NEWBURYPORT HARBOR
PLUM ISLAND NORTH POINT
NEWBURYPORT, MASSACHUSETTS

§204 PROJECT
BENEFICIAL USE OF DREDGED MATERIALS

APPENDIX B
COASTAL ENGINEERING

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Coastal Engineering

1.0 Study Overview

Plum Island and other local beaches surrounding Newburyport Harbor have sustained coastal storm damages and experienced localized, acute erosion rates along the beach face exposed to the Atlantic Ocean. Several structures at North Point, including residences and one commercial building, have potential for severe damages in the immediate future. Other areas of Plum Island's Atlantic facing shore have lost homes in the past five years. This erosion has generated a local interest in the placement of clean, sandy dredged material on the beaches. Dredged material will become available when the navigation channel for Newburyport Harbor is next maintained (estimated 2020-2021).

The erosion area at North Point State Reservation (North Point) is approximately 2,300 feet long to the west of the South Jetty. Much of the North Point's beach and dunes fronting the inlet have been lost over the past eight years. This leaves only a narrow buffer of remaining dune between the inlet waters and the developed shoreline. Damage and/or loss of residential and commercial property is likely during the next moderate coastal storm.

The US Army Corps of Engineers (USACE) conducted a Feasibility Study (FS) to develop a preliminary design alternative for beneficial use of dredged material at North Point. This Appendix documents the coastal engineering analysis and design efforts of the with- and without-project conditions to support the FS.

1.1 Study Area

The study area is within the City of Newburyport portion of Plum Island; located at its northern end. Plum Island (Island) is a barrier island located approximately 32 miles north of Boston. The Island is bound by the Atlantic Ocean to the east and extensive salt marsh to the west – between the island and the mainland. The northern end of the Island is primarily a residential area split between the Town of Newbury and the City of Newburyport. The southern areas of the Island are included within a State Park and the Parker River National Wildlife Refuge (PRNWR) located in the Towns of Newbury, Rowley and Ipswich. Plum Island is separated from Salisbury Beach to the North by the Merrimack River inlet including the Federal Navigation Channel for Newburyport Harbor. Newburyport Harbor has been maintained by the Federal Government for navigation purposes since the early 1800s. Federal maintenance dredging of the navigation channel is carried out periodically, and the dredged sand is placed by hopper dredge in the nearshore off Plum Island and Salisbury on either side of the inlet.

The project area is located within the inlet, between the south jetty and the channel (see Figure 1 from the Detailed Project Report [DPR]) within the City of Newburyport. It contains beachfront homes, businesses and a state park. At the southern end of the project area, shoreline retreat has exposed and ultimately flanked a rubblemound revetment constructed in 1970 to protect a former Coast Guard Station. The flanking has progressed such that, in aerial imagery, the former revetment now resembles a jetty spur; herein referred to as the South Jetty Spur.

1.2 Coastal Engineering Scope of Work

Coastal analysis and engineering work conducted in support of the FS include an evaluation of coastal climatology at the Site encompassing tidal regime, local wind wave conditions, and relative sea level rise predictions. Results of this coastal climatology analysis were then utilized to develop a preferred beach fill template and estimate its longevity within the placement area. The results of beach fill and longevity analyses will be used to inform the final design. A summary of the analyses is provided in Sections 2 through 4.

2.0 Coastal Climatology and Setting

The North Shore of Boston experiences coastal storms in the form of both tropical and extratropical systems (a.k.a. Nor'easters). Although Newburyport Harbor is protected from storm waves from most directions, the Site is exposed to incident waves form the northeast direction. Physical modeling conducted at the USACE Waterways Experiment Station (WES; Curren and Chatham 1979) showed that waves from the east and southeast directions tend to diffract around the south jetty to reach the site, thereby reducing their intensity. The modeling also showed that waves from the northeast are able to travel between the jetties and reach the Site relatively unobstructed, resulting in large wave heights near the shoreline.

