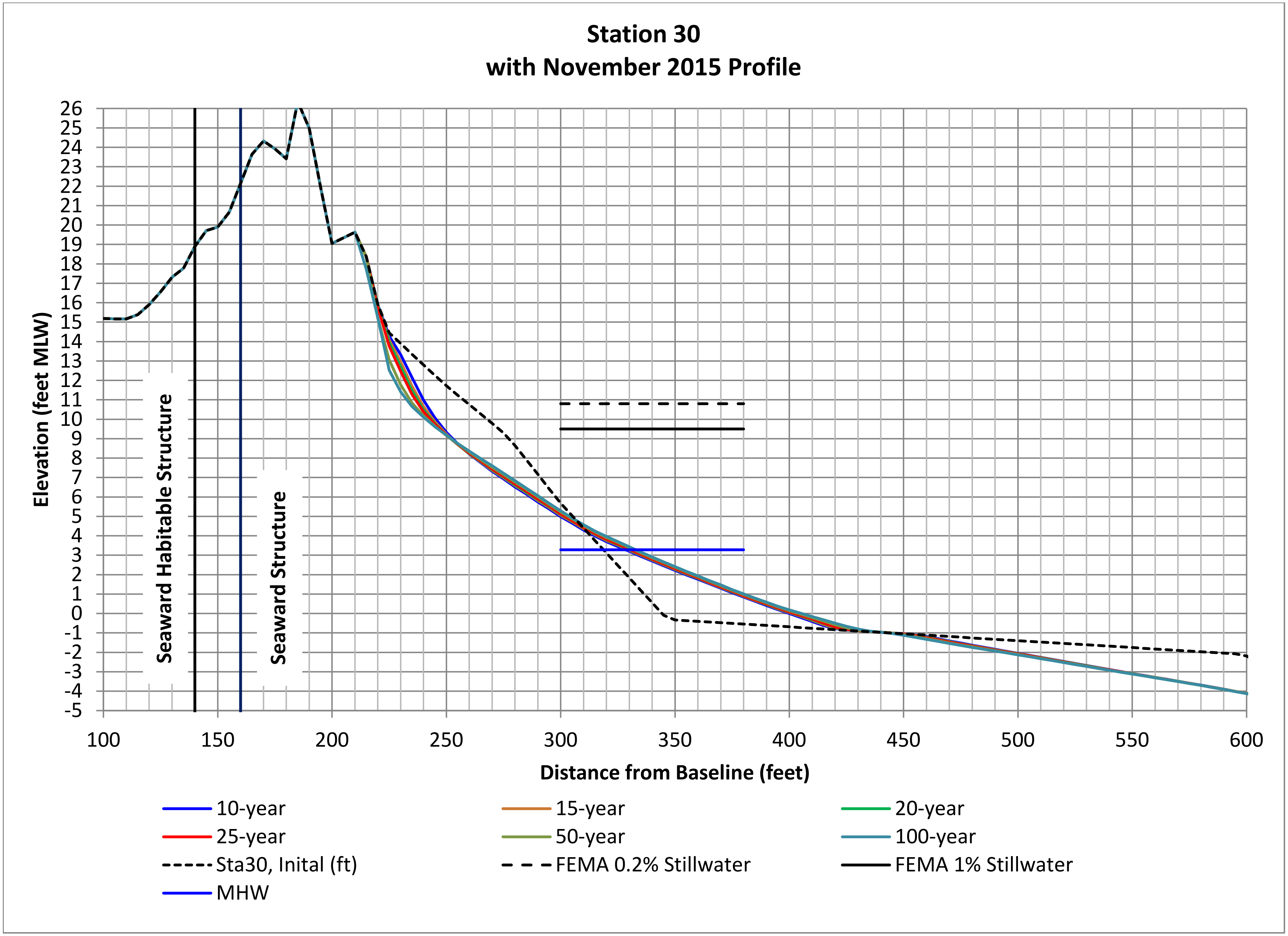

Station 10
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
Seaward Habitable Structure
Seaward Structure
10-year
15-year
20-year
25-year
50-year
100-year
Sta10, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW

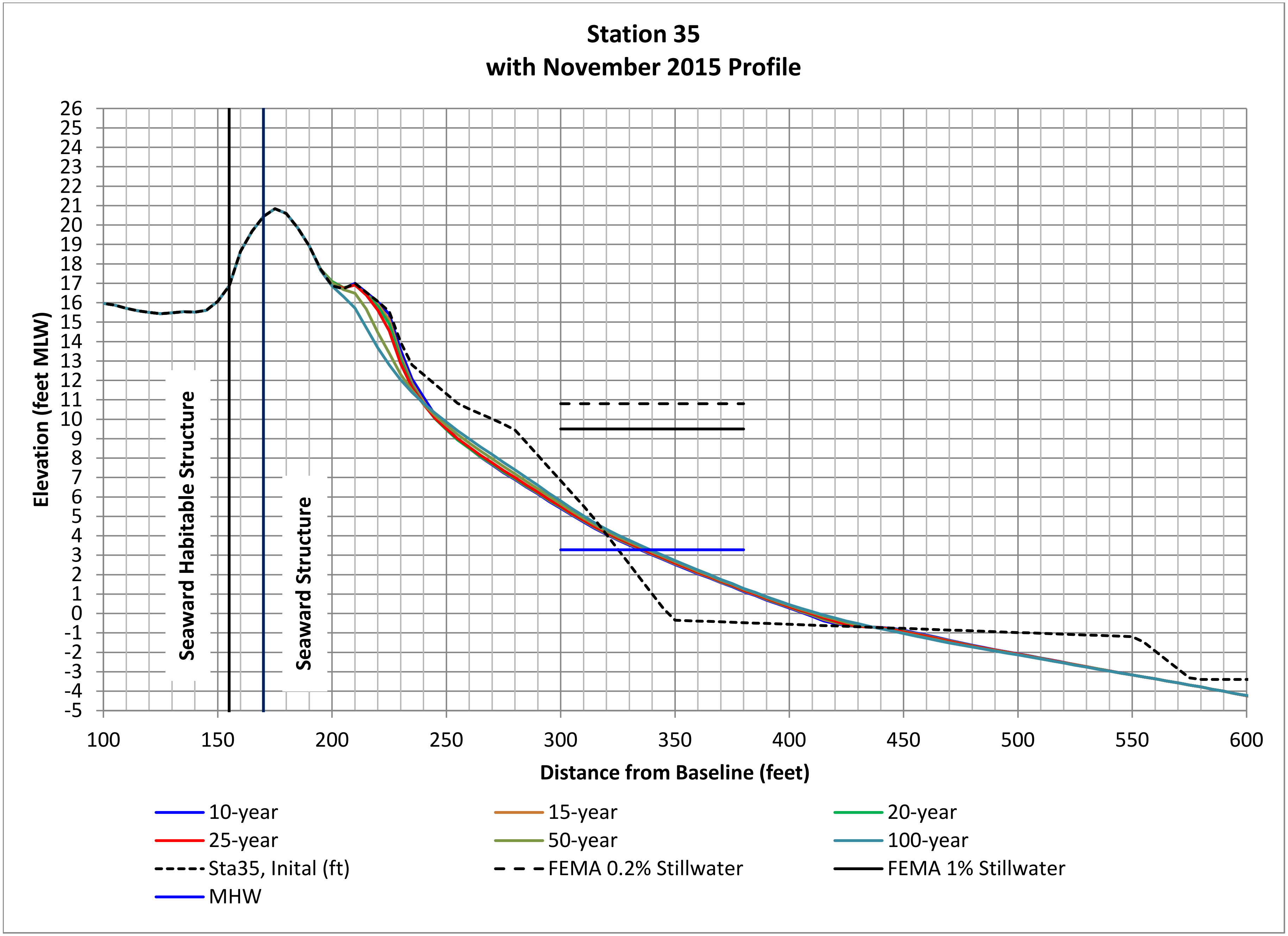


Station 15
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta15, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW


Station 20
with November 2015 Profile
Elevation (feet MLW)
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
Seaward Habitable Structure
Seaward Structure
100
150
200
250
300
350
400
450
500
550
600
Distance from Baseline (feet)
10-year
15-year
20-year
25-year
50-year
100-year
Sta20, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW

