C. EXISTING ENVIRONMENT

1.0 Existing Environment

1.1 Tides, Storm Surge and Sea Level Rise

Tides along the Marshfield and Duxbury coastline are semi diurnal, with two high and two low tides of about the same height each day. The mean tide range is approximately 9.1 ft. Specific tidal datums for the open coast of Marshfield and Duxbury are presented in Table C-1. Also shown in Table 1 are key storm surge elevations for this stretch of shoreline. The tidal datum elevations were obtained from NOAA (2020a) and surge elevations for the 10-, 50-, and 100-yr return period storms were obtained from the Federal Emergency Management Agency's (FEMA) Flood Insurance Study (2016).

Table C-1. Tidal Datums and Storm Surge Elevations for the Marshfield and Duxbury Shoreline.

Tidal Datum or Flood Condition	Elevation (ft, NAVD88)
Tidal Flood 100-Year Return	9.50
Tidal Flood 50-Year Return	9.10
Tidal Flood 10-Year Return	8.30
High Tide Line (HTL)	6.50
Mean Higher High Water (MHHW)	4.52
Mean High Water (MHW)	4.08
NAVD88	0.00
Mean Low Water (MLW)	-5.00
Mean Lower Low Water (MLLW)	-5.35

Moving into the 21st century and beyond, it is likely that other long-term processes such as sea level rise will have a significant effect on evolution of the coastlines in the Towns of Marshfield and Duxbury. Long-term measurements in Boston Harbor show that relative sea level, or the elevation of the sea with respect to the land, has been rising at an average of 2.83 mm per year, or 0.93 feet per century (Figure C-1).

The Intergovernmental Panel on Climate Change (IPCC) has spent considerable time and energy reviewing and analyzing the current state of knowledge of past and future changes in sea level in relation to climate change. Taking this information, the United States Army Corps of Engineers (USACE) developed guidance for incorporating sea-level change considerations in civil works programs (USACE, 2009, 2011). Using this information, a sea level rise scenario of 2.0 ft projected to occur in 2070 was used during resiliency planning for the Marshfield and Duxbury shorelines. This long-range planning is applicable when considering the effects of sea level rise on coastal engineering structures, such as seawalls and revetment, as these structures typically have a 50-yr design life. However, non-structural projects, such as beach and/or dune nourishment, typically have a much shorter design life (i.e., 5 to 10 years). For these types of projects, the effects of sea level rise are not typically considered during the design process.

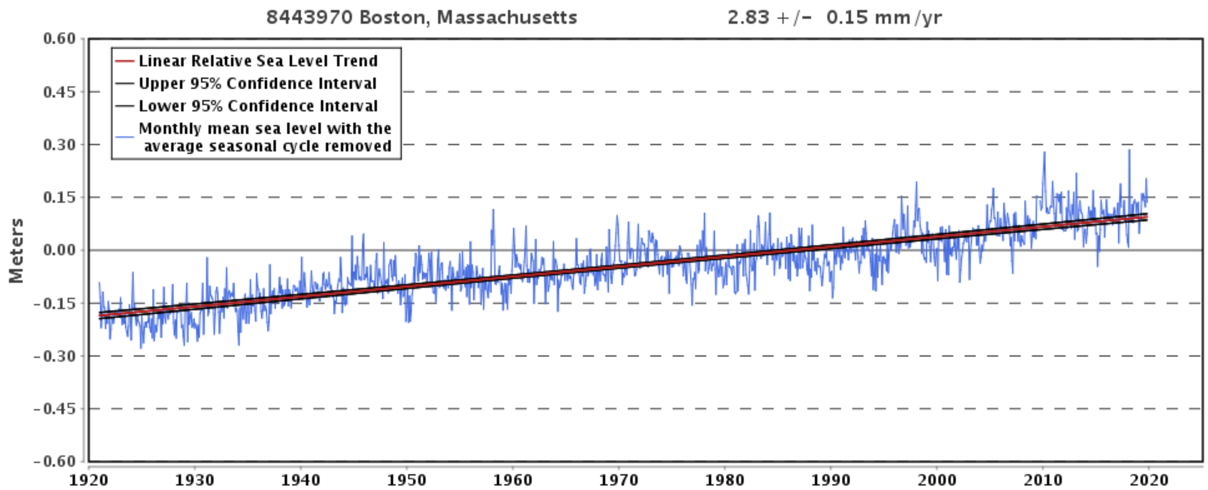


Figure C-1. Long-term mean sea level data for NOAA's Boston Harbor tide gage (NOAA, 2020b).

1.2. Bathymetry

A detailed bathymetric survey of the seafloor offshore of Marshfield and northern Duxbury was performed by the Woods Hole Group on November 7 and December 7, 2019. The Town of Marshfield Harbormaster's office supplied the survey vessel and boat captain. The survey area covered approximately 28,550 ft (8.7 km) in the longshore direction and extended offshore approximately 3,280 ft (1 km) from water depths of 9.8 to 40 ft NAVD88. Survey transects were spaced at 100-ft intervals.

The survey vessel was conducted using the Town of Marshfield's 31 ft SAFE boat equipped with an over-the side transducer mount and a power supply for survey electronics. A Trimble R8 RTK GPS with HYPACK 2019 survey software was used for navigation. Soundings were taken with a Teledyne Odom Echosounder single beam precision echosounder with a 200 kHz 8-degree transducer. Data were recorded by HYPACK acquisition software as time-stamped ASCII text values embedded with RTK position/tide data. The depth sounder incorporated transducer draft corrections, calibration for speed of sound through water and gain control. During post-processing of data, the soundings were referenced to the vertical geodetic datum NAVD88.

Data collected during the survey is presented in Figure C-2. Shallow areas are signified by blues and greens, whereas deeper areas are signified by oranges and reds. Notable features from this survey include nearshore bars with gradual slopes in the Rexhame Beach area and along the entire beach south of Green Harbor. Shallower water depths are also present directly offshore of Brant Rock. A deeper shore parallel trough, defined by the -40 ft NAVD88 contour, is located offshore of the Winslow Ave., Sunrise, and Fieldston Beaches. An area of deeper offshore bathymetry also exists offshore of the beaches at the southern end of the project area.

Bathymetric data shown in Figure C-2 will be combined with beach profile data collected as part of the 2019 CZM grant funded project (see Section 1.3), as well as publicly available data from the US Geological Survey (USGS) CoNED Topobathymetric Model (USGS, 2016).

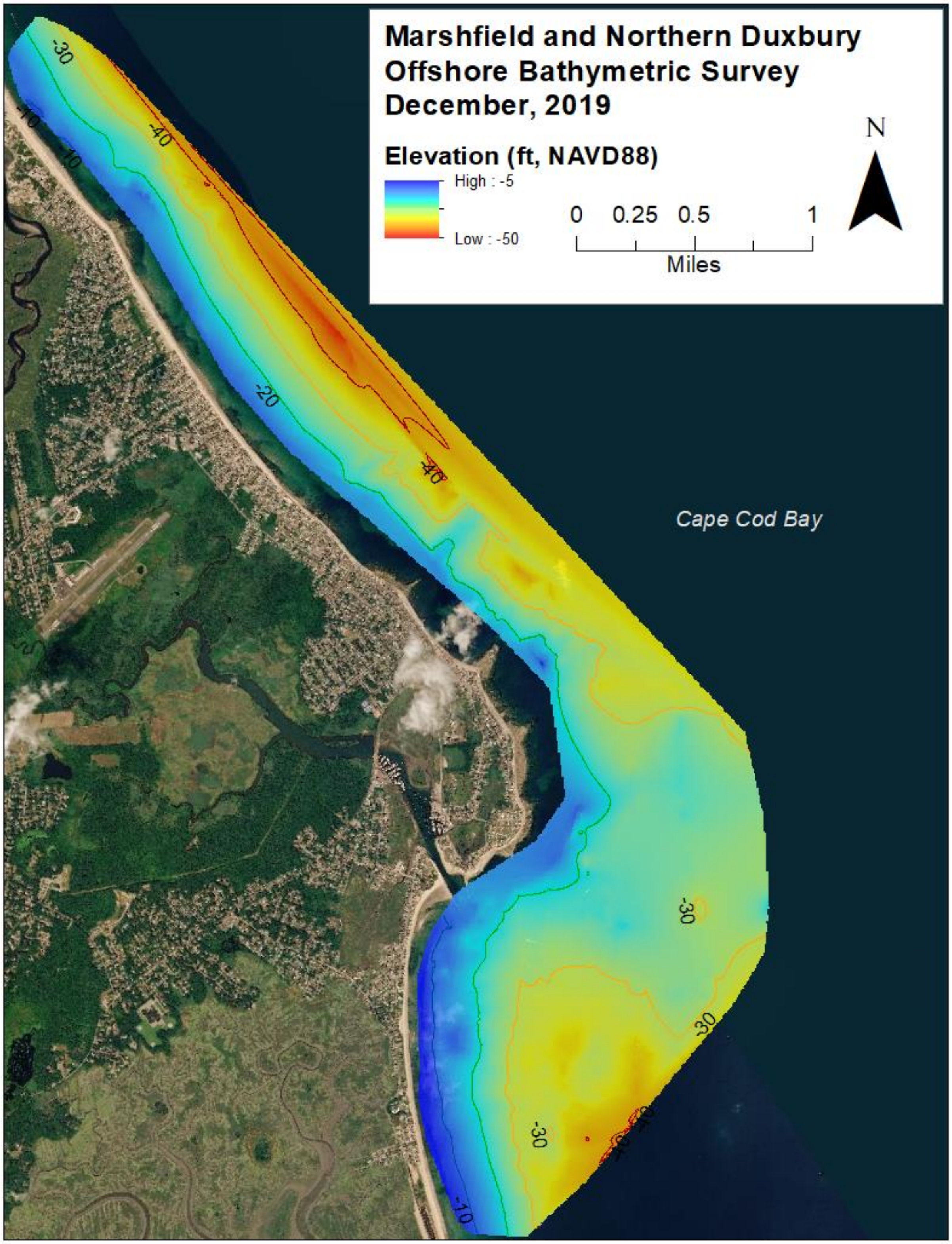


Figure C-2. Bathymetric survey data collected for the study area offshore of Marshfield and northern Duxbury in November and December 2019.

1.3. Beach Topography

The topography of the beaches along the Marshfield and northern Duxbury shorelines was surveyed by the Town of Marshfield and the Woods Hole Group. A total of twenty-three (23) shore normal transects were surveyed at the locations shown in Figure C-3. The Town of Marshfield collected data at transects 8 through 17 in October 2019, and the Woods Hole Group collected data at transects 1 through 7 and 18 through 23 in November 2019. Data were collected along each transect using an RTK GPS, starting at the landward end behind the coastal dunes or engineering structures, and extending seaward to wading depth. The surveys were conducted during the period three (3) hours before and after low tide, and most of the surveys extended to MLW, or beyond. Horizontal coordinates were referenced to the Massachusetts Mainland State Plane Coordinate System, NAD 83 ft, and elevations were referenced to the vertical data NAVD88 ft. Transect data for the Brant Rock area were derived from a 2010 topographic LiDAR and bathymetric data set developed by the US Army Corps of Engineers.

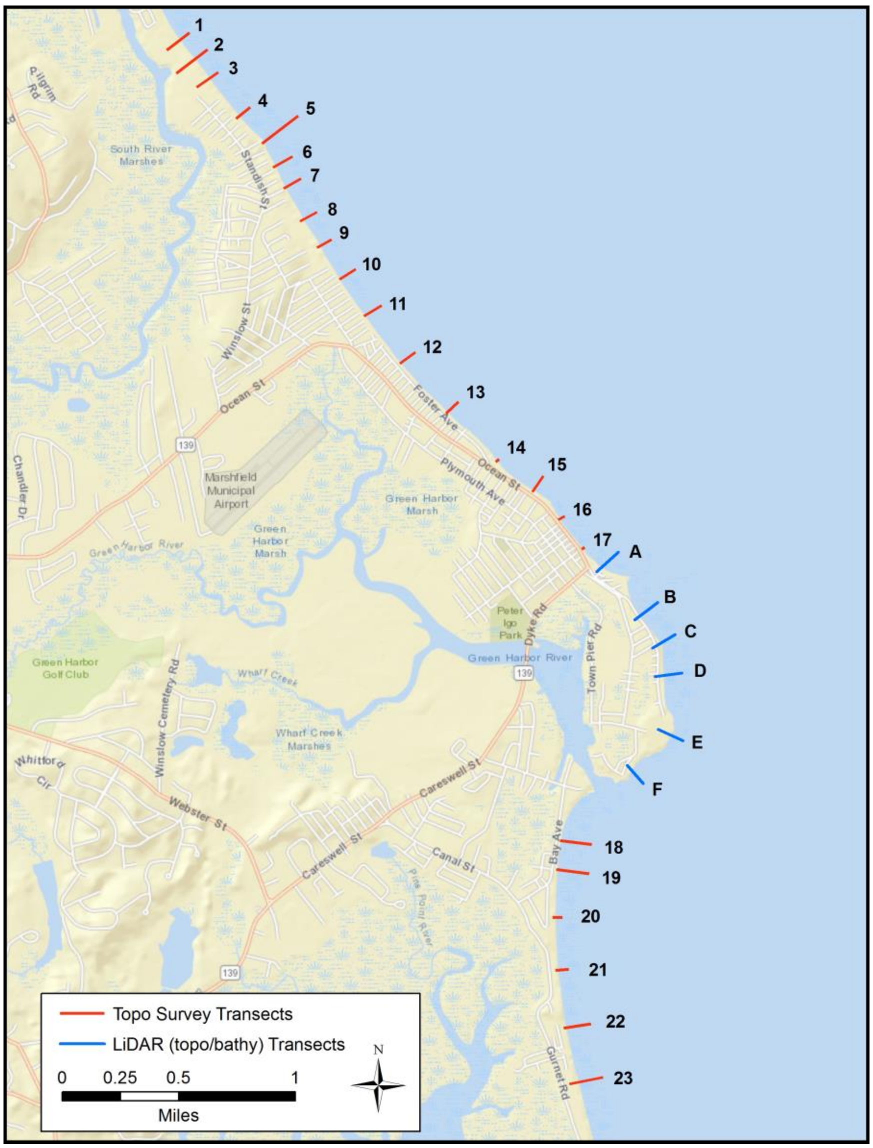


Figure C-3. Locations of topographic survey transects.

Most of the beaches along the northern part of Marshfield are backed by seawalls and/or revetments (Figure C-4). The only exceptions to this are sections of Rexhame Beach (Transects 1-3) and the Winslow Avenue beaches (Transects 8-9) that have naturally occurring dunes and no shore protection structures. The Rexhame Beach dunes are sandy features that extend to the banks of the South River on the western side of the barrier beach. The primary dune is approximately 125 ft wide and reaches a maximum elevation of 27 ft NAVD88 (Figure C-5a). Dunes at the Winslow Avenue beaches are generally low-lying features composed of cobble. The dunes are 140 to 200 ft wide and reach a maximum elevation of 15 ft NAVD88 (Figure C-5b). All of the other beaches north of Brant Rock are backed by seawalls and/or revetments (Figure C-6a-d). Crest elevations of the coastal engineering structures range from 16.0 to 26.6 ft NAVD88, and generally increase from north to south. In most locations, the beach elevations in front of the structures are significantly lower than the crest, leaving the face of the structures exposed to elevated water levels and waves during storms.

The average width of the high tide beach (between MHW and the toe of the dune or shore protection structure) in the Rexhame area is 150 ft (Figure C-4). A distinct narrowing of the high tide beach occurs south of Jackson Street (Transect 5) where a submerged ledge extends seaward from the beach. South of this point the high tide beach gradually narrows to less than 50 ft wide. In some locations in the Ocean Bluff area high tide extends to the shore protection structures, and there is virtually no high tide beach. The intertidal beach (between MHW and MLW) in the Rexhame area ranges between 100 and 150 ft. Beaches further to the south have extensive intertidal flats, with widths between 200 and 350 ft. Intertidal beaches between Ocean Bluff and Brant Rock are significantly narrower as the beach topography slopes steeply towards the east.

Most of the beaches in the project area south of Green Harbor are also backed by seawalls (Figure C-7). The only exceptions occur along the 650 ft long stretch of beach immediately south of Green Harbor (north of Transect 18), and a 350 ft stretch of beach at the end of Bay Road in the Town of Duxbury (south of Transect 20). The area closest to Green Harbor is characterized by wide coastal dune, beach and intertidal resources that are protected and anchored by the southern jetty at the harbor (Figure C-8a). The area at the end of Bay Ave contains a sandy dune approximately 100 ft wide that is fronted by a gently sloping coastal beach. All other sections of the beach are anchored by seawalls and/or revetments. Crest elevations of the walls are generally lower to the south of Green Harbor, ranging from 7.7 to 16.0 ft NAVD88 (Figure C-8b-8d). Lower beach elevations immediately in front of the structures leave 5 to 10 ft of the structures exposed to elevated water levels and waves during storms.

The average width of the high tide beach is less than 50 ft between Transects 18 and 22 (Figure C-7). Further to the south on the Duxbury Beach Reservation property (Transect 23) the high tide beach increases to over 100 ft wide. The intertidal beach along this stretch of the project area is relatively wide, ranging from 185 to 280 ft.

Beach profile data for all transects surveyed are shown on the engineering plans dated XXX, 2020.