The following sub-sections detail the specific tide and wave conditions typical for the Site.

2.1 Tidal Regime

The project area experiences semi-diurnal tides; two high and two low tides each day. The National Oceanic and Atmospheric Administration (NOAA) provides predicted tide levels for Plum Island, near the Merrimack River entrance (Station 8440452). The mean tide range at the river entrance is 8.00 feet. Table B-1 provides the tidal datums for the Plum Island station.

Table B-1. Plum Island Tidal Datums (NOAA Station 8440452)

Condition	Elevation (feet, MLLW)	Elevation (feet, NAVD88)
Mean Higher High Water (MHHW)	8.70	4.19
Mean High Water (MHW)	8.29	3.78
North American Vertical Datum of 1988[1] (NAVD88)	4.51	-0.22
Mean Sea Level (MSL)	4.29	-4.22
Mean Low Water (MLW)	0.29	-4.51
Mean Lower Low Water (MLLW)	0.00	-4.93

Note: Height of NAVD88 above MLLW computed using the NOAA VDatum tool (https://vdatum.noaa.gov) and the published coordinates for Station 8440452 (Latitude: 42° 49' N, Longitude: 70° 49.2' W).

2.2 Wind Waves

Wind wave conditions were evaluated for the Site by first examining the full record of hindcast wave data at the nearest USACE Wave Information Study (WIS) location (Station 63045). The record covers the period of time from January 1, 1980 through December 31, 2014, and provides hourly hindcast wave parameters including significant wave height, peak period, and direction. The directional distribution of wave heights over the record of the WIS station is provided in Figure B-1. The return-period wave heights at the WIS station are provided in Figure B-2. The full record of data was filtered by direction and the long-term average significant wave height was taken for all waves traveling from the northeastern direction (i.e., 30 to 60 degrees). Similarly, the long-term average peak wave period was also taken for the northeastern direction. An average northeastern significant wave height of 3.5 feet and peak wave period of 7.4 seconds were thus taken as the deepwater wave condition for this study.

The controlling depth at the harbor entrance occurs of the ebb shoal and is approximately 9.4 feet at MLLW (bottom elevation of -14 feet NAVD88; Figure B-3 at the end of this document). Given the location of WIS Station 63045 in approximately 86 meters of water depth, the deepwater wave required a shoaling analysis to understand incident wave conditions at the harbor entrance. The USACE Automated Coastal Engineering System (ACES) was utilized to apply linear wave theory for wave transformation from deep to intermediate water depth. The nearshore slope was assumed to be relatively flat and the incident crest angle was assumed to be zero degrees (i.e., negligible refraction from deepwater). The long-term average northeastern significant wave height at the harbor entrance was thus computed to be 3.8 feet.