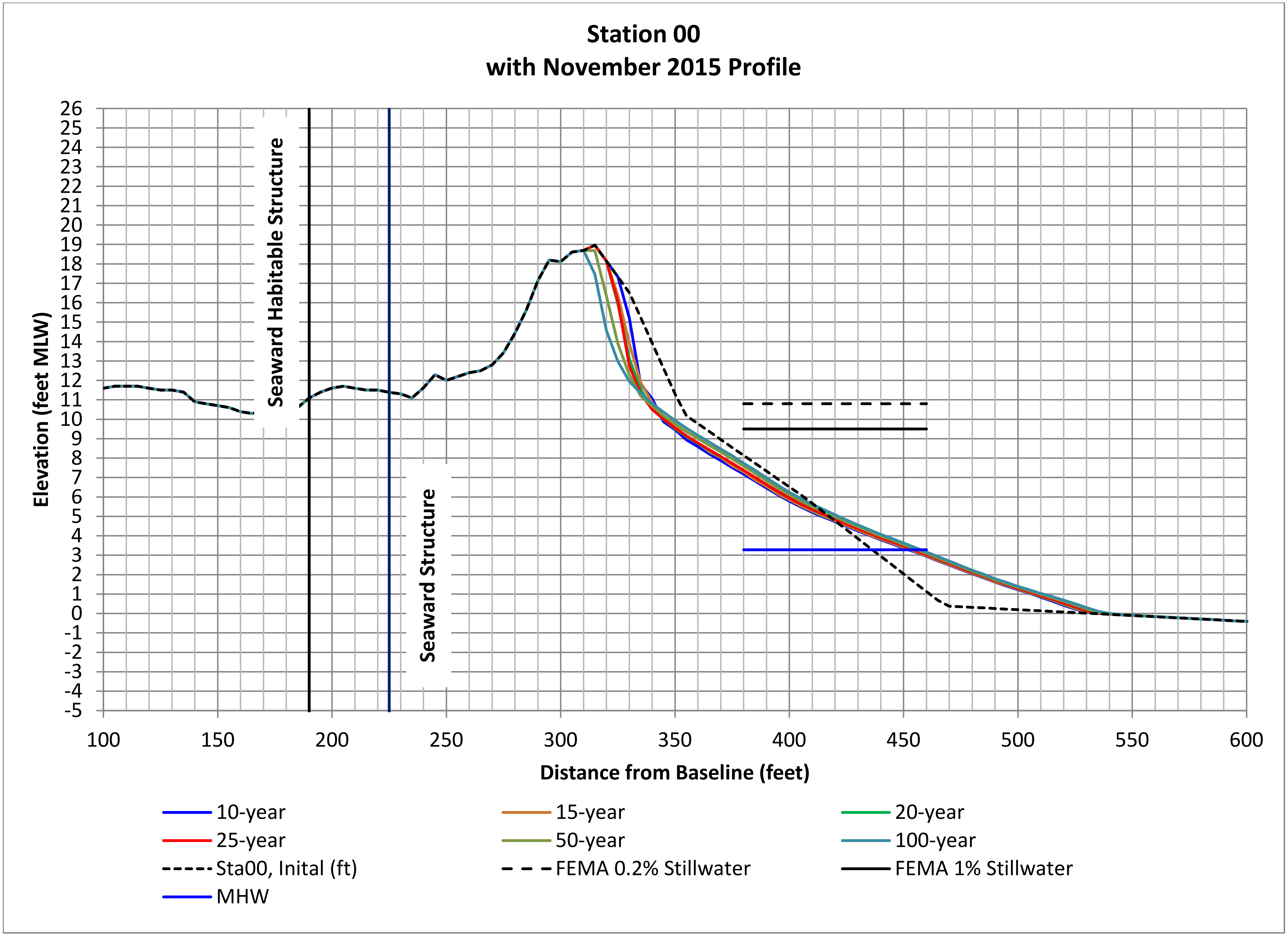

Station 25
with November 2015 Profile
Elevation (feet MLW)
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
Seaward Habitable Structure
Seaward Structure
100
150
200
250
300
350
400
450
500
550
600
Distance from Baseline (feet)
10-year
15-year
20-year
25-year
50-year
100-year
Sta25, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW

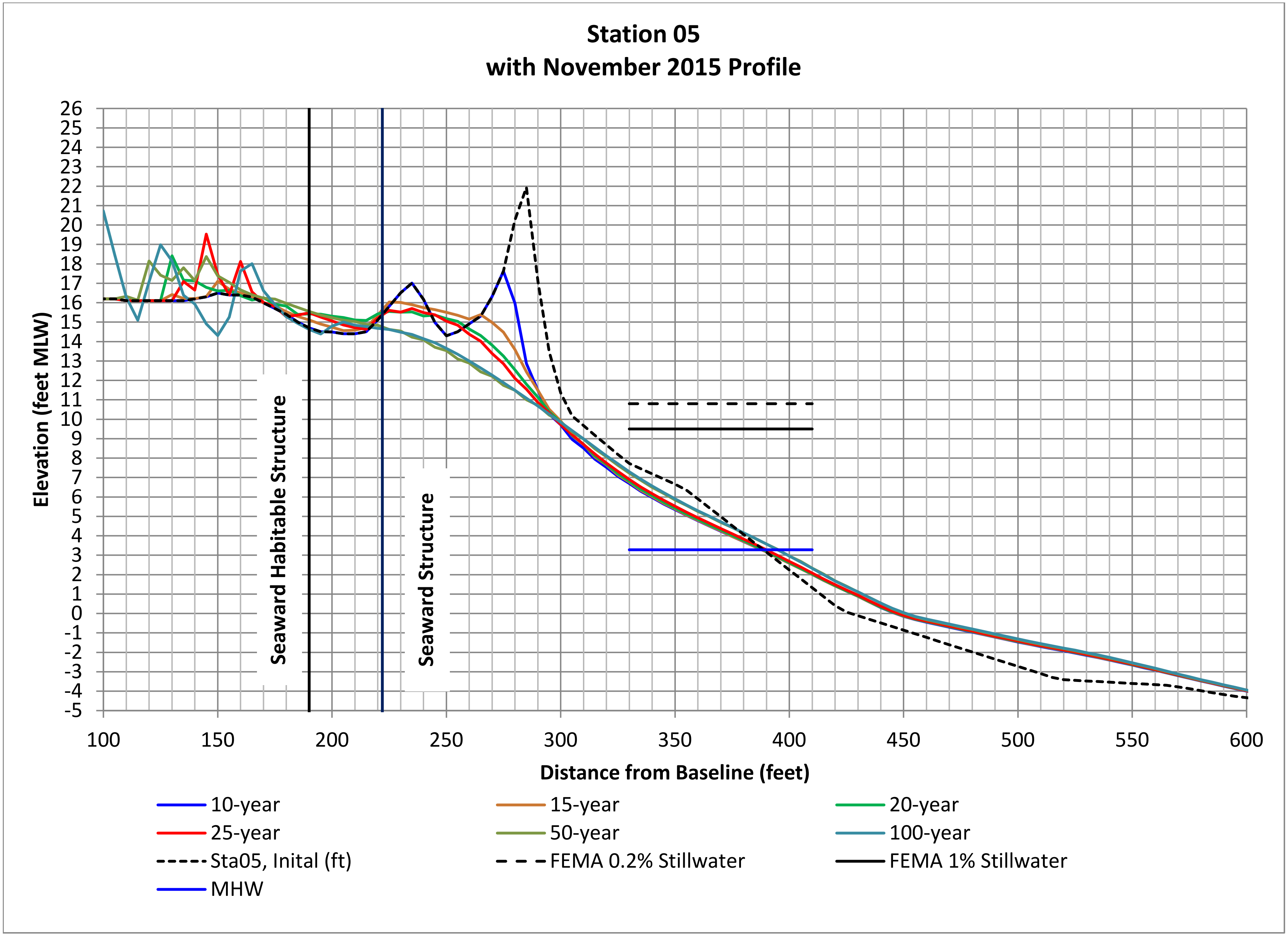

Station 30
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
10-year
15-year
20-year
25-year
50-year
100-year
Sta30, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW