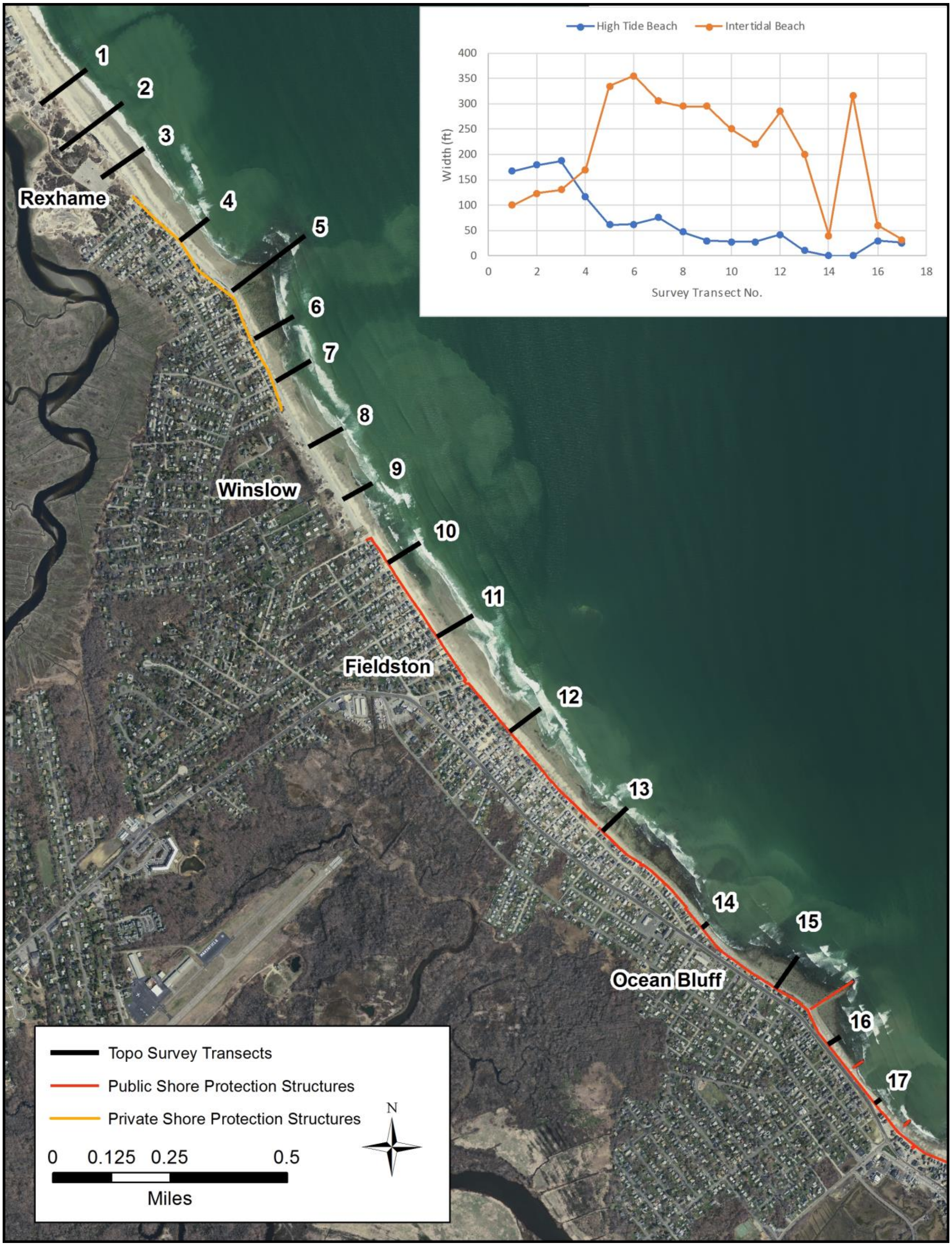


Figure C-4. Survey transects north of Brant Rock showing existing shore protection structures and widths of high tide and intertidal beaches.

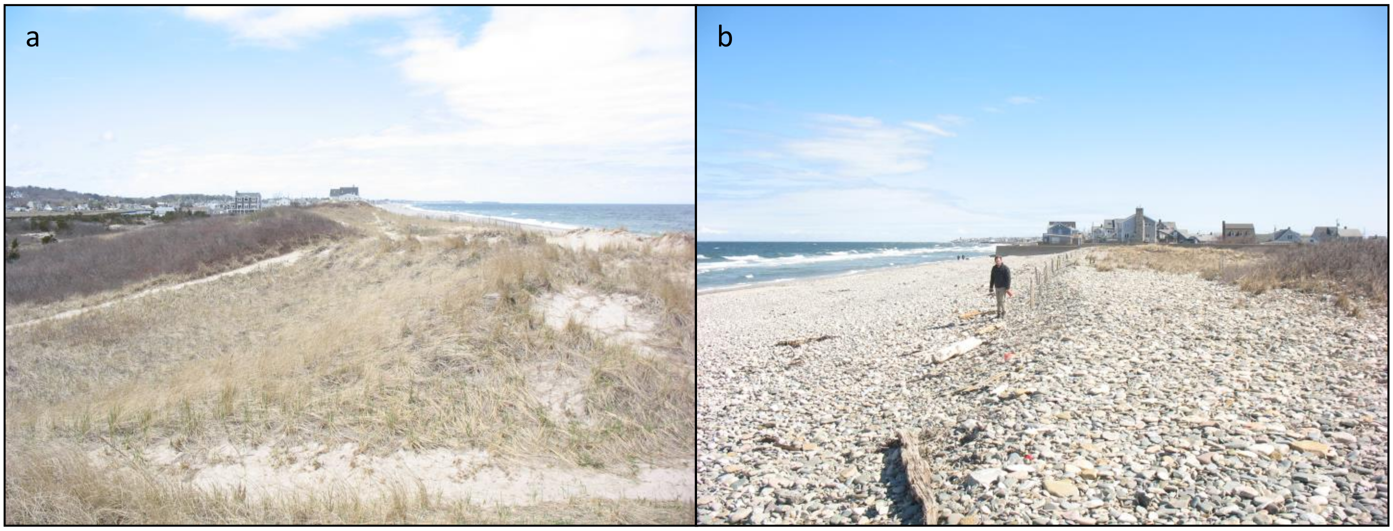


Figure C-5. Photos of primary coastal dune at Rexhame Beach (a) and cobble dune at Winslow Avenue beach (b).

Figure C-6. Photos of coastal engineering structures and coastal beach at Rexhame (a), Fieldston (b), Sunrise (c) and Ocean Bluff (d).

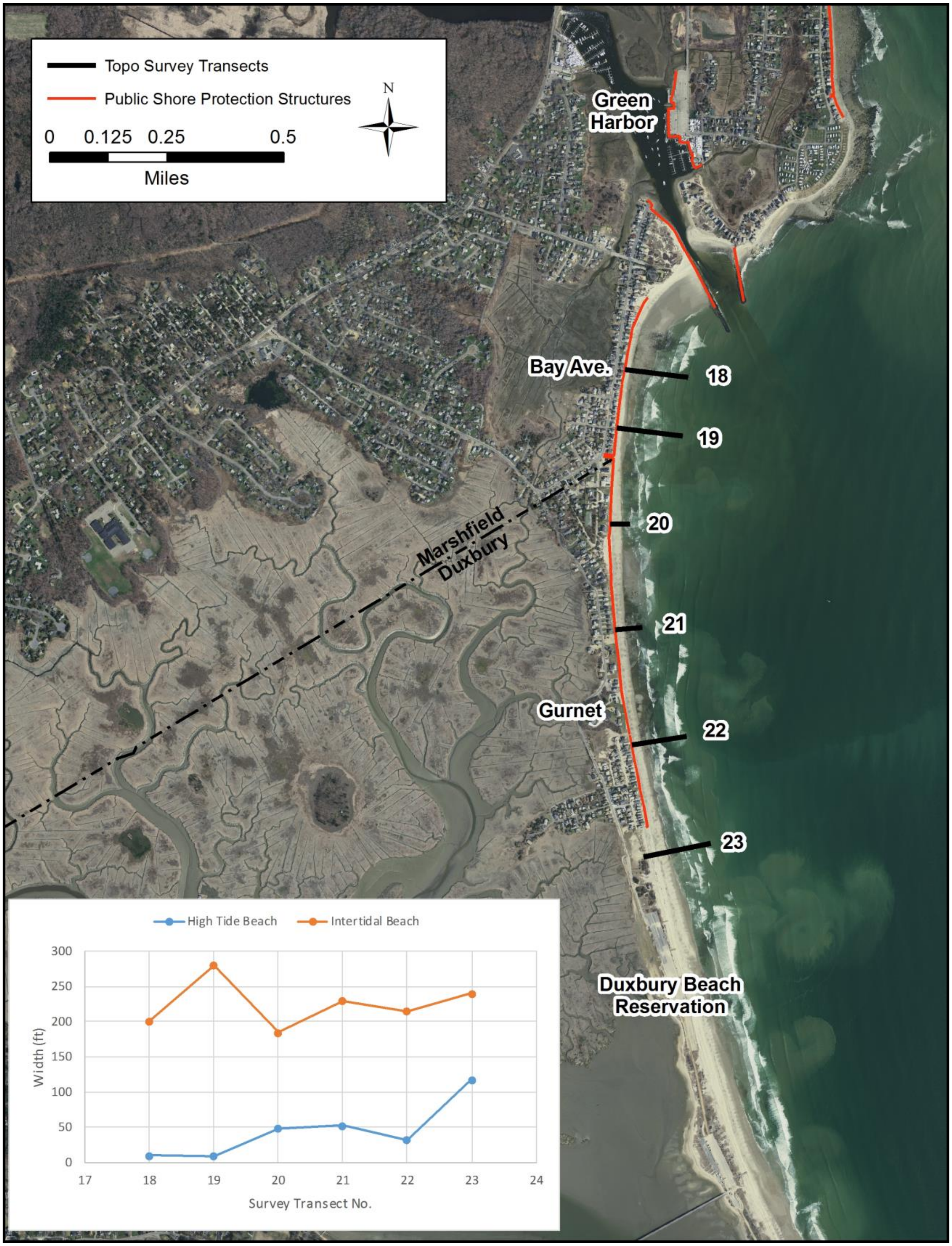


Figure C-7. Survey transects south of Green Harbor showing existing shore protection structures and widths of high tide and intertidal beaches.

Figure C-8. Photos of dune and beach south of Green Harbor (a), and coastal engineering structures and coastal beach along Bay Ave. (b-c), and along Gurnet Rd. in Duxbury (d).

1.4 Sediments

Information on sediment characteristics along the Marshfield and northern Duxbury coastline was obtained from a series of twenty-three (23) sediment samples collected throughout the project area. In addition, sediment data from previous work on the Marshfield Beach Management Plan (WHG, 2018) and a 2017 CZM funded grant project looking at beneficial reuse of dredged materials from Green Harbor were reviewed and summarized to gain a better understanding of changes in sediment characteristics over time. Figure C-9 shows the locations of the sediment samples from the three (3) studies. Larger scale maps showing sample IDs and locations for the northern, middle, and southern sections of the project area provided in Figures C-10, C-11, and C-12.

Sediment samples collected in Dec. 2019 were a combination of surface grabs and larger volume samples (i.e., 15 gallons). The larger volume samples were collected in areas were the beach was composed of a mixed grain size ranging from cobble down to fine-grained sand. By collecting a larger sample volume, it was possible to include the cobbles and coarser-grained material in the sample, and therefore develop a more representative grain size distribution for the beach. A total of six (6) large volume samples were collected, and at each location, a standard grab sample was also collected. By having co-located samples from the large volume and the standard grabs, it was possible to develop a grain size envelope that characterized the range of sediment sizes on the beach. In addition to the co-located samples (large volume and standard grabs), another eleven (11) standard grab samples were collected to characterize the sandier portions of the beach. To define cross-shore changes in sediment composition, samples were collected from the dunes (where present), MHW line and the mean tide line.

Sediment samples from the previous studies consisted of standard surface grabs collected from the mean tide line. Specific sampling locations were selected in the field to be representative of the average grain size condition at each sampling location. The only exception was the Green Harbor Channel sample, which was collected as a grab sample from a dredged material stockpile located on the north side of Green Harbor. This sample was collected to characterize the sediments dredged annually from the navigation channel at Green Harbor.

The sediment data provide insight on the local wave energy along the beach. For example, areas that have a higher percentage of coarse grain material (gravel or cobble) are more likely to experience higher wave energy conditions during storms. Table C-2 provides summary statistics for the project area beaches and dunes based on sediment samples collected between Aug. 2017 and Dec. 2019.

In general, the beaches are composed of a mixture of gravel and sand. Percentages of gravel range from 0.0 to 93%, and for sand the percentages range from 3.0 to 99.8% (Table C-2). The average D_{50} of the surface grab samples is 2.64 mm (granule); however, when the large volume samples are considered, the D_{50} increases to 5.88 mm (pebble). The average D_{50} for the dune sediments is 0.35 mm (medium sand). Laboratory results for the Dec. 2019 samples are provided in Appendix X.

Temporal changes in beach composition have been reported by Town of Marshfield and Duxbury staff, and by Woods Hole Group scientists; however, they are not necessarily represented in the data presented herein. Observations indicate that winter storms tend to remove sand from the high tide beach and portions of the intertidal flats, leaving the coarser grained cobble and gravel behind. Sandier sediments are then restored to portions of the beach during the calmer weather summer and fall seasons.

Table C-2. Summary Grain Size Statistics for Project Area Beaches.

Sample ID	D_{50} (mm)	% Cobble	% Gravel	% Sand	% Silt & Clay
01-DU-SAN	0.35	0	0.0	99.8	0.2
02-MTL-SAN	8.70	0	83.0	16.9	0.1
02-MTL-COB	14.40	4	93.0	3.0	0.0
03-MHW-SAN	0.55	0	1.0	98.9	0.1
04-MTL-SAN	7.50	0	71.0	28.9	0.1
05-MHW-SAN	0.50	0	20.0	79.9	0.1
06-MTL-SAN	0.53	0	37.0	62.6	0.4
07-DU-SAN	0.30	0	0.0	99.9	0.1
08-MTL-SAN	6.9	0	77.0	22.9	0.1
08-MTL-COB	19.0	4	90.0	6.0	0.0
09-MTL-SAN	1.14	0	41.0	58.8	0.2
10-MTL-SAN	4.00	0	70.0	29.8	0.2
10-MTL-COB	11.4	11	82.0	7.0	0.0
11-MTL-SAN	5.7	0	65.0	34.7	0.3
12-MTL-SAN	0.25	0	2.0	97.3	0.7
12-MTL-COB	32.00	34	53.0	13.0	0.0
13-MTL-SAN	5.90	0	78.0	21.9	0.1
14-MTL-COB	13.40	4	68.0	28.0	0.0
14-MTL-SAN	0.34	0	22.0	77.9	0.1
15-MTL-SAN	1.76	0	36.0	63.9	0.1
16-MTL-COB	13.10	10	89.0	1.0	0.0
16-MTL-SAN	1.75	0	40.0	59.9	0.1
17-MTL-SAN	0.23	0	0.0	99.9	0.1
Rexhame Beach	0.32	0	0.0	99.8	0.2
Sunrise/Fieldston	0.37	0	5.4	93.9	0.7
9th Street	3.36	0	44.0	55.4	0.6
Brant Rock	0.42	0	7.0	92.5	0.5
Green Harbor	0.37	0	5.1	94.2	0.7
Pearl Street	4.87	0	50.8	48.9	0.3

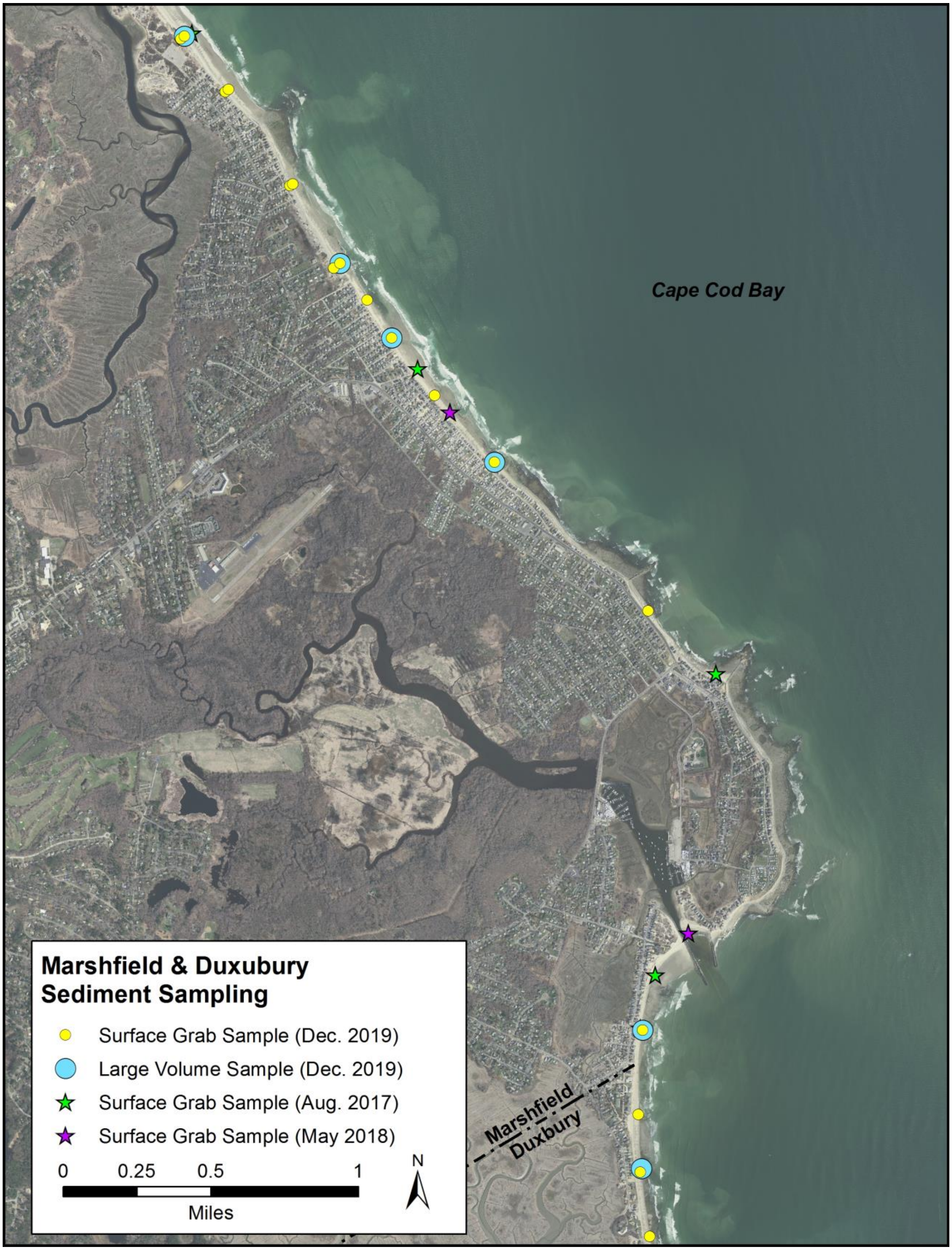


Figure C-9. Sediment samples collected along the Marshfield and northern Duxbury beaches between Aug. 2017 and Dec. 2019.

Figure C-10. Sediment samples collected along the northern beach of Marshfield between Aug. 2017 and Jan. 2019.

Figure C-11. Sediment samples collected along the central beaches of Marshfield between Aug. 2017 and Jan. 2019.

Figure C-12. Sediment samples collected along the beaches of southern Marshfield and northern Duxbury between Aug. 2017 and Jan. 2019.

1.5 Shoreline Change

Information on historical shoreline change along the project area coastline was obtained from the Massachusetts Shoreline Change Project (MSCP), 2018 Update (Himmelstoss, et. al., 2019). The MSCP compiled relative positions of shorelines between 1844 and 2014 for all seaward facing coastal areas within the Commonwealth of Massachusetts. The MSCP included shoreline positions in the Marshfield and Duxbury study area for the following years: 1848/1858, 1951/1952, 1978, 1994, 2000, 2001, 2008, 2011 and 2014.

