Assessment and Analysis of Adaptation Alternatives For Coskata-Coatue Wildlife Refuge Properties

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ACRONYMS

ADCIRC	ADvanced Circulations model
ARP	Annual Return Period
BH-FRM	The Boston Harbor Flood Risk Model
CA/T	Central Artery/Tunnel Project
CDFs	Cumulative probability Distribution Functions
CVA	Climate Vulnerability Assessment
CVI	Coastal Vulnerability Index
FHWA	Federal Highway Administration
LiDAR	Light Detection and Ranging
MA CZM	Massachusetts Coastal Zone Management
MassDOT	Massachusetts Department of Transportation
MC-FRM	Massachusetts Coastal Flood Risk Model
NACCS	North Atlantic Coast Comprehensive Study
NCF	Nantucket Conservation Foundation
SLAMM	Sea Level Affecting Marshes Model
SLR	Sea Level Rise
SWAN	Simulating Waves Nearshore
Trustees	The Trustees of Reservations

1.0 EXECUTIVE SUMMARY

The Coskata-Coatue Coastal Assessment and Analysis of Adaptation Alternatives project was undertaken to support and inform the project stakeholders coastal management strategy, which guides their work in effectively and responsibly managing their coastal properties to be more resilient to alteration from coastal erosion and storm impacts, to keep them open and accessible to the public, and to protect their fragile ecosystems, including wildlife species and habitats. This comprehensive analysis will help the Trustees of Reservations (Trustees) and the Nantucket Conservation Foundation (NCF) prioritize how best to proactively protect their vulnerable coastal properties, including some of the most beautiful, historic, and ecologically significant beaches in the region. This project provided an opportunity to develop and implement innovative approaches to preserve the integrity of the Trustees and Nantucket Conservation Foundation's many miles of barrier beaches, coastal dunes, coastal banks, wetland resources, and upland habitats along Nantucket Harbor, Nantucket Sound, and the Atlantic Ocean. Woods Hole Group developed innovative approaches to establish the Trustees and NCF as leaders in beach adaptation while meeting the stated goals of the project including:

1) Identifying adaptive alternatives to maintain barrier beach and dune integrity focused on the four selected areas (Figure 1) of high vulnerability to overwash and erosion including:
    a. The Haulover
    b. Coskata Pond
    c. The Galls
    d. Coatue Between 1st and 2nd Point

Figure 1. Locus map of the Trustees and Nantucket Conservation Foundation properties.

2) Perform coastal processes analyses to evaluate existing conditions and likely success of potential alternatives with respect to climate change, sea level rise, shoreline change and other environmental factors.

3) Prepare a report of the study's findings for each area of concern and incorporating a decision matrix with potential costs, permitting considerations, and expected lifespans of a collection of adaptation alternatives.

2.0 INTRODUCTION

2.1 GEOLOGIC EVOLUTION OF NANTUCKET

The geologic evolution of Cape Cod and the Islands can be directly linked to the advance and retreat of continental glaciers, and the rise in sea level that followed retreat of the last ice sheet. During the most recent glacial stage, which occurred between 75,000 and 21,000 years ago, more snow fell over the northern latitudes than melted each year. As the snow accumulated and compacted, it formed large ice sheets or glaciers. The Laurentide ice sheet (named after the Laurentian region of Canada where it first formed) spread into the United States, and extended south to New York City, Long Island, Martha's Vineyard, and Nantucket, covering all New England. This maximum southern extent of the ice sheet occurred approximately 21,000 years ago.

Three major lobes of the Laurentide ice sheet covered the Cape and Islands region: Buzzards Bay Lobe, Cape Cod Bay Lobe, and the South Channel Lobe. During its advance, the glacier carved the land underneath, each lobe tearing off large pieces of bedrock from the terrain in its path, sculpting ridges and valleys, and grinding larger rocks into sand and silt-sized particles. Nantucket was formed at the interlobate intersection between the Cape Cod and South Channel lobes at the point of their farthest southerly advance around 21,000 years ago (Figure 2).

Figure 2. Extents of Laurentide ice sheets (Oldale, Geologic History of Cape Cod, Massachusetts, 1976).

The ice sheet held this maximum position for more than 1,000 years, until a warming of the world's climate caused glacial melting. Evaporation rates exceeded snowfall rates, and the ice began to melt. As the ice receded, the sand, gravel, clay, and boulders that the glacier had accumulated were deposited in the form of moraines (accumulation of unconsolidated sediment/debris) and outwash plains (sediment deposited by glacial meltwater) to form Martha's Vineyard and Nantucket, as well as many adjacent shoals.

On Nantucket, as the ice sheet receded, glacial moraine deposits were left marking its most seaward advance. The Nantucket moraine occupied much of the area which is now the village of Nantucket to Polpis and Sankaty Head. Two additional moraine deposits to the north were Coskata Headland, and what is now Great Point. Point Rip, the gravelly shoal extending from the tip of Great Point is a remnant of this deposit. While the moraine deposits were once islands, an additional deposit known as the Coatue Platform was a submerged bench of glacial material on top of which Coatue Beach would eventually form (Rosen, 1972). Siasconset formed from outwash deposits at the foot of the ice sheet (Woods Hole Group, 1999).

As the glaciers receded northward, the earth's crust began to rebound, resulting in the emergence of the shoreline and a lowering of relative sea level between 10,000 and 12,000 years ago. Since then, the glacial rebound of the earth's crust has slowed while eustatic sea level (worldwide) has risen to present day levels. The rising relative sea level, waves, and currents, eroded glacial deposits and redeposited the sands and gravels to form shoals, beaches, and spits (Woods Hole Group, 1999).

Coatue Beach was formed as the northwest edge of Coskata Headland was eroded by waves and currents of Nantucket Sound. Sands and gravels were transported and deposited to the southwest by predominant northeast winds and currents forming the narrow spit which encloses Nantucket Harbor. Winds transported and redeposited beach sands to form the topography of Coatue Beach, defined by dune ridges oriented to the northwest, and backed by cuspate spits projecting into the Harbor. Several of the cuspate spits, including 1st Point and 2nd Point to the west, are home to salt marshes. The present-day vegetation grows atop a broad terrace of *Spartina alterniflora* peat, with depths ranging approximately 50-214 cm (Rosen, 1972). Peat deposits from historic marshes persist to the east along the leeside of Coatue Beach.

At the northeastern tip of Nantucket, waves and currents of the open Atlantic Ocean eroded and redeposited sediment between the areas of Coskata Headland and Great Point. This created a tombolo, or land-bridge, between the two glacial moraine deposits sometimes known as The Haulover beach.

2.2 SHORELINE CHANGES

The coastal shores of the island of Nantucket are constantly under dynamic interaction with wave forces affected by tides and occasional storm winds. The non-cohesive, coarse-grained sands along the exposed beaches and bluffs have little natural resilience against these forces and are easily displaced and relocated. Seasonal changes in predominant wind direction and frequency of storms alter the beach slopes affecting the interaction of waves running up through the intertidal shore. Breaking waves scour the beach and suspend their sand grains in restless flow until they are deposited by calmer waters. Those sands may accrete on a neighboring beach or accumulate in a nearby shoal until they are repositioned again in their ongoing migration.

The configuration of the exposed shoreline to the typical tidal currents and storm waves predicates the expected rate of shoreline change for a given area. The United States Geological Survey (USGS) has compiled available shoreline location data from different sources over time and evaluated that information in order to establish long- and short-term change rates (Figure 3). Their analysis indicates that the northwesterly corner of the island at Smith's Point and Tuckernuck has a consistent long-term erosion trend with the Atlantic Ocean facing shore of Muskeget Island having the highest long-term erosion rate in the state at almost 24 feet per year. The northeasterly corner of Nantucket at Great Point typically experiences accretion in the long-term.

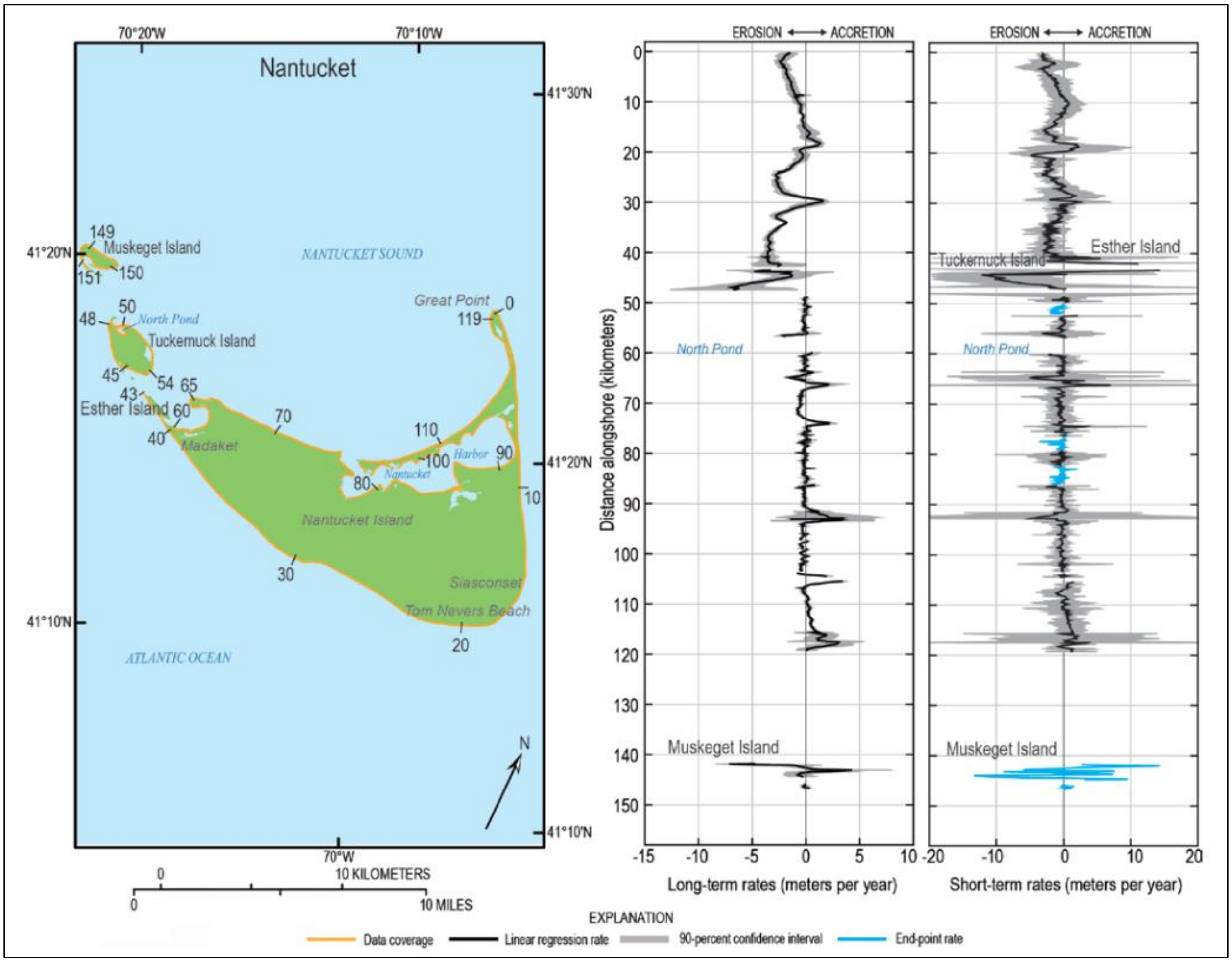


Figure 3. Map and graphs of short- and long-term shoreline change rates Massachusetts Shoreline Change Mapping and Analysis Project, USGS.

2.2.1 Shoreline Change Data Sources and Methodology

A computer-based shoreline mapping methodology within a Geographic Information System (GIS) framework was used to compile and analyze changes in historical shoreline position for the oceanside and Harbor side of Coatue Point and Great Point. The purpose of this task was to quantify the spatial and temporal changes in shoreline position using the most accurate data sources and compilation procedures available, and to evaluate the long-term and short-term rates of change. This evaluation included historical shoreline information from up to eight (8) different time periods from 1846 to 2013 from the Massachusetts Office of Coastal Zone Management's (CZM) Massachusetts Shoreline Change Project, as well as one (1) additional recent year (2019), see Figure 4. Assuming the trends continue at the same rate into the future, the information from the shoreline change analysis can also be used to predict patterns of shoreline erosion over the next several decades.

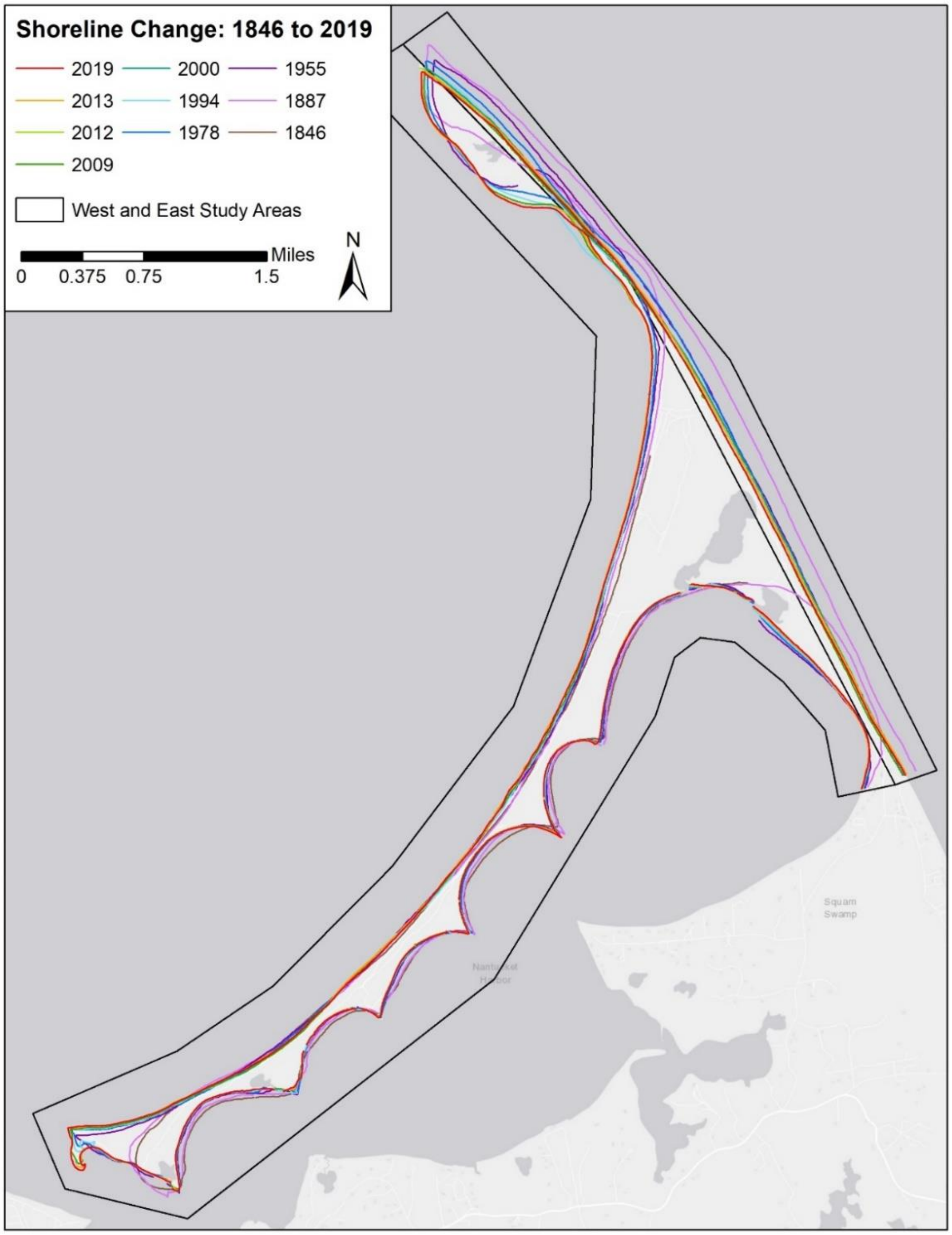


Figure 4. Historical shoreline positions from 1846 to 2019 for the complete study area.

CZM began the Massachusetts Shoreline Change Project in 1989 to provide reliable data on shoreline trends for coastal managers and property owners to support land-use decisions. For the western portion of the study area (Figure 4), CZM data include seven (7) mapped high water lines from 1846 to 2013. For the eastern portion of the study area (Figure 4), CZM data include eight (8) mapped high water lines from 1887 to 2013. High water lines were produced using historical and modern data sources including historical maps, aerial photographs, and LiDAR. Across the entire study area, a total of nine (9) CZM shoreline years are utilized in this analysis, which are listed in Table 1.

Table 1. Data Sources for Shoreline Change Analysis.

Year	Source	Analysis Area
2019	MassGIS	West & East
2013	CZM	West & East
2012	CZM	East
2009	CZM	West & East
2000	CZM	East
1994	CZM	West & East
1978	CZM	West & East
1955	CZM	West & East
1887	CZM	West & East
1846	CZM	West

In addition to the historical shorelines obtained from CZM, Woods Hole Group also compiled and analyzed recent aerial imagery from MassGIS Orthophotography (already georeferenced). Data covering eight (8) time periods in total were evaluated for the western portion of the study area spanning the 173-year period from 1846 to 2019 (Table 1). For the eastern study area, data covering nine (9) time periods in total were evaluated spanning the 132-year period from 1887 to 2019 (Table 1).

Using the georeferenced imagery from MassGIS, the location of the 2019 high water line (HWL) was identified and digitized. Once all shorelines (including those obtained from CZM) were brought to a common coordinate system, spatial and temporal changes in the shoreline position were computed using Digital Shoreline Analysis System (DSAS) software version 4.3. DSAS is a software developed by the USGS to calculate shoreline change over time within a GIS framework. Shoreline change rates were calculated by first identifying a series of shore normal transects along the coastline where discrete measurements of change could be made through time, and where rates of change could be determined. A total of 1,168 shore normal transects were established at 100 foot evenly spaced intervals along the coastline. At each transect, distances of shoreline movement were calculated, and annual rates of change were determined using the various time intervals between the data sources. Rates of change were calculated using the linear regression method. In this method, an average rate of change is based on a best-fit line to a series of points representing the shoreline position over time. The linear regression method is most accurate when looking at long-term averages and is most often used for planning purposes and management decisions.

The digitized positions of the shorelines are shown in Figure 45. Shoreline change rates were analyzed for the entire period for the western (1846 to 2019) and eastern (1887 to 2019) study areas to provide long-term trends, as well as for a shorter time frame (1978 to 2019) consistent across the entire study area. The long-term linear regression rate of shoreline change is presented in Figure 5 for the entire study area, as well as in Figures 6 through 9 for specific areas of interest. The long-term shoreline change rates displayed in Figures 5 through 9 are also presented in the graphs in Figures 10 through 12, along with the short-term rates of change. The short-term linear regression rate of shoreline change is also presented in Figure 13 for the entire study area, as well as in Figures 14 through 17 for specific areas of interest.