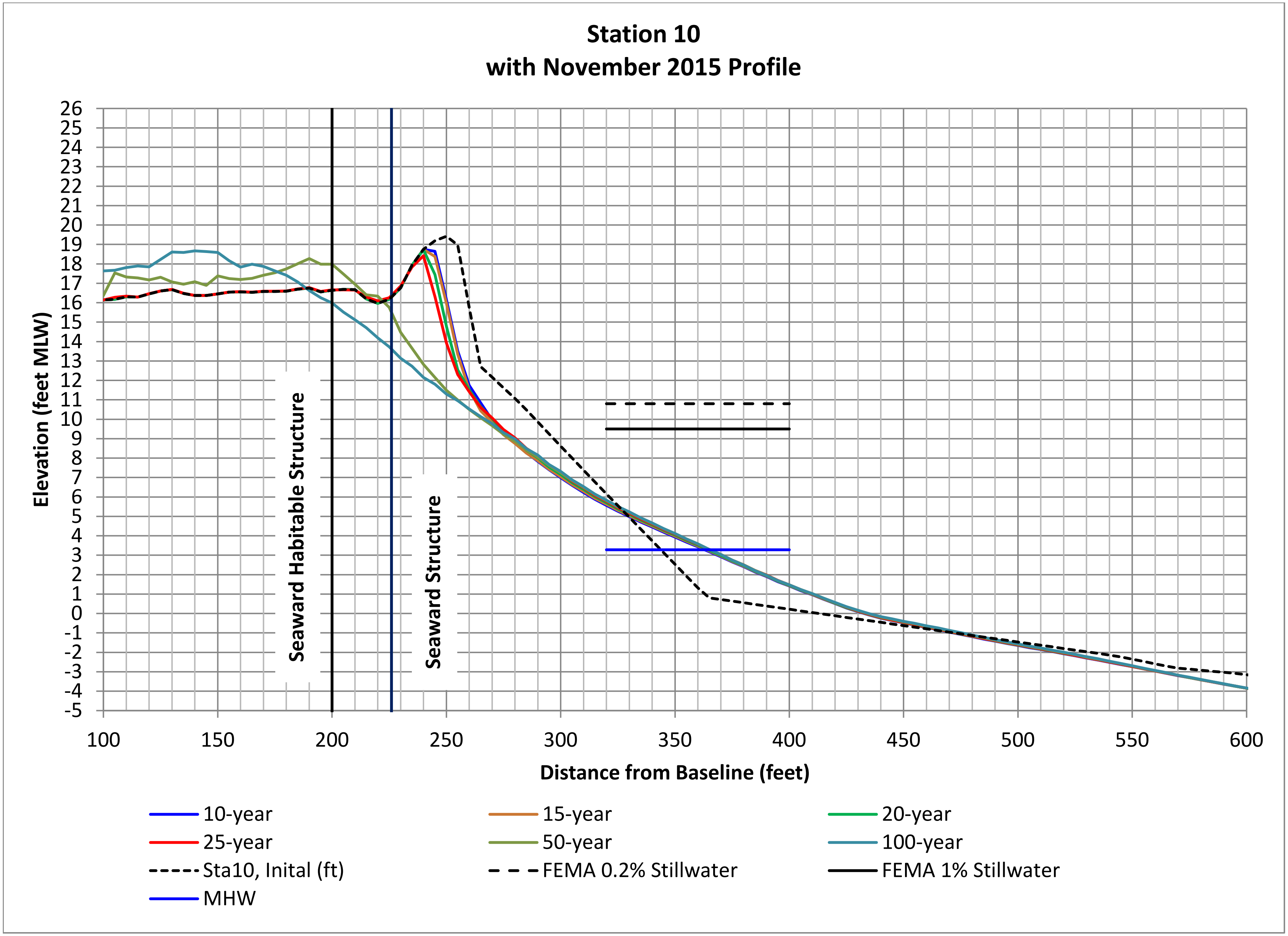


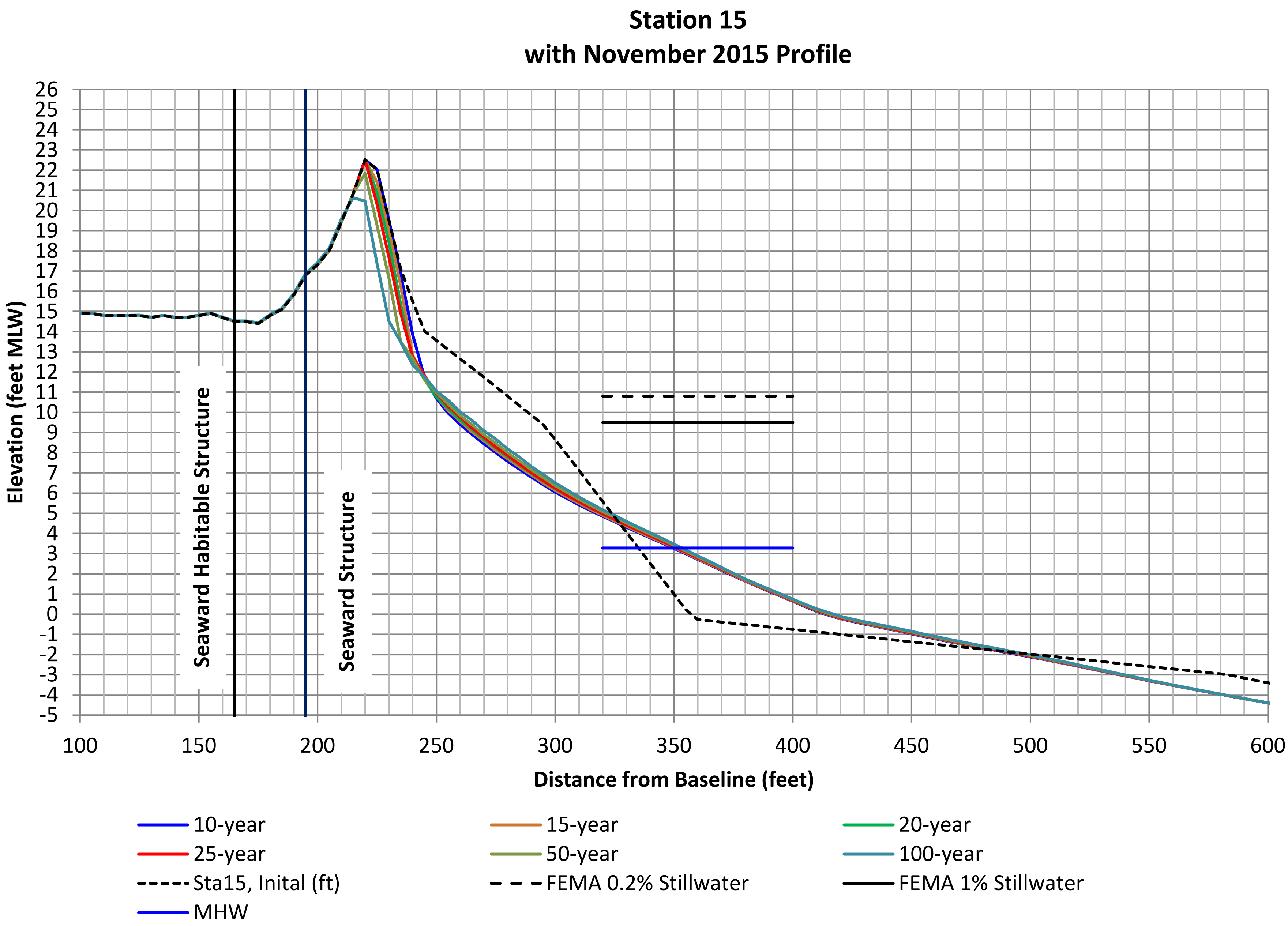
Station 35
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta35, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW

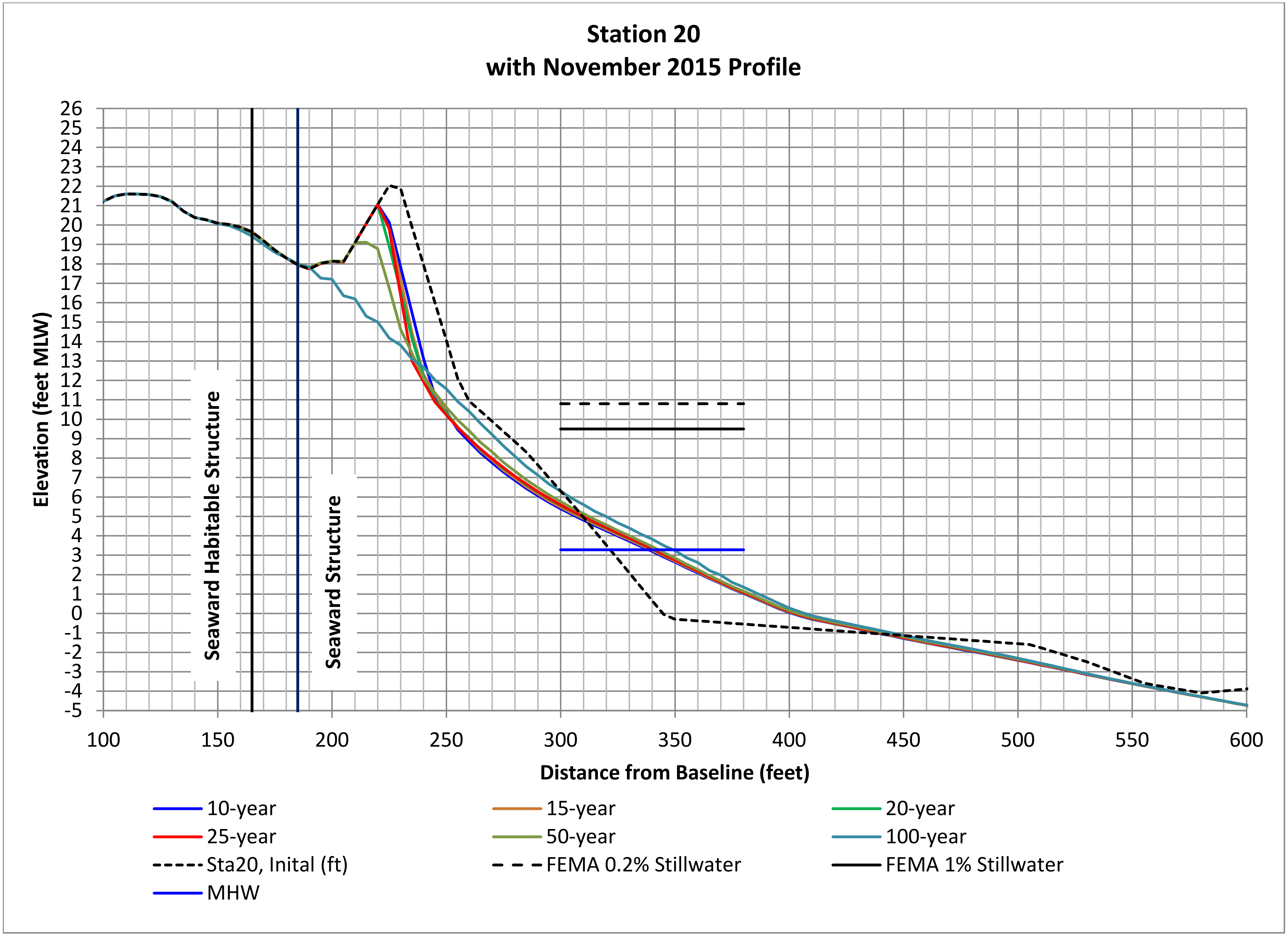
Appendix G: Beach Profile Storm Responses (With Sea Level Rise)


Station 00
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta00, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW


Station 05
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta05, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW


Station 10
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta10, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW


Station 15
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta15, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW


Station 20
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
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8
7
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4
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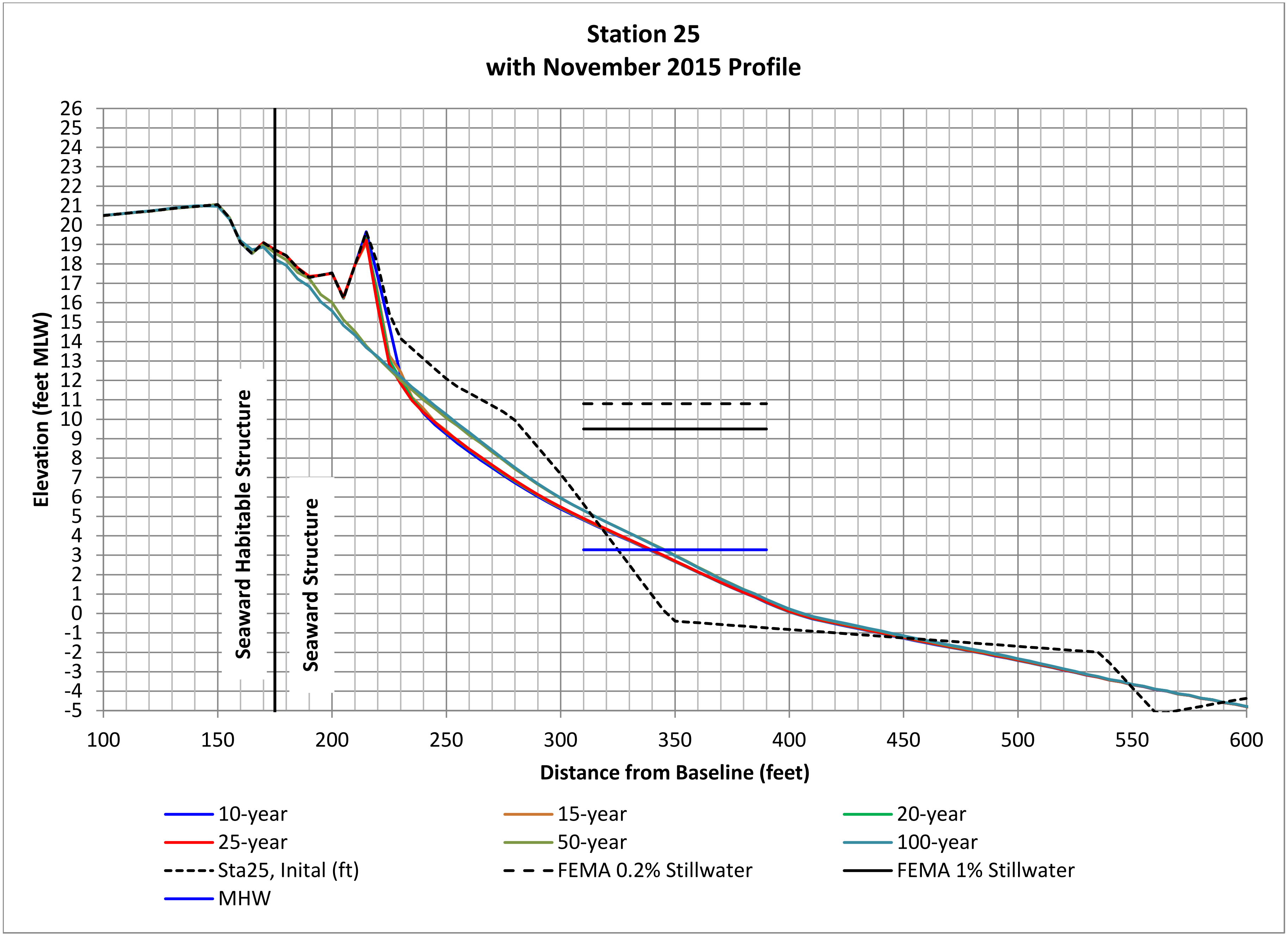
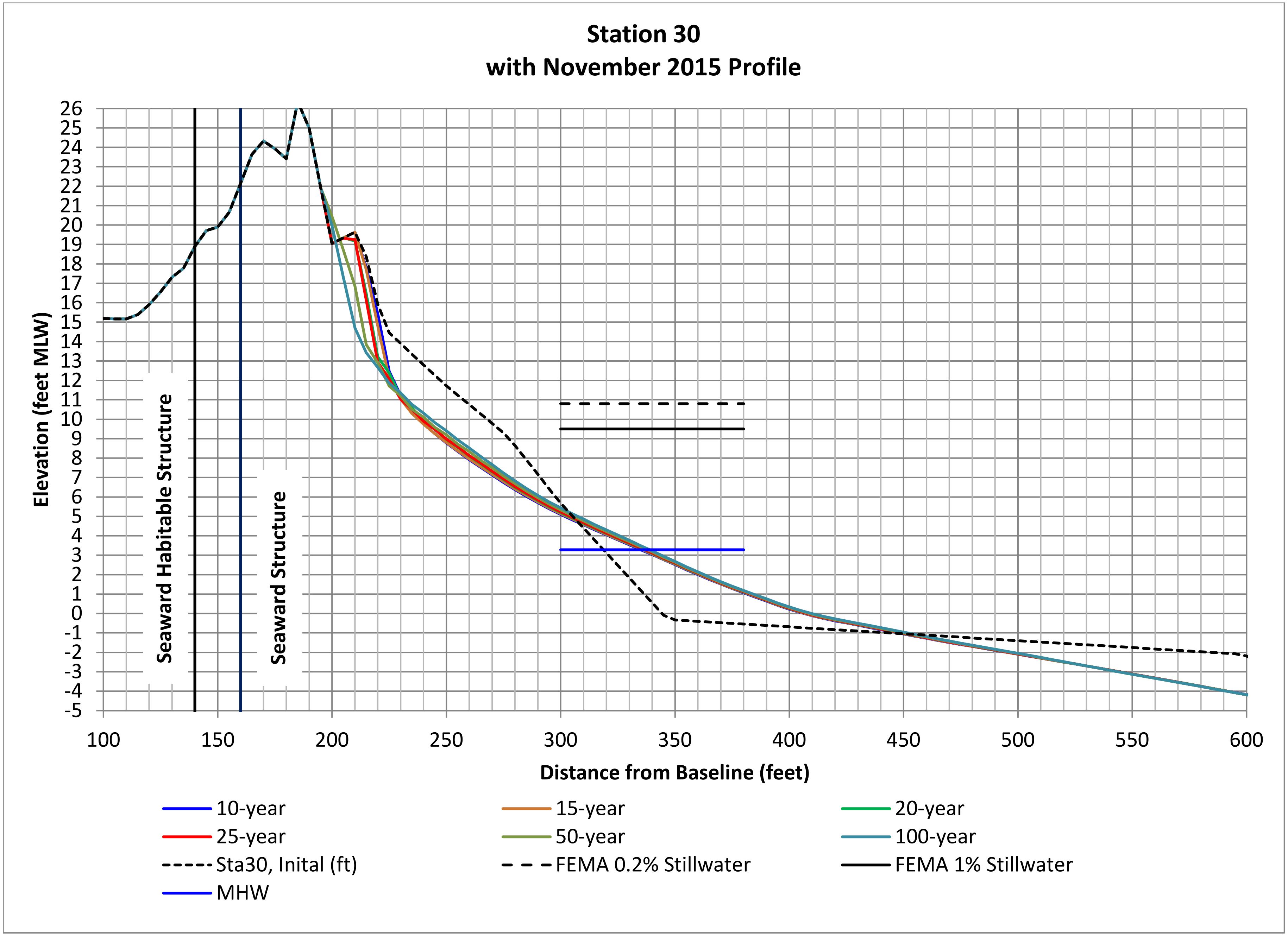
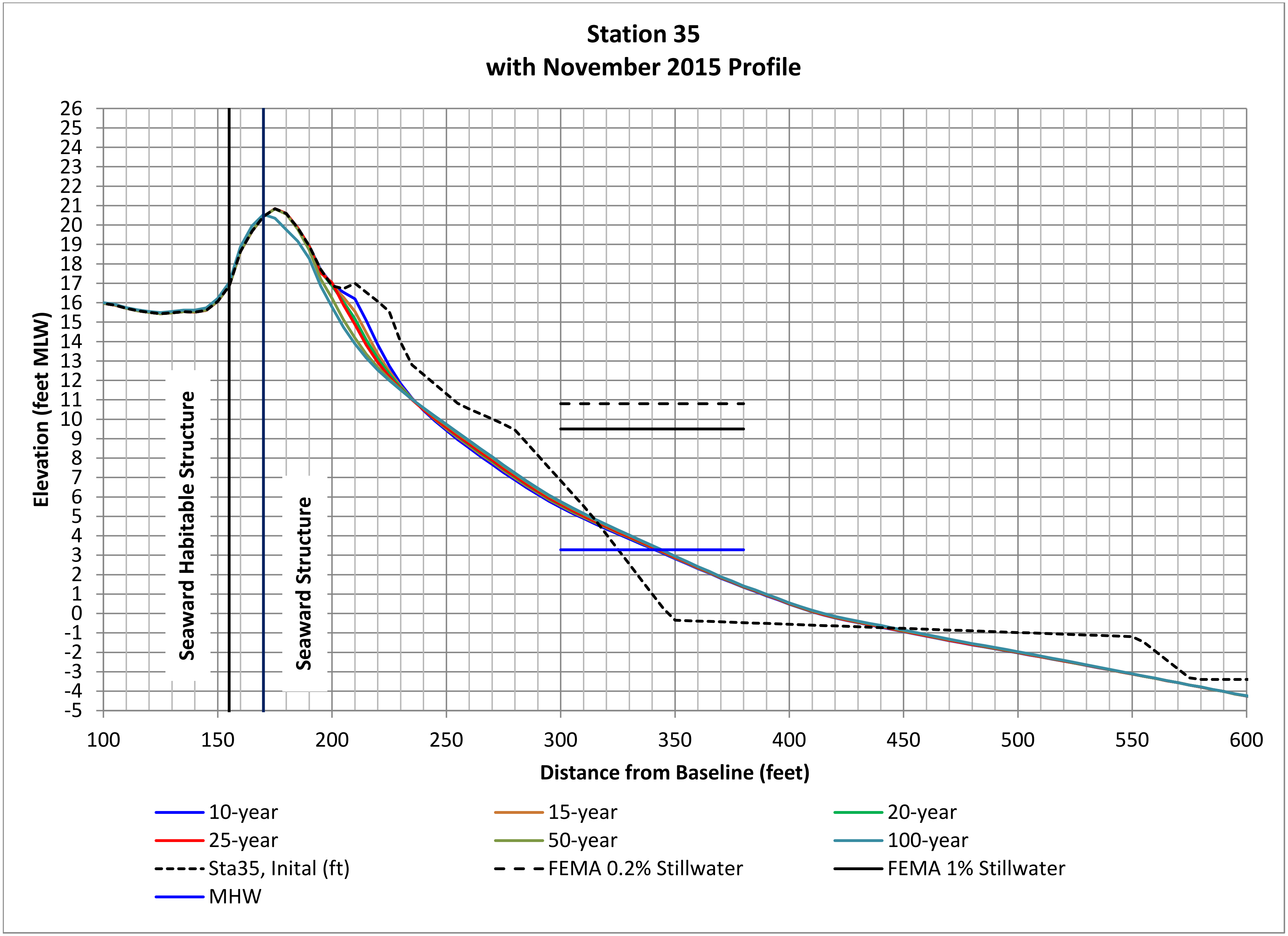
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta20, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW


Station 25
with November 2015 Profile
Elevation (feet MLW)
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
10-year
15-year
20-year
25-year
50-year
100-year
Sta25, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW


Station 30
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta30, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW


Station 35
with November 2015 Profile
Elevation (feet MLW)
Distance from Baseline (feet)
Seaward Habitable Structure
Seaward Structure
26
25
24
23
22
21
20
19
18
17
16
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12
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-1
-2
-3
-4
-5
100
150
200
250
300
350
400
450
500
550
600
10-year
15-year
20-year
25-year
50-year
100-year
Sta35, Inital (ft)
FEMA 0.2% Stillwater
FEMA 1% Stillwater
MHW

Appendix H: Tabulation of and Responses to Public Comments

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The findings and recommendations from the November 2016 Draft Report were presented in a public forum at the Virginia Aquarium & Marine Science Center on November 9, 2016. At the conclusion of the meeting, City representatives noted that the Draft Report and the meeting presentation materials would be made available on a City website. The City solicited the public's review and comments regarding these materials, and a number of residents responded by email. The table below summarizes the questions and specific comments contained within the emails received, and it provides responses to those comments that are within the scope of this study. Small typographical errors in some of the comments were corrected when they were copied into the table.