Both long- and short-term rates of shoreline change were determined by fitting a least squares regression line to the shoreline positions measured at a series of shore normal transects. Long-term rates were computed using all nine (9) shorelines between 1948/1858 and 2014 (Figure C-13), while the short-term rates were computed using the seven (7) shorelines between 1978 and 2014 (Figure 14). The slopes of the regression lines at each transect are the rates of shoreline change. Negative values indicate erosion and positive values indicate accretion, with rates of change shown in ft/yr. Figure C-15 shows the error bars associated with the short-term rates of change.

The long-term rates of change shown in Figure C-13 indicate areas of erosion less than 2 ft/yr in the Rexhame, Winslow Ave., and Fieldston Beach areas. Erosion is also indicated in South Brant Rock, Bay Ave, and along the southern end of Gurnet Rd. Beaches. Areas between Sunrise Beach and Brant Rock show accretion at rates of 2 ft/yr and less.

The short-term rates of change shown in Figures C-14 and C-15 are more indicative of existing conditions since they cover the time period after most of the seawalls and revetments were installed. The short-term data generally indicate accretion less than 2 ft/yr at the northern and southern ends of the project area (Rexhame and Gurnet Rd Beaches). Most shoreline areas in between indicate erosion at rates between 0 and 2 ft/yr. The error bars for the short-term rates of change shown in Figure C-15 suggest significant uncertainty with the rates of change at the northern end of the project area between Rexhame Public Beach and Fieldston Beach. Moving south, there is a clear trend of erosion at Sunrise Beach, Ocean Bluff and the Brant Rock areas. Between Brant Rock and Green Harbor the rates of change and associated errors are relatively small, suggesting a relatively stable shoreline with little erosion or accretion. South of Green Harbor, rates of erosion are greatest in the Bay Ave Beach area, and gradually decrease towards the south along Gurnet Rd. Beaches beyond the study area on the Duxbury Beach Reservation property show a trend of accretion over the short-term.

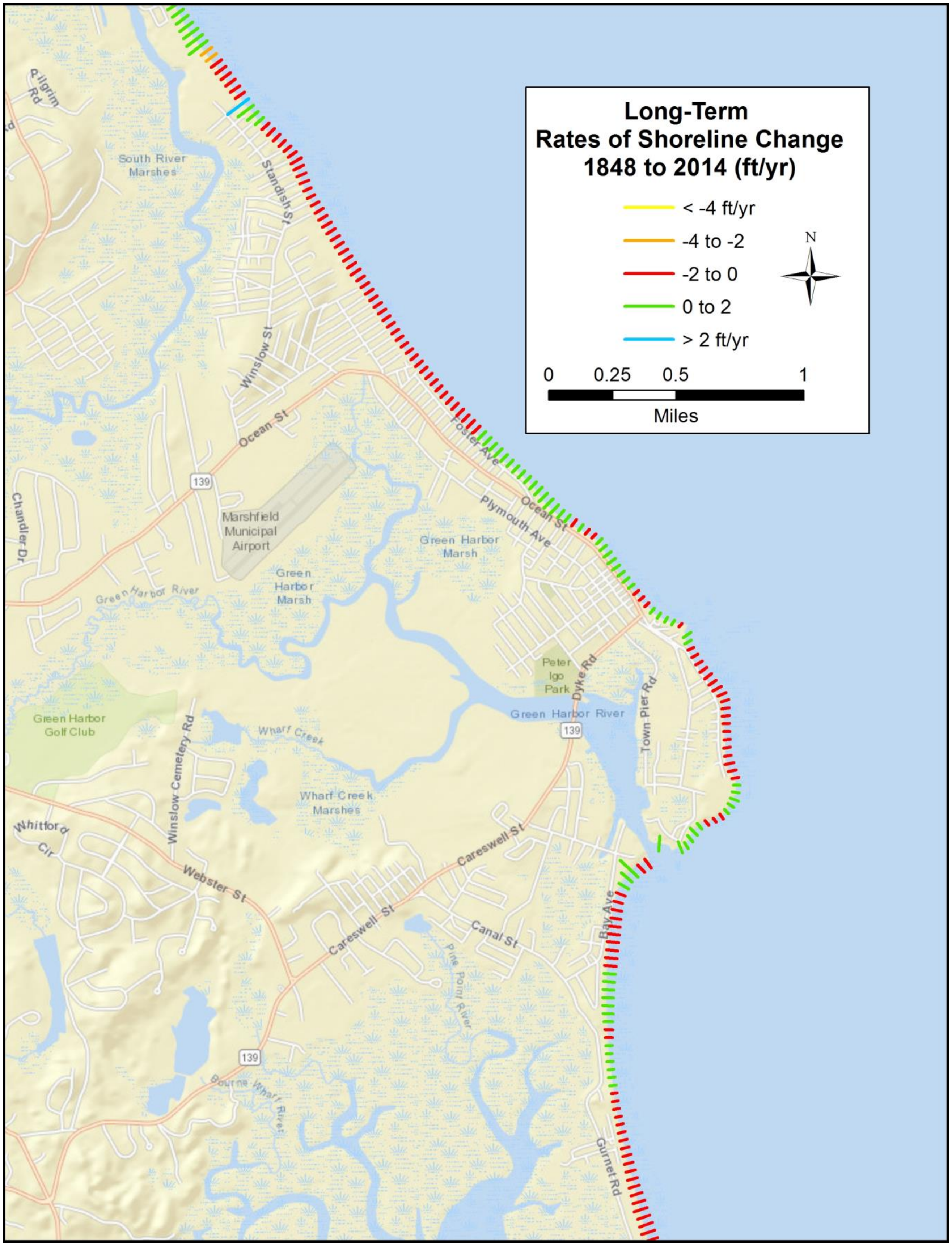


Figure C-13. Long-term linear regression rates of shoreline change for the project area.

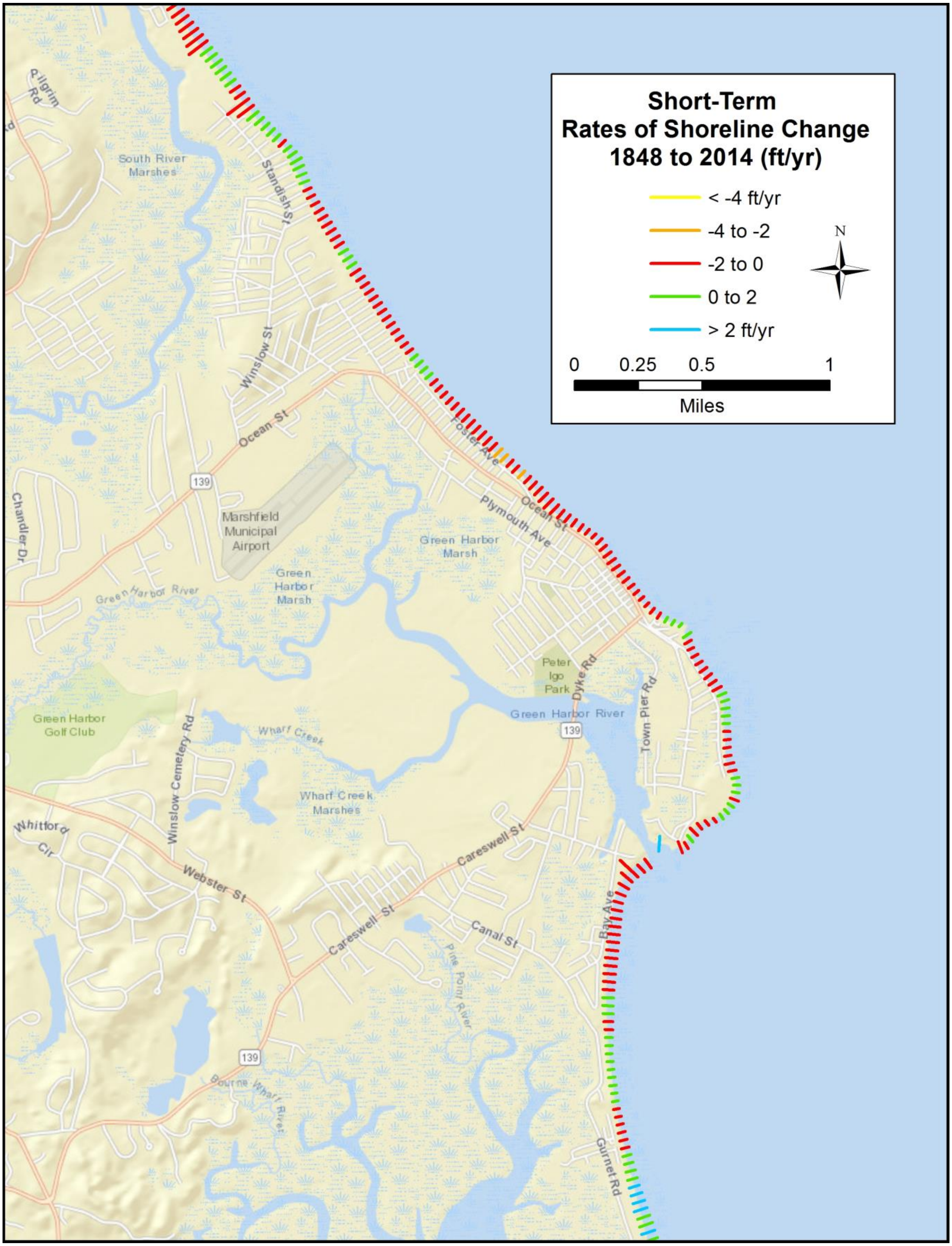


Figure C-14. Short-term linear regression rates of shoreline change for the project area.

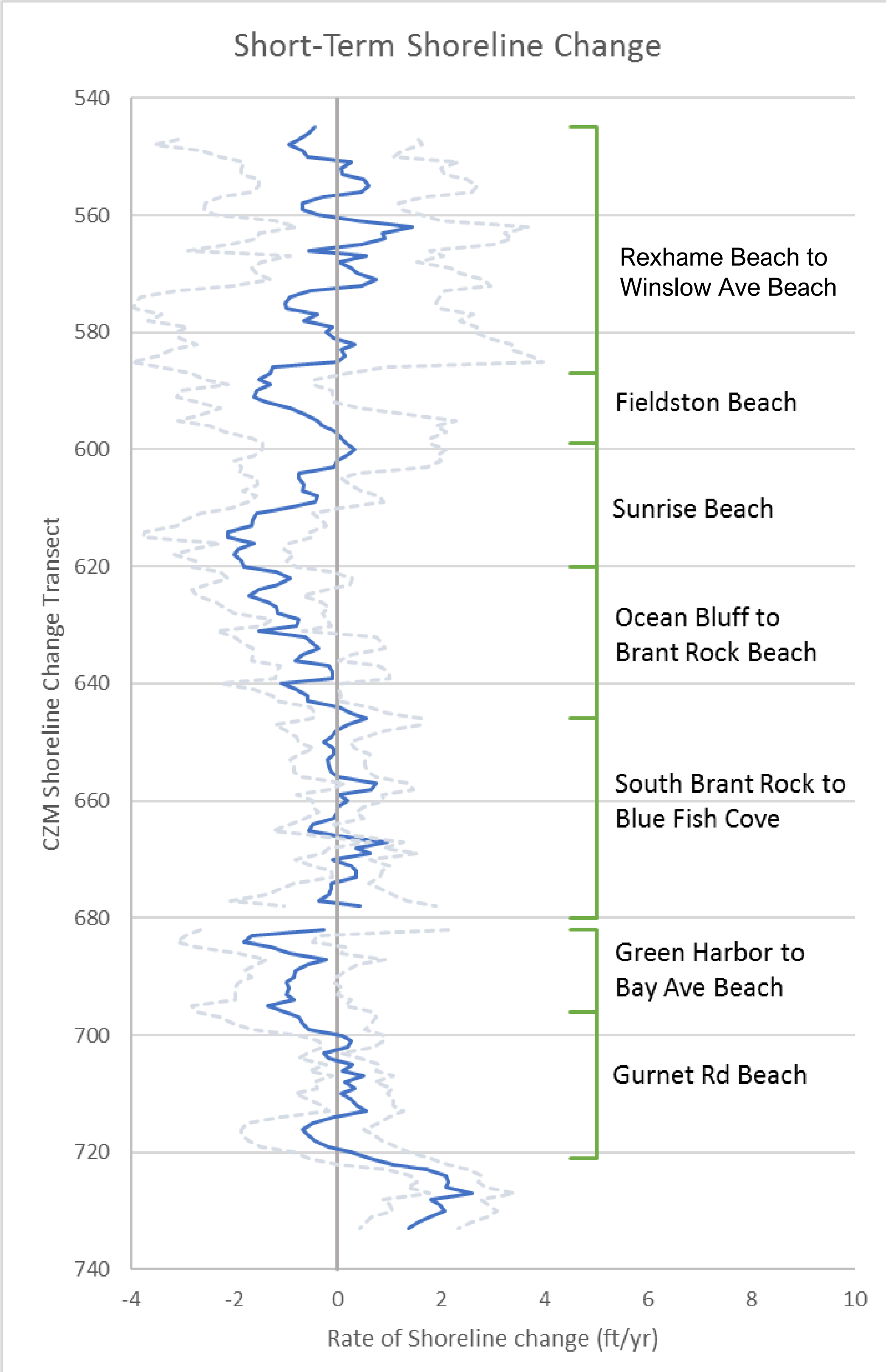


Figure C-15. Long-term linear regression rates of change with 90% confidence intervals as a function of distance from north to south along the Marshfield coastline.

In many places along the project coastline, the ability of the shoreline to retreat has been impacted by the construction of seawalls and revetments. Prior to this time the shoreline was able to retreat, but once the hard structures were encountered, continued landward migration was halted. Currently, locations where MHW is at the seawall, thereby inhibiting further landward horizontal erosion, include Fieldston and Sunrise Beaches, Ocean Bluff and Hewitt’s Point Beaches, the Brant Rock area, and beaches along Bay Ave and Gurnet Rd. In these locations, there has been vertical lowering of the beach face as storm waves interact with the seawalls and sediment is pulled offshore.

Figures C-16 through C-19 show longitudinal profiles of the beach elevation (north to south) at distances of 75 and 175 ft seaward of the coastal dunes (where present) or shore protection structures. Figures C-16 and C-17 include the Marshfield shoreline north of Green Harbor, and Figures C-18 and C-19 include the Marshfield and Duxbury shorelines south of Green Harbor. The beach elevations were derived from publicly available LiDAR data collected between 2000 and 2014.

The data show a significant lowering of the high tide beach for sections of the shoreline with hardened shore protection structures (Figure C-16). The beach elevation drops 10 to 12 ft between Rexhame Public Beach and the Ocean Bluff area. Changes in beach elevation are less pronounced along the low tide beach; however, the data indicate a clear lowering of the beach elevation between 2000 and 2010/2014 for the shoreline between Winslow Ave and Sunrise Beach (Figure C-17). To the south of Green Harbor, both the high and low tide beach elevations are lowest in the Bay Ave. Beach area, which is armored with hard shore protection structures (Figures C-18-C-19).

While the beach lowering in areas of the shoreline with shore protection structures is not reflected in the shoreline change data it, continues to have a negative impact on the beach resource. The associated loss of beach volume impacts nearshore wave dynamics, as greater water depths allow larger waves to propagate onshore. The increased wave energy associated with the larger waves results in additional scouring in front of the seawalls and overtopping of the structures.

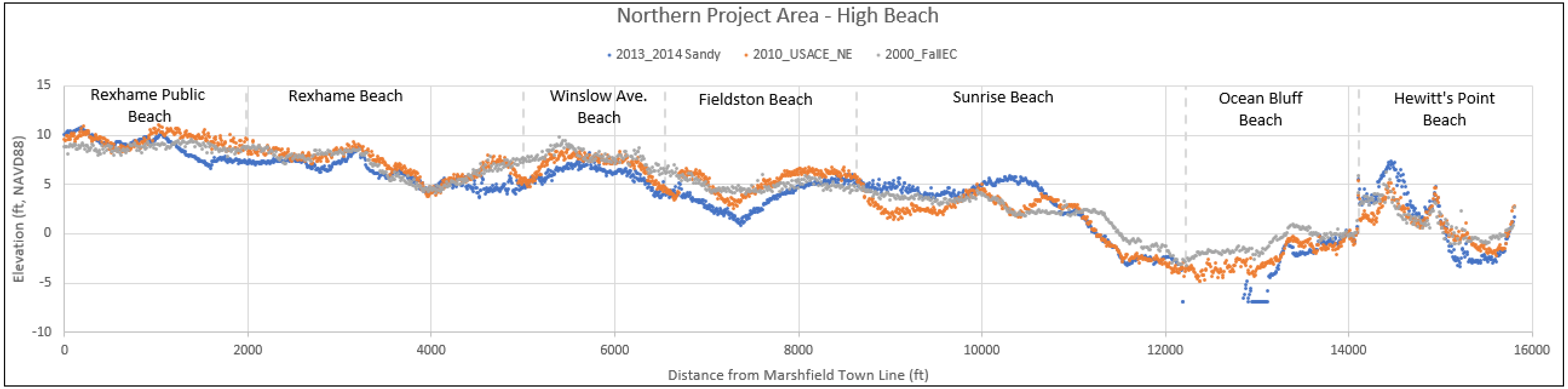


Figure C-16. Comparison of beach elevations from 2000 to 2014 between Rexhame Public Beach and Hewitt's Point Beach for a location 75 ft seaward of coastal dunes or shore protection structures.

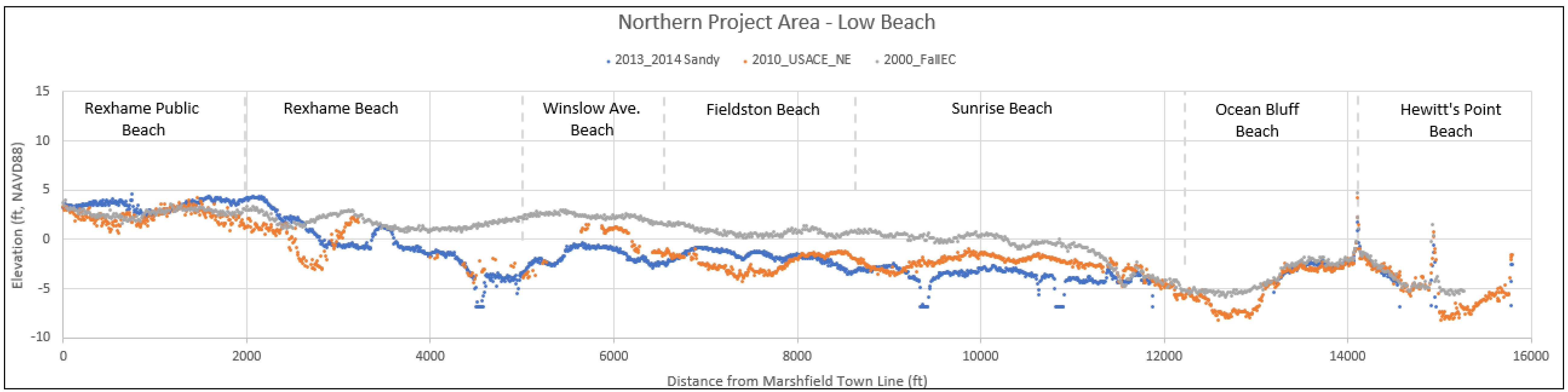


Figure C-17. Comparison of beach elevations from 2000 to 2014 between Rexhame Public Beach and Hewitt's Point Beach for a location 175 ft seaward of coastal dunes or shore protection structures.