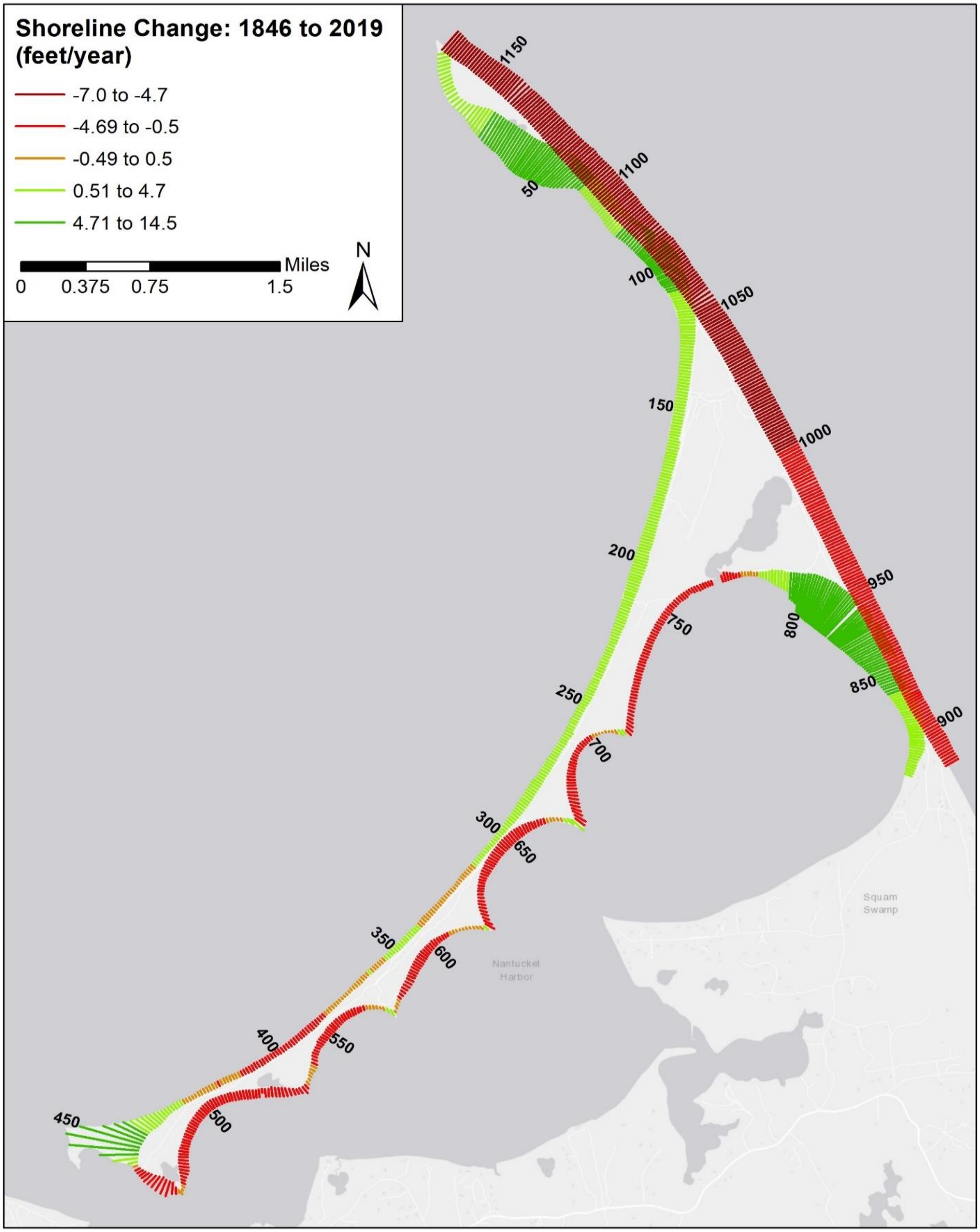


Figure 5. Long-term shoreline change rates for the western (1846-2019) and eastern (1887-2019) study areas. Negative values indicate erosion, while positive values indicate accretion.

2.2.2 Shoreline Change Discussion: Long-Term Rates

Overall, the long-term rate of change between 1846 and 2019 indicates that the entire eastern shoreline of Great Point is eroding, while the western side of the shoreline is accreting (Figure 5). This has resulted in the western migration of the point since 1887. Transects 1-100 on the western side of Great Point are accreting at an average rate of 5.8 feet/year (Figure 10), while transects 1,068-1,168 on the eastern side of the point are eroding at an average rate of -6.1 feet/year (Figure 11). This suggests that the long-term rate of accretion on the western shoreline is approximately equal to the rate of erosion on the eastern shoreline and that the landform is maintaining a relatively stable width.

Continuing west along the northern shoreline of Coatue Point, the shoreline is generally accreting or relatively stable with an average long-term shoreline change rate of 1.3 feet/year (transects 101-460). However, within this area, there is a small stretch of shoreline from transects 370 to 427 with an average long-term shoreline change rate of -0.5 feet/year, indicating erosion (Figure 10). Along the west shore of Coatue Point, rates of accretion increase sharply to an average of 8.5 feet/year (transects 446-453). This indicates a general sediment transport direction from the northeast to the southwest, with the barrier beach extending into the inlet. In contrast, the southern, Harbor side shoreline of Coatue Point is primarily experiencing erosion at an average long-term rate of -1.0 feet/year along transects 461-781 (Figure 12).

The shoreline directly north (transects 175-460) is accreting at an average long-term rate of 0.9 feet/year, indicating Coatue Point is relatively stable but may be migrating northward slightly. The unique current conditions present within Nantucket Harbor have resulted in a series of points on the southern shoreline of Coatue Point. Long-term shoreline change rates in Figure 5 indicate that erosion decreases in severity at the southern tips of the points; a trend also displayed in the graph in Figure 12, which contains a series of peaks of minor accretion corresponding to the points that make up the shoreline. South of transect 781, from transects 782 to 887, the Harbor side shoreline around Wauwinet is accreting at an average long-term rate of 5.5 feet/year (Figures 5 and 12).

Within the total study area, there were several areas of interest including The Galls, the area between 1st and 2nd Point, The Haulover, and Coskata Pond (Figures 6 through 9). Long-term shoreline trends within these areas generally follow the larger trends discussed in the context of the entire study area and are outlined below.

- The Galls: Located along a thin stretch of Great Point and experiencing erosion at an average of -5.8 feet/year (transects 1,050-1,110) on the oceanside and accretion at an average of 5.1 feet/year (transects 60-120) on the Harbor side (Figures 6, 10, and 11). This indicates a long-term westward migration of the landform in this area.
- 1st and 2nd Point: Eroding at an average long-term rate of -1.4 feet/year from transects 470 to 530 (Figures 7 and 12). Erosion decreases towards the points themselves, with minor accretion occurring at the points, and these features appear to be relatively stable, having persisted since the mid-1800s.
- The Haulover: Experiencing shoreline trends similar to The Galls (Figures 8 and 11); the Harbor side shoreline is accreting at an average long-term rate of 6.2 feet/year (transects 790-880), while the oceanside is eroding at an average rate of -3.3 feet/year (transects

890-960). However, in this location, accretion on the Harbor side is almost twice the rate of erosion on the oceanside.

- Coskata Pond: Eroding at an average rate of -4.4 feet/year (transects 960-1,010) (Figures 9 and 11).

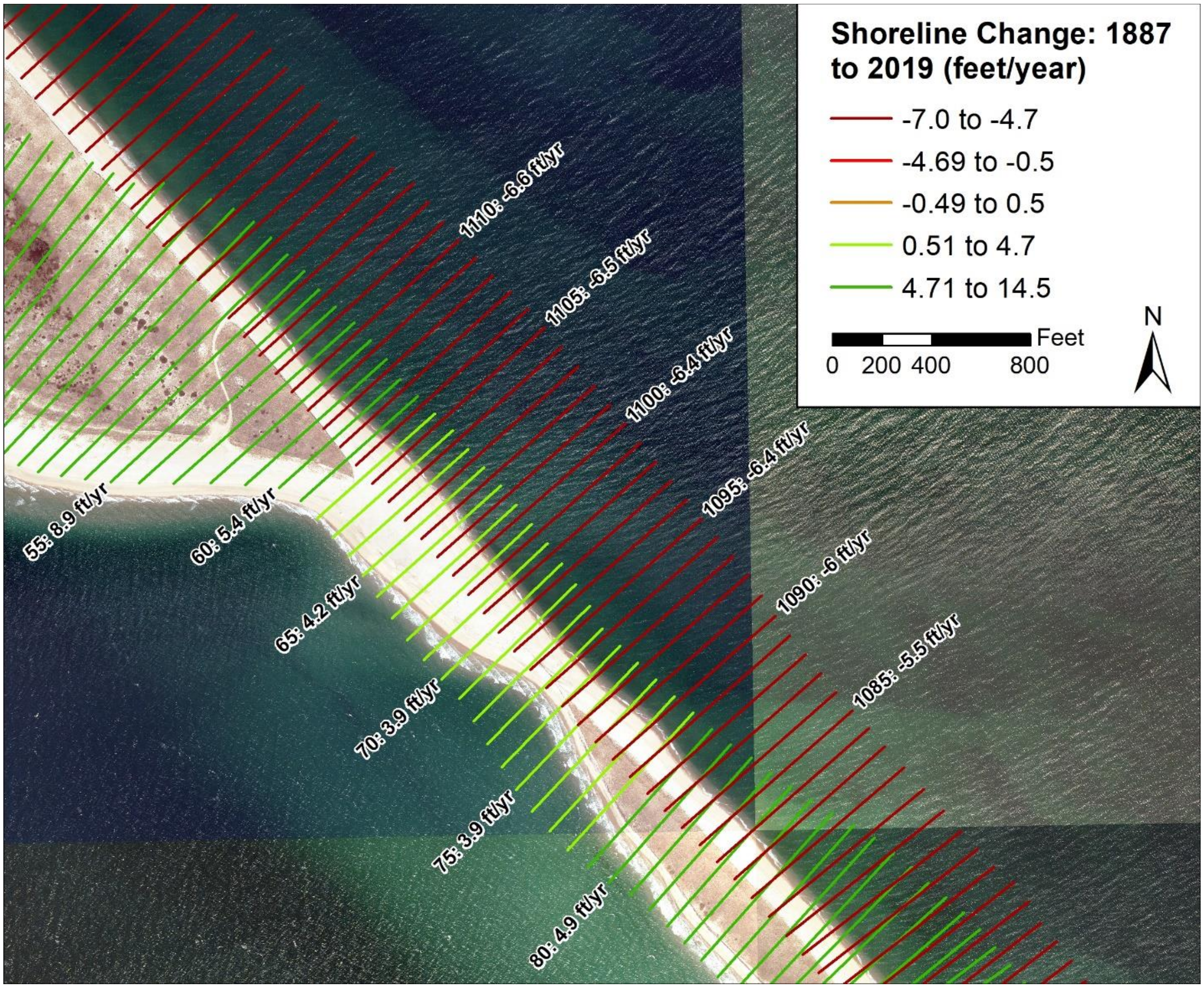


Figure 6. Long-term shoreline change rates for The Galls (1887-2019). Background imagery is 2019 MassGIS imagery. Negative values indicate erosion, while positive values indicate accretion.

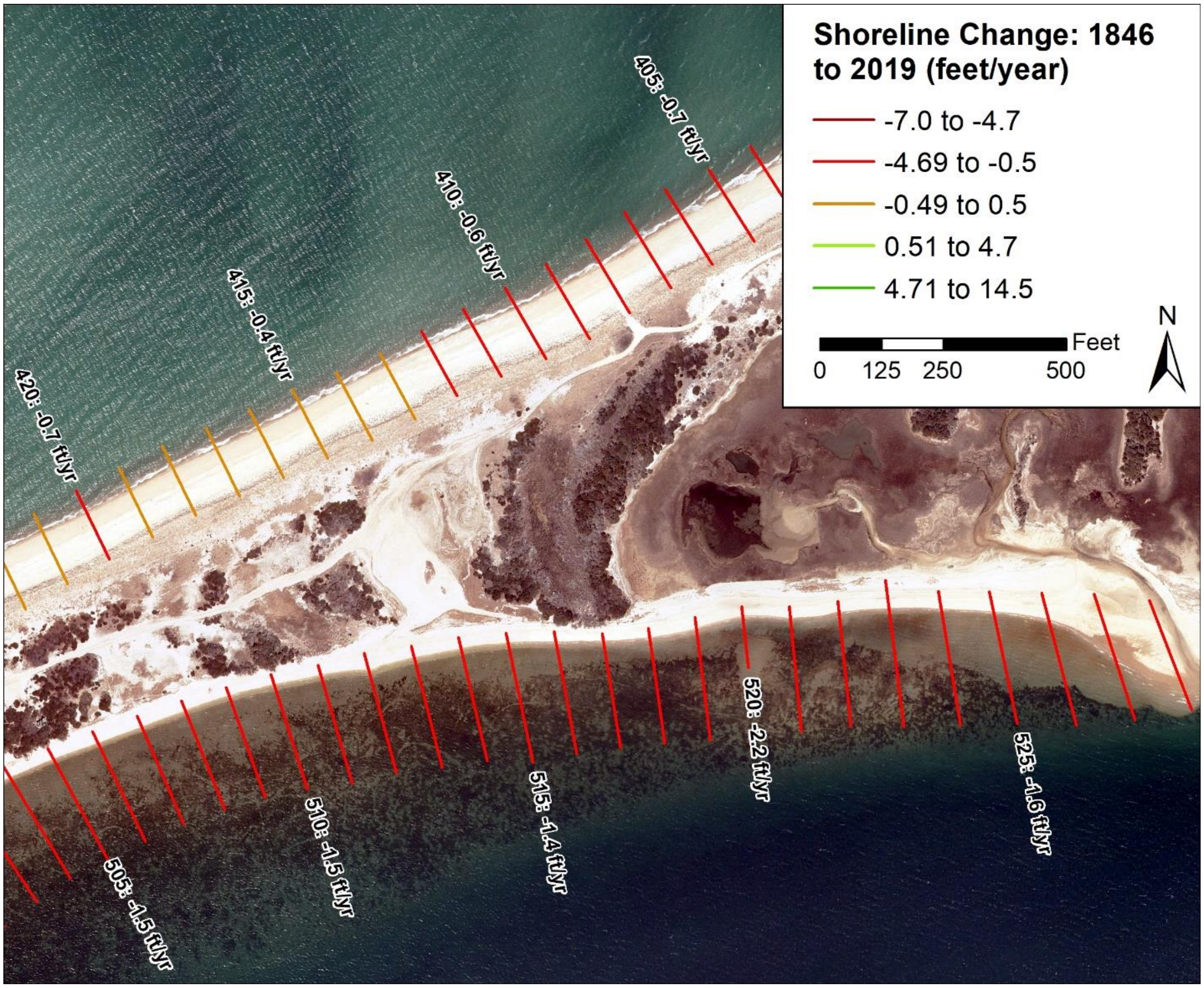


Figure 7. Long-term shoreline change rates between 1st and 2nd Point (1846-2019). Background imagery is 2019 MassGIS imagery. Negative values indicate erosion, while positive values indicate accretion.

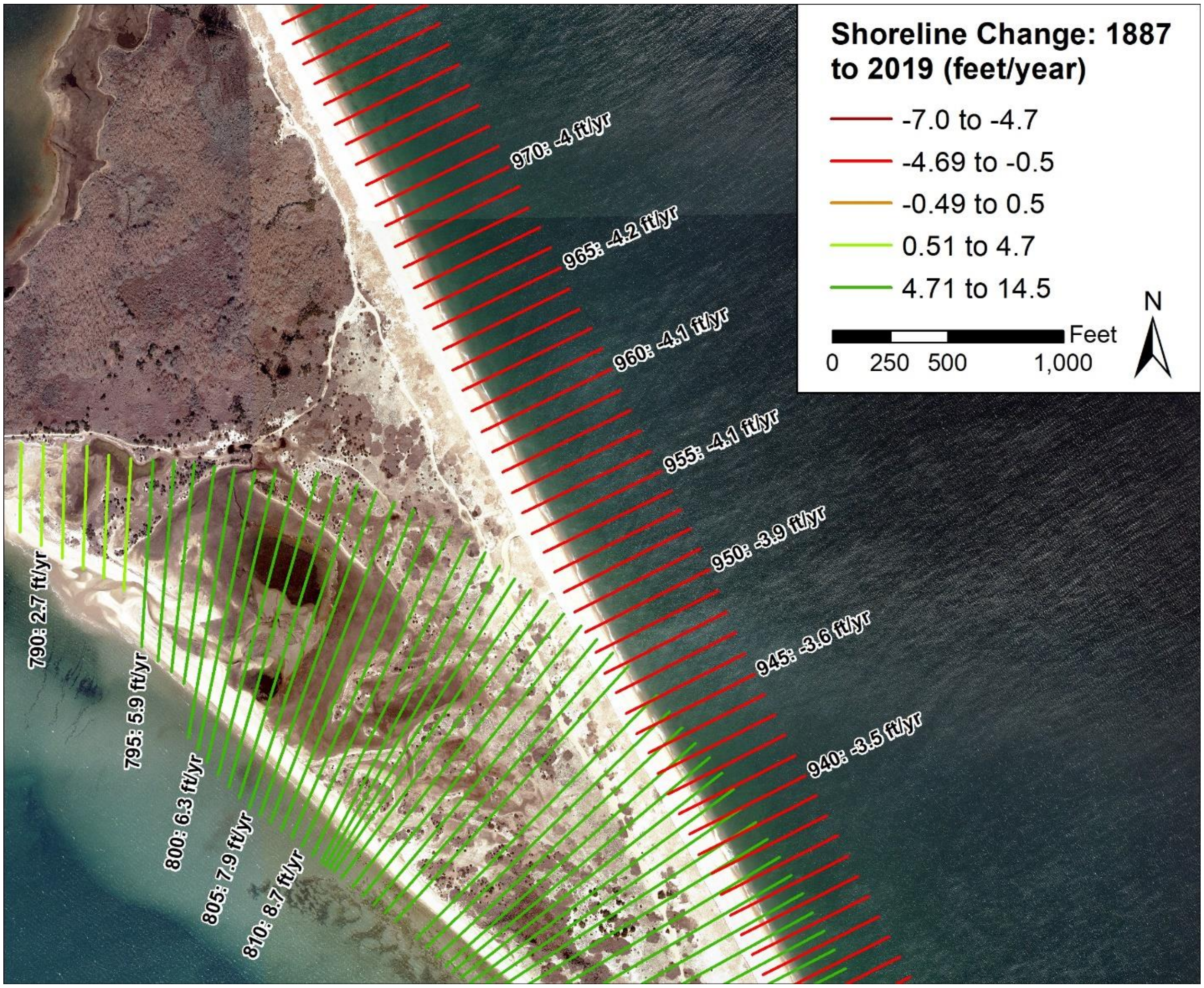


Figure 8. Long-term shoreline change rates for The Haulover (1887-2019). Background imagery is 2019 MassGIS imagery. Negative values indicate erosion, while positive values indicate accretion.