It is noted that several comments were received that, while relevant to the Croatan area, were not directly related to this particular study. Those comments have been noted by the City, but it is not appropriate for M&N to respond to those comments in this document, and they are marked simply as "Outside the scope of this study" in the table below.

Summary of and Responses to Comments Received

Number	Comment or Question Received	Response to Comment or Question
1	The Croatan Beach should be included in City services and not have the services end at Rudee Inlet.	City maintenance services are outside the scope of this study.
2	This is in stark contrast to the beach not more than a mile up at the oceanfront. While Croatan beach is dwindling, the Oceanfront beach (and North End neighborhoods – which, as you know, are NOT public beaches with lifeguards as Croatan beach, and no public parking lot as we do) only seems to be getting wider. It's almost an unbelievable comparison when you see the two beaches against one another. While I'm not an engineer, the casual observer can see where the money and focus is being spent, and where it isn't. We ask that the City of Virginia Beach do all they can to support the protection of Croatan Beach (as they already do with the Oceanfront as well as Sandbridge) to continue to provide this beach as one of the many tourist attractions within our community.	The comment is noted. The report recommends a beach nourishment project to establish a wider dry beach along Croatan.

Number	Comment or Question Received	Response to Comment or Question
3	Address the fact that the Dam Neck sand came from offshore and did not affect the littoral drift north to Croatan.	No change is made to the report. It is clarified here that the 2013 nourishment of the NAS Oceana Dam Neck Annex shoreline was constructed using sand from the Sandbridge Shoal Borrow Areas A and B, which are approximately 3 to 4 miles offshore. These are also the borrow areas used for nourishments of Sandbridge Beach. Utilizing sand from these borrow areas on the Outer Continental Shelf (OCS) does not remove sand from the stream flowing northward toward Croatan.
4	There was no consideration of the dredging of sand from the sand bar off Dam Neck, either, although it was reported to the working committee that this was done Moffatt and Nichol did not know about it or include it in their report.	See response to comment #3 above.
5	It was stated in the study that the beach will be replenished with 50' of flat beach from the toe of the dune, then 50' of graded beach. The 50' of flat beach is a concern. I, and many of my neighbors that I have talked to, although grateful for the replenishment, wondered if 50' of flat beach is sufficient to enjoy the beach in the same way we did for many years before erosion took its toll. It certainly is sufficient for walking and sitting, but not for recreation activities, such as Volleyball. A Volleyball net is 28' long, so without blocking the beach, 50' probably would not be enough. We would like to have a flat beach of at least 65', which would return the beach we once had. I realize, in the overall analysis that this may seem a minor concern, but if the goal is to return our beach to a width before we lost 110' to erosion, asking for 65' of flat beach seems reasonable.	The concern and comment are noted. The constructed width of the beach berm will be constrained by the beach width and Mean High Water (MHW) shoreline position, that can be permitted and designed to avoid adverse impacts on inlet maintenance and navigation safety.

Number	Comment or Question Received	Response to Comment or Question
6	There must be a long term solution, not an occasional band aid approach.	Beach nourishment is considered to be a long-term solution to address beach and dune erosion, with provision for future maintenance of the constructed project. The project design will include recommendations for future renourishment intervals and monitoring to determine when renourishment is needed.
7	The issue is the public beach and the safety issues being encountered. I have seen people resort to sitting on the dunes or even on the accesses. The lifeguards could not place chairs earlier this year and had to resort to beach chairs. This does not allow safe visualization. The ATV used by the lifeguards did not have safe access and came way too close to people this past season.	These concerns are noted and will be considered in the design of the recommended beach nourishment project.
8	The proposed criteria for beach berm width relative to vehicular and recreational usage are discussed a number of times here the criteria are in fact laid out or how they were arrived at is not obvious. Understanding those criteria and how they were arrived at is important because they are the basis for the recommendation for a large beach nourishment program. On the potential storm damage criteria alone, at this point, only a small area of the beach at the north end rather than the whole beach should have some type of restoration program.	The development of the beach width criteria is discussed in Chapter 7 of the report (page 68 of the draft report). Those criteria were developed in collaboration with the Croatan residents' steering committee members.

Number	Comment or Question Received	Response to Comment or Question
9	The beach berm will be widened to "50 ft between the toe of the dune and Mean High Water (MHW) shoreline position" adding 15 ft for vehicles, 10 feet for lifeguards and 25 feet for recreation past the lifeguard station (pg 68). Is that enough? I can't tell. The beach seems to be about that 50 ft wide at low tide. Its become much lower at high tide in winter in the last few years. Guess they need to tell us where the MHW mark is. So will it be twice as big if they do that? The beach has been averaging 75 feet wide for most of years before 2012, so, is this 50 feet in addition to the norm of 75 feet?	The report recommends nourishment to construct a beach berm that is 50 feet wide at an elevation of approximately 8 feet above Mean Low Water (MLW). This profile would have an additional width of approximately 50 feet between the seaward edge of the berm and the MHW line at 3.3 feet above MLW. At a typical high tide, a person on the beach would see approximately 100 feet of beach width between the toe of the dune and the water at high tide; waves would still wash up on the beach higher than the high tide line. The beach width criteria are discussed in Chapter 7, (page 68 of the draft report), and those widths were developed in collaboration with the Croatan residents' steering committee members.
10	Address the missing dredging data - just state that the report was done with all the available data and that a careful future watch will be kept on this data to assess complete data might show in relation to a correlation between the dredging and erosion.	The report notes the historical data available and the data gaps. The available data is sufficient to support the needs of the study and its conclusions.
11	In reviewing the study done by Moffatt and Nichol it is shown that they did not have the full information to complete their study (and they said that they could only work with the available information). There were many missing months in the tables relating to the amount of sand the City dredged which could easily explain why there was no correlation between dredging and sand volume loss at Croatan.	For impacts of data gaps on the study, see response to comment #10 above. As stated in the report and public briefing, it is not considered that dredging of the inlet's sand trap and navigation areas has the ability to increase or decrease rates of erosion and shoreline change on Croatan's beaches south of the weir. Only material that has already been transported by natural coastal processes (waves and currents) into the inlet is available to be dredged.

Number	Comment or Question Received	Response to Comment or Question
12	To make a statement that dredging and the Weir have no effect on beach erosion, without supporting statement is unfair. Perhaps you did not have enough information, considering that the City provided incomplete data (Draft Report). But that leads me to wonder how you could draw that conclusion. We disagree with the findings that dredging in the inlet has not caused any of the beach erosion, at least on the north end of the beach. Living beach front offers the advantage of witnessing what happens when dredging occurs for 2 or more days at a time, especially when the dredger is up against the beach. We witness the 2-3 foot "cliffs" that form on the beach, at least at the north end, when dredging is done. If you disagree with this, then please explain what creates this condition during dredging.	See also response to comments #10 and #11 above. Several things may be going on that could give the perception that dredging in the inlet and sand trap are linked to changes on the beach. First, dredging in the sand trap can result in changes on the beach inside the inlet (between the weir and the short jetty north of the weir). This is not the same as causing changes on the beach south of the weir and in front of homes. Second, when material is removed from the sand trap (dredged or excavated) and placed on the beach south of the weir, the placed sand is less compacted than the typical beach. When waves work on that newly-placed loose sand, the seaward edge of the placed sand area can be eroded to form a "scarp" (the word for the "cliff" noted by the commenter). The scarp is then smoothed out over a short time period of typical tide and wave action.
13	The 10K is in process, with excavation occurring at the beach/water line at the inlet. The excavation is creating "cliffs" on the beach, just beyond the berm that was built at the dune line for the trucks to utilize. After the tide went out, the cliffs were smoothed away. Also, during the times when the dredge was not operating, the beach at the north end widened considerably, allowing us to walk to and around the South Jetty. What explains these conditions if dredging practices are not responsible?	Regarding the "cliffs," see also response to comment #12 above. Regarding what happens when the dredge is not operating: If and when the dredge does not operate for a long period of time, it is possible for sand to build up in the sand trap so that it reaches or exceeds the weir elevation. If that happens, sand from south of the weir is prevented from traveling over the weir, and the dry beach can indeed become higher and wider. When the sand trap is dredged again, the sand that has built up at the weir will be moved over the weir and into the trap. The normal operation of the inlet assumes that the dredge will operate as often as possible, to maintain sand bypassing and navigation safety. Having the sand trap fill up is not intended to be the normal situation.

Number	Comment or Question Received	Response to Comment or Question
14	I heard at the meeting and read that dredging has not damaged Croatan's Beach. Today's pictures show during dredging that there is a sharp 3' to 4.5' drop from the edge of the beach to the water while further South there is a natural slope to the water's edge. There is a definite larger beach the closer to Pendleton. I have seen this many times and I have seen a steeper drop. This appears as visual evidence that dredging effects the beach. Please help me understand.	The presence of the inlet and the jetty and weir structures do have an effect on the maximum beach width that will naturally occur at the north end of Croatan. The direction of wave approach and storm activity will also affect the northern end of Croatan differently than the same coastal processes will affect the southern end of Croatan, because the processes have to interact with the inlet and the jetty structures. Thus, it is reasonable that the beach at the southern end of Croatan and in Camp Pendleton would generally be wider at times than at the northern end of Croatan. However, the process of dredging sediment that has gone over the weir or around the south jetty does not cause erosion on Croatan. The sand that is dredged has already moved off of Croatan before it is dredged.
15	I must tell you that the loss of sand is not due to storm irregularity. It's very clear that the weir is failing. Coupled with aggressive sand removal has left our beach in a serious predicament. There are several ways to combat this problem and I do appreciate the Sandune that was just built but that is simply a Band-Aid to this problem. Fix the problem and the sand will naturally replenish our beach. The current recommendation of just dumping sand is welcome but it is a short-term fix for a long-term problem. A great idea is to turn the sand that is being dredged out of Rudee and put it back on Croatan Beach. The City beach has more sand than it needs and this would help the homeowners that live on the ocean front and beachgoers.	Commenter's opinions on storms and the weir are noted. The recommended project to build beach width in the short term will rely on bringing additional sand into the system from an external source, with the possibility of using sand from maintenance of the inlet's deposition basin if it is feasible from technical, financial, and permitting perspectives.