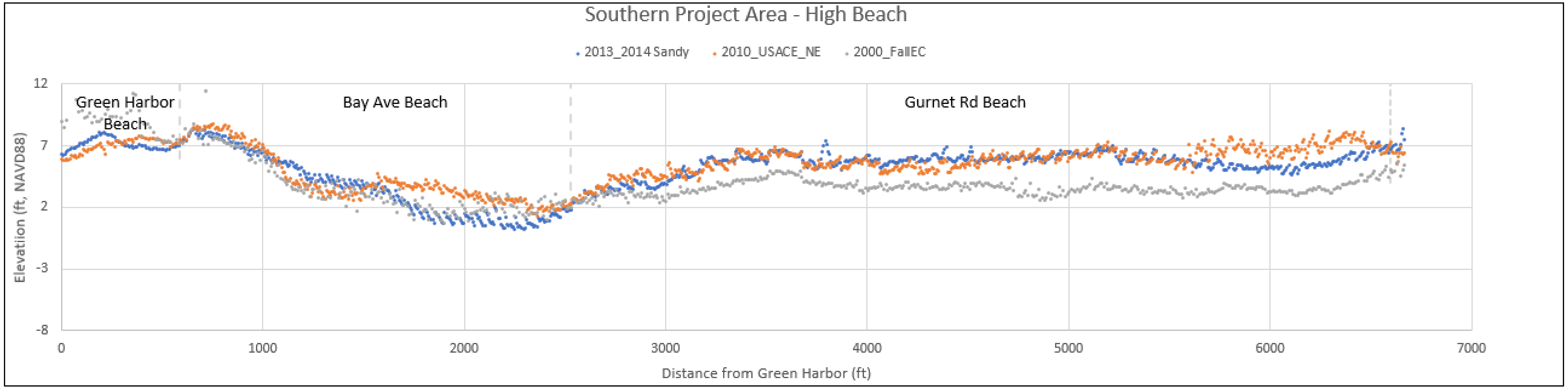


Figure C-18. Comparison of beach elevations from 2000 to 2014 between Green Harbor Beach and Gurnet Rd Beach for a location 75 ft seaward of coastal dunes or shore protection structures.

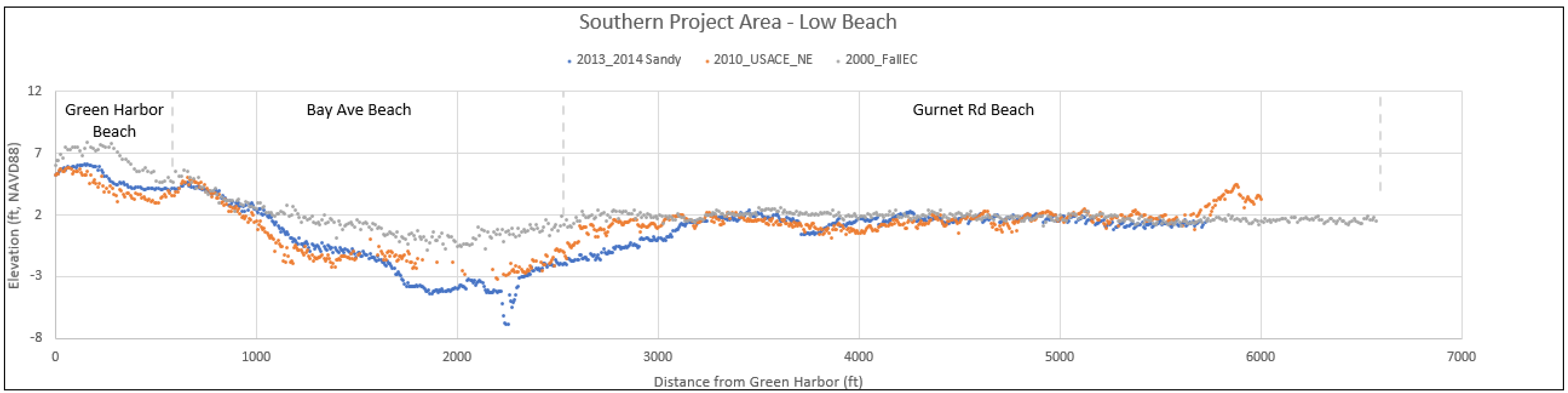


Figure C-19. Comparison of beach elevations from 2000 to 2014 between Green Harbor Beach and Gurnet Rd Beach for a location 175 ft seaward of coastal dunes or shore protection structures.

1.6 Wave Climatology

To accurately characterize sediment fluxes along a coastline to inform beach nourishment or erosion mitigation structural design, the offshore wave climate, and how energy is transferred into the near-shore zone, must be first understood. Wave transformation modeling is a powerful tool for providing information as to how an offshore packet of waves interacts with complex nearshore bathymetry as it reaches the shoreline. The level of interaction with the near-shore zone determines how much energy remains in the wave packet when it reaches the shore. The remaining wave energy that is distributed along the shoreline is indicative of the amount of sediment transport, and the direction of that sediment transport, that will occur.

Wave transformation modeling was previously conducted by Woods Hole Group for the coast of Duxbury, MA (Woods Hole Group, 2016). The goal of the current modeling effort was to extend the wave transformation model northward to include the coast of Marshfield, MA, using newly collected bathymetry data that accurately captures the irregular nearshore features off the coast of Marshfield. From these wave transformation model results, a sediment transport model was developed in order to characterize sediment fluxes and divergence on the Marshfield coastline. This report describes the wave model development, results for average annual conditions and results for extreme events along the Marshfield, MA coastline.

CMS-Wave version 3.2 (Lin et al, 2011), a spectral wave model, was chosen to model wave transformation processes for the Marshfield region. CMS-Wave, (formerly known as WABED, Wave-Action Balance Equation Diffraction) is a 2-dimensional, finite-difference, steady-state nearshore spectral wave model that solves the wave-action balance equation (Mase, 2001) on a uniform or non-uniform cartesian grid. The wave-action balance equation (eq. 1,2) is as follows:

$$\frac{\partial(C_x N)}{\partial x}+\frac{\partial(C_y N)}{\partial y}+\frac{\partial(C_\theta N)}{\partial \theta}=\frac{\kappa}{2\sigma}\left[\left(CC_g \cos^2\theta N_y\right)_y-\frac{CC_g}{2}\cos^2\theta N_{yy}\right]-\varepsilon_b N-S \tag{1}$$

where

$$N=\frac{E(\sigma,\theta)}{\sigma} \tag{2}$$

CMS-Wave has the capability to model and resolve wave processes such as wave refraction, diffraction, breaking, shoaling and interaction with shoreline structures (Lin et al., 2012). The spectral wave model runs as part of the Coastal Modeling System (CMS) developed by the Coastal Inlets Program of the U.S. Army Corps of Engineers (USACE) Research and Development Center (ERDC) and the USACE Coastal Hydraulics Laboratory (CHL). For this modeling effort, CMS-WAVE was run in half-plane mode where only waves directed onshore are simulated, which was deemed suitable for this application.

The bathymetric source for the offshore region of Marshfield is the 2016 USGS CoNED (1887-2016) New England topobathymetric digital elevation model, extracted relative to NAVD88 from NOAA's Data access viewer (https://coast.noaa.gov/dataviewer/#/lidar/search). For the nearshore region of Marshfield (out to a depth of approximately 40 feet), bathymetric data collected by Woods Hole Group in November 2019 were merged with the offshore data and interpolated to the grid to improve the local detail of the model's bathymetry.

The wave modeling was conducted using nested grid approach that included two grids (Table C-3). The first was a regional-scale, 50-m resolution parent grid, which covered the region of Marshfield and extended seaward to the 56-meter depth contour (Figure C-20), which coincided with the general location and depth of the USACE Wave Information Study (WIS) station 63060 in Massachusetts Bay. The second grid was a local scale grid, which was nested within the parent grid and included the Marshfield shoreline and extended to just offshore of Brant Point (Figure C-21). The resolution of this child grid was 10-meters, which was determined sufficient for both capturing necessary shoreline detail as well as remaining computationally efficient.

Table C-3. Grid Information Used for Wave Transformation Modeling.

Details	Regional-Scale Parent Grid	Local-Scale Child Grid
Grid Type	Uniform cartesian	Uniform cartesian
Resolution	50 m	10 m
X origin (MA State Plane Meters)	280634.27	269709.02
Y origin (MA State Plane Meters)	885628.69	878706.45
Grid Orientation	202.08 °	202.08 °
Depth at Boundary	56 m	12 m
Length of Seaward Boundary (km)	16.43 km	11.29 km

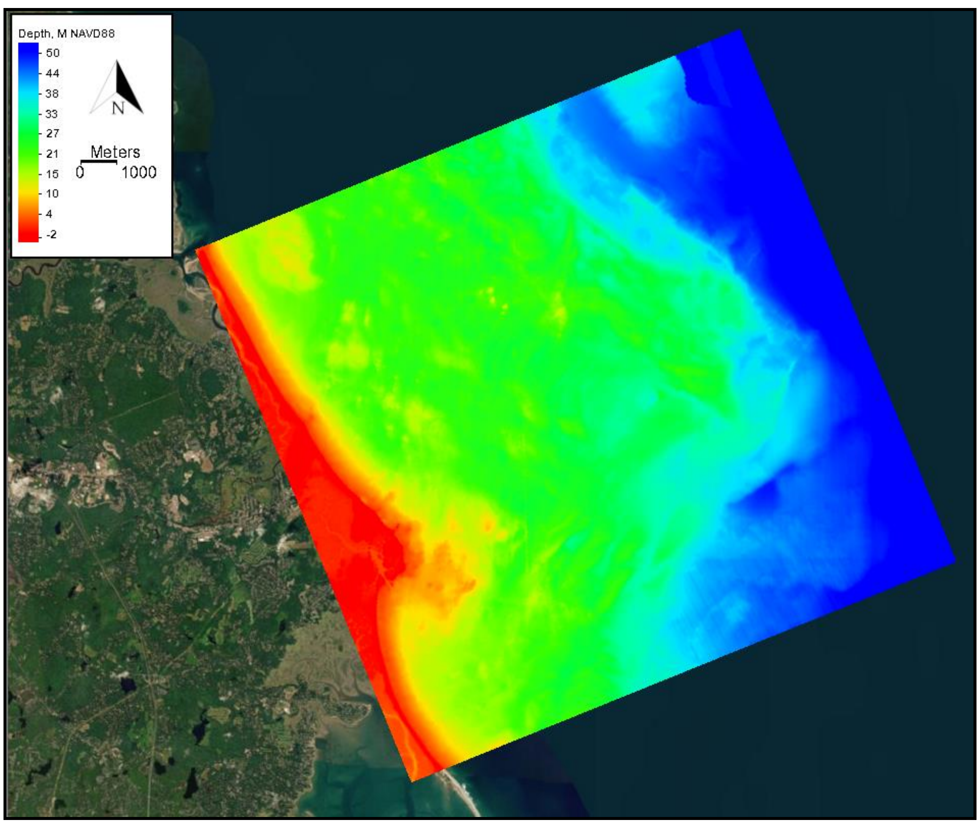


Figure C-20. Full extent of the 50-meter resolution parent grid.

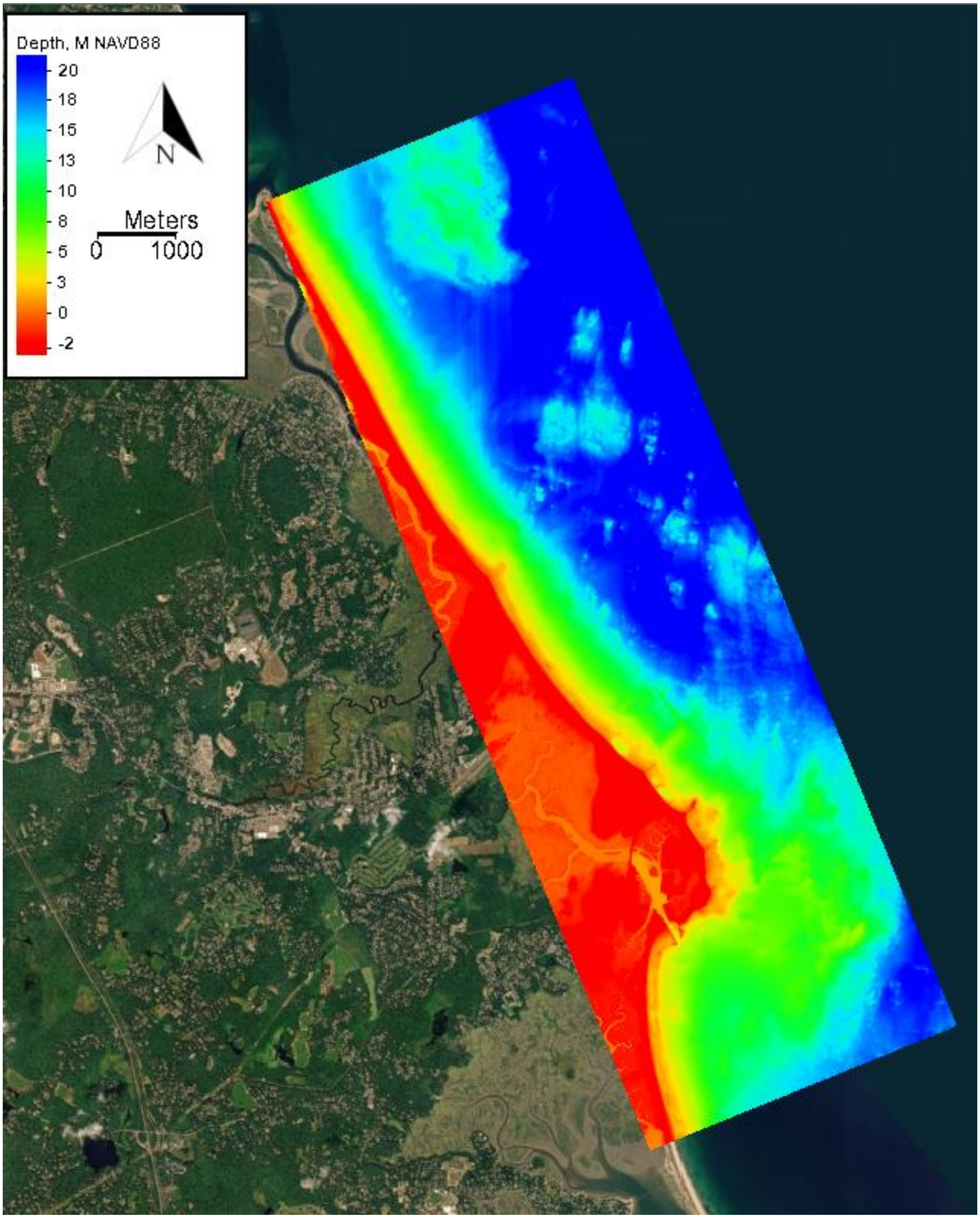


Figure C-21. The full extent of the 10-meter resolution nested grid.

There are two potential sources for wave data in the Marshfield offshore region of Massachusetts Bay. The first is from the National Oceanic and Atmospheric Administration's National Data Buoy Center (NOAA NDBC) station 44013. The second is the WIS station 63060. WIS information is produced from a hindcast wave model (WISWAVE) that predicts the local wave climate based on local and regional wind conditions (Resio and Tracy, 1983). WIS is a reasonable and widely used option when considering long-term average annual conditions. The locations of the two data buoys is presented in Figure C-22.

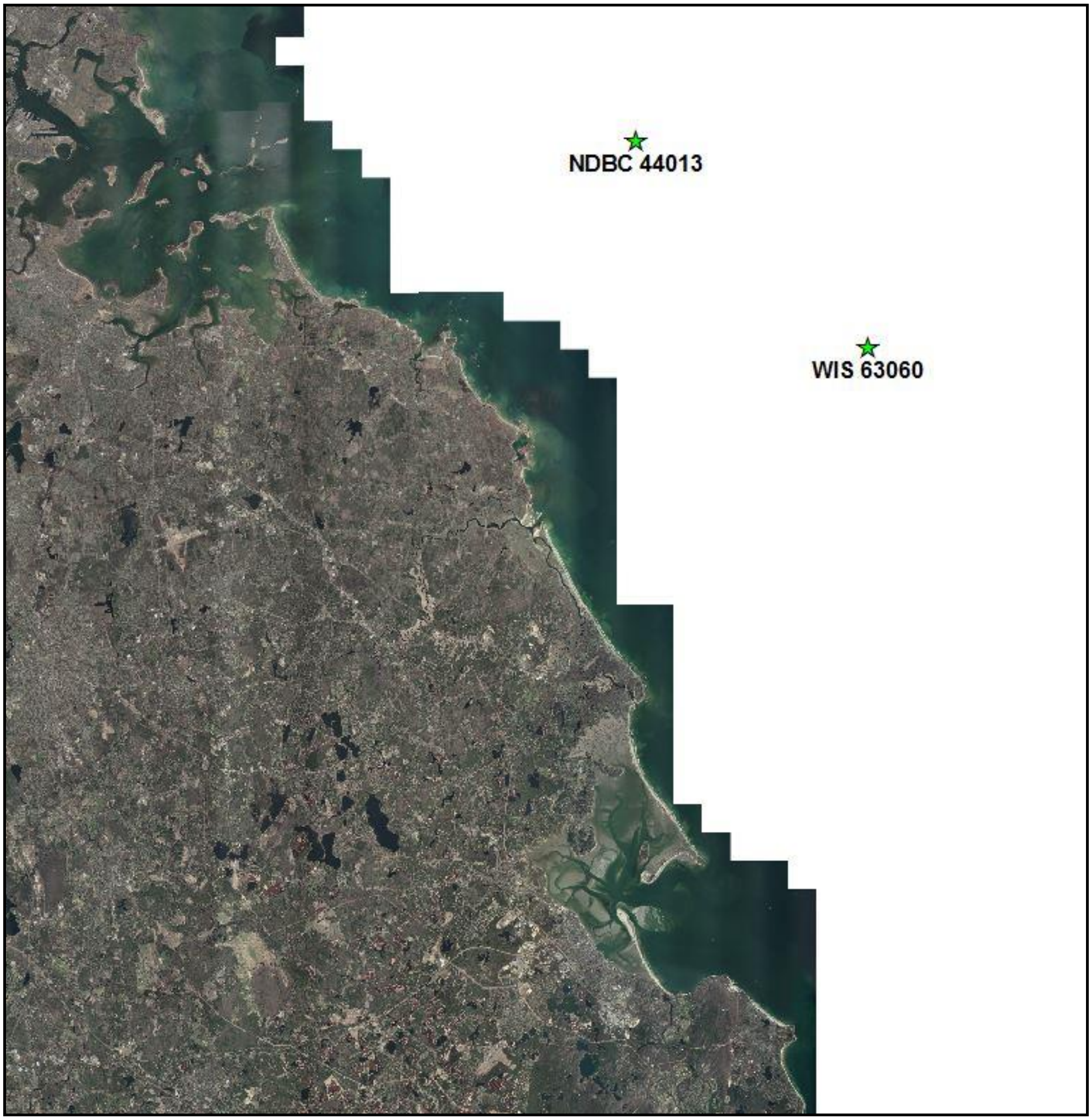


Figure C-22. Locations of offshore wave buoys in the vicinity of Marshfield, MA.