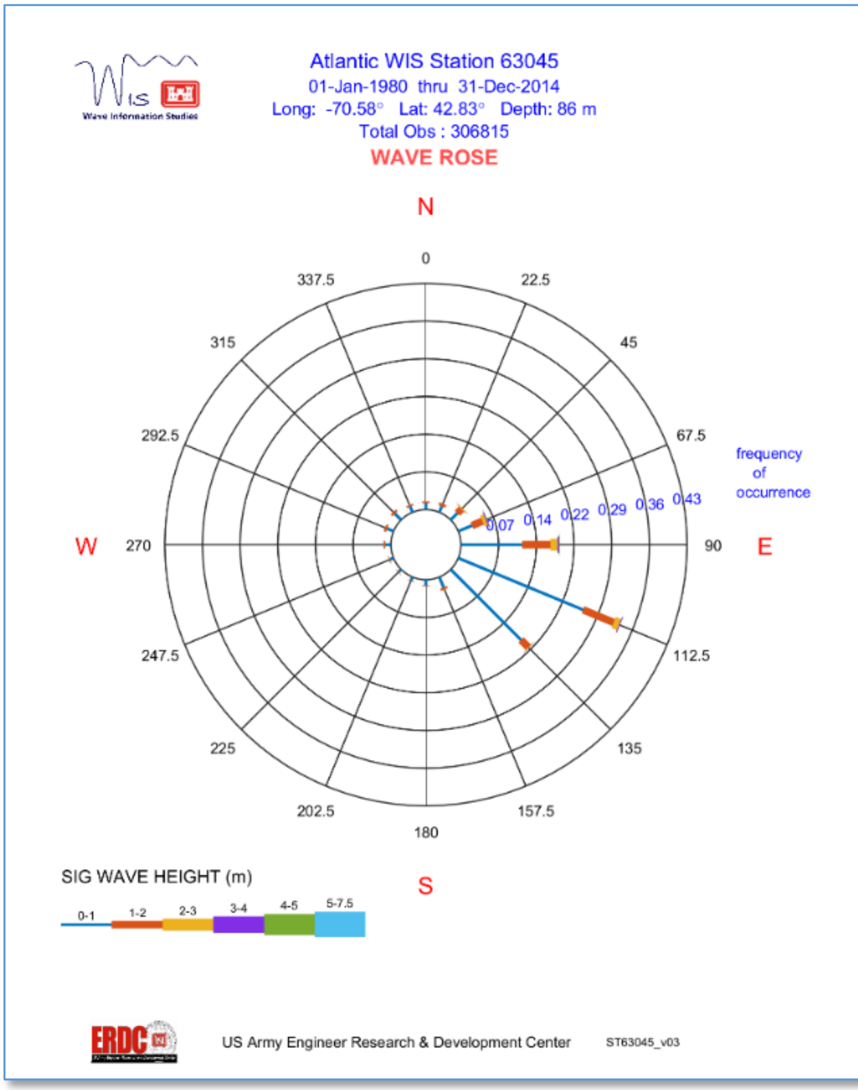
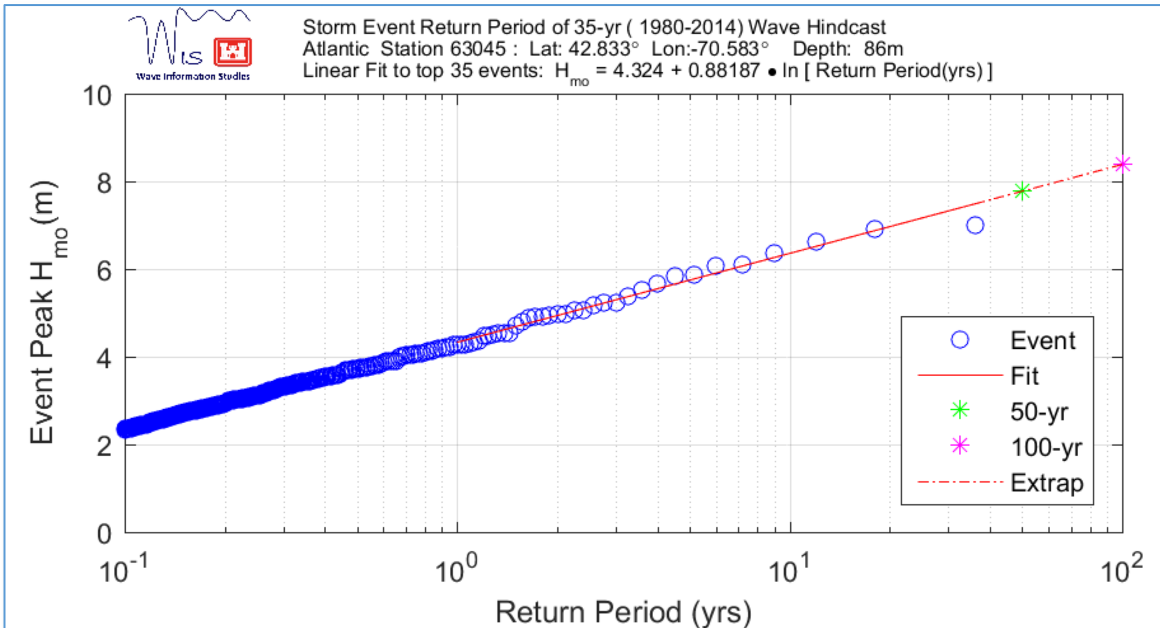