Number	Comment or Question Received	Response to Comment or Question
16	Wouldn't these drastic changes to our beach (which coincidentally occurred after the weir installation) warrant a study that considers the effects of the weir and dredging on the erosion?	The study evaluated historical shoreline positions and beach surveys over the past several decades. These data sets used in the study reflected the presence of the weir and the dredging operations that have been ongoing for decades. It is our position that the effects of the weir and dredging are indeed included in this study.
17	I absolutely believe that the bigger problem is the weir and jetty wall, and that a complete study and redesign of the jetty system is what is truly needed to put our beach back to where it should be. I think it is totally negligent for them to say that the dredging combined with our current weir/jetty system does not / has not had an impact on our beach. There is no doubt in my mind that when they dredge the inlet, it changes our beach immediately. Proof is in the pictures attached, taken 2 days ago, on 11/28/16. The dredging they just did for the emergency replenishment to our beach over the past couple weeks has caused a horrible cliff from the inlet almost all the way to Twilight. It is worse than I've ever seen it. It is dangerous at High Tide, as there is NO beach to walk on. If a child were to fall over the cliff, they would be in a serious situation. Walking on the beach at high tide means that you are walking on a completely slanted slope - not sure what to call it because it is not a dune, and it is not flat beach. It is not rocket science to conclude that the cliff that forms south of the weir is always in conjunction with dredging that has just occurred.	The comments are noted. Regarding the "cliff" formation, see response to comment #12 above.

Number	Comment or Question Received	Response to Comment or Question
18	The study did not demonstrate to me that the dredging/and current weir and jetty are not impacting the shape of the beach. It would be great if it could walk us through why there are currently 4 foot drops in areas of the beach after 2 days of dredging. It also appears that not enough data is collected about dredging, as in one month listed there was approximately 141, 000 cy taken. How are we to know if similar amounts were removed in the months that were omitted from data collection?	Regarding the "cliff"" formation, see response to comment #12 above. Regarding the dredging data: The larger dredging events in the report table and figure are associated with dredging of the inlet's deposition basin by Federal or City-contracted hopper dredges. Records on these special events are available and complete. The relevant report section, table, and figure have been revised from the draft report.
19	The study demonstrated with sea level rise the dunes would definitely be impacted if left alone, and if that is the case, there would be no usable beach. The study did not look at how the weir/jetty and beach system will be impacted with any SLR. I understand that the target being looked at is 18 inches. Do we know if the current system, with the recommendations for change will be adequate with 6-8 inches of SLR? As it is uncertain how quickly or slowly this is occurring, this could occur within the next 10-15 years. I would like to have answers to those questions, to allay the fear and trepidation I have about waiting for funding and permits to make such a gigantic project come to fruition. If you cannot answer those questions now, will those questions specifically be addressed in the sea level rise study?	The performance of the weir under various levels of future SLR is beyond the scope of this study. Both the actual occurring rate of SLR and the performance of the weir are items that will be closely monitored over the coming years and decades.

Number	Comment or Question Received	Response to Comment or Question
20	I don't believe that our erosion is from "natural change in wave patterns" either. There is a clear problem with how the jetty lets in sand from the south side of Rudee Inlet off Croatan beach then dredged and pumped North for close to 20 years. It concerns me that the City will spin its wheels bandaging the issue vs fixing the jetty.	The comment is noted. The weir in the south jetty is intended to allow sand that is moving northward to enter a sand trap area where it can be more safely and consistently dredged by the City's Rudee II pipeline dredge. In this respect, the weir appears to be functioning as it is intended to function. Beach nourishment to maintain a wider dry beach and a more robust dune system is considered to a long-term solution to beach erosion, and like any other infrastructure solution it requires programmed maintenance (in the form of periodic renourishments).
21	We have been distressed to see the decline of Croatan beach over the last few years in favor of the North end, and believe the decline may have expedited when the weir was installed.	The comment is noted. The shoreline positions and other data evaluated as part of this study did not indicate that the beach erosion observed over the last five to six years is correlated to the weir modifications constructed in 2004.
22	Flooding from Lake Christine was severe and I surmise that a major storm could present a two pronged problem which would include an ocean surge. I trust that your diligence as an engineer would cause you to present the best scenario for the residences while being mindful of the City's financial concerns. Part of the problem last month, I suspect, is directly responsible from the City's failure to replace the pipe which took water to the Ocean from Lake Christine. A smaller pipe which could not handle the surge was inserted into the larger pipe. The engineer at that time said this was a decision based on cost not efficacy.	The comment is noted. Flooding from interior waterways is outside the scope of this study.
23	As residents on Lake Christine, when a storm is coming, please do all you can to turn on the extra pumps to drain water out of Lake Christine. We were very close to having water come into our house during this last storm – as were many residents (a couple inches).	See response to comment #22 above.

Number	Comment or Question Received	Response to Comment or Question
24	Still the dunes will hold up in a 100 year storm with no habitat damage except maybe with the predicted 1.5 ft sea level rise. Then homes will be damaged. But that's years away. A dune was significantly wiped out after they did their measuring last spring and they note they need to investigate that? That was not supposed to happen I guess. I felt a little sorry for M&N as they had little data to analyze and a tight directive to look at "upland structure protection." They did try to address beach width and did support that …. Beach needs to be widened as the profile is too narrow for recreation and vehicular access and lifeguards according to city surveys and site visits.	The comments are noted and appreciated.
25	What can be done to stabilize the dunes once they have been rebuilt? It seems a pity to have renew them after each storm erodes the structure. Dune grass may offer a bit of protection, but there isn't any understructure to hold the sand in place.	It is recommended to plant appropriate native vegetation on the dune face and crest. The higher and wider beach berm elevation that would be part of the recommended beach nourishment project would also serve to mitigate erosion of the dune face. No "understructures" within the dune are recommended for this project.
26	What level of assurance does the City have that the proposed sand replenishment at Croatan will be successful in protecting the dunes and widening the beach over time? (How long would they expect the sand to stay on the beach?)	Estimation of expected post-construction erosion rates and future nourishment intervals is part of the work to be completed during detailed nourishment project design.
27	What needs to be addressed in any final design of the beach nourishment project is how the sand is kept in place. New plants have to be added and sand fencing needs to be installed properly. Watch will be kept on this data to assess complete data might show in relation to a correlation between the dredging and erosion.	See response to comment #25 above.

Number	Comment or Question Received	Response to Comment or Question
28	Is there a specific timing and frequency that is being recommended for monitoring? As we have seen from the study, there isn't consistent or always usable data, and that leaves the beach at a disadvantage when scientifically trying to justify why the replenishment or changes need to occur. I would hope that with specific recommendations, the budgeting will reflect that.	The City's intention is to conduct regular monitoring surveys twice per year along Croatan, once in the spring and once in the fall.
29	I would like to make sure your proposal will maintain at a minimum the width described in the report and would like to make sure this minimum will be maintained moving forward. How will you measure this minimum at the beginning of the summer?	The City's intention is to conduct regular monitoring surveys twice per year along Croatan, once in the spring and once in the fall. The surveys will serve to document the beach berm width and the total dry beach width, among other things. The beach width between nourishment events will be a result of the coastal processes affecting the beach; the detailed design of the nourishment project will recommend intervals between planned nourishment events to maintain a target beach profile.
30	We have no guarantee that the 408 permit will even be approved.	The comment is noted.
31	In the discussion in Section 8.3 the word potential is underlined. Is that underlining to emphasize that a potential is the criterion which triggers a review or is it the view of the report that there is only potential for increased dredging if a beach nourishment plan is put in place?	The "potential" in the referenced sentence refers to a criterion that would be likely to initiate a Section 408 review.

Number	Comment or Question Received	Response to Comment or Question
32	I agree that adding alot of sand might concern the Corps, causing sand to flow into the channel. But that's not for sure. It could be drawn right out to the sand bar. The sand could also stay put awhile, especially if they groom the beach regularly and maybe raise the weir. Anyway the volume is just natural since this is what we used to have on the beach before the jetty/weir. And we have a permit in review for 20,000 cu/yds already. So if they do need one I hope they get a "minor" permit application because that takes a few months where a major one could take years! Finally they do not say where they will get the sand. They also mention "option one and option two" but they never say what those are??? I am guessing the "weir profile modification" that is needed to thwart sea level rise is option 2. I think they should get on that right away.	It is expected that the recommended beach nourishment project will require a complete permit application and review, including a strong likelihood that a Section 408 review will be required. However, it is not expected that the permit application and review process will take multiple years. The type and specific location of the sand source for the recommended project will be determined during detailed design of the project. The references to Option 1 and Option 2 were mistakenly left in from an early draft of the report, when we were considering much smaller renourishment projects instead of the 130,000 cubic yard project recommended in the draft report. The report has been amended to remove references to Option 1 and Option 2.
33	Quite frankly the Conclusions and Recommendations section of the report is hardly that, as it continues to introduce data and tables rather than synthesizing the extensive information previously provided into concise conclusions and recommendations.	The comment is noted. The data and tables provided in Chapter 9 of the report are intended as a convenience to the reader, rather than referring the reader to turn back to earlier chapters where the data is originally presented.