Due to the proximity and matching depth of the seaward boundary of this model, WIS station 63060 was chosen to develop offshore boundary conditions for the wave transformation model. The 33-year hourly averaged wave information from WIS station 63060 is presented as a wave rose in Figure C-23. These data were subdivided into 22.5-degree directional bins to develop representative spectral inputs for the wave model. Table C-4 presents the analysis results of the 33- year dataset used to create the average annual conditions for the wave transformation modeling for Marshfield, MA. The results show the highest wave energy arrives from the NE directional bin (44.5 to 68 degrees) while the most frequent waves arrive from the E-ESE (90.5 to 113 degrees).

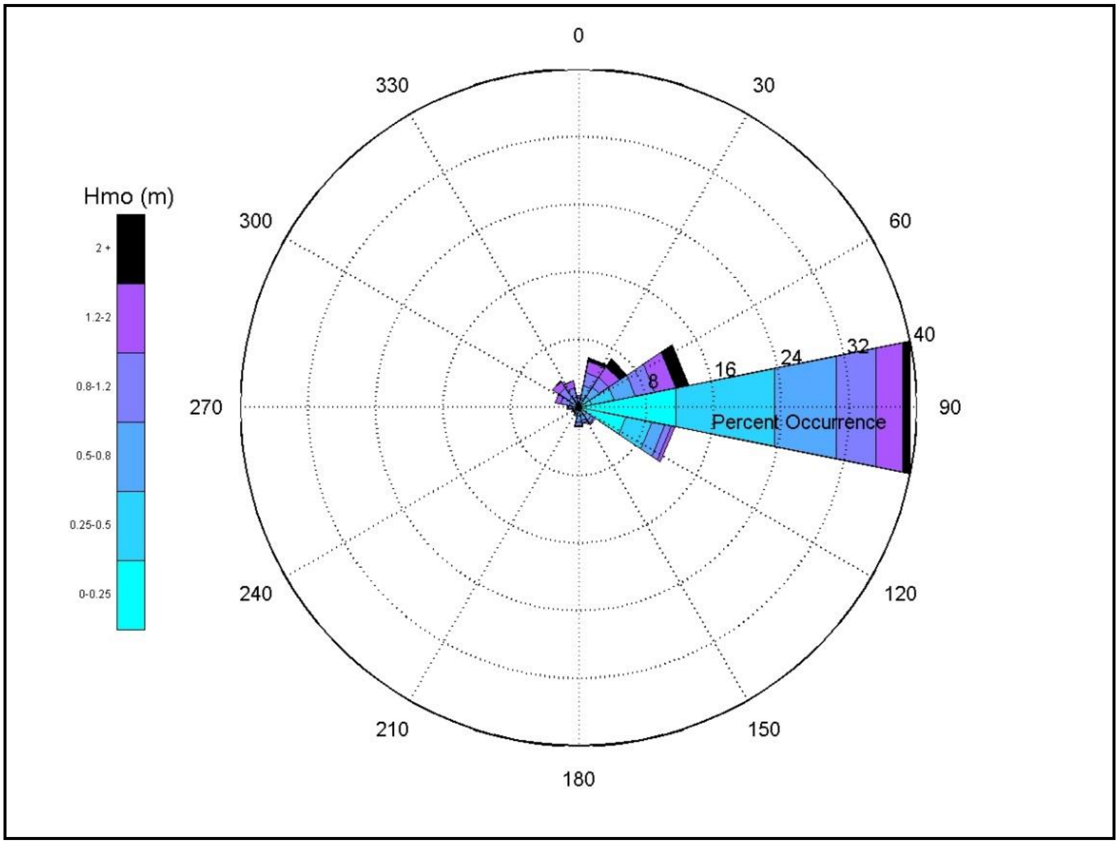


Figure C-23. 33-year hourly averaged wave heights and directions from WIS station 63030.

Table C-4. Input Conditions and Directional Bin Scenarios for the Wave Transformation Modeling.

Directional Bin (0°=N)	Approach Direction	Percent Occurrence	Sig. Wave Height (m)	Peak Period (sec)	Peak Direction (0°=N)
338 to 0.5	NNW	3.10	0.98	4.56	349.17
0.5 to 23.0	N - NNE	3.60	0.99	4.84	12.15
23.0 to 44.5	NNE-NE	5.50	1.14	5.35	34.96
44.5 to 68	NE	8.50	1.20	6.16	57.22
68.0 to 90.5	NE-E	27.70	0.76	7.84	81.31
90.5 to 113.0	E- ESE	30.0	0.43	7.58	98.99
113.0 to 135.5	SE	3.30	0.63	5.29	122.64
135.5 to 158.0	SSE	2.20	0.62	4.54	146.38
Calm	--	16.10	--	--	--

Extreme Event Modeling - High waves and increased sediment transport on open coastlines most often occur during high energy, or storm events. USACE has completed as part of the WIS project a series of analyses for extreme event return periods at station 63060. The results of these extreme event return-period analyses are presented in Figure C-24. For this modeling effort, two high energy return-period scenarios were chosen to use as inputs into the wave transformation model, details of which are presented in Table C-5. The wave heights and for these two scenarios were chosen from the return period analysis of the 33-year wave hindcast at station 63060. The wave period corresponding to each high-energy wave height was derived using the relationship between peak wave height and wave period for storm events. The wave direction was calculated as the mean wave direction of all storms used in the WIS station 63060 return-period analysis. Storm surge elevations corresponding for each scenario were collected from USACE's Tidal Flood Profiles of the New England Coast (USACE, 1988).

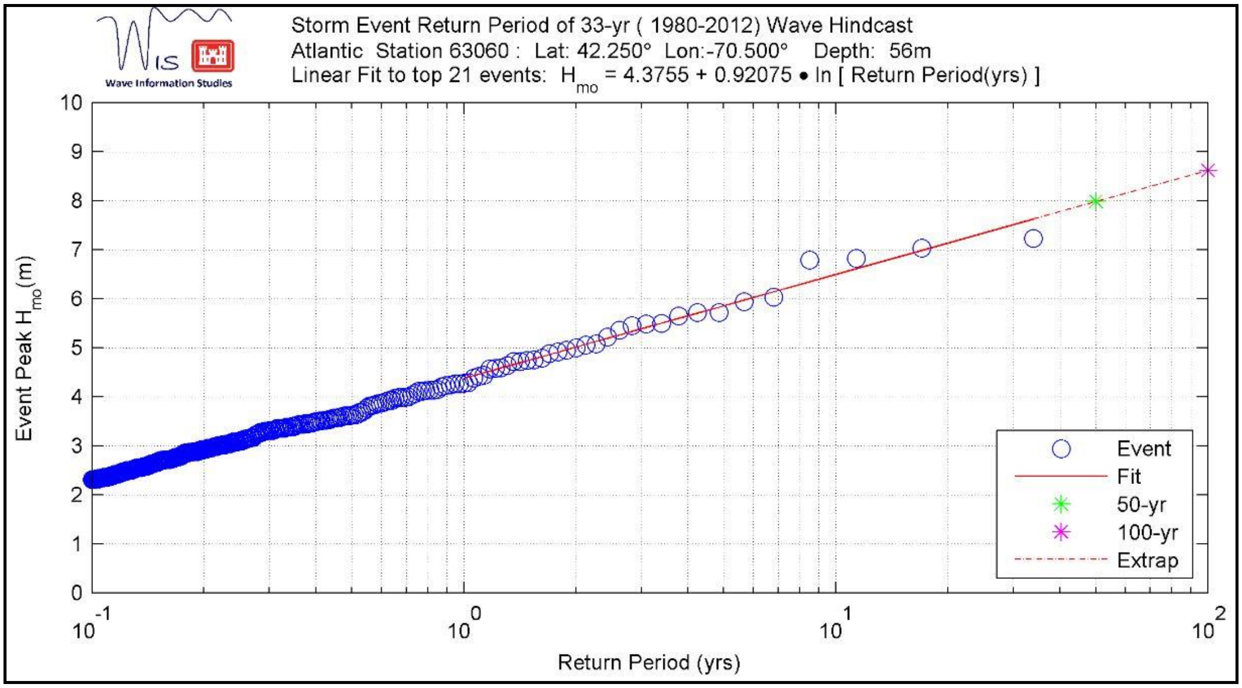


Figure C-24. Storm event return periods for the 33-year dataset at WIS Station 63060 (USACE, 2012).

Table C-5. Wave Input Conditions for High Energy Events.

Event	Storm Surge [m_NAVD88]	Wave Height [m]	Wave Period [sec]	Wave Direction [0°=N]
10-Year	2.47	6.5	12.0	55.4
50-Year	2.77	8.0	13.3	55.4

Model Validation - Before modeling average annual and extreme storm conditions, the wave model performance was first evaluated by running the model and comparing the results to a wave ADCP that was deployed by Woods Hole Group in May-June 2015. Time-series of significant wave height (m), period (s) and wave direction (degrees) output from the model were compared with the ADCP measurements are presented in Figure C-25. Considerable noise (high-frequency oscillations) is present in the ADCP data for wave period and direction during periods of low wave energy, which is expected. The model can capture key high energy events as well as reasonably predict during calm periods but tends to over-predict wave heights at the location of the ADCP. This can be attributed to the spatially constant wind forcing in the model from a single point offshore. The wind inputs from the NDBC buoy may not be fully representative of the winds occurring at the ADCP location, which explains the increased wave heights. Visually however, the model follows the trend of the observations well and captures periods of high and low energy. This indicates reasonable model-data fit, which demonstrates the model is sufficient for characterizing wave transformation processes in the region.

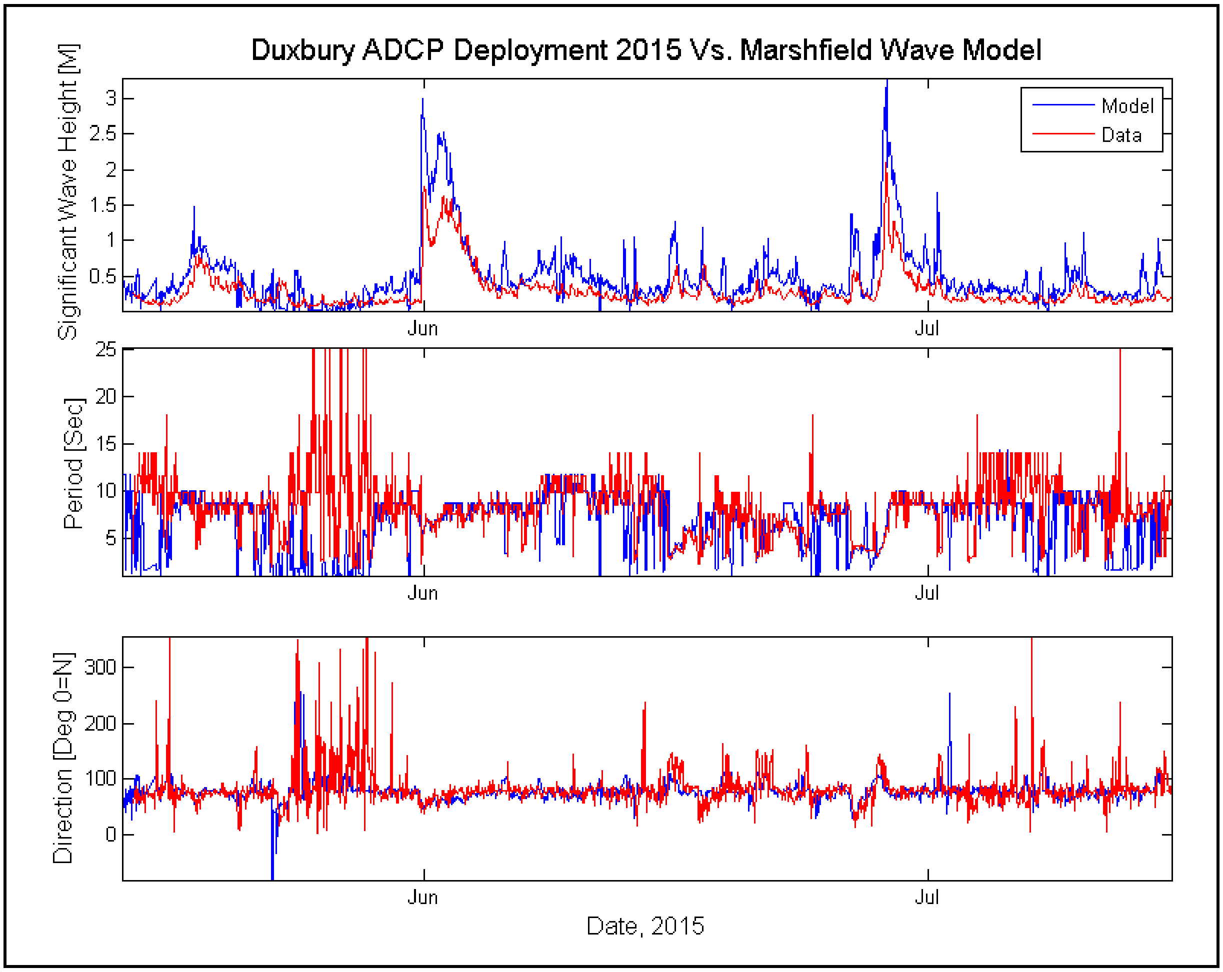


Figure C-25. Observational data collected from an ADCP deployed in May 2015 compared to CMS-Wave model output for wave direction, wave period and significant wave height for the verification run. Model output is represented in red, and the ADCP observational data is represented in blue.

Wave transformation model simulations were performed for each of the average annual and storm conditions listed in Tables C-4 and C-5. An example of the CMS-Wave model output for one of the more energetic directional bins (44.5 to 68 degrees) is shown in Figure C-26. Figures showing the model results for all conditions simulated are included in Section K.

The wave model results shown in Figure C-26 are for waves arriving from NE–ENE and indicate wave heights are larger along the sections of the shoreline due to energy focusing. The increases in wave height appear to occur where waves refract around shallow rocky formations in the nearshore or in the vicinity of shoreline structures (groins).

A close-up view of the wave model results around Brant Rock is shown as an inset in Figure C-26. This is an area of significant wave energy as the nearshore bathymetric features cause waves to shoal, refract, and diffract in this region.

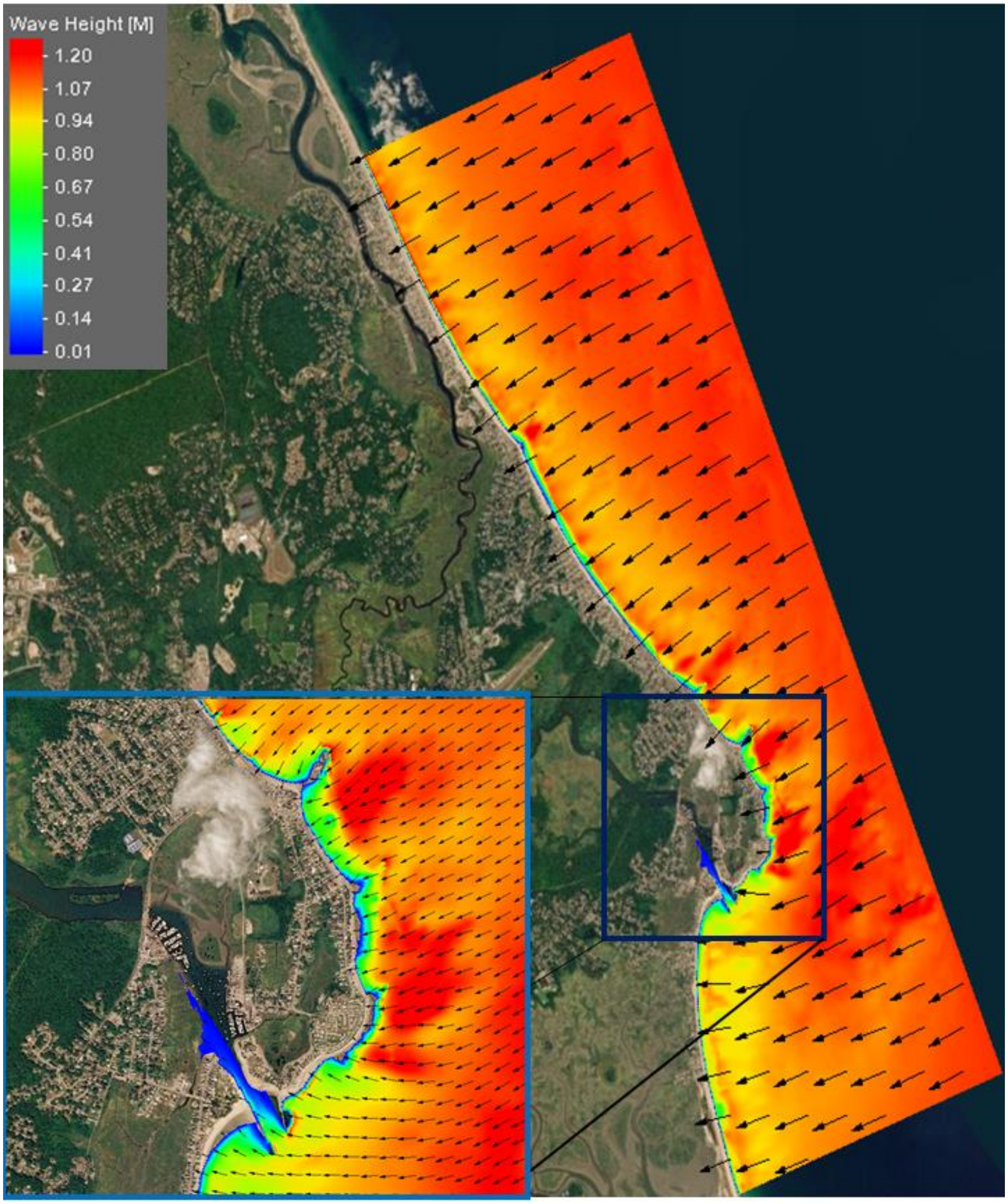


Figure C-26. Results of the local wave model for the NE-ENE approach direction (44.5° to 68.0 ° [N = 0°]).