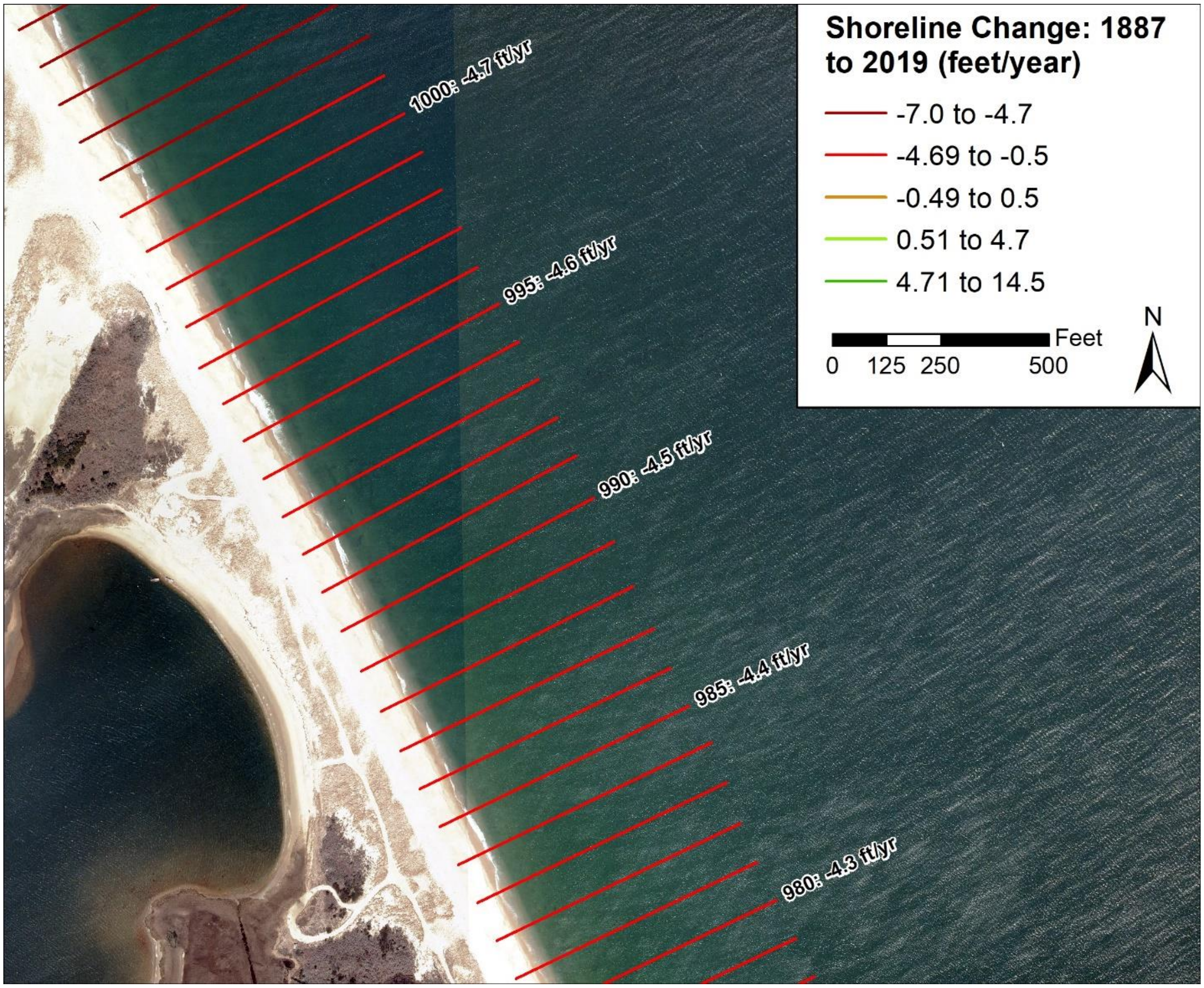


Figure 9. Long-term shoreline change rates for Coskata Pond (1887-2019). Background imagery is 2019 MassGIS imagery. Negative values indicate erosion, while positive values indicate accretion.

2.2.3 Shoreline Change Discussion: Short-Term Rates

Short-term shoreline trends for the time from 1978 to 2019 were also analyzed (Figure 13). Overall, the entire eastern shoreline of Great Point is still eroding, while the western shoreline is accreting. Average short-term shoreline change rate for transects 1-100 on the western shoreline is 4.3 feet/year (Figure 10), which is slightly lower than the long-term average rate of 5.8 feet/year. On the eastern shoreline of Great Point from transects 1,068 to 1,168, the shoreline is eroding at an average short-term rate of -4.7 feet/year (Figure 11), which is also lower compared to the long-term rate but is approximately equal to the short-term rate of accretion, indicating stable westward migration of Great Point.

West of Great Point, the northern shoreline of Coatue Point is generally accreting (Figure 10), with an average short-term shoreline change rate of 1.7 feet/year (transects 101-460), like the long-term rate for this area. In contrast to the long-term rates, short-term rates for this area indicate a few additional areas along the northern shoreline of Coatue Point experiencing moderate erosion, including transects 297-304 and 329-400 (Figure 10). The average short-term rate of accretion increases at the west shore of Coatue Point, to 8.0 feet/year (transects 447-552), which is comparable to the long-term rate in the same area of 8.5 feet/year.

The Harbor side shoreline of Coatue Point is still experiencing erosion in the short-term of -0.8 feet/year from transects 461 to 884 (Figure 12). Like the long-term trend, erosion decreases towards the southern tips of the point features located along the Harbor side shoreline, to the point of some minor accretion being observed at the points themselves. In contrast to the average long-term trend, the average short-term shoreline change rates for the Harbor side shoreline around Wauwinet (transects 782-884) indicate an average erosion rate of -1.4 feet/year (Figure 12) rather than an accretion rate of 5.5 feet/year for approximately the same area in the long-term.

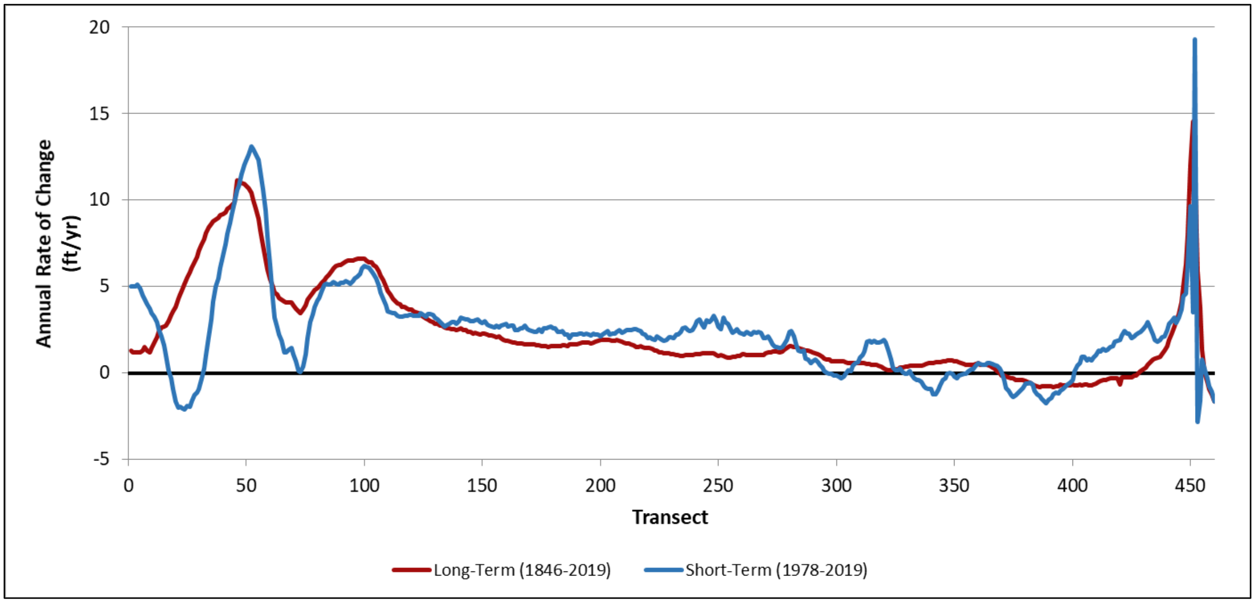


Figure 10. Long-term (1846-2019) and Short-term (1978-2019) shoreline change rates for transects 1-460.

Short-term shoreline trends within the specific areas of interest are outlined below.

- The Galls: Average short-term shoreline change rates are comparable to long-term trends, showing erosion on the oceanside of -3.4 feet/year (transects 1,050-1,110), which is approximately equal to accretion on the Harbor side of 3.9 feet/year (transects 60-120), indicating relatively stable migration of the landform (Figures 10, 11, and 14).
- 1st and 2nd Point: The shoreline is eroding at an average of -0.7 feet/year, half the long-term erosion rate for this area (transects 470-530) (Figures 12 and 15).
- The Haulover: The Harbor side shoreline is eroding at an average short-term rate of -1.7 feet/year (transects 790-880), while the oceanside is eroding at an average rate of -1.1 feet/year (transects 890-960) (Figures 11, 12, and 16). These short-term data indicate that in more recent years, the strip of land between the Harbor and the ocean is narrowing.

- Coskata Pond: Average short-term trends for the oceanside shoreline indicate a slightly less severe erosional trend of -3.4 feet/year (transects 960-1,010), compared to the long-term rate of -4.4 feet/year for the same area (Figures 11 and 17).

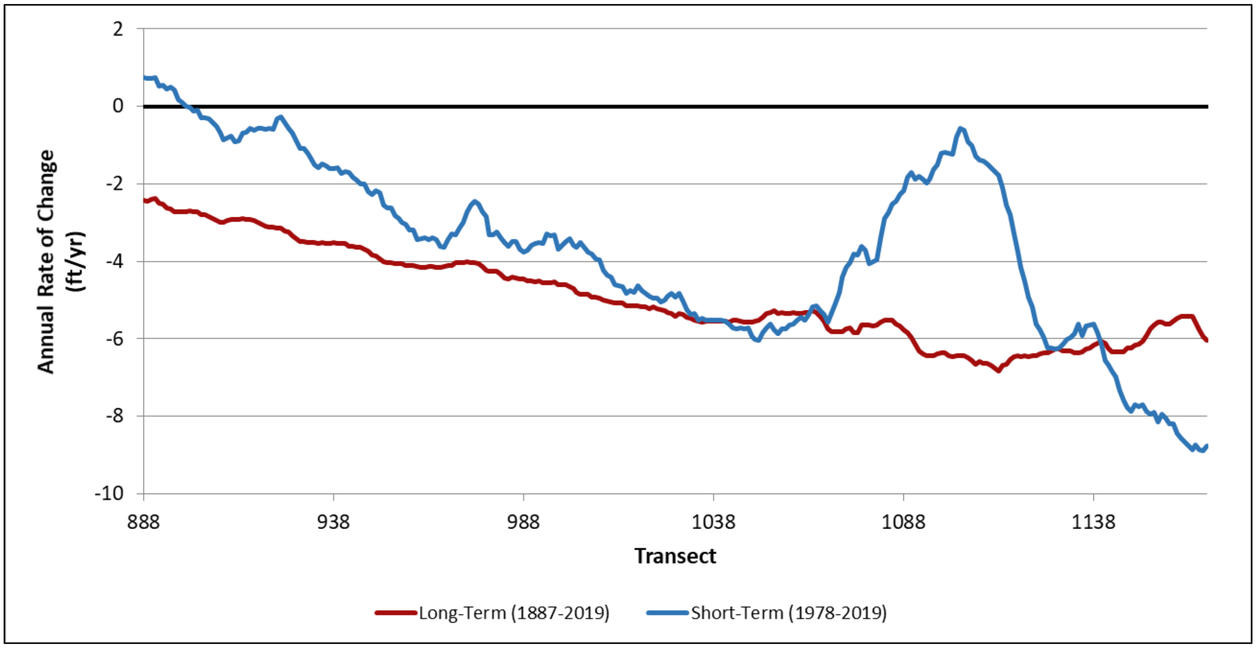


Figure 11. Long-term (1846-2019) and Short-term (1978-2019) shoreline change rates for transects 888-1,168.

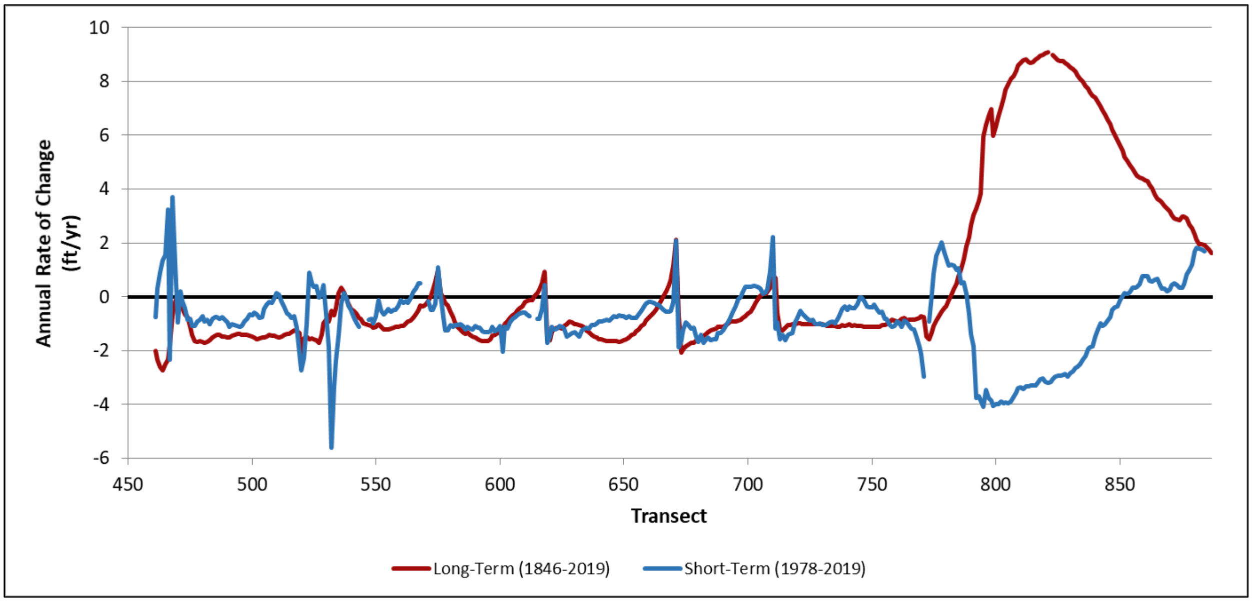


Figure 12. Long-term (1846-2019) and Short-term (1978-2019) shoreline change rates for transects 461-887.

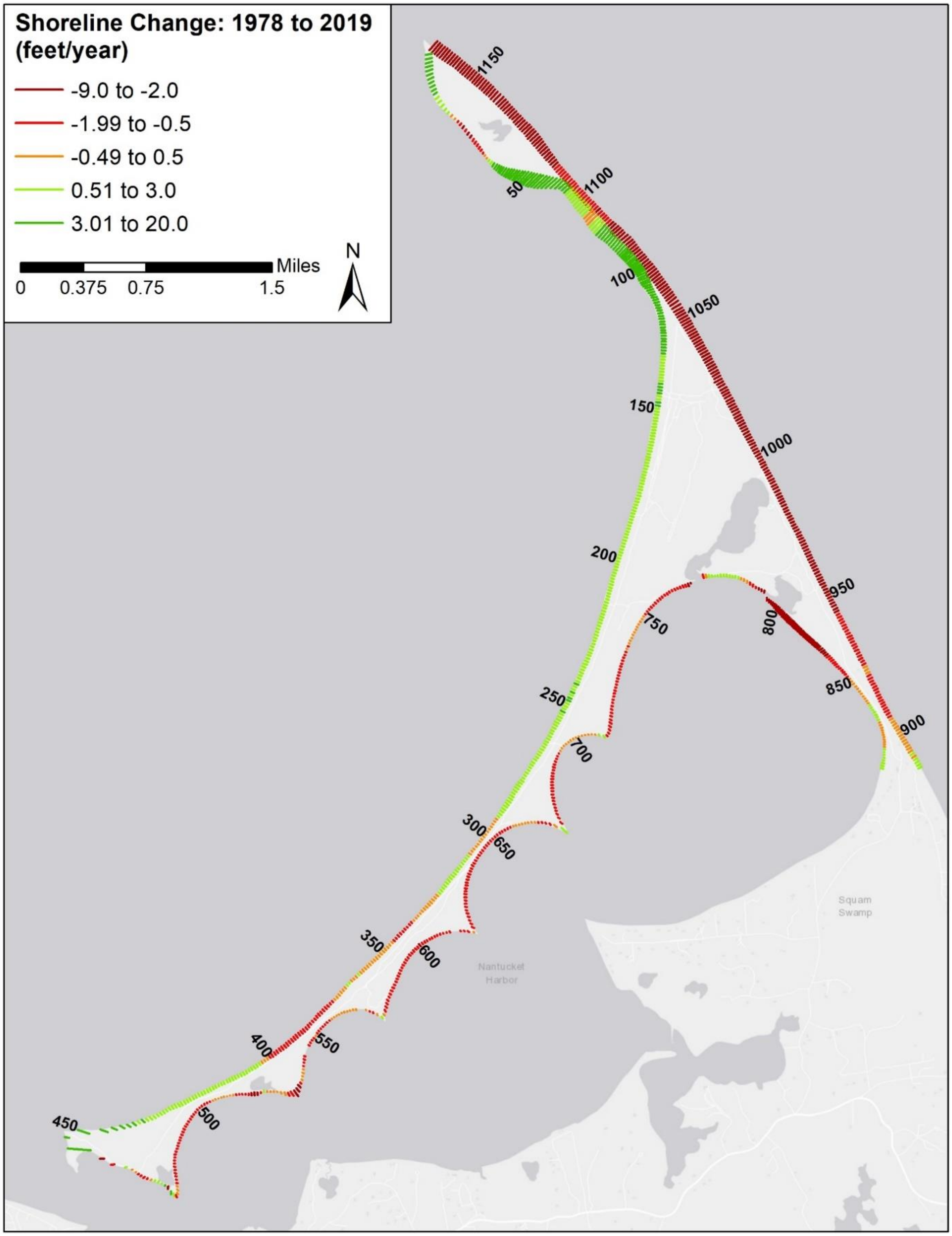


Figure 13. Short-term shoreline change rates for the entire study area (1978-2019). Negative values indicate erosion, while positive values indicate accretion.

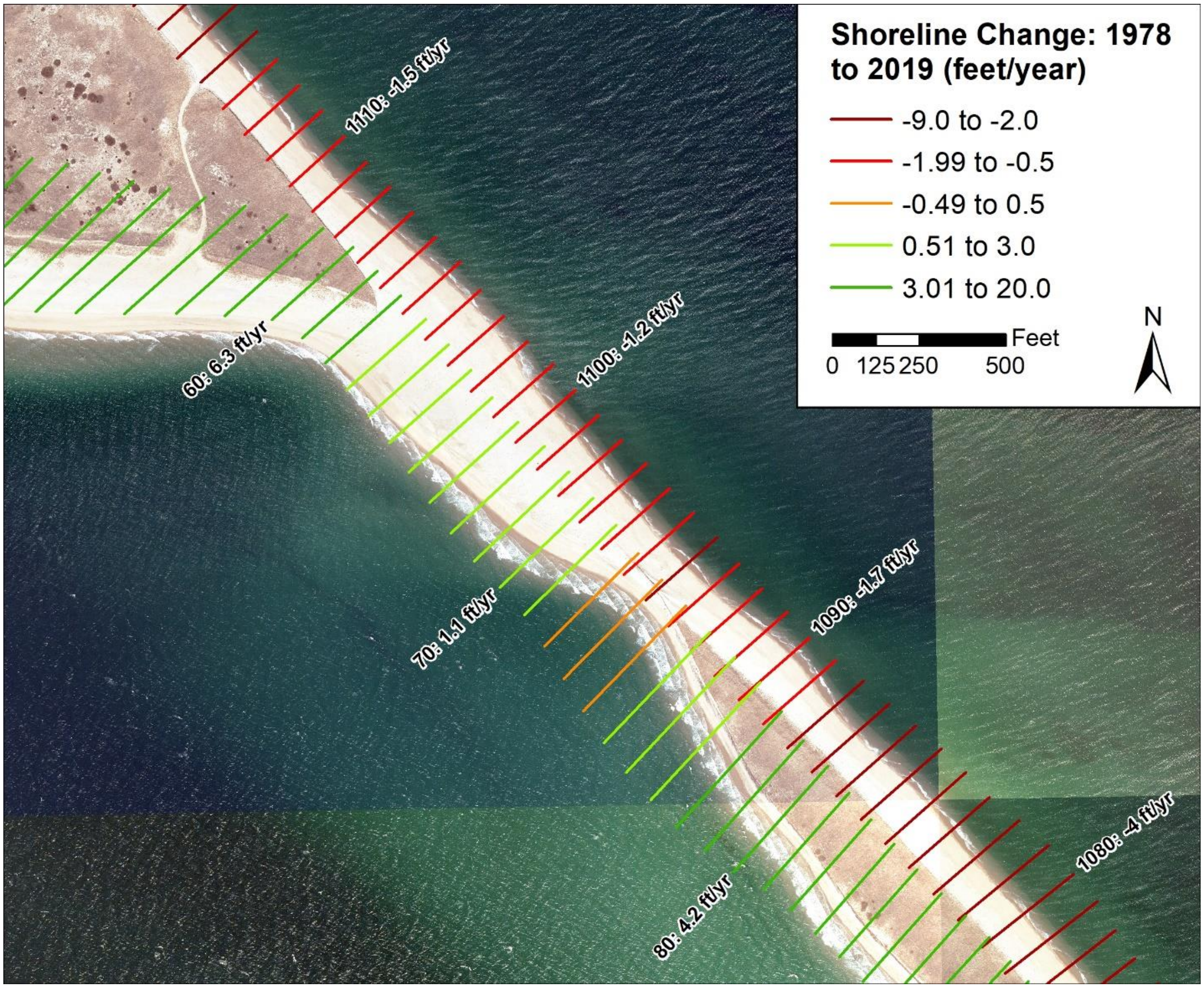


Figure 14. Short-term shoreline change rates for The Galls (1978-2019). Background imagery is 2019 MassGIS imagery. Negative values indicate erosion, while positive values indicate accretion.