Figure B-1. Hindcast Wave Climate for Wave Information Study (WIS) Station 63045



Top 10 events based on Peak H_{mo}

Event	Date/Time(UTC)	H_{mo}	T_p	θ_{mean}	Event	Date/Time(UTC)	H_{mo}	T_p	θ_{mean}
1	2012/10/30 01:00	7.00	13.15	101.0	6	1992/12/12 08:00	6.08	12.77	93.0
2	2010/02/26 07:00	6.92	12.83	98.0	7	2013/02/09 03:00	5.86	10.81	61.0
3	1991/10/31 05:00	6.61	17.00	86.0	8	2014/12/09 21:00	5.84	11.73	98.0
4	1980/01/16 12:00	6.37	12.79	80.0	9	2007/04/16 15:00	5.66	10.64	98.0
5	2010/03/14 15:00	6.11	12.08	99.0	10	1993/03/14 08:00	5.51	11.17	100.0

An event is defined as any period when H_{mo} > 2.00m θ_{mean} is direction that waves are arriving from

ERDC US Army Engineer Research & Development Center   ST63045_v03

Figure B-2. Hindcast Return Period Analysis for Wave Information Study (WIS) Station 63045

Wave energy entering the inlet is dissipated as waves are diffracted and reflected between the jetties and refracted as they approach North Point (Li et al. 2018). In order to estimate wave conditions incident to the Site, an analysis was undertaken to estimate the effective transmission coefficient between waves outside and inside the harbor entrance. The analysis examined test results from physical modeling of Newburyport Harbor conducted at WES (Curren and Chatham 1979). Reported wave heights from the model gage immediately outside of the harbor (Gage 1) were plotted against wave heights during the same tests from the gage near the inner shoreline, west of the south jetty (Gage 12). Figure B-4 shows the relative location of the model gages. Figure B-5 shows the relative wave heights recorded at each gage. From this analysis, it was determined that wave heights approaching the Site within the Harbor can be estimated to be equal to approximately 0.54 times the wave height outside of the Harbor. The transmission coefficient was applied by multiplying the incident design wave height (3.8 feet) by 0.54. The transmitted long-term average northeastern significant wave height was thus computed to be 2.1 feet.