Number	Comment or Question Received	Response to Comment or Question
34	The presentation is interesting because it provides information not contained in the report-specifically the beach nourishment history of the entire beach. The question is what is the point of providing that information? Providing gross volumes of sand rather than cy/foot or mile seems of little use and even then what would be the purpose to make the point that the area north of the jetty has received attention and south has not? Further, the slide titled “Sand Added in Beach Nourishments” is confusing. The flesh colored bubble to the far right indicates the city and the Corps of Engineers provided 1,300,000 cy in 2013 but also states and average of 260,000 cy per year?	The information was provided in the public presentation to add context to the discussion of the rate of sediment transport along the Virginia Beach Atlantic Ocean shoreline. The beach width and shoreline change noticed by the public at Sandbridge, Dam Neck, and the Resort Beach / North End is strongly influenced by the fact that those beaches have received large volumes of beach renourishment sand. In contrast, Croatan has not received renourishments of similar magnitude per foot. The slide acknowledges that fact. Apologies for the confusion between the 2013 Resort Beach / North End nourishment volume and the average cubic yards per year. The 1,300,000 is the volume actually placed in 2013 as part of the planned renourishment of the federal project north of Rudee Inlet. The 260,000 cy per year was intended to show how much this total volume would be if averaged over the time between the original nourishment and the 2013 renourishment. However, an inaccurate number of years was used in the math. The 1,300,000 cy should have been divided by approximately 11 years (2013 - 2002) for an average volume need of approximately 120,000 cy per year. However, it is stressed that the Resort Beach and North End are not nourished in this amount each year; they are renourished in large volumes after long intervals. The graphics from Slide 4 and Slide 6 of the November 2009 public presentation have been included – with the inaccurate information described in the paragraph above removed – as figures below this table.

Number	Comment or Question Received	Response to Comment or Question
35	Pictures in the report - many of the pictures in the report would serve the readers much more effectively if they were time stamped so it is obvious that corresponding north and south views were in fact taken at about the same time and some indication the tidal state at the time of the pictures would be useful. Similarly, post storm pictures should indicate whether there is still any storm surge or that steady state had been achieved. Finally with the numbered pictures many which include walkway structures what is trying to be communicated? Is the focus dune crest, dune toe, and beach berm as pictured in Slide 8 of the presentation or is it the structures? If the structures, were they displaced in a single storm or any or all displaced over.	The comment about time stamps is noted. Unfortunately, the source images did not include time stamps actually on the photos. The photos in the body of the report (Section 5.4) are from the March 30, 2016 site visit. The captions have been amended in the text to note the date and the location of the photos. Photos in Appendix A are also from the March 30, 2016 site visit, and the key map in the Appendix indicates the photo locations. Tidal conditions during the site visit were approximately typical, with no storm surge occurring at that time. In all of the photos that contain walkway structures, the structures are helpful as a reference to put the dune face (including dune erosion) and beach slopes into visual perspective. The photos document the site visit and help to illustrate the difference between Segment I and Segment II as described in the text. The additional photos used in the public meeting slides were provided to illustrate changes in the beach and dune over time.
36	Address that the sand pushes on Croatan - just state that this was not considered in the report unless there is some information that the consultants considered that is not in the report - in any event just say what the facts are.	The sand pushes that have historically occurred do not add volume to the beach system as a whole; they only move sand from the lower part of the beach to the upper beach and dune area. These are usually done just before a storm is expected, and the changes in the beach profile due to these actions is a short-term change. This study is primarily concerned with longer-term trends and long-term beach and dune management actions. Thus, the short-term sand pushes were not explicitly considered in this study.

Number	Comment or Question Received	Response to Comment or Question
37	We are all encouraged by the City's willingness to attempt a correction of the beach by adding sand, but we are at the same time nervous that this will not be the solution. Many residents have observed that the sand loss accelerated after the 2009 sand push which radically increased the slope of the beach. This sand push and the later ones were not considered as being a possible cause of erosion by the Moffatt and Nichol study either. Many residents continue to worry that the most recent sand push which has left a very steep slope on the beach reaching to the dunes will have a similar effect of speeding up erosion.	See also response to comment #36 above. In moving sand from the lower part of the beach to the upper beach and dune, sand pushes trade dry beach width (and shoreline position) for a gain in sand volume higher up on the beach. But sand pushes do not cause significant additional erosion of sand volume from the beach profile, beyond what would have occurred in the storm without the sand push.
38	I would like to be assured that the replenishment comes from "new" sand and that no sand is pushed from the shoreline - as has been done previously.	Sand for the recommended nourishment project would be brought in from an external sand source, not pushed from the lower beach or borrowed from the sand bar along Croatan. It is possible that sand dredged as part of expected maintenance of the inlet's outer deposition basin could be used to provide part of the nourishment material, if it is financially feasible and if permits can be obtained.
39	On page 19, there are two references to a “companion sediment budget study (in progress.)” The first is in the 1st line at the top of the page and the second in in the 7th line from the bottom. Can you tell me what this is about, how it will be used, and when it will be done?	The sediment budget study report is focused on answering questions raised by USACE during their review of the City's permit application to borrow 20,000 cy annually from the sand trap, for placement on Croatan's beach and dunes. The draft report has been completed and submitted to / reviewed by USACE. The final report is expected to be completed in April 2017.

Number	Comment or Question Received	Response to Comment or Question
40	Address the effect of the sand tightening on the north side of the inlet on the net amount of sand moving to Croatan each year.	The "sand tightening" of the inlet's north jetty is considered to have reduced the rate of sediment moving from the resort beach southward into the inlet's navigation channel. Sediment deposited in the navigation channel remains in the channel unless it is mechanically dredged and placed. None of the inlet dredging permits presently allow for placement of dredged sediment on Croatan. Thus, any sediment dredged from the navigation channel is placed north of the inlet. It is considered that the sand tightening of the north jetty has not had any significant impact on sediment volumes moving from north of the inlet southwards to affect Croatan.
41	This points up the importance of [another commenter's] request .... that the City continue to monitor the beach and collect the relevant data so the effects of dredging can be studied. The consultants point to the direction of the waves as being the only significant change and by the process of deduction have determined that this must be the cause of Croatan's sand loss. This conclusion does not hold up, however, as the resort strip, the north end, Dam Neck and Sandbridge were all affected by these same waves and did not experience the same destructive erosion (or any erosion at all?).	The other beaches noted - North End / Resort Beach, Dam Neck, and Sandbridge - do experience erosion due to storms and less intense but continual wave action in most years. At the same time, each of these other beaches are nourished with significant volumes of sand every 5 to 10 years, and the City's resort area and Sandbridge beaches are regularly groomed. This can give the appearance that the other beaches are subject to less erosion than Croatan, but all of these beaches do experience sand volume loss due to the same processes that erode sand volume from Croatan.
42	Why didn't the Ocean Front, Dam Neck or Pendleton's Beach erode like Croatan's from wind and wave action? I know the Oceanfront was discussed at the meeting and I think it was said the Oceanfront had some erosion but not at the same rate as Croatan.	See response to comment #41 above.

Number	Comment or Question Received	Response to Comment or Question
43	I'm betting that we're the only small, quiet neighborhood in North America, if not the world, which has a public parking lot and a nearly $1M bathroom/bathing facility in it. And all of a sudden we woke up one morning & Croatan beach had been renamed "Croatan Beach Public Park." On that very day, the beach became the property of the City of Virginia Beach, and the responsibility of The City. The City forced it down our throats, so now the City must pay for all the sand replenishments. The sand washes north from Sandbridge & the City scoops it up to put on the Big Beach. Well, turn the scoops around & send some of that sand south for Croatan Beach Public Park.	Sand for the recommended nourishment project would be brought in from an external sand source, not borrowed from material that is continually dredged and placed north of the inlet. It is possible that sand dredged as part of expected maintenance of the inlet's outer deposition basin could be used to provide part of the nourishment material, if it is financially feasible and if permits can be obtained. In addition, the City has already submitted a permit application to borrow approximately 20,000 cubic yards per year from the sand trap for placement on Croatan, as needed. That permit application is still in review by the regulatory agencies.
44	The draft report states on Page 77 "An objective of the study is to determine whether observed shoreline and dune changes can be correlated with dune and beach management practices." Where are the specific conclusions to satisfy that objective discussed? Page 80 of the report states that inlet dredging volume does not appear to correlate with changes in the beach and shoreline. However, other practices including the 2004 changes to the weir, the recent significant downstream nourishment and attendant removal of sand from the sea south of Croatan, as well as beach repair practices and structure placement over the dunes have not been discussed.	The Conclusions and Recommendations section of the report has been amended to address the questions raised in this comment.
45	SBEACH - the report states it was calibrated against various data and had good or acceptable correlation. Was any confirmatory checking of the modeling done with other models or programs?	The calibration process itself is a check of the SBEACH model's skill at reproducing observed (surveyed) beach profile changes in a historical storm event. The scope of work did not include the use of additional models to parallel the SBEACH simulations. Had an additional computer model been utilized, it too would have needed to be calibrated in a similar manner to that carried out with SBEACH.

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46	I believe we all see the beach getting smaller but I still don't know why. Did this report find a cause? If so could you point it out to me in the report. It seems to me that all the repairs have disappeared.	The report's Conclusions and Recommendations (Chapter 9) notes at the top of page 78 that the general shoreline retreat since 2012 coincides with an apparent increase in the frequency of northeasterly-approaching offshore wave heights. The direction of wave approach to the shoreline has a significant influence on sediment transport direction. A greater percentage of transport from north to south would tend to move sand from the north end of Croatan toward the south, which would be expected to result in shoreline retreat. Chapter 4 of the report discusses waves in greater detail.
47	The weir has a "strong influence on shoreline position over a short south distance" but not as far as Twilight Lane. That sounds like guessing. They found no "particular correlation" between dredging and erosion, but never say whether they looked at any data except "historical" observation, so this is NOT a reliable conclusion.	In general, historical records are the most reliable form of data that can be used in a study such as this. Historical observations and records can be extended through the use of calculations and model simulations, but would not normally take precedence over the historical data.
48	They agree "more regular shoreline surveys are needed" since the data is inadequate …. the beach width has decreased consistently from 2013-2015, about 30 feet at the north end and the shoreline has consistently decreased since 2012. For some reason they only included 2006, 2015 and 2016 beach widths. Probably no data. They use Google aerial views which is less reliable than on site measuring. VIMS was doing a good job on this but they stopped for some reason. They agree we need to start a regular shoreline and beach width measuring program again. Anyway, the beach is 20 feet less wide this year, on average since 2006, despite nourishment since 2008.	Correct, there was no beach profile survey data available between 2006 and 2015. The aerial photos were used as an efficient source of available information to examine shoreline change trends.