1.7 Sediment Transport

An understanding of how waves interact with the complex nearshore bathymetry is important to determine estimates of sediment movement in the nearshore region. The results of the transformation-scale wave modeling conducted for Marshfield, therefore, act as the key input for alongshore sediment transport modeling and evaluation of beach nourishment activities. The intent of the sediment transport modeling is to represent the alongshore currents and sediment transport driven by breaking waves in the surf zone. The model provides estimates of sediment flux to identify trends of erosion and accretion along the shoreline. This section describes the development of the physical process-based sediment transport model for Marshfield and northern Duxbury, the model inputs, and results of the sediment transport modeling.

To accurately model sediment transport processes along the Marshfield and northern Duxbury coastline, the characteristics of the naturally occurring sediments on the beach must first be identified. Grain size characterization is also important for the design of beach nourishment and erosion mitigation alternatives developed as part of this study.

The grain size information for the sediment transport modeling were sourced from the sediment sampling that was completed in December 2019 by Woods Hole Group (Table C-1). During this sampling effort 26 surface grab samples were collected at the dune and the mean tide line. Further information regarding this sediment sampling effort is discussed in Section 1.4 above.

The coastline extending southward from the northern Marshfield border to the outer beach in Duxbury is characterized by a mixture of gravel and sand with isolated areas of larger grained sediments. The average sediment type for the Marshfield coastline is a granular sand with a D50 (median grain-size) of 2.65 mm. The smallest D50 occurs for a predominantly sand sample at station 12-MTL-SAN, with a value of 0.25 mm. The largest D50 occurs for a predominantly cobble sample at station 12-MTL-COB, with a value of 32 mm. The median sand grain size for the beach is 1.75 mm occurring at station 16-MTL-SAN and the median gravel/pebble grain size is 19 mm occurring at station 8-MTL-COB. These values were used as the representative grain-sizes for sand and cobble, respectively, in the mixed-grain size sediment transport analysis.

Sediment transport in the coastal zone is characterized by the interaction between onshore wave energy and nearshore features together with sediment grain size and available sediment supply. Modeling sediment transport in the coastal zone numerically involves solving the physics of wave energy and sediment transport with simplifying assumptions. The sediment transport model used for this modeling effort is a process-based model which identifies patterns of regional sediment transport in the presence of a time-varying wave field. Due to the mixed-granular characteristics of the natural sediments occurring on the Marshfield coastline, a sediment transport approach that incorporates multiple grain sizes, along with their relative contributions, was developed and utilized for this modeling effort. This approach is described in the following sections.

The sediment transport model used to simulate sediment fluxes on the Marshfield coastline was a process-based numerical model which solves the steady-state, depth averaged mass and momentum equations, coupled with the calculations for long-shore sediment transport adopted from the methodology developed by Haas and Hanes (2004).

The sediment transport model used a series of cells covering the section of beach and surf zone where wave-induced sediment transport occurs. Based on the wave model results, a cell can either accumulate sediment or lose sediment as the wave energy is applied. Cells that gain more sediment than they lose are described as accreting (sediment is converging in the cell), whereas cells that lose more sediment than they gain are described as eroding (sediment is diverging in the cell). A cell that loses the same amount of sediment that it gains is described as stable, indicating no accretion or erosion is occurring.

A high-resolution bathymetric grid was generated using the nearshore bathymetry/topography from the transformation-scale wave model (CMS-WAVE) for Marshfield and northern Duxbury. The grid for the sediment transport model was the higher resolution local grid of the wave transformation model with 10-meter cells spanning 11.29 km in the along-shore direction and 3.4 km in the onshore direction. Results from the wave transformation model for both average annual conditions and the high-energy events were used as input to the high-resolution sediment transport model. Table C-6 presents the information for the grid used in sediment transport model. The orientation of the grid was altered for the portion of shoreline south of Green Harbor to more accurately represent a shore-normal orientation.

Table C-6. Grid Information for Sediment Transport Model

Details	Sediment Modeling Grid
Grid Type	Uniform cartesian
Resolution	10 m
Scale	Local
X origin (MA State Plane Meters)	269709.02
Y origin (MA State Plane Meters)	878706.45
Grid Orientation	202.08 °
Depth at Boundary	12 m
Length of Seaward Boundary (km)	11.29 km

To identify erosional and accretional patterns on specific sections of the Marshfield and northern Duxbury coastline, sediment transport trends were characterized using modeled rates and direction of sediment transport. The model computed the sediment flux, a representation of the rate of sediment moving along the coastline, in cubic meters per year. Positive and negative fluxes indicate the direction of sediment movement relative to the model's grid orientation. It is important to note that the model computes the potential for sediment transport. The calculations assume that sediment is infinitely available for transport, and therefore model overpredicts rates of transport along stretches of shoreline that are sediment starved.

The transformation-scale wave model results discussed in Section 1.6 above were used as input into the sediment transport model. Sediment transport was first evaluated for average annual conditions by simulating each average directional wave case (Figure C-27). This was completed using both the representative sand grain size, as well as the representative cobble grain size. The results from these cases were then combined to produce an annual pattern of sediment transport (Table C-7). Finally, storms were evaluated in order to determine the episodic transport which occurs during extreme storm events.

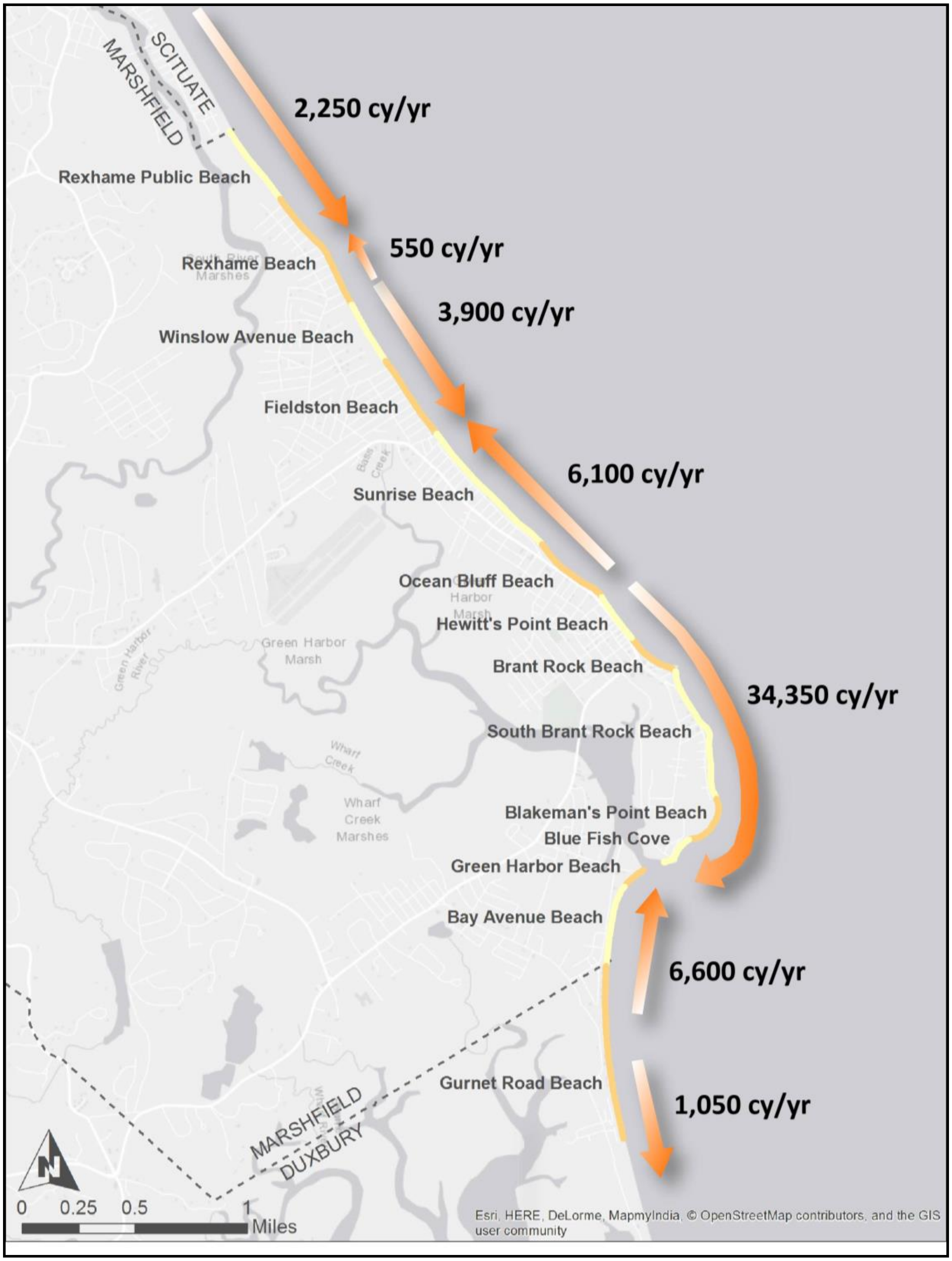


Figure C-27. Sediment transport from the average annual wave bin condition.

Table C-7. Table of Sediment Transport Results for Average Annual Conditions.

Beach	Sediment Flux (cu yards/year)	Direction
Rexhame Beach (North)	2,250	Southward
Rexhame Beach (South)	550	Northward
Winslow Avenue Beach/Fieldston	3,900	Southward
Sunrise/Ocean Bluff	6,100	Northward
Green Harbor Beach/Bay Ave Beach	6,600	Northward
North Duxbury	1,050	Southward

1.8 Regulated Environmental Resources

1.8.1 Land Under the Ocean (310 CMR 10.25)

Land Under the Ocean resource extends from the MLW line seaward to the boundary of the Marshfield and Duxbury jurisdictions. Nearshore areas of Land Under the Ocean are significant to the protection of the following interests: water circulation, distribution of sediment grain size, water quality, finfish habitat, and important food for wildlife. Essential Fish Habitat (EFH) resources documented by the National Marine Fisheries Service (NMFS) to be in Land Under the Ocean in the vicinity of the project site are described in the following section. Eelgrass resources have not been mapped in the waters offshore of the project area.

Essential Fish Habitat (EFH)

Thirty-one federally-managed species have designated Essential Fish Habitat (EFH) in the project area (https://www.habitat.noaa.gov/application/efhmapper/index.html). Table C-8 lists these species by life stage. The project area also lies within a Habitat Areas of Particular Concern (HAPC) for juvenile cod and may also be an HAPC for summer flounder.

Most of the species with EFH in the project area are present from spring through fall, so wintertime construction windows would provide protection from direct effects on species (but not on their habitat). However, winter flounder may be present in winter, and they spawn inshore during late winter and early spring, so this species, and its spawning habitat would be directly affected. Similarly, shellfish including sea scallop and surf clams are present year-round and, if present within the project area, would be vulnerable to direct impacts from project construction.

Habitat preferences for EFH species are provided in Table C-9. Habitat preferences among species range from shallow sandy areas to rocky mid-depth areas to deepwater marine. Because the project area has a mix of sand, gravel and cobble, most substrate types are represented. Construction activity will cause habitat alteration (alteration in water depths, placement of sand in intertidal areas). This will cause temporary impacts to habitat for any species whose habitat overlaps with the project area. Impacts to EFH will be assessed in conjunction with the federal project permitting.

Table C-8. Species with Designated EFH in the Project Area by Life Stage.

Species	Eggs	Larvae	Juveniles	Adults
New England Management Council Species				
Atlantic Sea Scallop (*Placopecten magellanicus*)	X	X	X	X
Atlantic Wolffish (*Anarhichas lupus*)	X	X	X	X
Haddock (*Melanogrammus aeglefinus)*			X	
Winter Flounder (*Pseudopleuronectes americanus*)	X	X	X	X
Little Skate (*Leucoraja erinacea*)	Not well known	No larval stage	X	X
Ocean Pout (*Macrozoarces americanus*)	X		X	X
Atlantic Herring (*Clupea harengus*)		X	X	X
Atlantic Cod (*Gadus morhua*)	X	X	X	X
Pollock (*Pollachius virens*)		X	X	X
Red Hake (*Urophycis chuss*)	X	X	X	X
Silver Hake (*Merluccius bilinearis*)	X	X		X
Yellowtail Flounder (*Limanda ferruginea*)	X	X	X	X
Monkfish (*Lophius americanus*)	X	X		
White Hake (*Urophycis tenuis*)	X	X	X	X
Windowpane Flounder (*Scophthalmus aquosus*)	X	X	X	X
Winter Skate (*Leucoraja ocellata*)	Not well known	No larval stage	X	X
American Plaice (*Hippoglossoides platessoides*)	X	X	X	X
Thorny Skate (*Amblyraja radiata*)			X	
Secretarial Management Species				
Bluefin Tuna (*Thunnus thynnus*)				X
Basking Shark (*Cetorhinus maximus*)	No egg stage	No larval stage	X	X
White Shark (*Carcharodon carcharias)*	No egg stage	No larval stage	X	X
Sand Tiger Shark (*Carcharias taurus*)	No egg stage	No larval stage	X	
Mid-Atlantic Management Council Species				
Northern Shortfin Squid (*Illex illecebrosus*)				X
Longfin Inshore Squid (*Doryteuthis pealeii*)			X	X
Bluefish (*Pomatomus saltatrix*)			X	X
Atlantic Butterfish (*Peprilus triacanthus*)	X		X	X
Spiny Dogfish (*Squalus acanthias*)			X[1]	X
Atlantic Surfclam (*Spisula solidissima*)			X	X
Summer Flounder (*Paralichthys dentatus*)		X		X
Scup (*Stenotomus chrysops*)			X	X
Black Sea Bass (*Centropristis striata*)				X
NEFMC Habitat Areas of Particular Concern				
Inshore 20m Juvenile Cod				
Summer Flounder (Likely)				

Table C-9. Habitats Used by EFH Species in the Project Area.

Species	Comment
New England Management Council Species	
Atlantic Sea Scallop (*Placopecten magellanicus*)	Commercially valued shellfish, common offshore in medium and fine-grained sands, temperatures less than 77F (25C). Adults and juveniles occur all year. Spawning occurs in late Sept -o early October (MA DMF, 2011) Adults can survive in salinities as low as 12.5ppt but more commonly are found in waters above 28ppt. (NMFS/NERO, 2001)
Atlantic Wolffish (*Anarhichas lupus*)	Demersal fish preferring complex habitats with large stones and rocks that provide shelter and resting sites. Occasionally seen in soft sediments including sand and mud. Adults and juveniles could be present any time. Spawning occurs in late summer. Found at depths of 20-240 m in the Gulf of Maine; also found at shallower depths in more northern areas. (NMFS/NEFMC 2009)
Haddock (*Melanogrammus aeglefinus)*	Eggs and juveniles occur in water column and epipelagic zone; juveniles and adults are demersal benthivores. Haddock feed and spawn on sand, rock, gravel and mud. In winter adults prefer deeper waters and move shoreward in summer. When summer temperatures reach 10-11C they move to colder deeper waters. (NOAA, 2005a)
Winter Flounder (*Pseudopleuronectes americanus*)	Demersal species. Adults migrate inshore in fall and early winter, spawn in late winter and early spring when temperatures are less than about 3.5-5.5C, then leave inshore areas after spawning (although some adults remain inshore year-round). Eggs are demersal, adhesive, found at water temps of 10C or less and in salinities ranging from 10-30ppt. Larvae are initially planktonic but become bottom oriented as metamorphosis approaches. Young of the Year (YOY) develop inshore in shallow water for the first year and then move to deeper waters. Substrate includes mud to sand or gravel for eggs, larvae and YOY; adults occur on mud, sand, cobble, rocks and boulder (NOAA, 1999a)
Little Skate (*Leucoraja erinacea*)	Substrate preferences are sand or gravelly bottoms but also found on mud. Skates remain buried in depressions during the day and are more active at night. They move onshore/offshore with seasonal temperature changes. Temperature range is 1-21C; most are found between 2-15C. (NOAA, 2003a)
Ocean Pout (*Macrozoarces americanus*)	Demersal fish in all life stages. Spawning in water <50m in late summer – fall; adults make nests in holes, crevices, etc. Spawning occurs on rough bottom areas. Preferred substrate for adults is variable, sand, gravel, rough bottom but rarely mud. Depths variable 1-300+m but prefer 15-110m. Preferred temperature <10 C for spawning and eggs; Adults and Juveniles occur at temperatures 2-14C, mostly 2-10C. (NOAA, 1999b)
Atlantic Herring (*Clupea harengus*)	Pelagic species but spawns on bottom. Occurs inshore and offshore in summer and fall; Diel vertical migration; depths to about 300m; mostly <80m in fall and shallower in spring. Pre-spawning aggregations more abundant over gravel and sand. Eggs demersal, egg "beds" in coastal water and offshore banks with strong bottom currents and coarse substrate; depths 5-90m. Adults most abundant at 27-35 ppt salinity. (NOAA, 2005b)
Atlantic Cod (*Gadus morhua*)	Occupies mixed areas of water column. Larvae and eggs generally at surface but move deeper with age. Larvae migrate vertically in reaction to light. Adults are mostly on bottom during the day and move up into the water column at night. Found on various substrate but adults prefer rocky, pebbly, gravelly areas and avoid finer sediments. Juveniles use vegetation for predator avoidance. Salinities mostly 30-35ppt; adults generally found in temperatures <10C; younger life stages occur in cool water, mostly 4-8C although juveniles are more tolerant of temperature extremes from 6-20C. (NOAA, 1999c)
Pollock (*Pollachius virens*)	Pelagic schooling species. Often found on inshore and offshore banks. Adults are unselective for bottom type, associated with sediments ranging from gravels to clay. Occurs at depths from 15-300+m, but mostly 75-175m. Temperature range 0-14C but preferred range is 6-8C. (NOAA, 1999d)
Red Hake (*Urophycis chuss*)	Demersal species. Migrates inshore in spring and summer to spawn, and offshore in fall. Preference for soft sand or muddy substrates. Preferred temperature 5-12C. Juveniles seek shelter from predators in sea scallop beds. (NOAA, 2018)
Silver Hake (*Merluccius bilinearis*)	Demersal species. Migrates inshore in spring and summer to spawn, and offshore in fall. Preference for soft sand or muddy substrates. Preferred temperature 7-10C. (NOAA, 2018). Silver hake occur on substrates from gravel to fine silt and clay but are mainly associated with finer sediments (NOAA, 1999e)
Yellowtail Flounder (*Limanda ferruginea*)	Demersal species, prefers sand or sand and mud substrate. Spawning occurs in March through August at temperatures of 5-12C. Temperature range approximately 2-18C. Found at depths of 10-1200m; adults concentrated at depths of 37-73m. Salinity range approximately 32-33.5ppt. (NOAA, 1999f)
Monkfish (*Lophius americanus*)	Demersal piscivores found from inshore to depths of 900m. Seasonal onshore offshore migrations occur and are related to spawning and food availability. (NOAA, 2016) Substrates include sand-shell mix, algae covered rocks, hard sand, pebbly gravel or mud. Eggs and juveniles are found in the water column at depths 15-1000 and temperatures >18C. (NOAA, 1998)
White Hake (*Urophycis tenuis*)	Demersal species, prefers muddy and fine-grained sandy substrates. Eggs and larvae are planktonic, occurring in depths of 10-250 m. Juveniles become pelagic and occur inshore at depths of 5-75 m in spring and autumn when temps are 4-19C. Adults occur inshore and offshore, to depths of 350m. Prey on shrimp, crustaceans, fish including their own young. May occur in project area year round. (NOAA, 1999g)
Windowpane Flounder (*Scophthalmus aquosus*)	Demersal fish, occurring in nearshore bays and estuaries to depths of 75m. Prefers muddy or fine sandy substrate. Preys on polychaetas, crustaceans, small fishes. Temperature range 4-19C in inshore MA waters. (NOAA, 1999h)
Winter Skate (*Leucoraja ocellata*)	Substrate preferences are sand or gravelly bottoms but also found on mud. Skates remain buried in depressions during the day and are more active at night. They move onshore/offshore with seasonal temperature changes. Generally caught at depths from shoreline to 370m. Temperature range is -1 to 20C (NOAA, 2003b)
American Plaice (*Hippoglossoides platessoides*)	Demersal species but eggs and larvae are pelagic. Substrates include fine sand and gravel. Temperature range 2-17C. Salinity range 20-32+ throughout range. Occurs inshore and offshore. (NOAA, 1999i)
Thorny Skate (*Amblyraja radiata*)	Found on a wide range of substrates including sand, gravel, broken shell, pebbles and soft mud. Found at depths of 18-1200m. Temperature range is -1 to 14C. Salinity 31-36ppt. Opportunistic feeder on most abundant and available prey including bivalves, squid, polychaetas, zooplankton. (NOAA, 2003c)