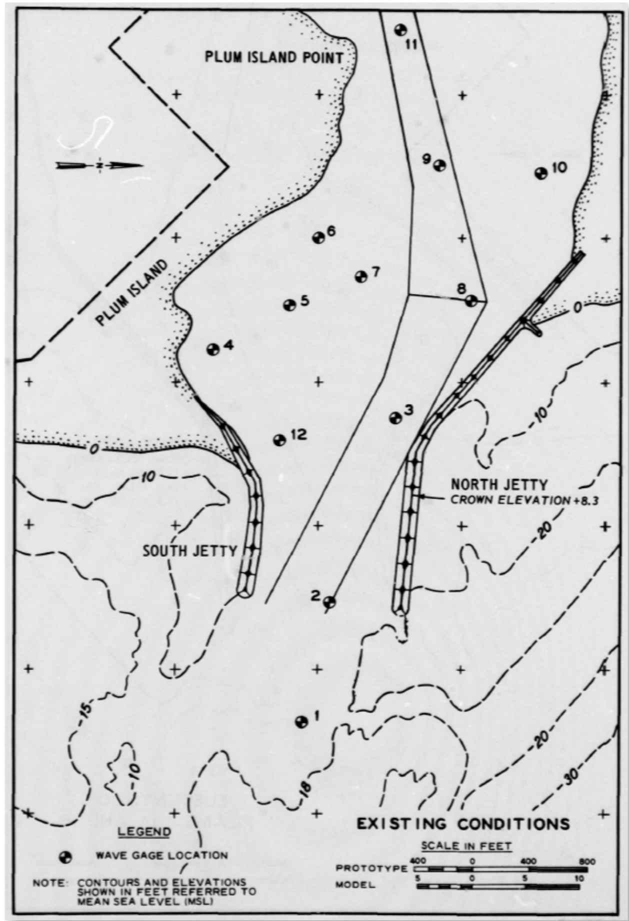


Figure B-4. Existing Conditions and Gages for Physical Model (Curren and Chatham 1979)

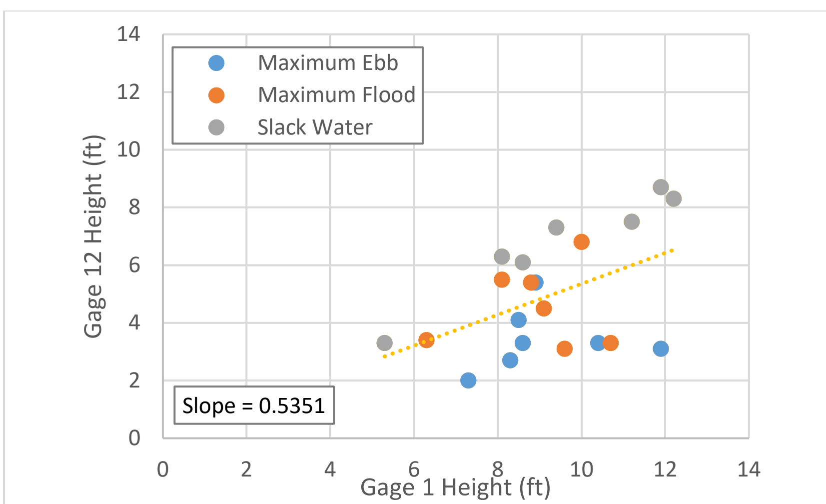


Figure B-5 Predicted Wave Height Comparison between Gage 1 (outside harbor) and Gage 12 (inside harbor) for Northeasterly Waves (Curren and Chatham 1979)

3.0 Beach Fill Design and Longevity

The anticipated volume of suitable material from the federal navigation dredging project is approximately 220,000 cubic yards. In support of its navigation mission, USACE is considering placing 57,000 cubic yards of the dredged material behind the South Jetty Spur to protect the South Jetty from flanking risk. Therefore, dredged material placed on the same beach, but solely to protect the homes at North Point, would account for the remaining 163,000 cubic yards. Considering the two volumes of material would be placed in tandem, this study will evaluate longevity of the fill as one project consisting of 220,000 cubic yards of material.

Beach fill design parameters were selected in order to maximize the longevity of the project for the given placement volume. To support this analysis, site bathymetry and topography data were extracted from 2018 LiDAR collected by the Joint Airborne Bathymetry LiDAR Technical Center of Expertise (JABLTCX) and then locally supplemented with site-specific beach surveys conducted by USACE in February 2020. The beach fill design parameters included project length, equilibrated berm width, berm elevation, and depth of closure.

3.1 Depth of Closure

The depth of closure was calculated based on Hallermeier (1981) and Birkemeier (1985). These methodologies utilize an "effective wave height" defined as

$$H_E = H_m + 5.6\sigma$$

where H_m is the annual mean wave height, and σ is the standard deviation of the annual wave height, both in meters. From Section 2.2, the long-term average northeastern, deepwater significant wave height is 3.5 feet, or 1.08 meters. The standard deviation of the northeastern wave heights at the WIS station is 0.67 meters; therefore, the deepwater effective wave height was determined to be 4.8 meters, or 15.9 feet. In accordance with Hallermeier, depth of closure must be computed with an effective peak period taken to be the "typical period of measured high waves" (Hallermeier 1978). From Figure B-2, the effective wave period for this analysis was assumed to be 12 seconds.