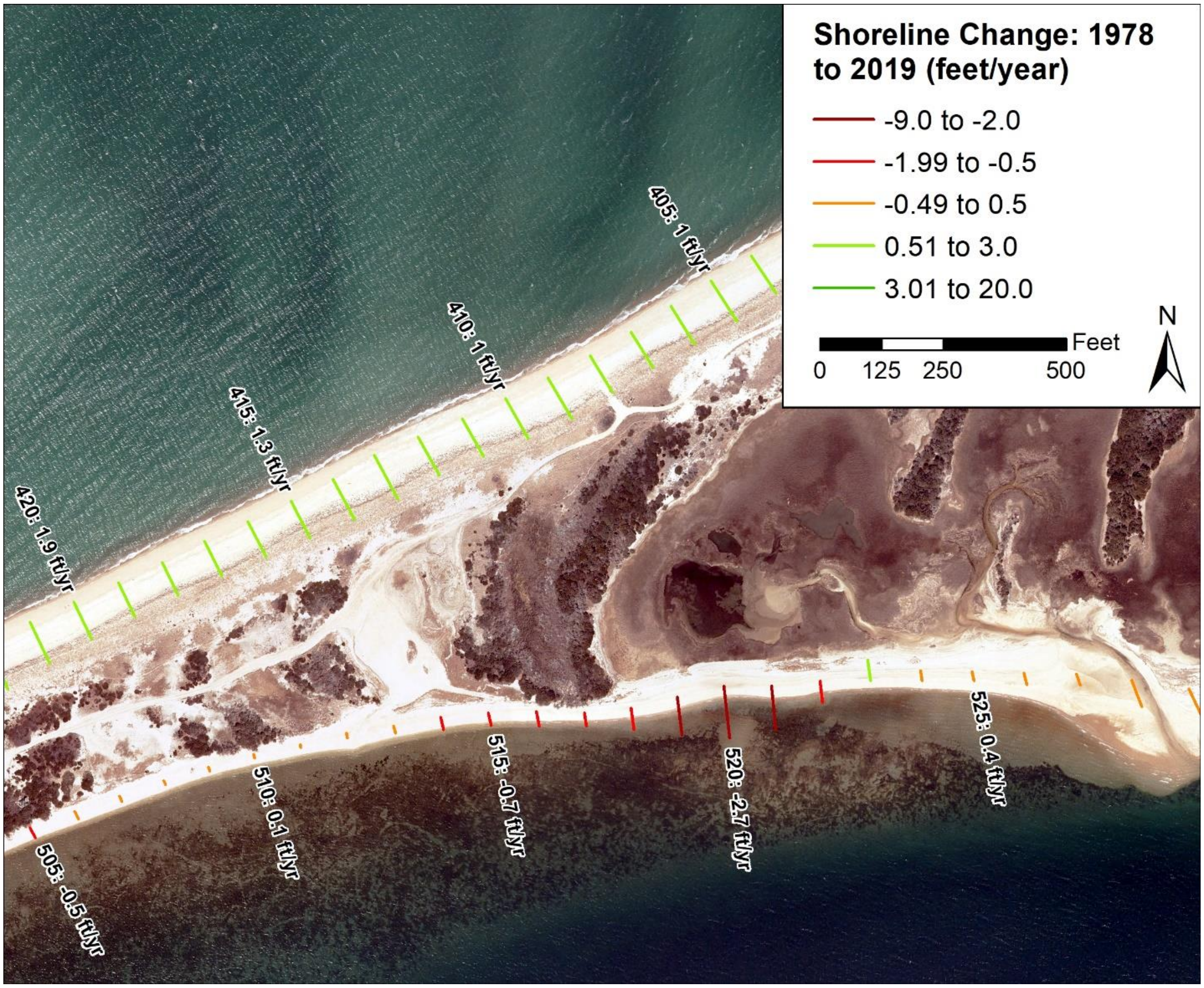


Figure 15. Short-term shoreline change rates between 1st and 2nd Point (1978-2019). Background imagery is 2019 MassGIS imagery. Negative values indicate erosion, while positive values indicate accretion.

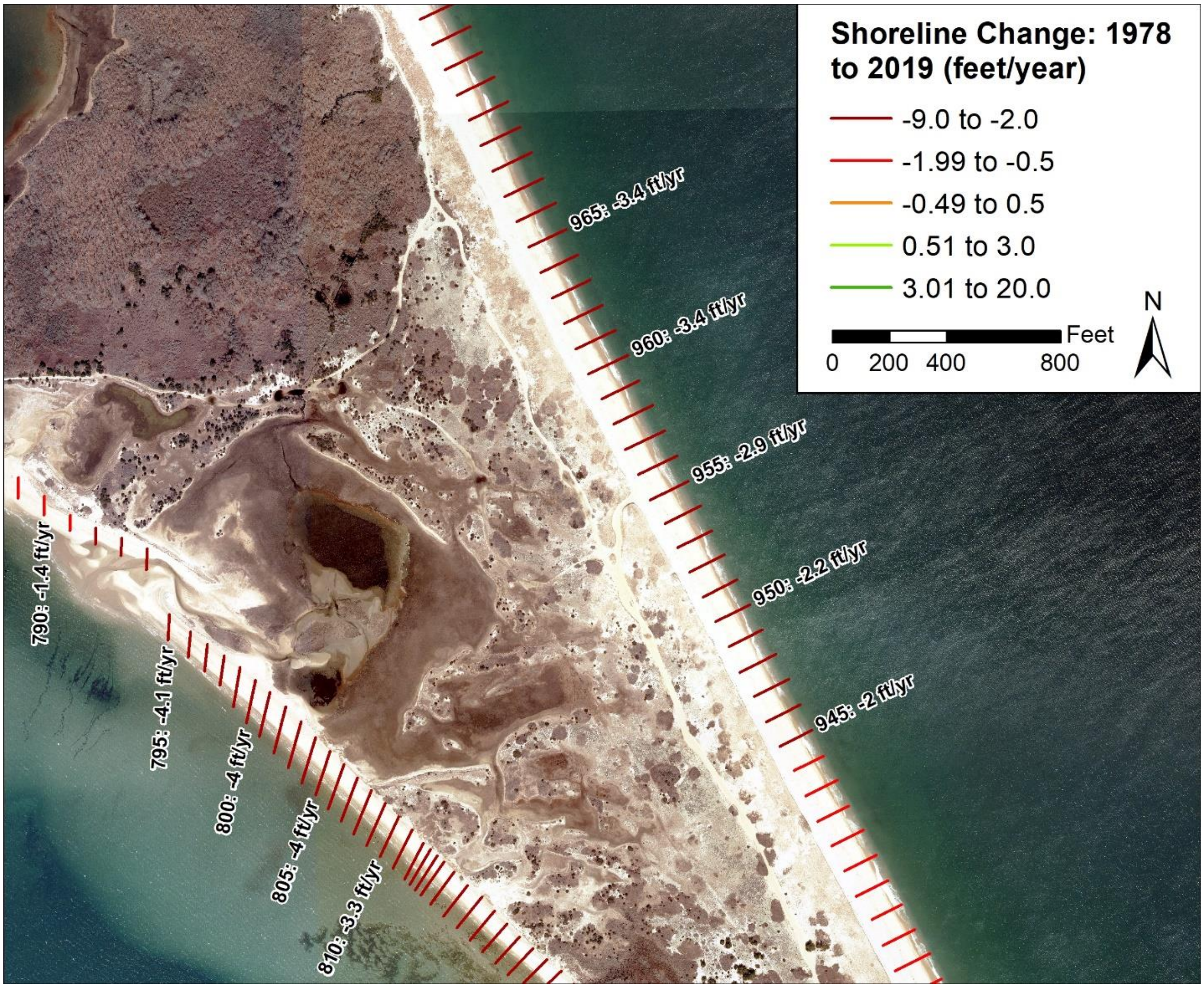


Figure 16. Short-term shoreline change rates for The Haulover (1978-2019). Background imagery is 2019 MassGIS imagery. Negative values indicate erosion, while positive values indicate accretion.

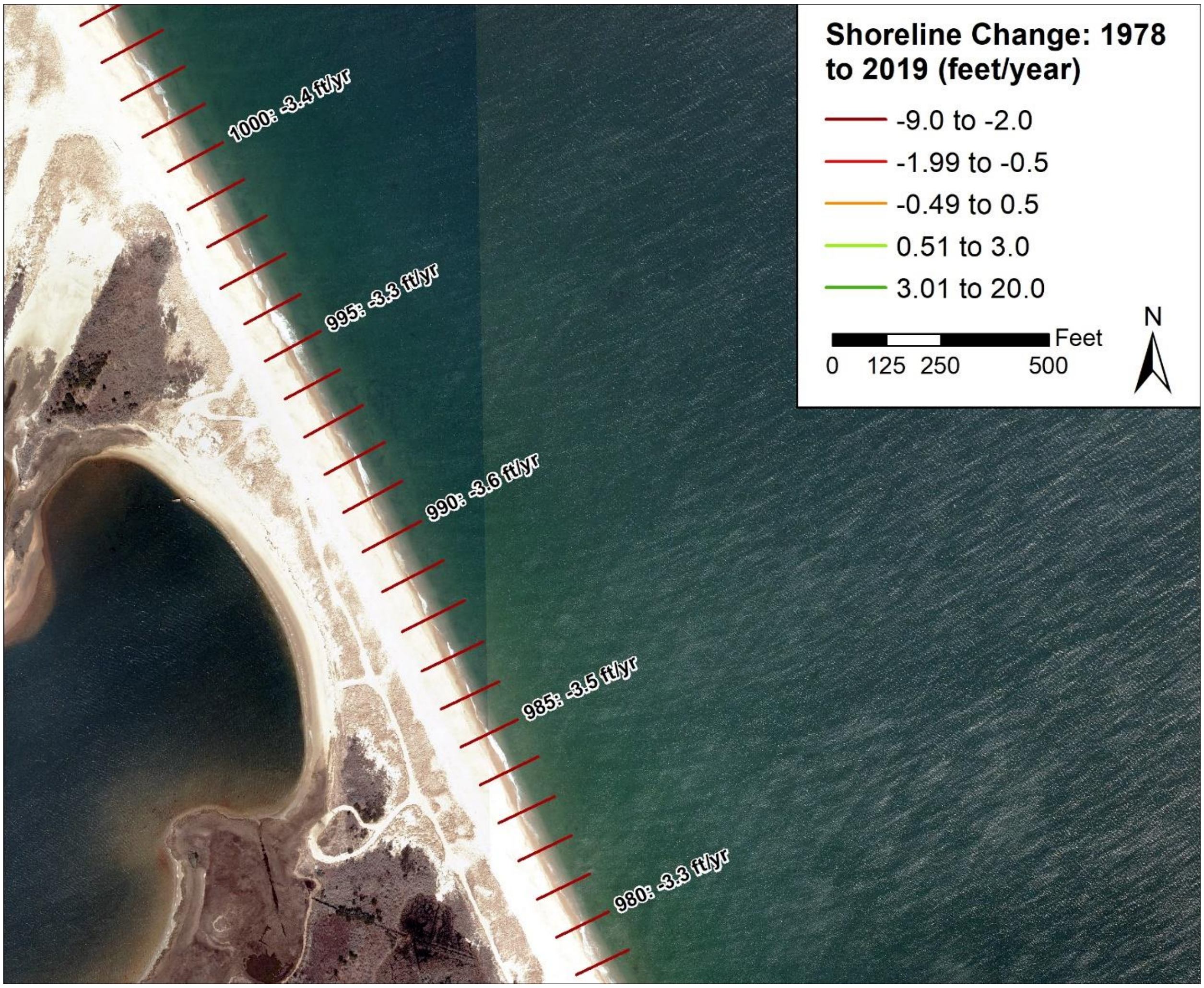


Figure 17. Short-term shoreline change rates for Coskata Pond (1978-2019). Background imagery is 2019 MassGIS imagery. Negative values indicate erosion, while positive values indicate accretion.

2.2.4 Future Shoreline Projections

Information developed during the shoreline change analysis can be used to evaluate the potential for future changes to the Great Point area by projecting the average rates of change forward to 2030, 2050 and 2070. The average rate of short-term shoreline change was determined by calculating a five-point rolling average for each transect within each area of interest (i.e., for each transect, the rate of shoreline change of two transects on each side of the transect in question were averaged along with the rate of change of the transect in question). The shoreline retreat estimates are based on the average short-term rates of change for each area of interest. The magnitude of shoreline retreat from present day conditions for each area of interest is presented in Table 2.

Table 2. Shoreline retreat and future mean high water elevations used to project future shoreline positions.

Year	Average Rate of Shoreline Change (ft/yr)	Average Magnitude of Shoreline Retreat (from 2019)	MHW (ft, NAVD88)
The Haulover (*Atlantic Shoreline*)			
2030	-2.5 ft/yr	-27.6 feet	3.7
2050		-77.7 feet	5.0
2070		-127.8 feet	6.9
The Haulover (*Nantucket Harbor Shoreline*)			
2030	-3.1 ft/yr	-33.6 feet	3.4
2050		-94.8 feet	4.7
2070		-155.9 feet	6.5
Coskata Pond (*Atlantic Shoreline*)			
2030	-3.5 ft/yr	-38.5 feet	3.8
2050		-108.4 feet	5.1
2070		-178.8 feet	7.0
The Galls (*Atlantic Shoreline*)			
2030	-2.9 ft/yr	-32.1 feet	3.7
2050		-90.5 feet	5.0
2070		-148.8 feet	6.9
The Galls (*Nantucket Harbor Shoreline*)			
2030	+5.9 ft/yr	+65.1 feet	3.3
2050		+183.6 feet	4.7
2070		+302.0 feet	6.5
Between 1st and 2nd Point (Nantucket Sound Shoreline)			
2030	+0.9 ft/yr	+10.3 feet	3.3
2050		+29.1 feet	4.7
2070		+47.8 feet	6.5
Between 1st and 2nd Point (Nantucket Harbor Shoreline)			
2030	-0.5 ft/yr	-5.5 feet	3.4
2050		-15.6 feet	4.7
2070		-25.7 feet	6.5

The magnitude of shoreline change based on average erosion rates can then be combined with the impacts of expected sea level rise to develop a more comprehensive picture of future change. Estimates of local mean high water (MHW) elevation have been extracted from the MC-FRM; these estimates represent a high sea level rise scenario. Table 2 shows the MHW elevation estimates along with the projected magnitude of change from erosion only.

Future MHW data from Table 2 were then compared to high resolution LiDAR elevation data from 2018, or in the case of the area between 1st and 2nd Point – 2016 LiDAR, to estimate the combined impacts of shoreline erosion and sea level rise on the Great Point shorelines. In some locations, sea level rise can have a significant effect on shoreline migration; this is particularly true for relatively flat, low-lying areas (Figure 18-A). This is certainly the case for some areas of the study area. In other areas, however, the topography rises relatively steeply up the frontal beach and dune system with upland forested areas behind, reaching elevations well above the 2070 projected MHW. In these locations, the impact of sea level rise will be dwarfed by the ongoing impact of coastal erosion (Figure 18-B). The fact that this site is a barrier beach, adds another potential source of change. For example, the coastal dunes can be overwashed during even moderate energy storms, and the entire barrier beach can migrate overtime. General principals of barrier beach dynamics in combination with the cross-shore modeling results discussed in Section 6.0 were therefore also applied to the topography at each area of interest.

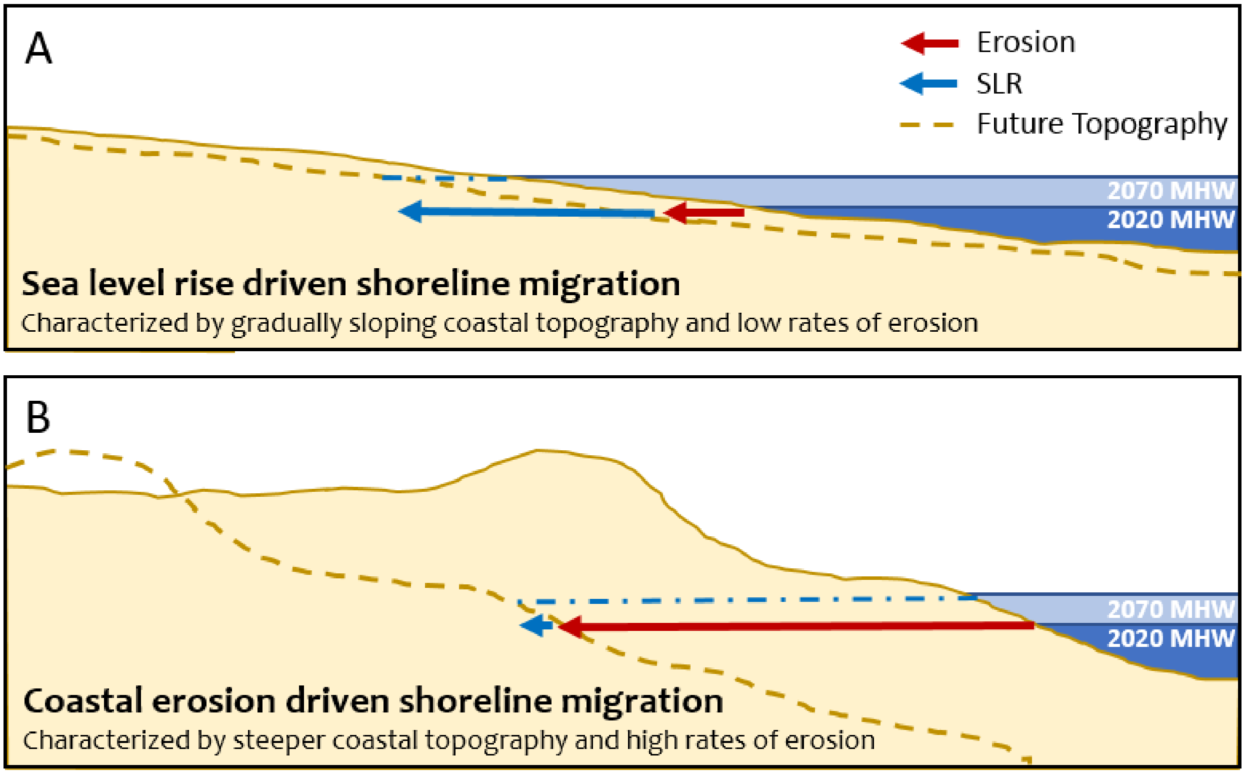


Figure 18. Major processes affecting shoreline migration. A) Sea level rise can be a major contributor to shoreline migration in areas of gradually sloping topography and low erosion rates. B) Coastal erosion can dwarf the impacts of sea level rise with respect to shoreline migration in areas of steeper topography with high rates of erosion.