Secretarial Management Species	
Bluefin Tuna (*Thunnus thynnus*)	Long lived, top predator, pelagic fish. Eggs pelagic. Spawning occurs mid-April to June, mainly in the Gulf of Mexico. Occurs in New England during summer. Feeds on fish, squid and crustaceans. (NOAA, undated online information *https://www.fisheries.noaa.gov/species/western-atlantic-bluefin-tuna*)
Basking Shark (*Cetorhinus maximus*)	Migratory coastal pelagic species found in all temperature areas. Slow moving, filter feeder. Occurs in New England during summer months. (*https://www.floridamuseum.ufl.edu/discover-fish/species-profiles/cetorhinus-maximus/*)
White Shark (*Carcharodon carcharias)*	Migratory epipelagic species found in coastal and offshore areas along the continental shelf and islands. Occurs in summer in New England. Feeds on fish, marine mammals, other sharks. (*https://www.nefsc.noaa.gov/nefsc/Narragansett/sharks/white-shark.html*)
Sand Tiger Shark (*Carcharias taurus*)	Migratory species found in surf zone, coastal waters and shallow bays to outer continental shelf. Generally bottom dwelling. (*https://www.nefsc.noaa.gov/nefsc/Narragansett/sharks/sandtiger-shark.html*)
Mid-Atlantic Management Council Species	
Northern Shortfin Squid (*Illex illecebrosus*)	Occurs in water column over various sediment types including sand-silt. Avoids areas inhabited by anemones. Found at temperatures 3.5-20C, salinity generally 30-36.5ppt. In coastal waters during spring and summer. Migrates off continental shelf in fall. (NOAA, 2004)
Longfin Inshore Squid (*Doryteuthis pealeii*)	Occurs in water column over mud or sandy mud at temperatures 9-21C, salinity generally 30-34 ppt. In coastal waters during spring and summer. Migrates offshore to deeper waters in winter. Occurs in Gulf of Maine from March to October. When inshore is found at depths to 180m (NOAA, 2005c)
Bluefish (*Pomatomus saltatrix*)	Pelagic species. Adults generally oceanic nearshore to well offshore over continental shelf. In summer juveniles are found near shorelines or in tidal creeks, also open bay or channel waters Can occur in surf zone. Mostly found over sand substrates but some mud, silt, clay. Also uses areas with seagrass, marsh vegetation. Occurs in New England during summer, in water temperatures 14-30C. Prefers ocean salinities. Sight feeder, preys on other fish mainly.(NOAA, 2006)
Atlantic Butterfish (*Peprilus triacanthus*)	Eggs are pelagic, occurring in surface waters from continental shelf to estuaries and bays; Juveniles and adults found from surface to depth in waters to 330m. Common in inshore areas including the surf zone. Schools found over sandy, sandy-silt, and muddy substrates. Temperatures 4-26C. Salinities 3-37 ppt. (NOAA, 1999j)
Spiny Dogfish (*Squalus acanthias*)	Epibenthic species but does move through the water column. Occurs in coastal and offshore waters to 3,0000ft, usually near bottom waters at temperatures 6-11C. (*https://www.nefsc.noaa.gov/nefsc/Narragansett/sharks/spiny-dogfish.html*) Although, they can tolerate brackish water they prefer full strength seawater and do not enter freshwater habitats; Found north of Cape Cod in summer and move to Long Island area in fall and farther south in winter (*https://www.floridamuseum.ufl.edu/discover-fish/species-profiles/squalus-acanthias/)*
Atlantic Surfclam (*Spisula solidissima*)	Commercially valued shellfish occurring in nearshore and offshore areas. Adults burrow in medium to coarse sand and gravel substrates, also found in silty to fine sand. Does not burrow in mud. Spawning occurs from 19.5-30C; Salinities 14-52 ppt in lab studies. (NOAA, 1999k)
Summer Flounder (*Paralichthys dentatus*)	Demersal fish. Adults occur in a variety of substrates including sand and mud, seagrass beds, and marsh creeks. Adults migrate inshore in April-June, often found in high salinity portions of estuaries. Opportunistic feeders, with fish and crustaceans making up most of the diet (NOAA, 1999l)
Scup (*Stenotomus chrysops*)	Pelagic species occurring in mid-to deepwater parts of the water column during winter, shallower in summer. Found in New England during warmer months. Adults spawn during spring and summer in inshore areas from Delaware Bay to Southern New England (not as far north as project area). Juveniles and adults are found on a variety of substrates from fine to silty sand or mud; also found over mussel beds, rocks and other structures. Temperature tolerance >7 to 27C. (NOAA, 1999m)
Black Sea Bass (*Centropristis striata*)	Demersal species associated with structurally complex habitats, including rocky reef, cobble and rock fields, and exposed stiff clay. Over winters offshore at depths of 30-400m. Moves inshore during spring and offshore in fall. Temperatures 3-21C but mostly found at 9-12C. Salinity 32-36ppt. Depths 1-400m. (NOAA, 2007)

1.8.2 Coastal Beaches (310 CMR 10.27)

The coastal beach includes those unconsolidated sediments subject to wave, tidal and coastal storm action that form the gently sloping shores of the project area, including nearshore tidal flats. The coastal beach extends from the mean low water line (MLW) landward to the seaward toe of the coastal dune or coastal engineering structures. The coastal beach in the project area is shown in Figures C-28 and C-29. Delineations for coastal beach were made using a combination of data from the Woods Hole Group topographic survey and MassGIS data. A description of the beach is provided in Section 1.3 above. Cross-sections of the beach resource are included in the Engineering Plans dated XX, 2020 (Section P).

1.8.3 Coastal Dunes (310 CMR 10.28)

Coastal dunes include natural hills, mounds or ridges of sediment landward of the coastal beach, that have been deposited by wind action, storm overwash, or man-made dune restoration projects. The locations of coastal dunes in the project area are shown in Figures C-28 and C-29 and a description is provided in Section C.1.3 above. Delineations for coastal dune were made using a combination of data from the Woods Hole Group topographic survey and MassGIS data.

1.8.4 Barrier Beaches (310 CMR 10.29)

Barrier beaches are narrow low-lying strips of land that generally consist of coastal beaches and coastal dunes. Barrier beaches extend roughly parallel to the trend of the coast and are separated from the mainland by a narrow body of fresh, brackish or saline water, or a marsh system. The delineation for barrier beaches for the project area was obtained from MassGIS and is shown in Figures C-28 and C-29.

Figure C-28. Coastal beach, dune and barrier beach resources in northern end of project.

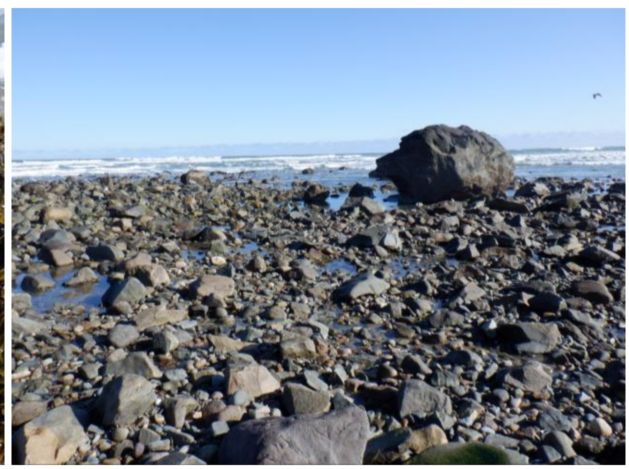
Figure C-29. Coastal beach, dune and barrier beach resources in southern end of project.

1.8.5 Rocky Intertidal Shores (310 CMR 10.31)

To assess the intertidal habitat throughout the project area, a rocky intertidal shore survey was conducted on November 19 and 21, 2019. The survey was conducted around the time of low tide. The southern portion of the project area, consisting of approximately 1.25 miles south of Green Harbor, was surveyed on November 19, while the northern portion of the project area, approximately 3.5 miles from Brant Rock to the Scituate Town line, was surveyed on November 21. There is an approximately 0.75 mile shoreline area between Brant Rock and Green Harbor that was not surveyed; this area is known to be predominantly rocky intertidal shore and is outside of the proposed project area. In the 4.75 miles of ocean facing beach that was surveyed, six (6) discrete areas of rocky intertidal shore were discovered (Figure C-30). These areas range in size from 10,028 sq ft to more than 600,000 sq ft in area, summing to a total area of 1,244,070 sq ft (28.5 acres) rocky intertidal shore within the proposed project area.

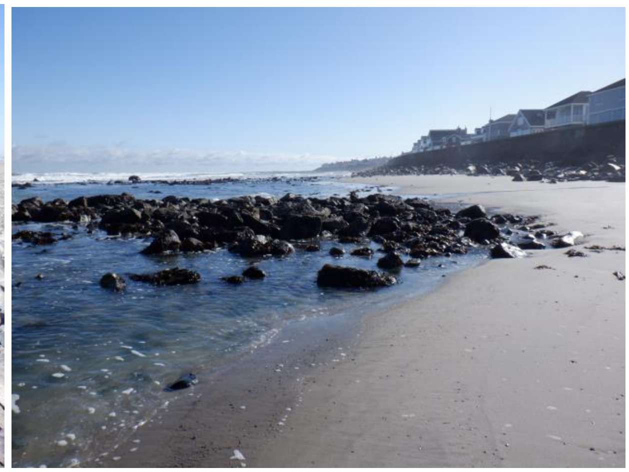
The main characteristics of the six (6) surveyed rocky intertidal shore areas are described below (from north to south):

1. Rexhame: The rocky intertidal shore area in the Old Rexhame area stretches from approximately Jackson Street to Atlantic Street and comprises 232,733 sq ft (5.3 acres). It is characterized by large boulders, tide pools, and attached fauna and macroalgae.



2. Sunrise Beach: There are two (2) surveyed rocky intertidal shore areas along Sunrise Beach. The first extends from approximately 9th Road to 5th Road and is 47,343 sq ft (1.1 acres). This area, is substantially different that the other rocky intertidal shore areas delineated as part of this project, as it consists of ocean rounded boulders piled up at the base of the seawall. With rock greater than 10 inches in diameter (i.e., boulders) located below the MHW line, this area technically meets the definition of rocky intertidal shore. However, given the lack of attached biota, and the roundness of the stones – indicating that the wave action in this area is strong enough to move these boulders around, it is unlikely that this area provides the same habitat functions as the other mapped rocky intertidal shore areas along the beach. The second rocky intertidal shore area along Sunrise Beach is just offshore Brook Street and is 68,665 sq ft (1.6

acres). This area is located lower on the beach and is characterized by significant quantities of attached macroalgae.



3. Brant Rock: The most significant rocky intertidal shore areas were mapped in the Brant Rock Beach area. Two discrete sections of rocky intertidal shore were identified in this area. The first extends from approximately Chickatawbut Avenue to Samoset Avenue and is 247,522 sq ft (5.7 acres). This area is characterized by large boulders, tide pools, and attached fauna and macroalgae. The second area is centered around the large Brant Rock groin, and encompasses the large bedrock outcrops that comprise Brant Rock itself; this area extended from just north of the Brant Rock groin to the southern extend of the survey area at approximately Bradford Street. Note that this is not the southern terminus of the rocky intertidal shore habitat, as the survey did not extend further to the south beyond the limits of the areas planned for beach nourishment.

4. Green Harbor: There was only one small (10,028 sq ft; 0.2 acres) area of rocky intertidal shore mapped south of the Green Harbor entrance. This area consisted of small, scattered boulders (boulders are defined as having a dimeter greater than 10 inches), with attached fauna and macroalgae.

5. Duxbury: No rocky intertidal shore was observed in the Duxbury portion of the survey area.

Figure C-30. Mapped rocky intertidal shore habitat within the proposed project area.

1.8.6 Land Containing Shellfish (310 CR 10.34)

A shellfish survey was conducted in the nearshore subtidal areas offshore of Marshfield and Duxbury on January 22 and 23, 2020. The purpose of the work was to document shellfish resources, particularly surf clams, in the nearshore area in the vicinity of the proposed project.

The survey was done by towing a hydraulic dredge along transect lines approximately parallel to the shoreline in waters ranging from approximately -10 to -22 ft MLLW. A total of 18 tows of approximately ¼ mile length were conducted along the Marshfield and Duxbury shoreline. A commercial grade hydraulic clam dredge measuring 15 in wide and 12 in high was used to collect surf clams and other species. The dredge was equipped with a 2.5 in mesh, and was operated from the 31 ft JC Sportfisher Dawn Treader, operated by Marine Imaging Technologies of Bourne, MA (Figure C-31).

Figure C-31. Vessel used for shellfish survey (a) and hydraulic dredge used to sample shellfish (b).

The survey area and actual towed lines are illustrated in Figure C-32. A total of eight planned tows were not completed. Five of these (tows 13, 16, 17, 18 and 19) were not conducted due to excessively rocky substrate and associated potential for damage to the equipment. One tow (10) was moved inland to avoid rocky substrate at the target area but was not conducted because the substrate in the new area was too uneven to safely tow the dredge.

Two planned tows (tows 20 and 21) were not completed for two reasons: trawling in this area posed a risk to the equipment, and the substrate was unfavorable to surf clams. Tows 20 and 21 were located in the vicinity of the former disposal area near the entrance channel to Green Harbor. One tow in this area was attempted (tow 20), but the first attempt resulted in equipment breakage (hydraulic hose rupture) and returned three boulders, approximately 12-16” in diameter, along with a gray clay in the damaged hose and adhered to the dredge. A second attempt resulted in removal of the door latch on the dredge. At this time trawling in this area ceased because of the dangerous nature of trawling in this area, as well as the unfavorable substrate for surf clams (clay with large boulders). Three tows (6, 11, 15) were completed, but cut short due to rocky substrate shown on sidescan sonar in real time.

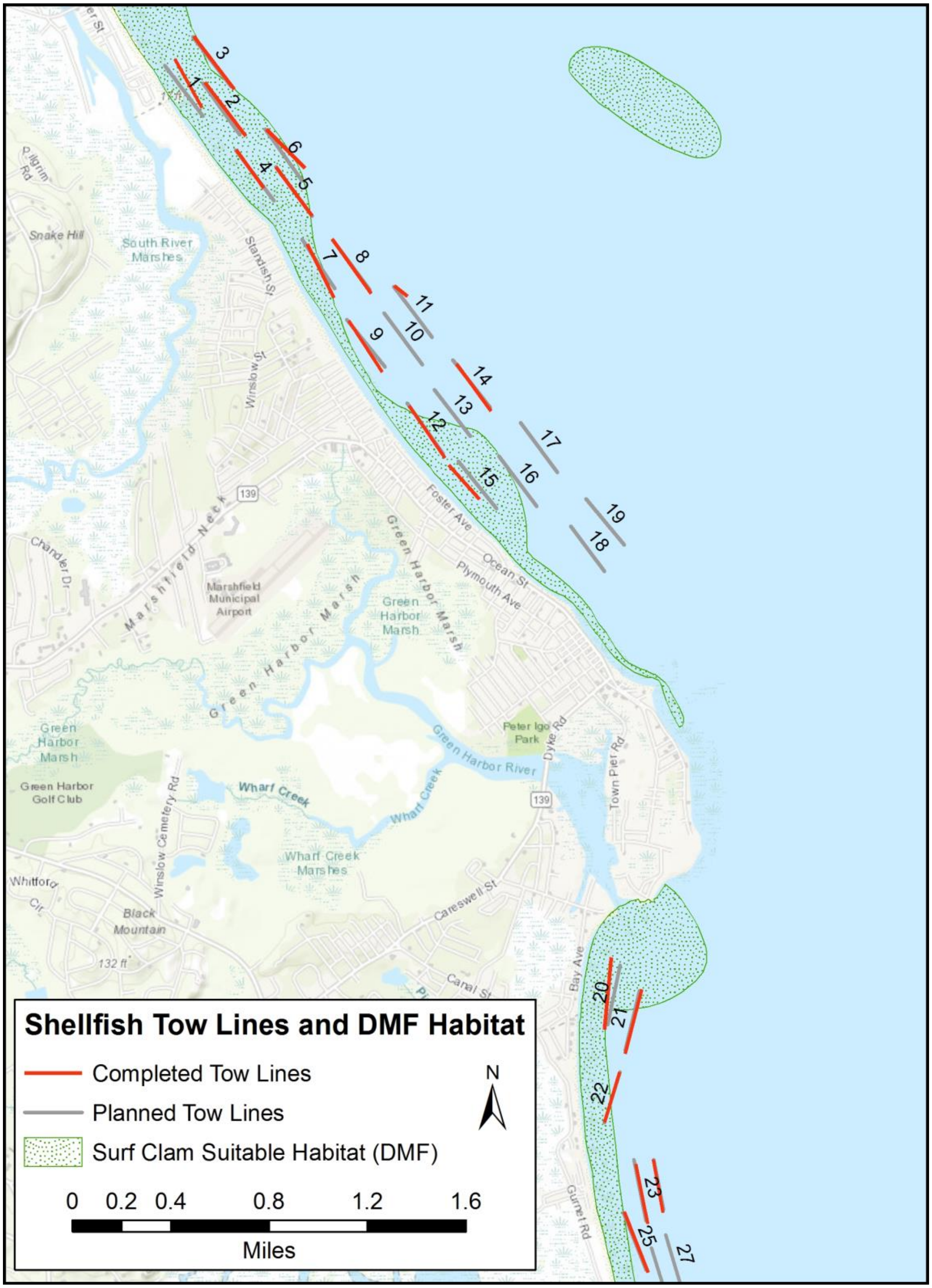


Figure C-32. Map showing locations of planned and complete shellfish survey tow lines.