Using an effective wave height of 4.8 meters and effective peak wave period of 12 seconds, depth of closure was computed for three methods from Hallermeier and Birkemeier. These methods are defined as follows:

$$h_c = 2.28H_E - 68.5\left(\frac{H_E^2}{gT_E^2}\right) \qquad \text{(Hallermeier 1978)}$$

$$h_c = 1.75H_E - 57.9\left(\frac{H_E^2}{gT_E^2}\right) \qquad \text{(Birkemeier 1985)}$$

$$h_c = 1.57H_E \qquad \text{(simplified; Birkemeier 1985)}$$

The three depth of closure methods yielded values of 18.3, 14.0, and 13.3 feet. The average of 15.2 feet was used as depth of closure for this study.

3.2 Berm Elevation

The recommended berm elevation was based on average site conditions through examination of beach profile data over surveys from 2018 and 2020. A total of 10 cross-shore transects were established to evaluate site topography and assign appropriate beach fill parameters. Figure B-6 at the end of this document provides a plan view of the Site and the cross-shore transects as well as the 2020 USACE survey points. Station identifiers for these transects were determined using the South Jetty Spur as the starting position (i.e., 0+00). Figure B-7 at the end of this document shows a comparison of beach elevation data at each transect. From examination of the beach profiles, it was determined that a stable berm has not existed at the Site for some time. A final recommended berm elevation of 8.5 feet NAVD88 was recommended based on the 2018 profiles of transects located at the southern extent of the Site (Transects 0+00, 2+83, and 5+39). These first three transects exhibit the clearest example of a stable berm over any of the surveys examined for this study.

3.3 Berm Width and Project Length

Given the recommended berm elevation and estimated depth of closure, Beach Morphology Analysis Package (BMAP) software was utilized to determine the fill placement densities for a range of berm widths between 100 and 500 feet. For this analysis, it was assumed that the dredged material was compatible with the existing beach sand. This allowed the beach fill design to be simplified in that the existing profile could simply be translated seaward by the width of the berm. Although a number of alternatives were considered, the design berm width was ultimately selected as the distance to advance the 8.5 feet NAVD88 contour to the shore-parallel position of the South Jetty Spur (350 feet; see Civil Design Appendix)

The recommended project length was determined by extending the design berm width and elevation along the shoreline until a total placement volume of approximately 220,000 cubic yards was achieved. Additional detail describing this analysis is provided in the Civil Design Appendix. From this analysis, it was determined a berm width of 350 feet over a project length of approximately 875 feet will meet a nourishment volume of approximately 220,000 cubic yards. This volume includes a fill taper of approximately 45 degrees relative to the shoreline to tie-in to the existing beach at the northern extent of the project.

3.4 Beach Fill Longevity

Beach fill longevity was determined as the length of time after which approximately 30% of the fill would be remaining within the original placement footprint via coastal processes (e.g., waves and littoral drift). The computations for beach fill longevity were completed for a theoretical barrier island beach adjacent to an inlet, located downdrift of a littoral barrier (i.e., South Jetty), and experiencing uniform background erosion (Dean 2008; Sections 6.1.4 and 6.2.4). The methods described by Dean utilize the local background erosion rate, median sediment diameter, and incident breaking wave height. From the recent FID, the background erosion rate at the Site was determined to be 53 feet per year by examining the average shoreline recession rate of the 5 and 12 feet NAVD88 contours between 2013 and 2018 (USACE 2019). The median sediment diameter was taken as 1.5 millimeters based on an average of six sediment samples collected from the channel in 2016 (USACE 2016). The breaking wave height was taken as 2.1 feet (Section 2.2). The overall beach fill longevity was determined to be approximately 28 months. Table B-3 provides a summary of the change in remaining volume in time for the recommended fill template. Figure B-8 at the end of this document provides a plan view of the construction footprint of the design berm and the estimated position of the 8.5 feet NAVD88 contour in the first 3 years following placement.