Figures 19 through 26 present summary graphics of the projected future high-water line positions. The first figure for each area of interest (Figures 18, 20, 22, and 24) includes a representative cross-section, which shows projected future topographic changes, water level increases and change in shoreline position. The changes indicated by these data were then used to apply future shoreline positions to a plan view for each area of interest (Figures 20, 22, 24, and 26). Where possible, shoreline positions were estimated for all three outyears: 2030, 2050, and 2070. However, at Coskata Pond and The Galls, due to the low-lying elevations and the likelihood that the entire barrier beach may be inundated by sea level rise, 2070 shorelines are not presented (Figures 19 through 25). A summary of the projected changes for each area of interest is provided below:

2.2.4.1 Coskata Pond

The existing (2018) topographic profile from a representative area of the Coskata Pond area of interest is shown in black in Figure 19. Based on the measured average shoreline retreat rate, cross-shore modeling results, and the expected coastal processes that will likely occur at this site over the next few decades, this topographic profile was adjusted for 2030 (red line) and 2050 (orange line) (Figure 19). The elevations of mean high water in 2030 (light blue) and 2050 (medium blue) are also shown relative to the landform (Figure 19). This area is expected to erode at approximately -3.5 feet/year while also being further impacted by overwash during storms. Through further lowering of the beach elevation during future storms, combined with almost two feet of sea level rise between 2050 and 2070, a dry high tide beach is not expected in this location by 2070, and it is therefore not displayed on Figure 19. The information from Figure 19 was then used to develop projected future high-water lines on a plan view of the Coskata Pond area of interest (Figure 20).

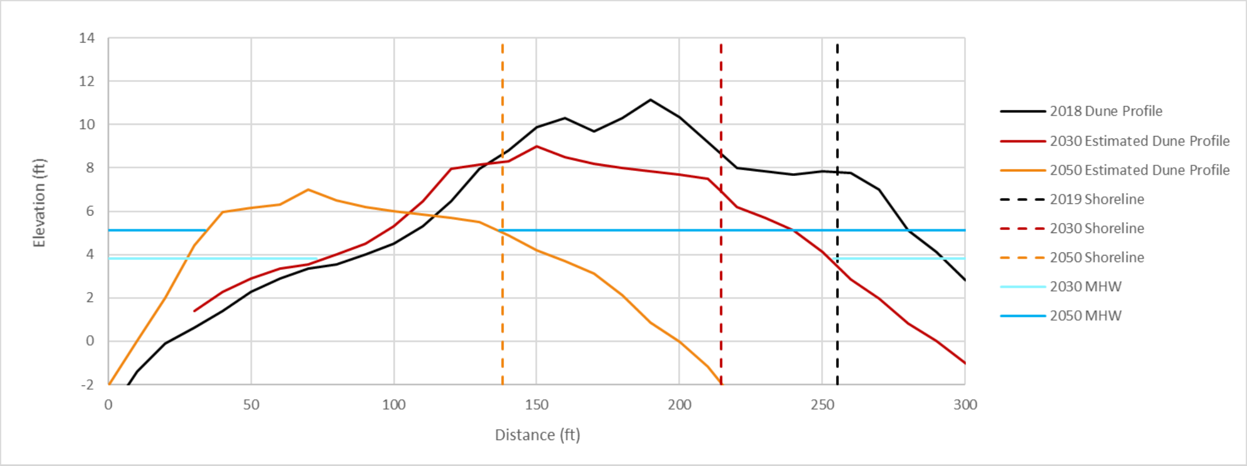
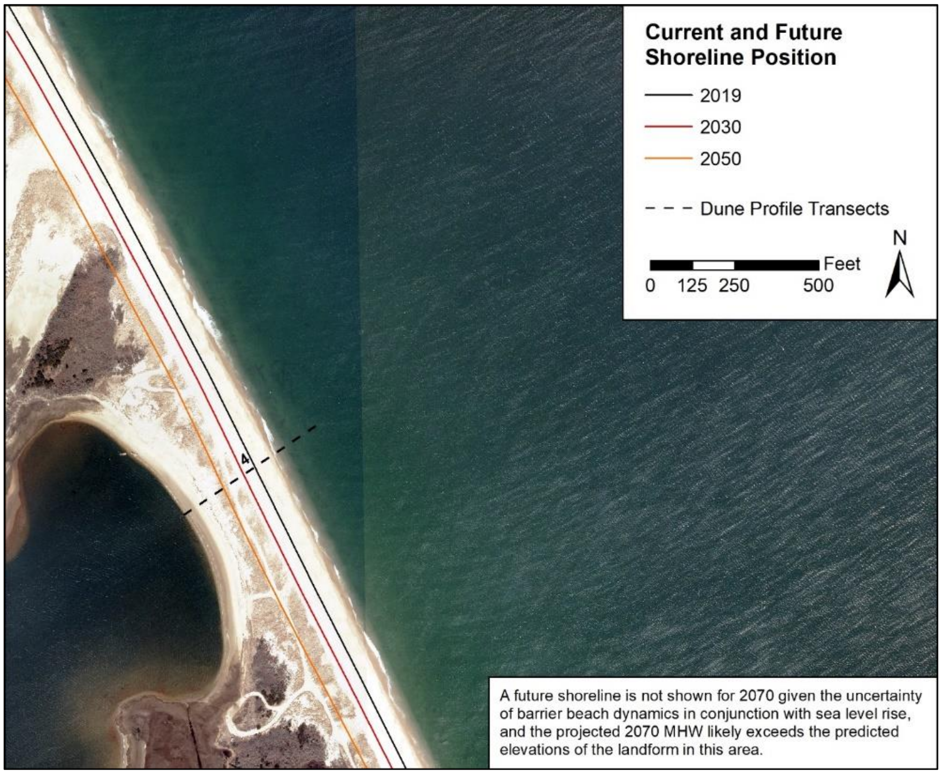


Figure 19. Recent and future dune profiles at Transect 4 east of Coskata Pond. Shoreline positions corresponding to Figure 20 are plotted in dashed lines.



A future shoreline is not shown for 2070 given the uncertainty of barrier beach dynamics in conjunction with sea level rise, and the projected 2070 MHW likely exceeds the predicted elevations of the landform in this area.

Figure 20. Current and future shoreline positions for Coskata Pond. Dune profile transect data for Transect 4 is displayed in Figure 19.

2.2.4.2 The Galls

The existing (2018) topographic profile from a representative area within The Galls area of interest is shown in black in Figure 21. Based on the measured average shoreline retreat rate, cross-shore modeling results, and the expected coastal processes that will likely occur at this site over the next few decades, this topographic profile was adjusted for 2030 (red line) and 2050 (orange line) (Figure 21). The elevations of MHW in 2030 (light blue) and 2050 (medium blue) are also shown relative to the landform (Figure 21). Overall, based on recent trends, this area is expected to continue eroding from the ocean side, at approximately -2.9 feet/year, in addition to being further impacted by overwash in storms, while at the same time accreting on the Nantucket Harbor side, at approximately +5.9 feet/year. Based on shoreline change rates alone, this would indicate an overall widening and westward shift of the barrier beach in this location, since the rate of accretion on the Harbor side is much greater than the rate of erosion on the ocean side. However, due to the extremely low elevations across much of the interior portions of the barrier and the water level changes predicted under a high sea level rise scenario, by 2050 the barrier at the north end of this area of interest (i.e., Transect 1) is projected to experience significant narrowing. A similar, though less dramatic narrowing is also projected for the southern portion of this area of interest (i.e., Transect 3) (Figure 22). The center (i.e., the most low-lying, narrow portion) of this area of interest (i.e., Transect 2) is not expected to have any dry area at high tide (Figure 22) by 2050. No portion of this area of interest is expected to persist by 2070.

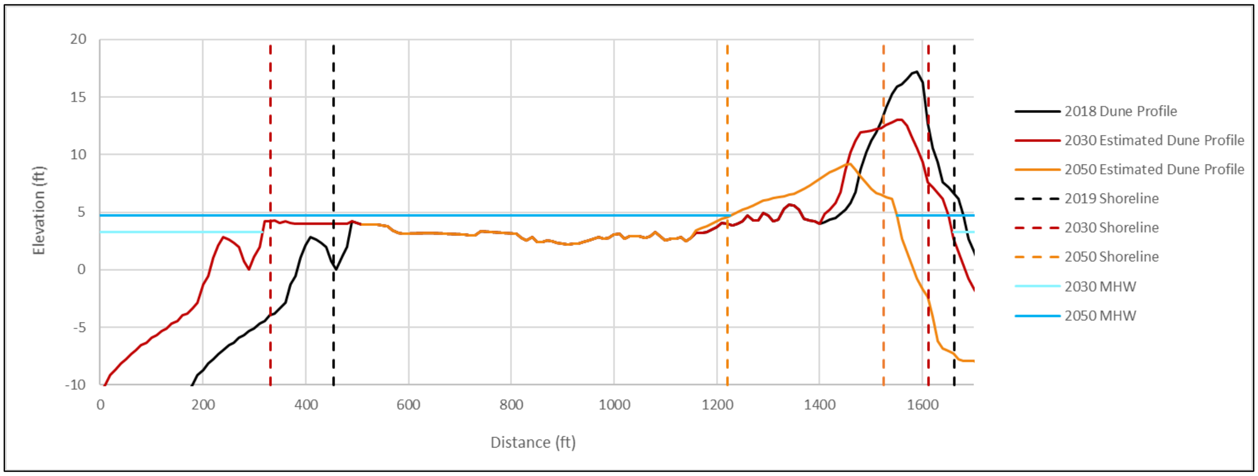
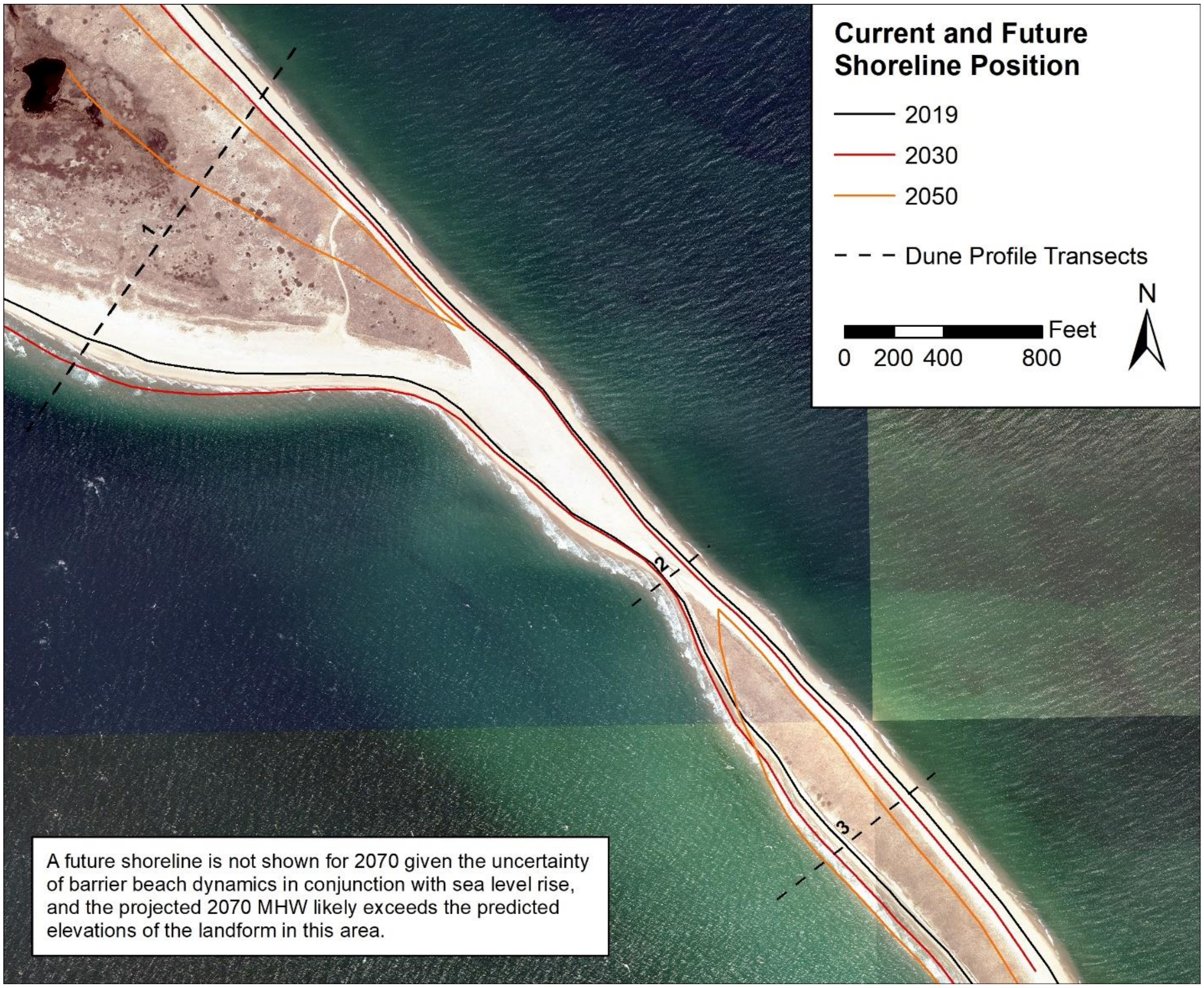


Figure 21. Recent and future dune profiles at Transect 1 at The Galls. Shoreline positions corresponding to Figure 22 are plotted in dashed lines.



A future shoreline is not shown for 2070 given the uncertainty of barrier beach dynamics in conjunction with sea level rise, and the projected 2070 MHW likely exceeds the predicted elevations of the landform in this area.

Figure 22. Current and future shoreline positions for The Galls. Dune profile transect data for Transect 1 is displayed in Figure 21.

2.2.4.3 The Haulover

The existing (2018) topographic profile from a representative portion of The Haulover area of interest is shown in black in Figure 23. Based on the measured average shoreline retreat rate, cross-shore modeling results, and the expected coastal processes that will likely occur at this site over the next few decades, this topographic profile was adjusted for 2030 (red line) and 2050 (orange line) (Figure 23). The elevations of mean high water in 2030 (light blue) and 2050 (medium blue) are also shown relative to the landform (Figure 23). Overall, based on recent trends, this area is expected to continue eroding from both sides: the ocean side would likely continue to erode at approximately -2.5 feet/year, in addition to being further impacted by overwash during storms, while at the same time the shoreline on the Nantucket Harbor side will continue to erode at approximately -3.1 feet/year. This results in an overall narrowing of the landform, even before the impacts of sea level rise are considered. When sea level rise is considered alongside the other impacts, the potential future changes are even more dramatic. For example, once the initial rise on the Nantucket Harbor side is overtopped, it is expected that the small ridges in the low-lying portion of this area will be flattened out by regular wave and tidal action, resulting in a much narrower landform by 2050 (particularly at Transect 6, Figures 23 and 24). The combination of continued erosion, storm impacts, overwash, and sea level rise will likely result in no dry land persisting in the vicinity of Transect 6 at high tide by 2070; the 2070 shoreline was therefore not shown in Figure 23, or in the area of transect 6 in Figure 24. However, given the higher elevations, dense vegetation, and different geology of the northern portion of this area of interest, it is expected that a portion of this landform will persist through 2070. The projected 2070 shoreline is shown in green on Figure 24 for this area (i.e., in the vicinity of Transect 5).

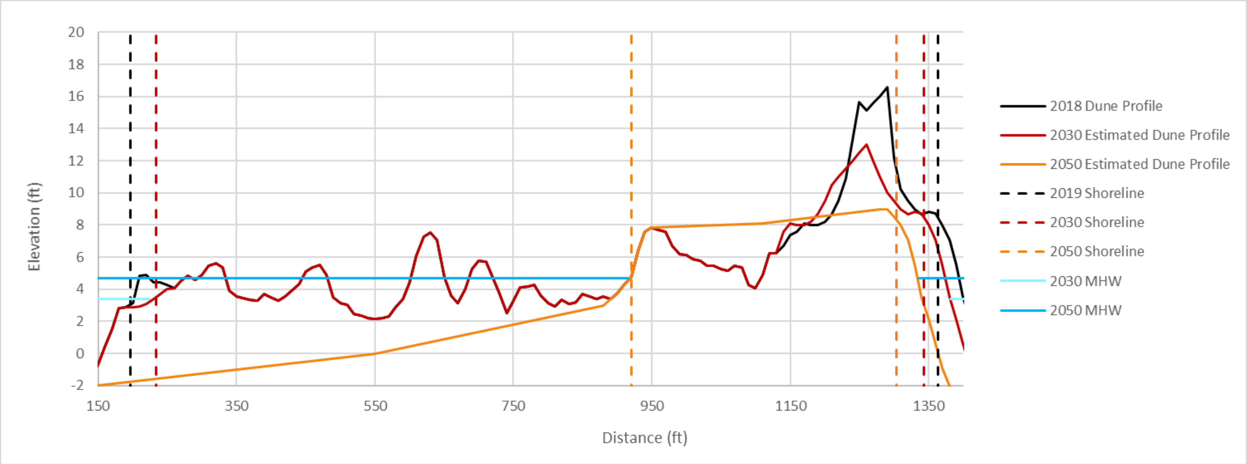


Figure 23. Recent and future dune profiles at Transect 6 at The Haulover. Shoreline positions corresponding to Figure 24 are plotted in dashed lines.

Figure 24. Current and future shoreline positions for The Haulover. Dune profile transect data for Transect 6 is displayed in Figure 23.

2.2.4.4 Between 1st and 2nd Point

The existing (2016) topographic profile from a representative area of the area of interest between 1st and 2nd Point is shown in black in Figure 25. Based on the measured average shoreline retreat rate, cross-shore modeling results, and the expected coastal processes that will likely occur at this site over the next few decades, this topographic profile was adjusted for 2030 (red line), 2050 (orange line), and 2070 (green line) (Figure 25). The elevations of MHW in 2030 (light blue), 2050 (medium blue), and 2070 (dark blue) are also shown relative to the landform (Figure 25). Based on recent trends, this area is expected to continue to have minor accretion on the Nantucket Sound side, at approximately +0.9 feet/year, while remaining relatively stable on the Nantucket Harbor side. It is also worth noting that the cross-shore modeling did not indicate significant storm damage or overwash in this area, likely due to the relatively protected nature of both shorelines. As such, the topographic profiles for future outyears were not adjusted vertically as they were in other areas of interest. Based on this information alone, this portion of Great Point would be expected to widen over time. However, due to the low elevations along the Nantucket Harbor side, sea level rise is expected to significantly narrow the barrier beach here over time. This is shown in cross-section view in Figure 25 (for Transect 7), as well as in plan view in Figure 26. Note that the horizontal change in high waterline increases as you move east, due to the large low-lying wetland areas on the Harbor side of the barrier. It is anticipated that the low, smaller barrier beach separating those wetlands from the Harbor will not persist by 2030 due to increased water levels.

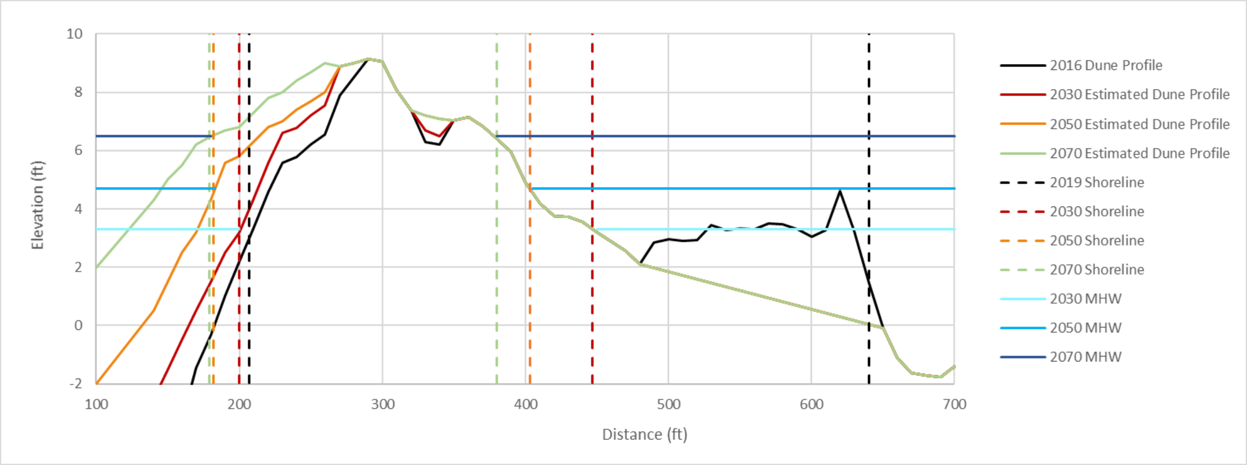


Figure 25. Recent and future dune profiles at Transect 7 between 1st and 2nd Point. Shoreline positions corresponding to Figure 26 are plotted in dashed lines.