Number	Comment or Question Received	Response to Comment or Question
49	We urge your support, and that of Virginia Beach government's, to place Croatan beach and dunes as the top priority shoreline replenishment project in 2017.	Comment is noted and appreciated. Design and construction of a beach nourishment project is subject to funding and permitting, and project funding is outside the scope of this study's report.
50	Although not included in the study, on question, we were told that it would be 2018 before the work could be started. This was a startling and extremely discouraging answer. This beach cannot survive another 2017 winter/summer and most likely another 2018 winter, under the same conditions that we experienced in 2016, where the frequency and intensity of the storms was substantially increased over previous years.	Comment is noted and appreciated. Design and construction of a beach nourishment project is subject to funding and permitting, and project funding is outside the scope of this study's report.
51	To make existing conditions worse, on Oct. 4th, in preparation for "Matthew", the City began restoring dunes that were destroyed from previous storms. However, rather than begin the 10K, removing the needed sand from the inlet, a "sand push" was done utilizing sand from the beach. The beach was literally scraped clean of loose sand, which by effect, lowered the beach even further. Since that time, during many high tides, the water is at the toe of the dune. Additionally, the water now encroaches upon the stairs of our walkway, covering at least the bottom 3 stairs. If this continues, the stairs, being made of wood, will rot and fall away. The City had ample notice that "Matthew" was coming, allowing plenty of time to bring in an excavator to extract the sand from the inlet. Now that our beach is in worse shape than it has ever been, we are told that we must manage with what we have until sometime in 2018. A beach that is no longer accreting, cannot recover from this loss of sand. I do not mean to offend, but this is unconscionable.	Comment is noted and appreciated. Design and construction of a beach nourishment project is subject to funding and permitting, and project funding is outside the scope of this study's report.

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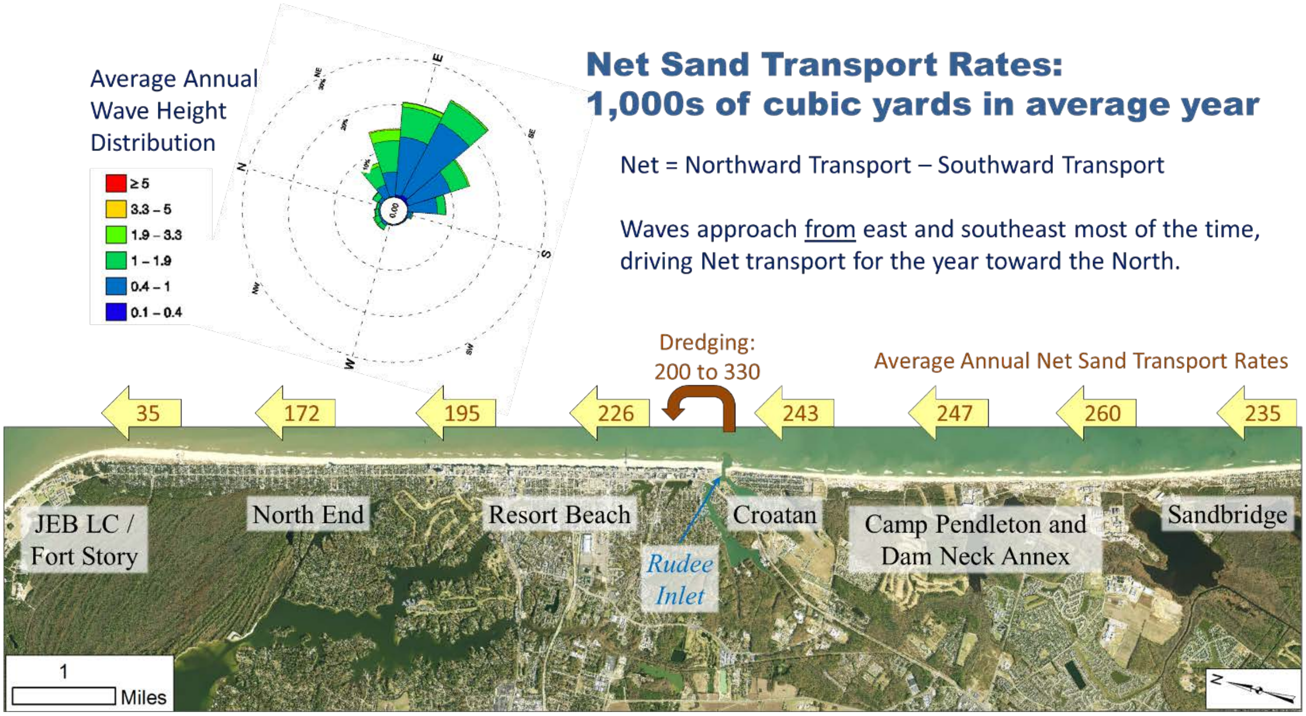
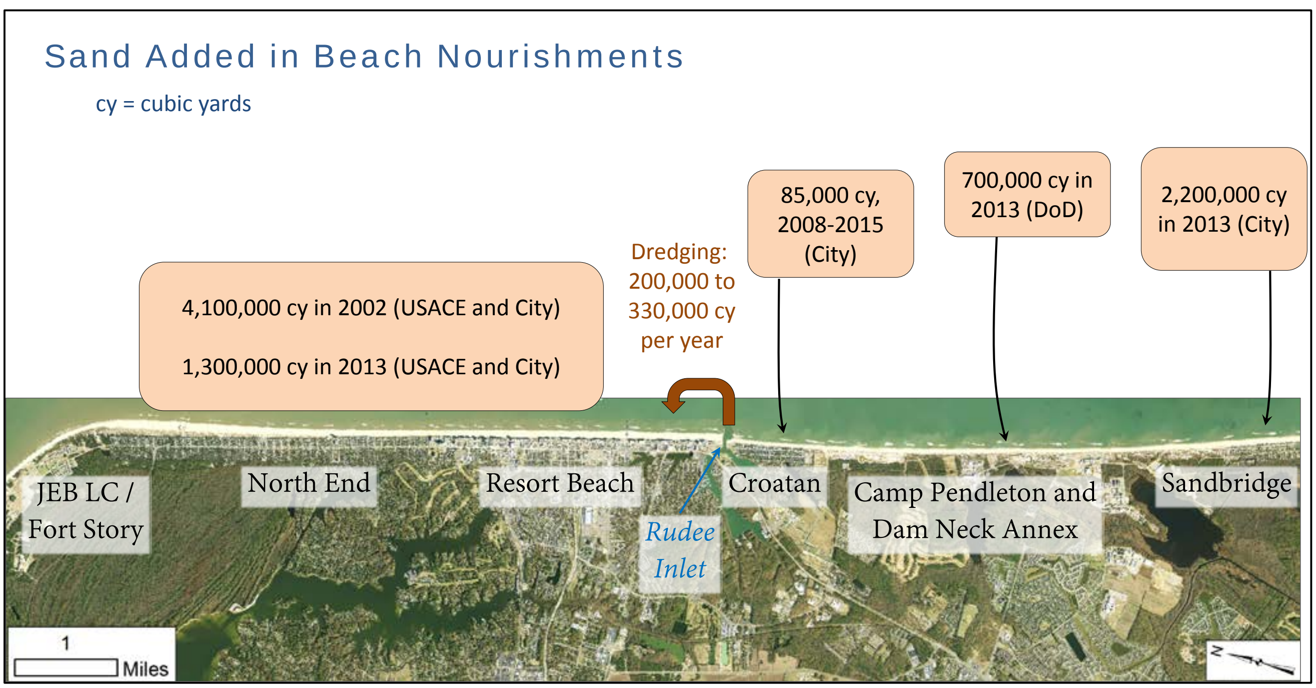
52	According to a speaker at the meeting on Nov. 9, the amount of dredge from Rudee Inlet and placed on the Oceanfront Beach is minute compared to the sand the Oceanfront has from Thimble Shoals. Is it not a cost savings to add Croatan to the Assessment & Monitoring for the Oceanfront rather than separate efforts especially when weather/wind/wave action causes the damage? Then both beaches receive coinciding solutions using a single 408 permit and the hunt for money to fund will be a single line item on the City's budget.	Comment is noted and appreciated. Tying nourishment at Croatan to the Federal nourishment project north of the inlet has significantly larger permitting, financial and legal considerations than conducting the initial Croatan beach nourishment as a standalone project.
53	I am in total support of the City’s proposed beach replenishment project however I feel strongly that it is a very temporary fix, and a bandaid at best. I appreciate that the City is now taking concern about the diminished Croatan shoreline, but the fact is that it has been neglected for many years by the City. Waiting until 2018 feels like the City does not take our concerns to heart. It is frustrating and ridiculous that this can not be fixed as an emergency situation in 2017.	Comment is noted and appreciated. See responses to comments #6 and #49 above.
54	I feel the report was lacking in more recent data to come to some of their conclusions. I don’t feel like they had enough data from 2016, where a significant amount of erosion occurred due to several large storms and dredging of the inlet. Because of this, I go back to my concern that a replenishment occurring in 2018 is not soon enough.	The report notes that M&N performed two field inspections of Croatan in 2016 (March and August), with many photos and notes taken during each inspection. Beach profile surveys from August 2016 were included in the study and the report. No aerial photos were available from 2016 at the time of writing the report. The technical analysis phase was ended in late August / early September 2016 in order to complete the report in time for review and preparation for the November 2016 public meeting.



Net sand transport rates along Virginia Beach Atlantic Coast; Transport values (except for Dredging) are as interpreted from USACE, 2008; "A Wave Climate and Littoral Sediment Transport Study for Virginia Beach, VA – Rudee Inlet to Cape Henry"; Dredging as discussed in Section 3.2.



Representative beach nourishment event volumes along Virginia Beach Atlantic Coast