Table B-3. Predicted Fill Material Remaining within Project Footprint

Months after Construction	Percent of Fill Remaining in Placement Footprint
6	75
12	60
18	48
24	36
30	26
36	16

4.0 Sea Level Change

The USACE Sea Level Change Curve Calculator (Version 2019.21) was used to predict three local relative sea level change (SLC) scenarios in accordance with ER 1100-2-8162 (USACE 2013). The purpose of the ER is to incorporate relative sea level changes into the project alternatives and design. The three SLC scenarios are illustrated by curves representing the low (historic) rate of SLC at the project area, an intermediate rate (modified NRC Curve I), and a high rate of SLC (modified NRC Curve III).

The historic rate of SLC was taken from the NOAA gage in Boston (Station 8443970) – the nearest long-term gage to the project site. The historic mean sea level trend at Boston from 1921 to 2018, which was used for this evaluation, is 2.83 millimeters per year or 0.93 feet per century. Projections for each SLC scenario are provided in Figure B-9 to the year 2050. Projections are provided relative to 1992 Mean Sea Level because that year represents the middle of the present tidal epoch (1983-2001).

A ten year period of analysis from 2021-2030 was used to assess the economic benefits of the proposed nourishment. From Figure B-9, the relative increases in sea level from 2021 to 2030 for the low, intermediate, and high rates of SLC are 0.08, 0.14, and 0.31 feet, respectively. These relative projections of SLC are assumed to have negligible impact on the project performance.

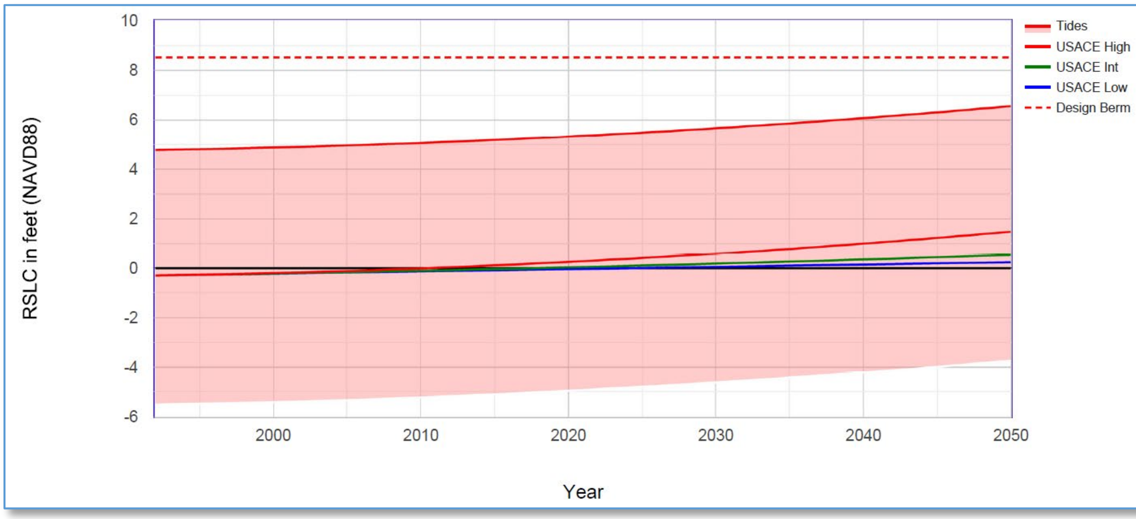


Figure B-9. Sea Level Change Projections for North Point (USACE 2019)

5.0 Summary and Conclusions

The Water Management Section's coastal assessment reviewed available water level and wave data and recommended beach fill parameters to be used for the formulation and design of plan alternatives and as input to the economic analysis for the Tentatively Selected Plan. The final recommended beach fill template consisted of a 350-foot wide placement berm at an elevation of 8.5 feet NAVD88. The full-width project length to utilize 220,000 cubic yards is approximately 875 feet.

6.0 References

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