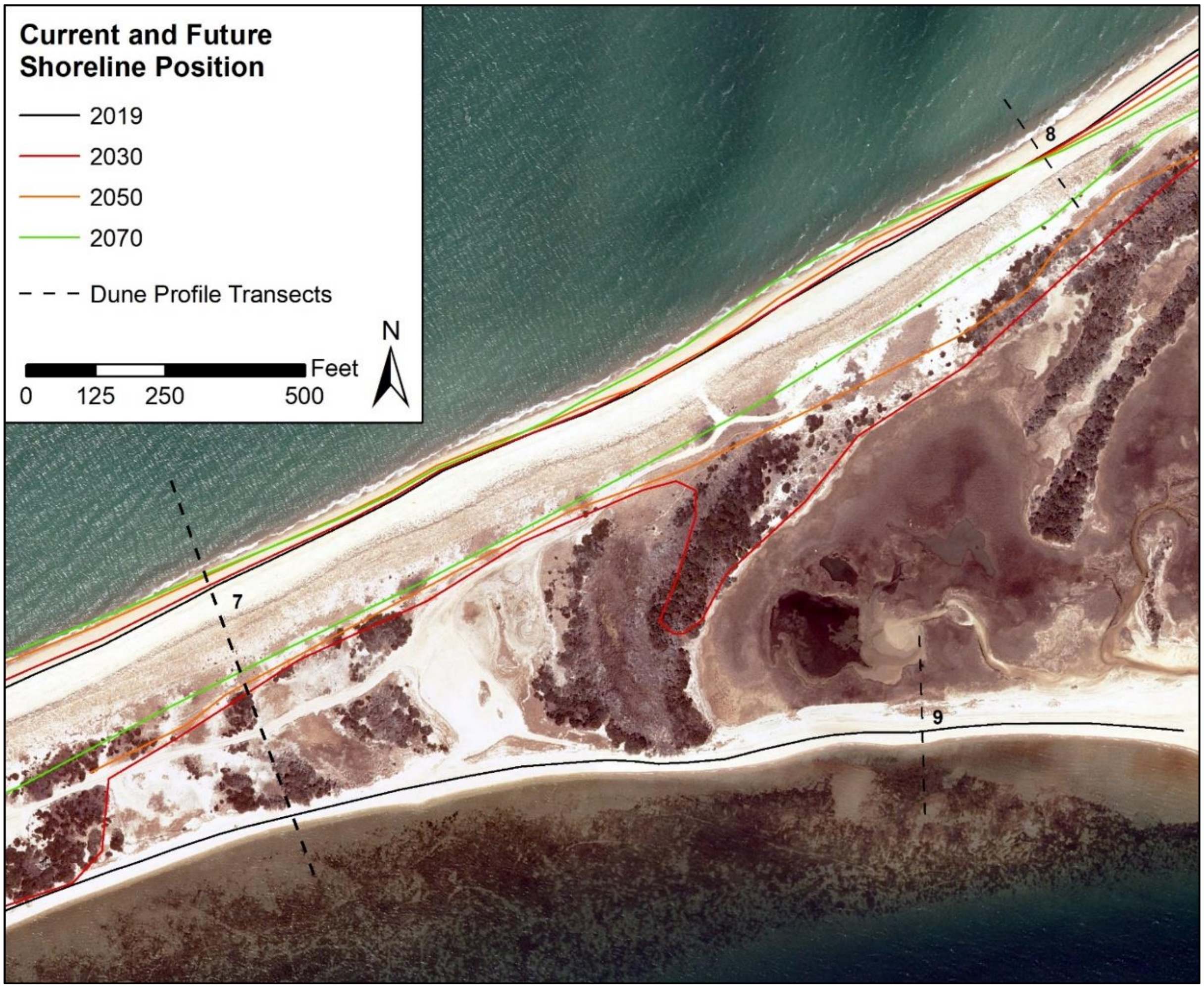


Figure 26. Current and future shoreline positions between 1st and 2nd Point. Dune profile transect data for Transect 7 is displayed in Figure 25.

2.3 BREAKTHROUGHS

The barrier beach system of Coskata-Coatue lies between Nantucket Harbor, Nantucket Sound, and the Atlantic Ocean. It is exposed to waves with long fetch runs across the open ocean to the east and north. Tidal surges can also occur within the enclosed Nantucket Harbor.

2.3.1 Historic Barrier Beach Breaks

The Haulover: The narrow barrier beach section north of Wauwinet is known as The Haulover, so named because fisherman would drag their boats across the dunes between the Harbor and the ocean rather than sailing around Great Point to access the fishing grounds to the east. Before a planned channel could be cut through the barrier, a nor'easter storm in December 1896 breached the barrier (

Figure 27) and created a natural channel that remained open for almost a decade (Rosen, 1972).

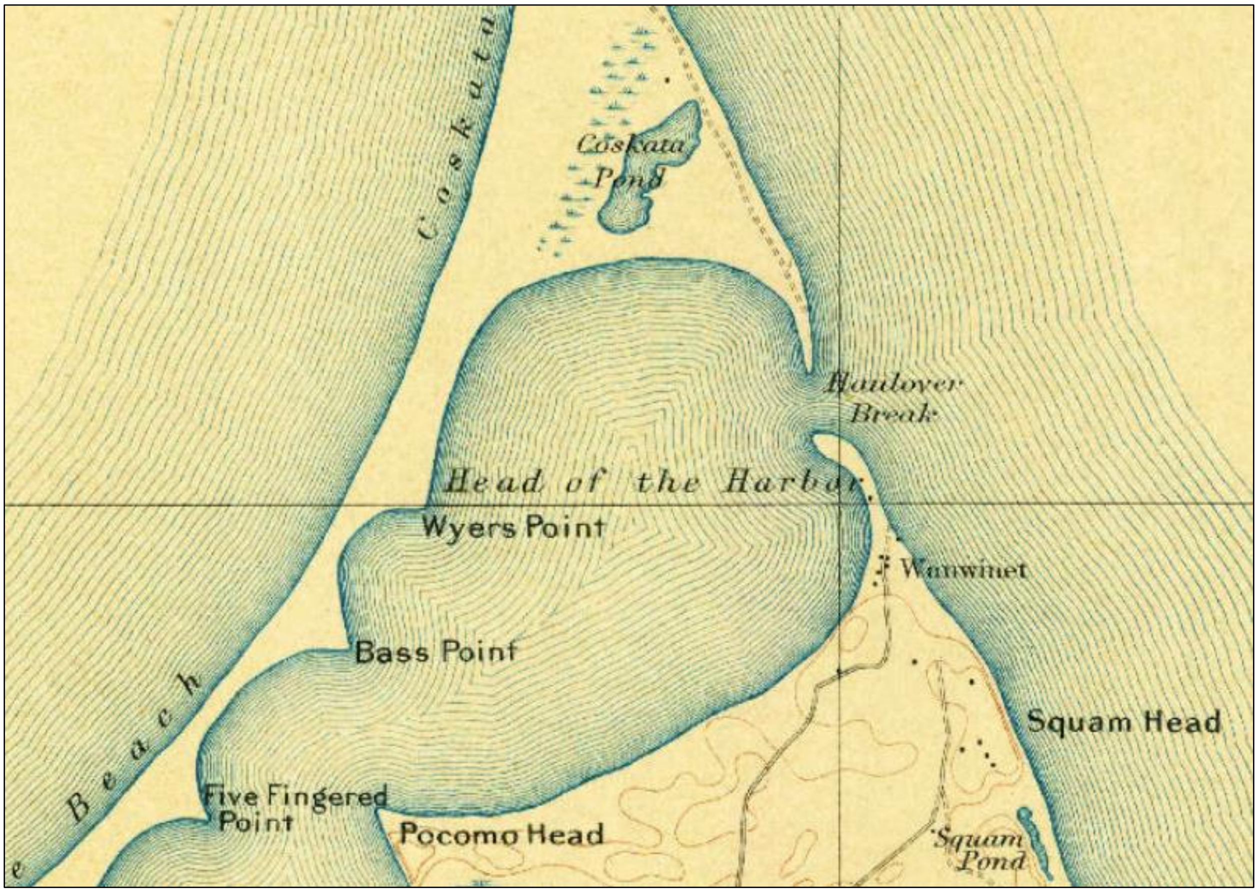


Figure 27. 1901 USGS Topographic map showing the The Haulover Break.

The Galls: The low-lying stretch of barrier beach known as The Galls that connects Coskata to Great Point has been overwashed during high seas and has occasionally breached completely. These events can vary in severity and duration but result in Great Point being inaccessible by vehicles. Several occurrences have been documented by islanders over the years. The Nantucket Historical Association has photographs of the separated Great Point in its records (Figures 28, 29, and 30).

These help to reinforce the legend and lore of the destructive effects of coastal storms on these exposed areas. Additional destructive events are known to have impacted this area, such as the March 1984 storm that felled the Great Point lighthouse and breached The Galls.

Figure 28. Overwash at The Galls in the 1970's (Image courtesy of Nantucket Historical Association).

Figure 29. Breach at The Galls after the December 1991 No Name storm (Image courtesy of Nantucket Historical Association).

Figure 30. Breach remaining at The Galls in January 1992 (Image courtesy of Nantucket Historical Association).

2.4 SHORELINE CHANGE ANALYSIS

2.4.1 Dynamic Nature of Coskata-Coatue Study Area

The Coskata-Coatue study area is an example of a very dynamic and transitional barrier beach system. The area is influenced by the local hydrodynamics (e.g., waves, currents, sediment transport) and geomorphological (e.g., sediment type) conditions and can change or evolve within a variety of time scales. Observed long-terms trends (i.e., decades) can show patterns of accretion, erosion, or shifting due to normal local hydrodynamic conditions, but can also evolve very quickly due to local coastal storm impacts (e.g., Nor'easters).

To gain a better understanding of this dynamic coastline, a geospatial analysis of the historic shorelines at the Coskata-Coatue study area was completed to visualize the dramatic change between 1887 and 2019. Shoreline data were collected from the Office of Coastal Zone Management (1887-2014) or created from the digitization of available ortho imagery (e.g., 2019). The shoreline location data were then separated into individual years to be representative for a particular year. Geospatial analysis tools in ArcGIS were then used to join different shorelines to compare the overall change between selected time periods.

Figures 31 and 32 visualize the results of the coastal shoreline change between selected time periods. For each inlay within the figures below, the land that remained land is indicated in a tan color, land that eroded is red, and land that was gained is blue. It is important to emphasize that land considered to have eroded (red) during any particular time frame is not necessarily lost from this barrier beach system. The land most likely shifted or transitioned to the position indicated in blue for that particular time frame. Figure 31 shows the overall change throughout the analysis timeframe (1887-2019) while Figure 32 shows the change between individual time periods.

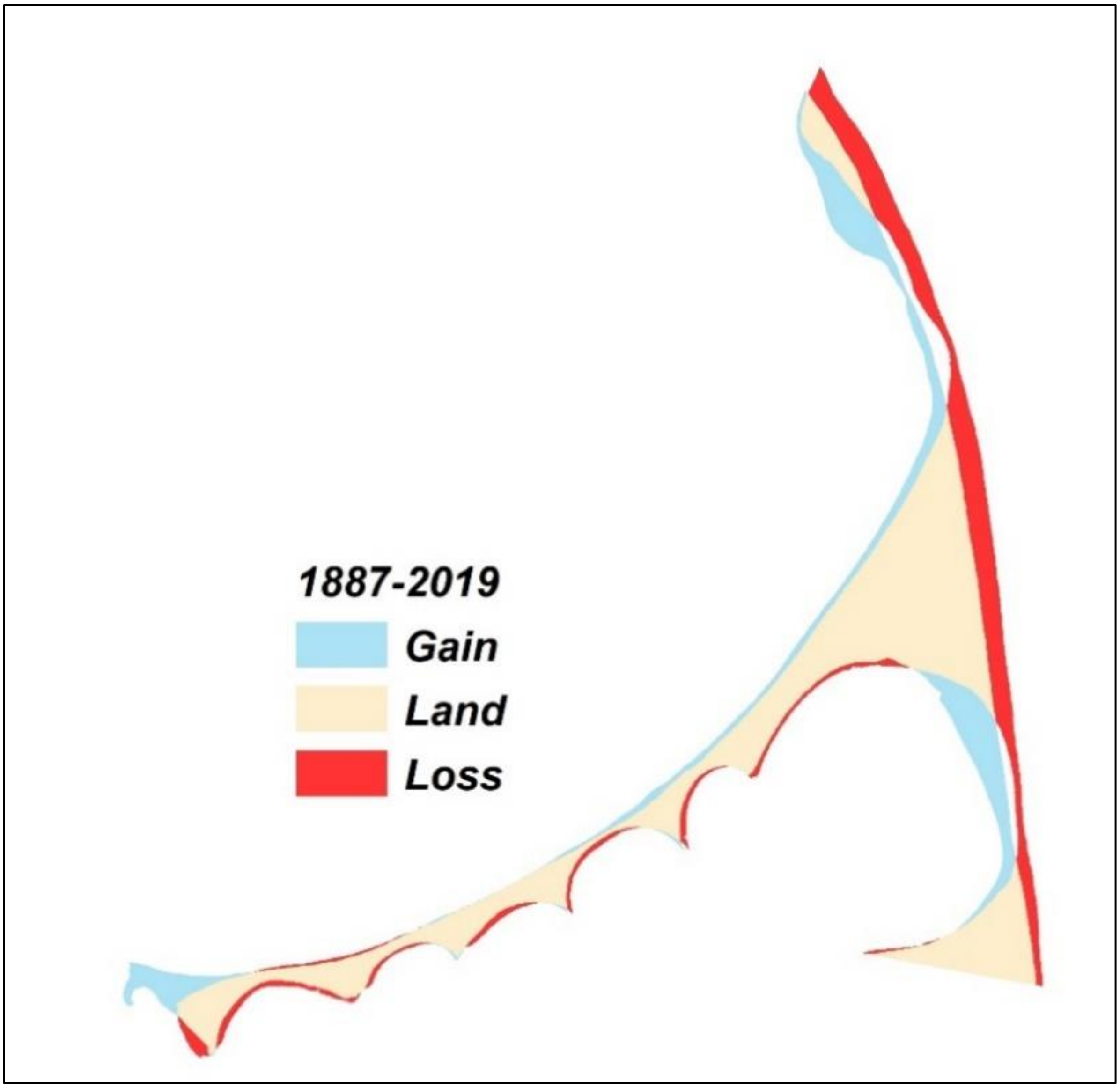


Figure 31. Overall shoreline change for Coskata-Coatue Study Area (1887-2019).

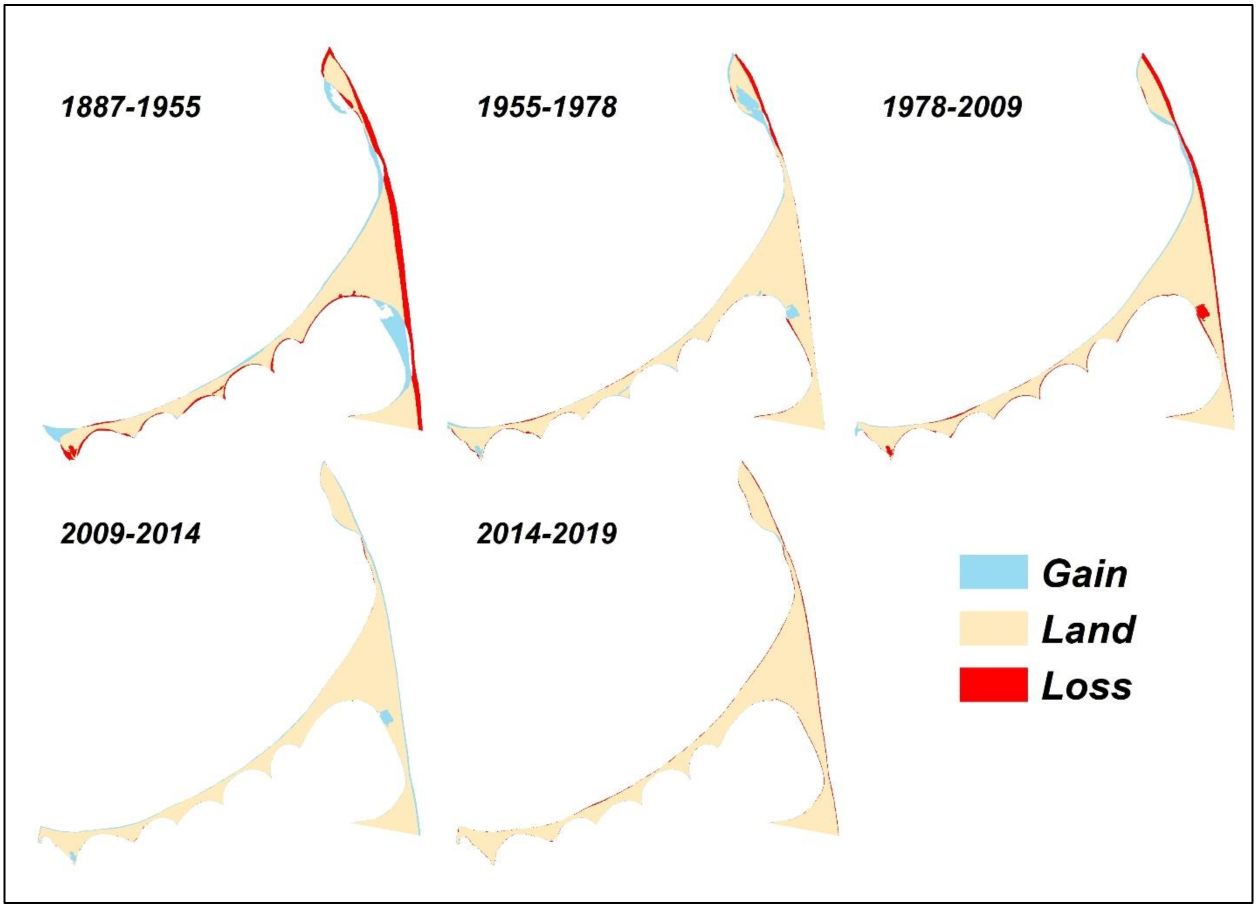


Figure 32. Incremental shoreline change for Coskata-Coatue through time (1887-2018).

The coastal beach and shoreline at Coskata-Coatue has changed significantly through time. Overall, the Coskata-Coatue has shifted in the southwestern direction. The coastal beach facing the Atlantic Ocean experiences significant coastal erosion while the coastal beach landscape facing both Nantucket Sound and Nantucket Harbor has accreting sand. Figure 33 visualizes the overall trend of land accretion and erosion that has occurred throughout the time of this analysis (1887-2019). The green-blue colors represent the shoreline gain between two time periods and the tan represents the historical 1887 land position (CZM shoreline). The yellow-red colors represent the shoreline loss between two time periods and the tan represents the current 2019 land position (digitized from current orthoimagery). It cannot be assumed that areas in blue/green or red/yellow are net gain/loss of sediment from this barrier beach system but rather visualizes how the coastline for each time has shifted in the southwest direction. Therefore, if this pattern of change continues, it is likely that the coastal beach at Coskata-Coatue will continue to retreat in the southwest direction.