Shellfish and other species were collected were identified and classified as juveniles and adults. Surf clams were classified in three categories: >3”, 3 – 5”, and > 5”. Other species were measured, fish as longest length, and crabs as carapace width. Species obtained during the tows included:

- Surf Clam (*Spisula solidissima*)
- Cancer crab (*Cancer irroratus*)
- Winter flounder (*Pseudopleuronectes americanus*)

Due to the 2.5 in size of the mesh in the dredge, some juveniles may have been present but not retained in the dredge. However, one very small (0.5 in) juvenile surf clam was found beneath the dredge during transit between tows, likely caught in rocks or sediment that was occasionally present in or on the edges of the dredge when hauled in. Some of the clams came up damaged due to crushing of shell on contact with the dredge blade. Figure C-33 shows species obtained in select tows 5, 2, and 14). Table C-10 provides species and the size of individuals obtained in each tow.

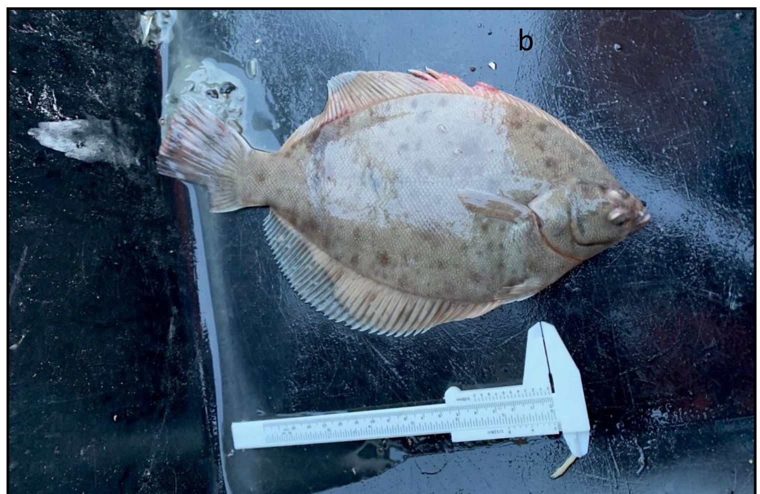


Figure 33. Surf clams (a), flounder (b) and cancer crab (c) collected during tows 5, 14, and 2, respectively.

Table C-10. Habitats Used by EFH Species in the Project Area.

Tow #	Surf Clams >3"	Surf Clams 3 - 5"	Surf Clams >5"	Other Species & Size	Notes
1					No animals. 2 rocks (2-4")
2	1 (just under 3")			1 Cancer crab (3" carapace width)	Lots of rocks and gravel in dredge
3					No animals. Many rocks (at least 30 rocks) and gravel. Rocks 1-2" mostly; some up to 3.5"
4	4				No rocks
5	4	2			Few rocks
6					No animals. Stopped tow early because of rock/boulders on sidescan indicating dangerous area for towing equipment
7	1	1			Rocks in dredge
8	1	1			Rocks and gravel in dredge
9					No animals. Rocks and gravel in dredge
10					After 2 attempts tow was abandoned
11					Few rocks. No animals. Cut tow short due to excessive rocky area on sidescan, indicating risk to equipment
12					No animals. 1 rock in dredge (4")
13					Too rocky to trawl
14				Windowpane flounder (9")	Few rocks in dredge
15		1			Dredge retrieved with large amounts of peat
16					Too rocky to trawl
17					Too rocky to trawl
18					Too rocky to trawl
19					Too rocky to trawl
20					Dredge got caught up on rocks. Stopped tow. Found 3 large rocks (12 - 16") in dredge. Fine clay/silt on sizes / top of dredge. On second attempt the dredge door handle became dislodged. Abandoned this tow
21					Tow not attempted. Adjacent to disposal site, and to tow #20 which has unfavorable substrate (boulders and clay) for clams
22					Nothing in dredge. Checked to ensure working correctly
23					No animals. No rocks. Dredge working correctly
24					No animals. No rocks. Dredge working correctly
25		1			
Totals	**11**	**6**		**2**	

The surf clam survey was conducted as planned, with the exception of certain tows which were impossible to conduct due to unfavorable substrate and associated risk of damage to equipment. Numbers of surf clams and other species were low. Low numbers of surf clams could be associated with the precise spatial extent of sampling during the tows. Specifically, the dredge penetrates only about 6-10 in into the sediment. Surf clams may burrow deeper into sediment during winter due to colder temperatures at the sediment-water interface. Additionally, there may be more clams in shallower water, closer to the intertidal. These very shallow areas were not sampled due to time constraints and lack of adequate water depth for safe sampling.

1.8.7 Estimated Habitats of Rare Wildlife (310 CMR 10.37)

According to the Massachusetts Natural Heritage & Endangered Species Program (NHESP), Division of Fisheries & Wildlife, portions of the project area are located within estimated and priority habitat for state-listed rare species. The northern end of the project area around Rexhame Beach is located within priority and estimated habitat for the Piping Plover and Seabeach Needlegrass, both with threatened state status (Figure C-34). The southern end of the project area falls within priority and estimated habitat for the Piping Plover and Least Tern (Figure C-35). The Least Tern has a state status as a species of special concern. These species are protected under the Massachusetts Endangered Species Act and its implementing regulations (321 CMR 10.00), as well as the Wetlands Protection Act and its implementing regulations (310 CMR 10.00). A letter from NHESP dated Jan. 30, 2020 listing the protected species in the project area is provided in Section M.

1.8.9 Land Subject to Coastal Storm Flowage (310 CMR 10.57)

Land subject to coastal storm flowage is land subject to any inundation caused by coastal storms up to and including that caused by the 100-year storm, surge of record, or storm of record, whichever is greater, and includes both V zones (velocity zones or areas of wave action), and A zones (the extent of the quantifiable 100-year coastal floodplain). The entire project area is mapped on the FEMA Flood Insurance Rate Maps (FIRM) as being in land subject to coastal storm flowage.

1.9 Historic and Archaeological Resources

Historic and archaeological resources are not generally known to exist in the project area. Consultation with Massachusetts Historical Commission (MHC) and the Bureau of Underwater Archeological Research (BUAR) will be performed as part of the permitting process.

Figure C-34. Massachusetts NHESP estimated and priority habitat areas for the northern project area.

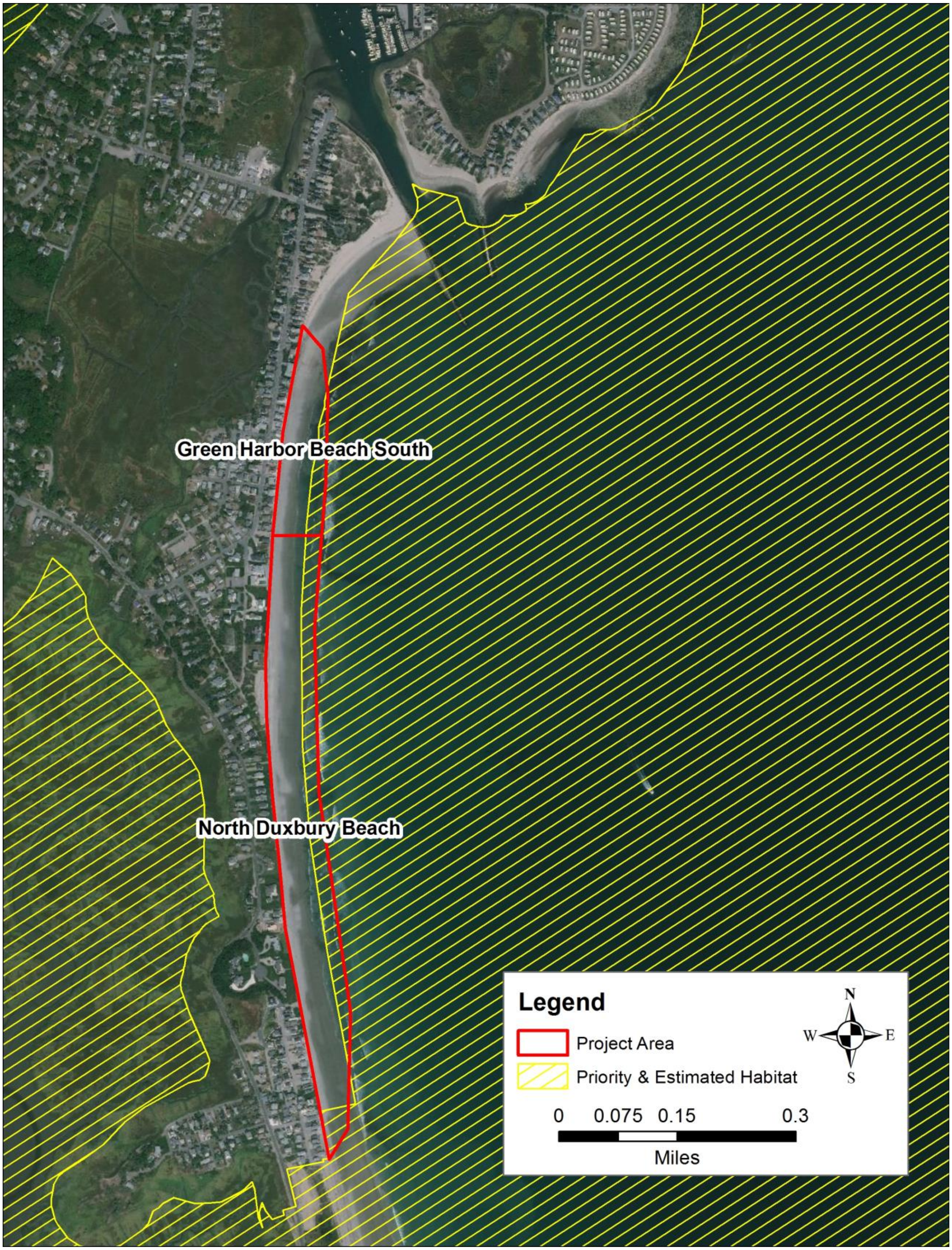


Figure C- 35. Massachusetts NHESP estimated and priority habitat areas for the southern project area.

1.10 Property Ownership

Review of the Marshfield and Duxbury assessors' databases indicate that that very few shorefront properties are owned by the municipalities (Figure C-36). Despite this fact, the towns provide public beach services at the following locations: Rexhame, Winslow Avenue, Fieldston, Sunrise, Brant Rock, and Green Harbor Beach, and Duxbury Beach. In the event that public agencies (i.e., towns, state, or federal govt.) fund the implementation of beach/dune nourishment on privately owned beaches, it will be necessary to secure the appropriate easements from the property owners. The easements would grant in perpetuity a public on-foot right-of-passage along and across the shore of the coastline between the mean high-water line and the entire nourished area. As part of the planning process for publicly funded beach nourishment, the town has drafted sample "Beach Nourishment Easement", "Release of Land Damage", and "Notification Letters" that were sent to all affected property owners in the event of a nourishment project. A list of affected property owners, and related correspondence is provided in Section N.

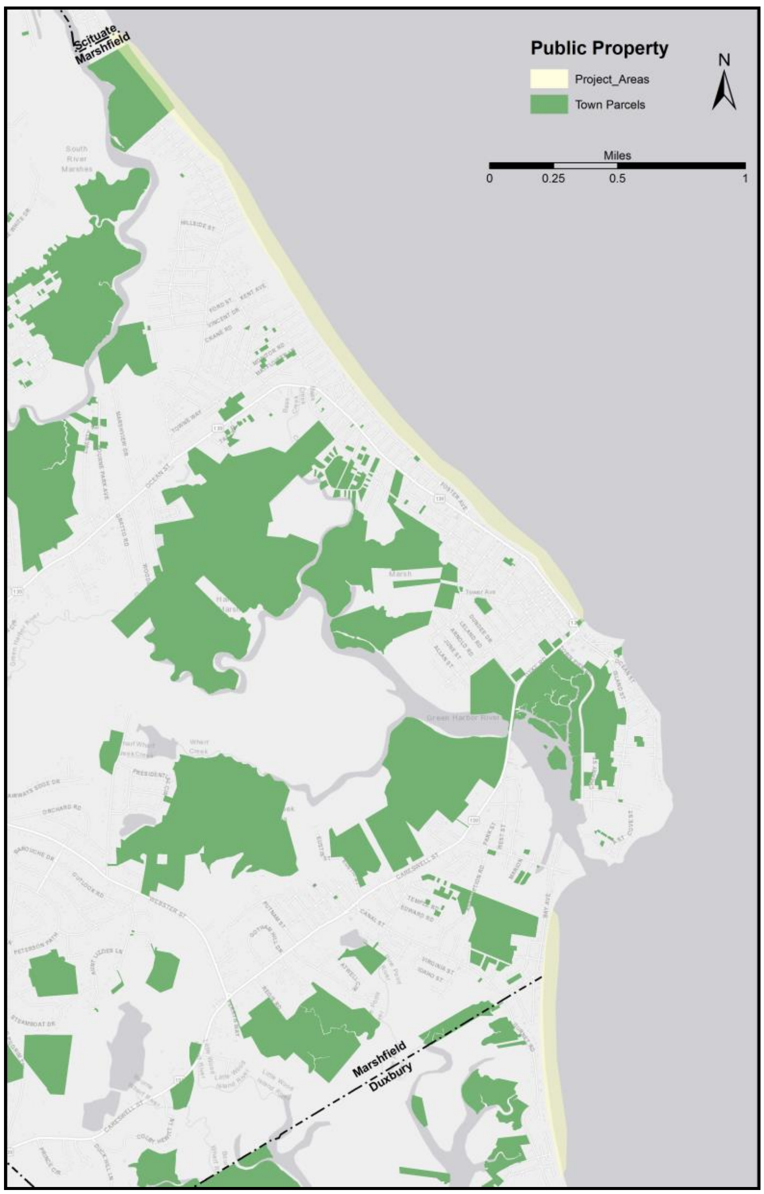


Figure C-36. Publicly owned lands in Marshfield and Duxbury.

1.11 Repetitive Loss Areas

FEMA flood claim data for the period 1978 through 2017 were reviewed to evaluate specific areas of Marshfield and Duxbury with high numbers of repetitive loss properties. The data are useful in prioritizing beaches with high probability of flood and/or storm damage for future resiliency projects. Sunrise Beach in Marshfield and Gurnet Rd. Beach in Duxbury had the highest number of repetitive loss properties, followed by the Brant Rock area and Bay Ave. Beaches in Marshfield (Figure C-37).

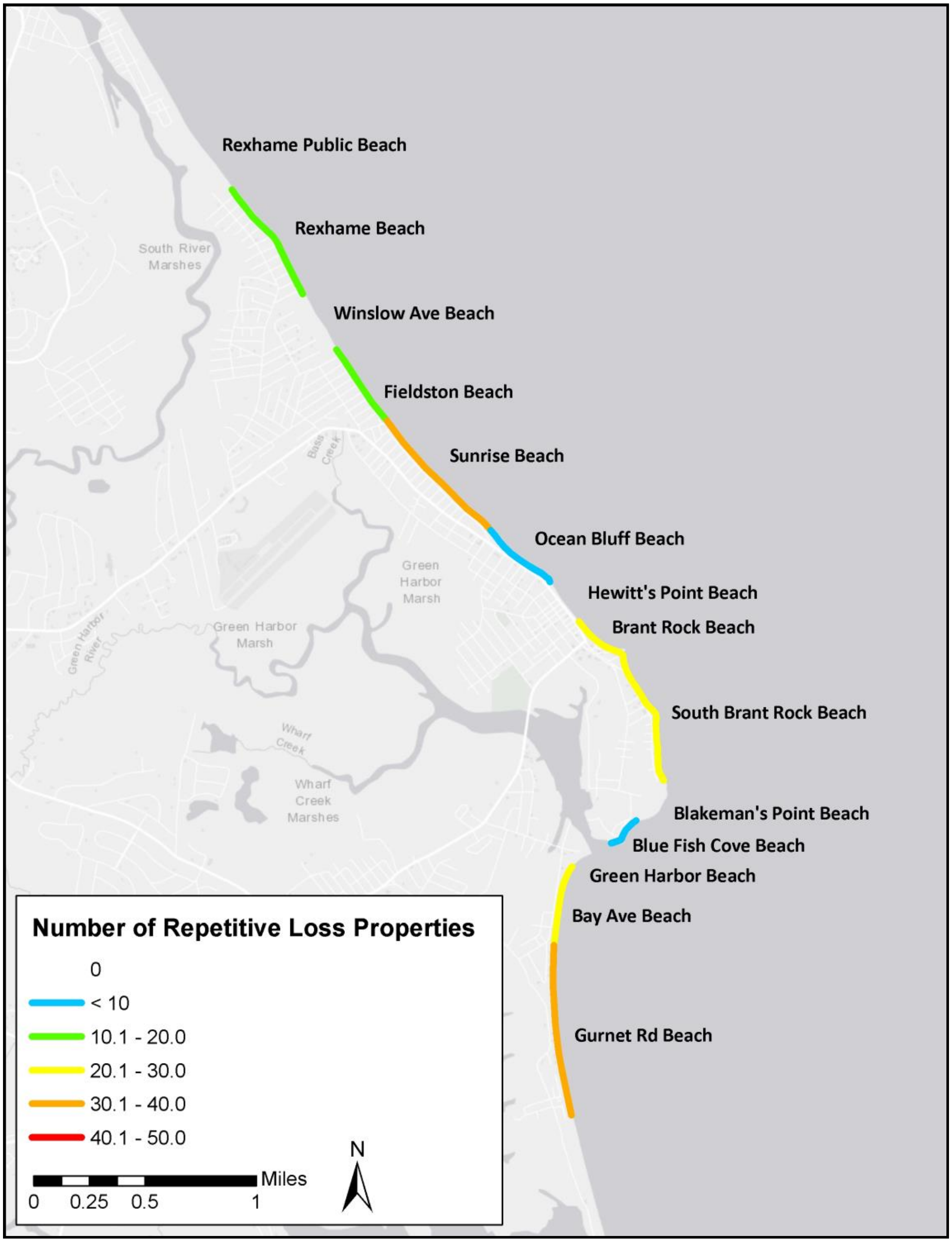


Figure C-37. Number of repetitive loss properties in each beach for the period 1978 to 2017.