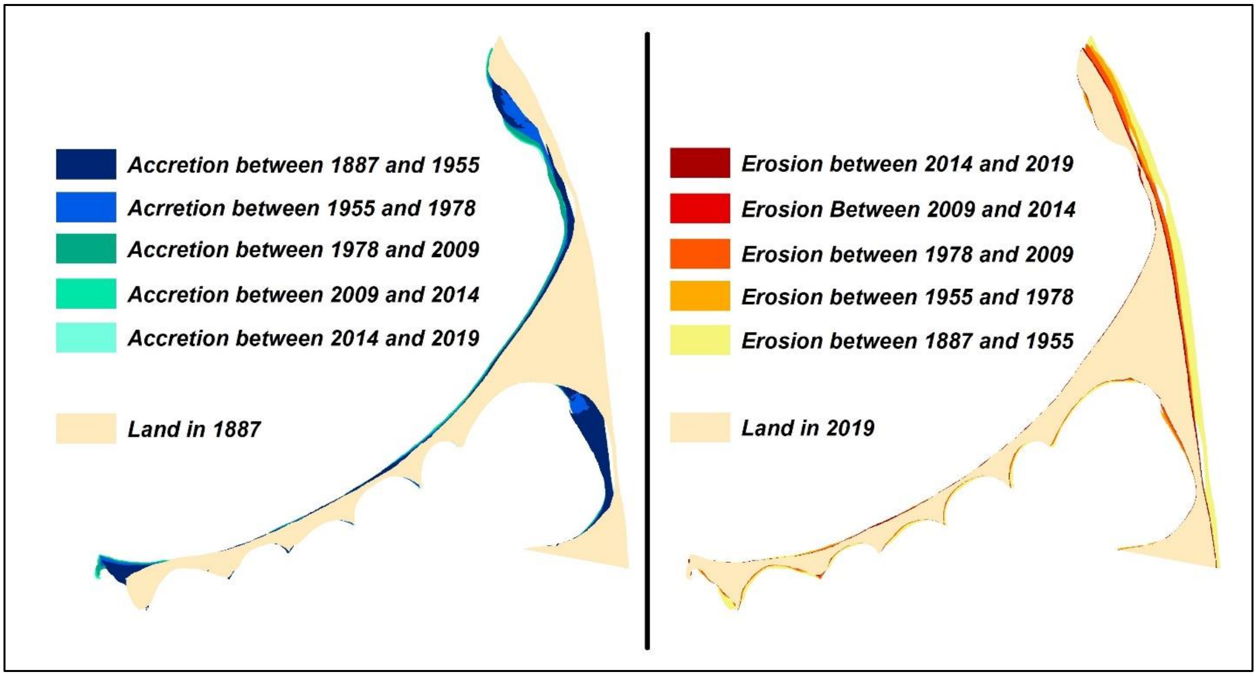


Figure 33. Accretional and erosional trends of shoreline at Coskata-Coatue through time.

Overall, this area of Coskata-Coatue is very vulnerable to the threat of coastal beach erosion and migration, especially if these erosional trends continue. One area to pay attention to is the presence/position of The Galls area, as this area has seen an overall narrowing of the beach landscape through time. The acreage of land change between each time period has been calculated as part of this analysis and is shown in Table 3. The greatest net loss changed occurred between 1978-2009 with a net loss of -115.1 acres of land. However, there has also been a significant net gain of 134.8 acres of land between the 2009–2014-time frame. Overall, from 1887-2019, there was a total net loss of land of -62.7 acres.

It is important to better understand the actual rate of loss for each period, which is also shown in Table 3. Rate of loss was determined by calculating the amount of land loss per year within that period. The time between 1978-2009, the loss rate was roughly -3.71 acres/year over the 31-year timeframe. This rate, however, did change to 26.95 acres/year (net gain rate) in the 2009-2014 timeframe. By the 2014–2019-time frame (5 years), the net loss change rate increased significantly to 11.98 acres/year. Overall, the Coskata-Coatue study area experienced a net loss rate of -0.48 acres/year between 1887-1955. Overall, this data shows there is a long-term trend of erosion at this study area. However, it is also important to note that the amount of sediment that is lost will vary in time and depends on the local hydrodynamic conditions that are the driving force behind these changes.

Table 3. Results of area change analysis for Coskata-Coatue study area.

Time Period	Net Change (Acres)	Number of Years	Net Change Rate (Acres/Year)
1887-1955	-81.7	68	-1.20
1955-1978	59.0	23	2.56
1978-2009	-115.1	31	-3.71
2009-2014	134.8	5	26.95
2014-2019	-59.9	5	-11.98
Total (1887-2019)	**-62.7**	**132**	**-0.48**

3.0 COASTAL INUNDATION ASSESSMENT

3.1 NUISANCE FLOODING

Flooding issues resulting from long-term shifts in tidal datums due to sea level rise can significantly impact the Coskata-Coatue area. Tidal flooding or nuisance flooding can potentially expose the landscape to flooding daily, likely complicating or disrupting access through low-lying areas. Based off work included in the Trustees' State of the Coast Report for the Islands (2021), sea level rise projections were used to develop future Mean Higher High Water (MHHW) tidal elevations for the Coskata-Coatue Study area.

The MHHW tidal datums developed from regional Sea Level Rise projections are included in Table 4. Present Day MHHW values are a reasonable representative estimation of MHHW for the entire town with future MHHW elevations developed by linear increases from Present Day MHHW values. There are some non-linear effects on tides that are not captured in these values and an updated more spatially variant data set is still in progress (Bosma et al 2021). MHHW values were developed for two separate coastlines: the Nantucket Sound westward facing shoreline and the Atlantic Ocean facing shoreline. Within ArcGIS, the two datasets were merged to create one continuous dataset covering the study area.

Table 4. MHHW Tidal Datums for Coskata-Coatue Study Area.

MHHW Tidal Datum (feet NAVD88)	Present Day	2030	2050	2070
Nantucket Sound Shoreline	1.90	3.25	4.56	6.37
Atlantic Ocean Shoreline	2.20	3.55	4.86	6.67

Visualizations of the MHHW tidal flooding extents are represented in Figure 34. In general, Coatue Ave and Great Point Road are vulnerable to nuisance flooding which can restrict and/or disrupt access to the greater study area daily. Coatue Ave along the 1st and 2nd Point study site becomes vulnerable to nuisance flooding in Present Day. Great Point Rod along The Haulover site is vulnerable starting in 2030. By 2050, the area where Wauwinet Road turns into Great Point Road becomes vulnerable to daily tidal flooding.

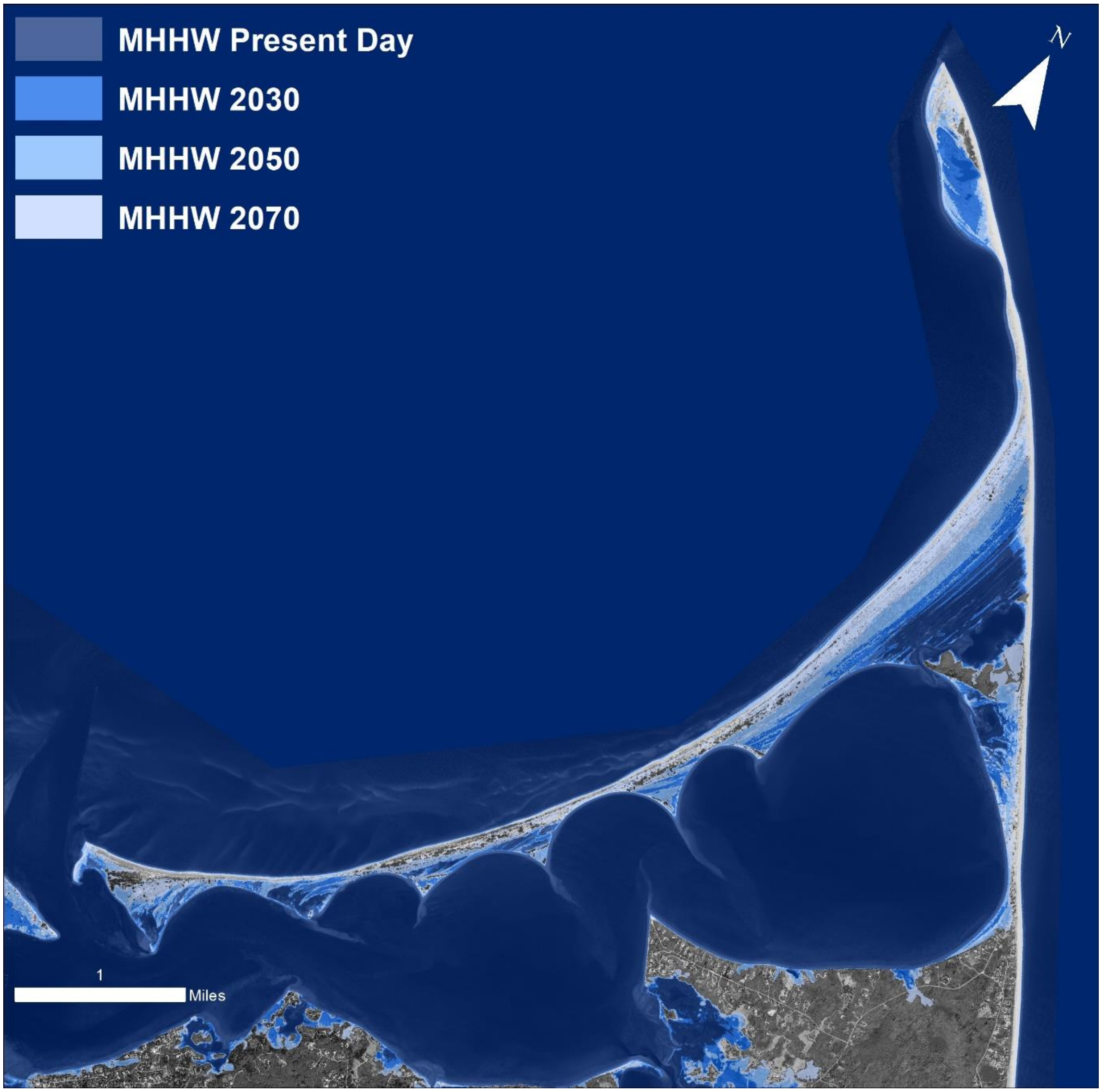


Figure 34. MHHW Tidal benchmarks for Coskata-Coatue study area.

Site specific MHHW visualizations are captured in Figure 35. The MHHW benchmarks show that daily flooding will impact the low-lying areas of each study site through 2070. Encroachment of the tide inland can reduce the amount of usable beach area for residents and visitors. Additionally, each study site seems to be resilient to over wash through 2070, as there is no connection of the MHHW tidal benchmark across the landscape at each location. However, coastal erosion due to episodic storms now and in the future can alter the topography of the area affecting how tidal flooding is expressed over the landscape through time.

Portions of Coatue Ave running between the 1st and 2nd Point study site currently experiences daily tidal flooding which will become more significant by 2030 through 2070. In both The

Haulover and Coskata Pond study sites, Great Point Road is impacted by tidal flooding. Great Point Road along The Haulover site is first impacted by tidal flooding from the Nantucket Harbor in 2030 potentially restricting access further North to Great Point. For Coskata Pond, flooding along this section of Great Point Road does not occur until 2070. While The Galls area seems to be protected from wash over events from daily tidal flooding in 2070, access to this area and further North will ultimately be affected by daily tidal flooding at southerly areas like Coskata Pond and The Haulover site locations.

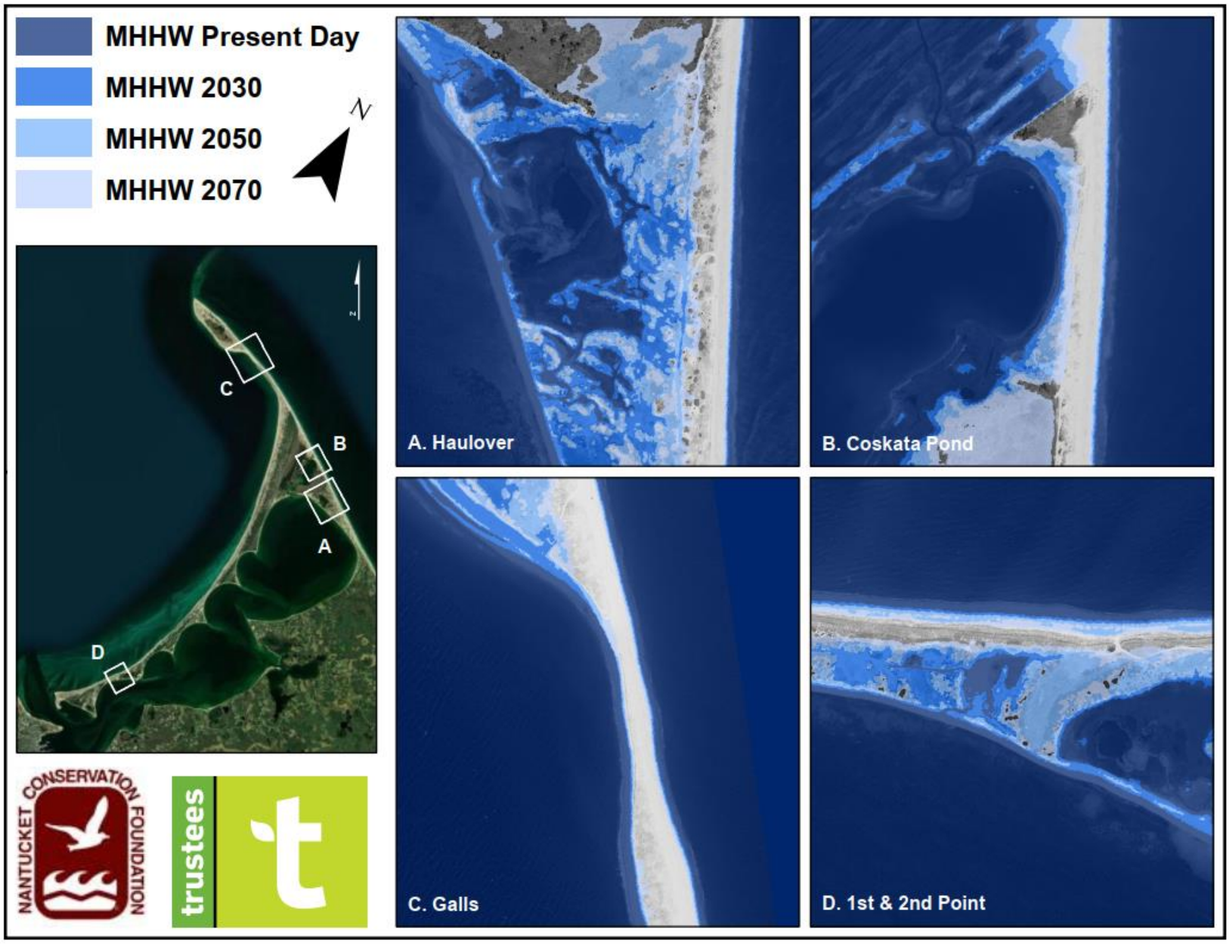
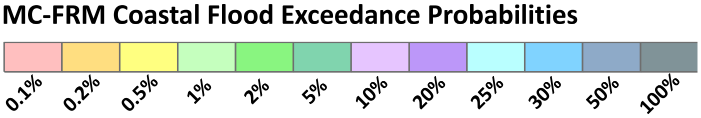


Figure 35. MHHW Tidal benchmarks for each study site.

3.2 PROBABILITY OF INUNDATION- PRESENT DAY, 2030, 2050, AND 2070

Episodic impacts from more frequent and more intense coastal storms present a significant threat to the Coskata-Coatue study area. It is also in a high energy wave zone with potential for overwash and breaching events. Flooding, coastal erosion, and changes in geomorphic features can restrict or disrupt access throughout the area especially where roads and infrastructure are located on the beach and/or exposed to wave action from coastal storms. The Massachusetts Coastal Flood Risk Model (MC-FRM) results for Present Day, 2030, 2050 and 2070 were used to develop inundation maps. The inundation maps provide the annual chance of inundation from coastal storm surge across the Coskata-Coatue landscape. Inundation probabilities are represented as follows:



Overall, the Coskata-Coatue study area is extremely vulnerable to storm surge inundation in Present Day and future climate conditions. In Present Day, approximately 91% of the study area has a 100% chance of inundation each year. By 2070, this area increases to 98% of the total study area that will have a 100% chance of inundation each year. The probability of inundation results for the Coatue-Coskata study area for all out years are displayed in Figure 36.

Figure 36. MC-FRM Probability of inundation results for Present Day and Future Climate Conditions.

The MC-FRM projections were provided for individual study sites within the study area to assess the differences in storm surge inundation impacts on a more refined scale for points of interest. The individual areas include the area between 1st and 2nd Point on the inner Harbor shoreline, Coskata Pond, The Haulover, and The Galls. The locus map in Figure 35 shows the location of each of these areas. Figure 36 show MC-FRM inundation for Present Day, 2030, 2050, and 2070 for each of the study areas.

3.2.1 The Haulover Study Area

The Haulover study area is low-lying, fronted by the Atlantic Ocean, and backed by the Nantucket Harbor. Great Point Road runs along this study area providing access to Coskata-Coatue. The eastern shoreline facing the Atlantic Ocean is exposed to wave action increasing the risk of coastal erosion. Overall, this study area is primarily flooded from the Harbor and will become inundated under storm surge conditions annually starting in Present day (100% chance event). The crossover area between the Atlantic Ocean facing shoreline and the inner shoreline is also vulnerable to storm surge flooding. In Present Day, this area has an annual chance between 0.5% and 2% chance of flooding across the study area (Figure 37). This increases to 1-5% in 2030 and 2-10% in 2050, annually. By 2070, this area will have a 10-50% annual chance of experiencing flooding across the shoreline during coastal storms.

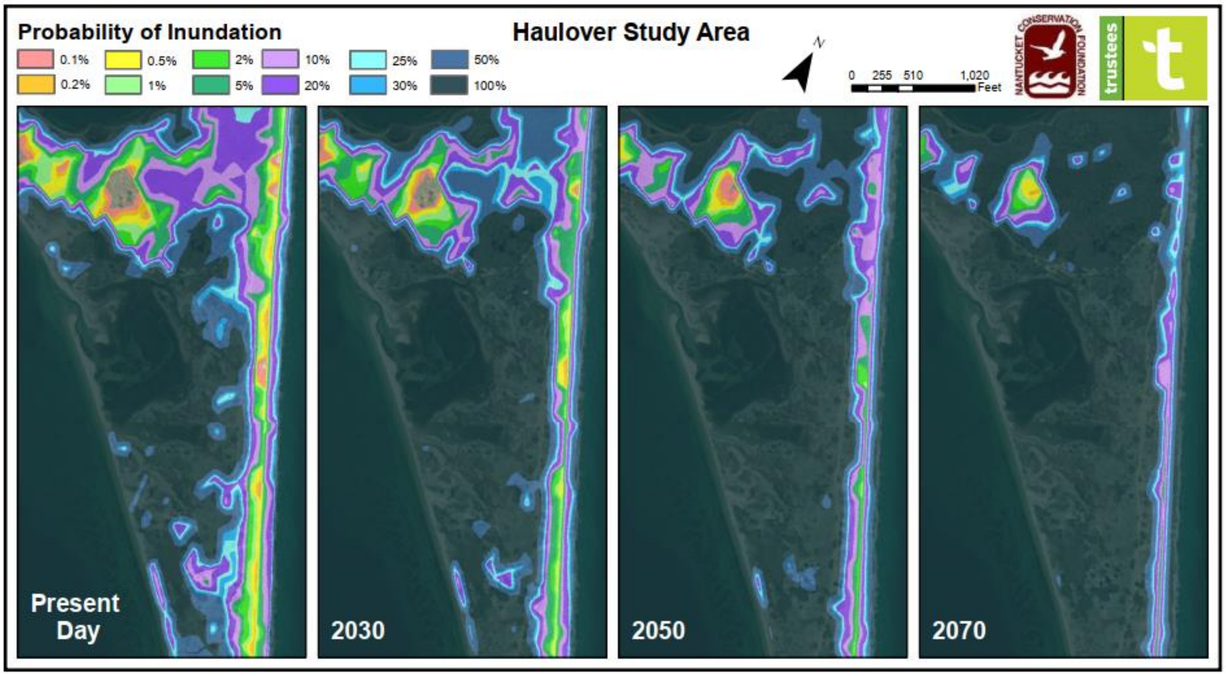


Figure 37. MC-FRM Probability of inundation results for The Haulover study area.

3.2.2 Coskata Pond Study Area

Coskata Pond is connected by a small tidal creek to the Nantucket Harbor and backed by the eastern shoreline of Nantucket facing the Atlantic Ocean. The eastern shoreline facing the Atlantic Ocean, including a segment of Great Point Road running directly along the beach, is exposed to wave action increasing the risk of coastal erosion in this study area. Erosion of this area can damage/erode this roadway restricting/disrupting access to Coskata-Coatue.

Overall, this study area is primarily flooded from the Harbor and will become inundated under storm surge conditions annually starting in Present day (100% chance event). The crossover area between the Atlantic Ocean facing shoreline and the inner shoreline of the pond is also vulnerable to storm surge flooding. In Present Day, this area has an annual chance between 5% and 10 %

chance of flooding across the study area (Figure 38). This increases to 10-25% in 2030 and 20-50% in 2050, annually. By 2070, this area will experience flooding across the shoreline during coastal storms annually (100% chance).

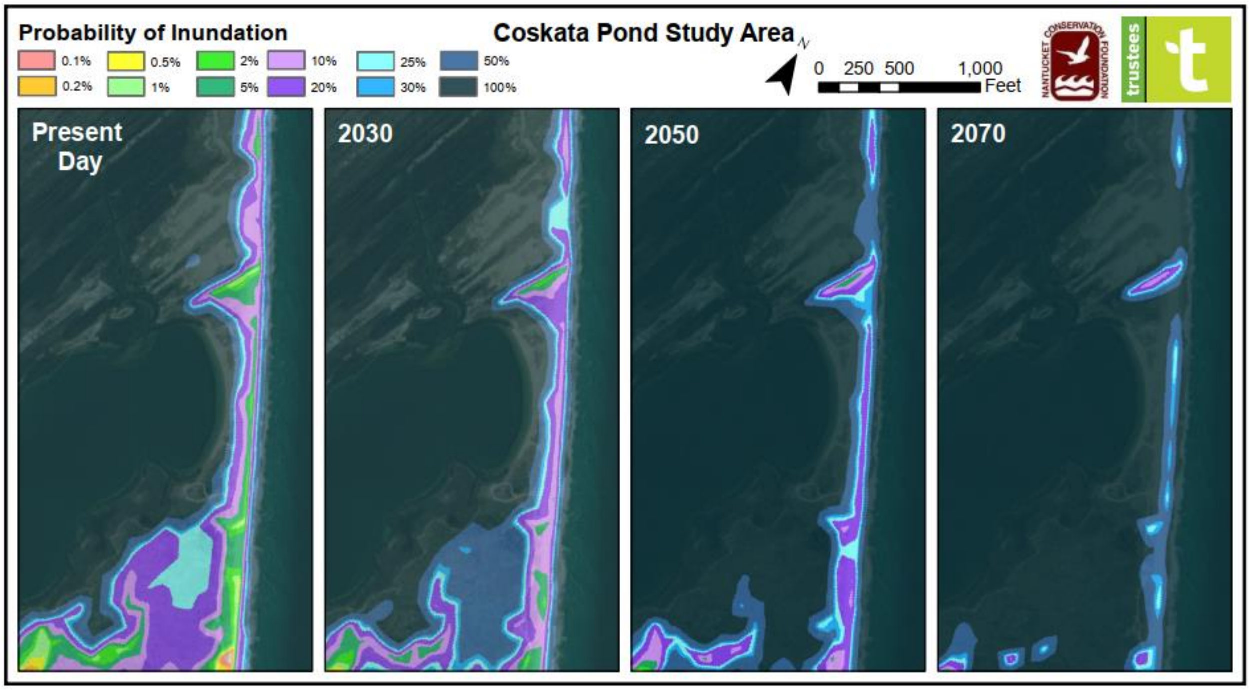


Figure 38. MC-FRM Probability of inundation results for the Coskata Pond study area.

3.2.3 The Galls Study Area

The Galls study area is an extremely low-lying beach area which provides a critical link between Great Point and the Mainland of Nantucket. Situated between Nantucket Sound on the western shoreline and the Atlantic Ocean on the Eastern edge, The Galls is exposed to wave action and extremely vulnerable to coastal erosion, breaches, and overwash events. Historically, this area has experienced breaches and overwash events. The most recent breach was in 1991 due to Hurricane Bob. Coastal erosion and over washing of this area can restrict/disrupt access to the Great Point Lighthouse, an iconic monument and important tourism spot on Great Point.

Overall, this study area is extremely vulnerable to flood inundation from storm surge annually (100% chance event). Regarding episodic overwash events, in Present Day this area has an annual chance of flooding between 5% and 20 % (Figure 39). Between 2030 and 2050, this area will have an annual chance of 10-50% of experiencing overwash events. By 2070, this area will experience flooding across the beach during coastal storms annually (100% chance).

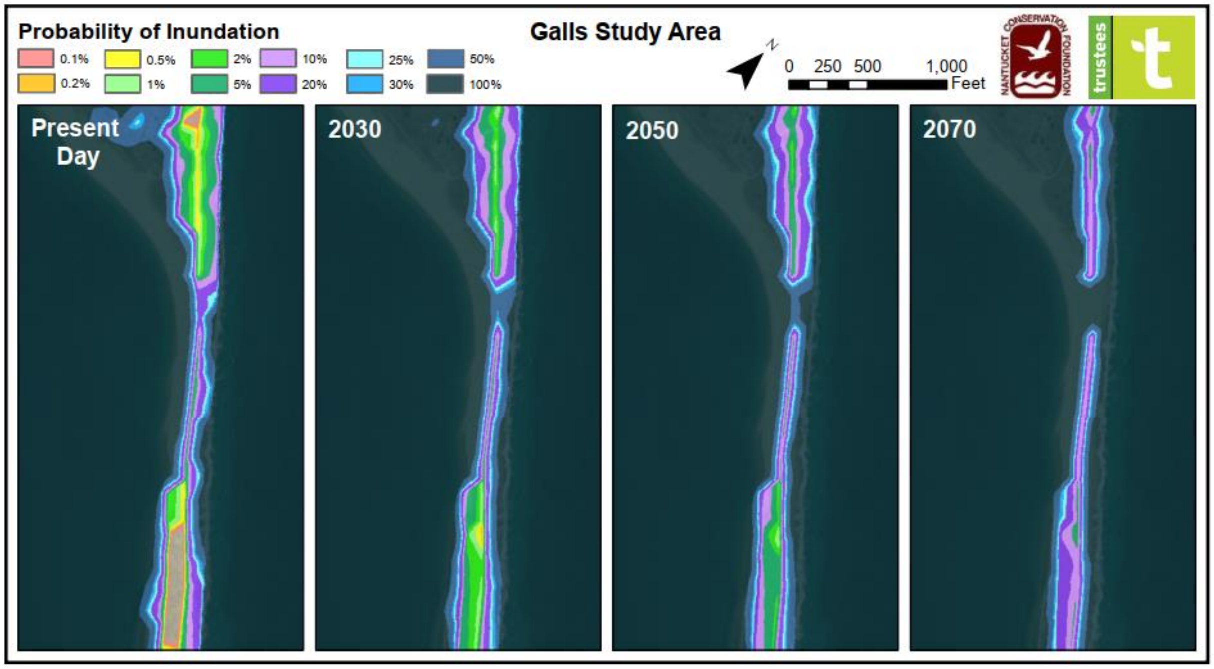


Figure 39. MC-FRM Probability of inundation results for The Galls study area.

3.2.4 Between 1st and 2nd Point Study Area

The area between 1st and 2nd Point is a stretch of low-lying beach that runs along Coatue Avenue. This area is exposed to wave action on the front side facing Nantucket sound and backed by Nantucket Harbor and is extremely vulnerable to storm surge. Overall, this study area is primarily flooded from the Harbor and will become inundated under storm surge conditions annually starting in Present day (100% chance event). This area is also vulnerable to total overwash activity (flooding crossing between Nantucket Sound and the Harbor). In Present Day, this area has at least a 10% annual chance of being flooded across the study area (Figure 40). This increases to 20% in 2030 and 25% in 2050, annually. By 2070, this area, annually, will experience flooding across the shoreline during coastal storms.

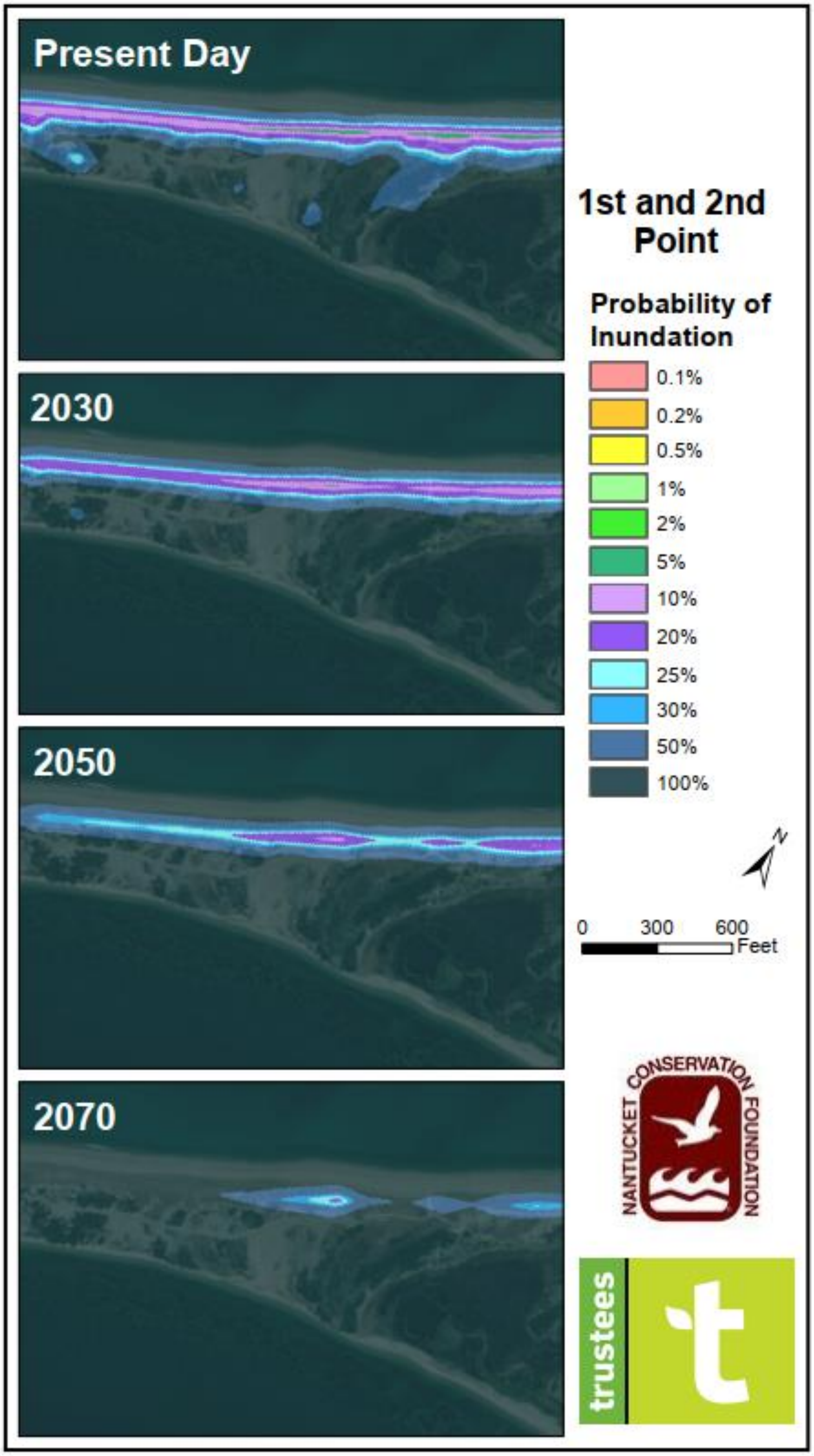


Figure 40. MC-FRM Probability of inundation results for the 1st and 2nd Point study area.

3.3 NUISANCE AND STORM SURGE FLOODING IMPACTS ON INFRASTRUCTURE

After understanding the impacts of tidal and storm surge flooding to the general landscape, a simplified assessment on impacts to roadway mileage and structures at risk to both flooding scenarios was completed. Miles of roads and number of structures potentially flooding from Mean Higher High Water (MHHW), and the 10% and 1% chance storms were quantified for the study area for Present Day, 2030, 2050, and 2070. Table 5 shows the results of the full assessment.

Table 5. Nuisance and Storm Surge flooding Impacts to Roadways and Structures.

	Present Day		2030		2050		2070	
Roads (20.8 miles)	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent
Nuisance (MHHW)	1.2	6%	4.6	22%	8.9	43%	16.9	81%
Storm Event (10%)	18.5	89%	20.0	96%	20.5	99%	20.7	100%
Storm Event (1%)	20.5	99%	20.6	99%	20.8	100%	20.8	100%
Structures (52)	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent
Nuisance (MHHW)	0	0%	0	0%	7	13%	17	33%
Storm Event (10%)	19	37%	25	48%	35	67%	47	90%
Storm Event (1%)	35	67%	48	92%	50	96%	51	98%

Presently, there are 1.2 miles of roads and no structures exposed to daily tidal flooding. Future projections indicated this potential exposure to nuisance flooding may increase to 9 miles and 7 structures by 2050 and 17 miles and 17 structures by 2070. In present day, flooded roadways are concentrated at the 1st and 2nd Point study area along Coatue Ave. In 2050, the intersection of Great Point Road and Wauwinet Road is an additional area of roadway that could become flooded from daily tides. Great Point Road running along The Haulover site becomes inundated by 2070. The structures vulnerable to daily tidal flooding by 2050 are concentrated at the beginning of Great Point Rd where Great Point access begins and includes a few structures on the Harbor facing shoreline of Coatue Ave.

The 10% chance event was used to screen the number of structures and roadways vulnerable to storm surge flooding, since the cumulative risk of this event occurring over the typical lifespan of a mortgage or roadway is nearly 100%. Currently, 19 structures and 18.5 miles of roadways are potentially exposed to the 10% chance event. MC-FRM projections indicate this exposure could increase to 47 structures and 20.7 road miles by 2070.

Potential exposure to storm surge associated with the 1% chance event was also evaluated, since the 1% probability level is used in FEMA mapping and familiar to the public. Currently, 35 structures and 20.5 road miles are potentially exposed to the 1% chance event. MC-FRM projections indicate this exposure could increase to 51 structures and 20.8 road miles by 2070. The full results for structures and roadways potentially exposed to nuisance and storm surge flooding are presented in Table 5.

The flooding extents of MHHW and the 1% chance storm for 2050 climate conditions shoreline is presented in Figure 41. The number of structures and miles of roadways impacted by both flooding scenarios is also shown in the map.

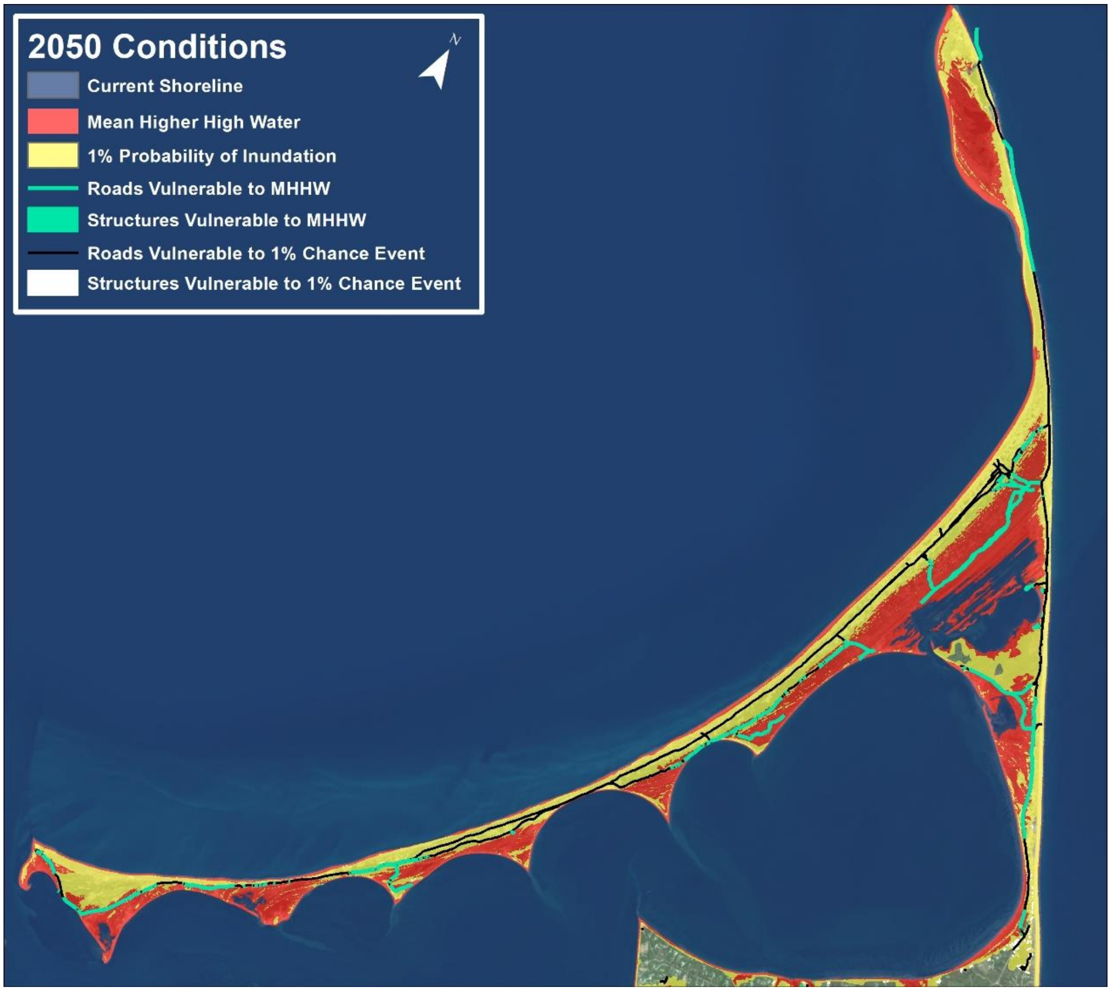


Figure 41. Roadway and structure impacts by MHHW and the 1% chance storm.

4.0 EXISTING CONDITIONS

Tara Marden and Joel Kubick of the Woods Hole Group visited the Trustees' and NCF's properties on Coskata-Coatue on March 16, 2021, accompanied by Karen Beattie and Dr. Jennifer Karberg from the NCF and Shea Fee from the Trustees. The day long trip traversed the entire Coskata-Coatue Wildlife Refuge and included a more comprehensive stop and discussion at each of the sites shown in Figure 42. Observations from the day and evaluation of additional available information compiled specific to each of the four areas of interest are discussed below.

Figure 42. Locus map of the four areas of interest.

4.1 THE HAULOVER

The Haulover is a narrow section of low-lying topography that separates the Atlantic Ocean to the east and Nantucket Harbor to the west. Despite its small area, it contains a variety of habitats, including coastal beaches and dunes, salt marsh and tidal flats, freshwater wetlands, and an upland maritime forest. The ocean-facing coastal each is relatively wide with a gentle slope and is comprised of medium to coarse grained sand (Figure 43 left). The coastal dune is vegetated predominantly with beach grass, but also contains eastern red cedars and other maritime shrubs (e.g., northern bayberry) (Figure 43 right). The seaward face of the coastal dune extends approximately five (5) feet high from the coastal beach. Portions of the foredune ridge showed evidence of recent erosion, but the overall coastal dune system is expansive and healthy despite its low profile.

Figure 43. The coastal beach and coastal dune at The Haulover; the ocean-facing coastal beach facing north (left); the views from the primary dune crest at The Haulover - looking west towards Nantucket Harbor (right).

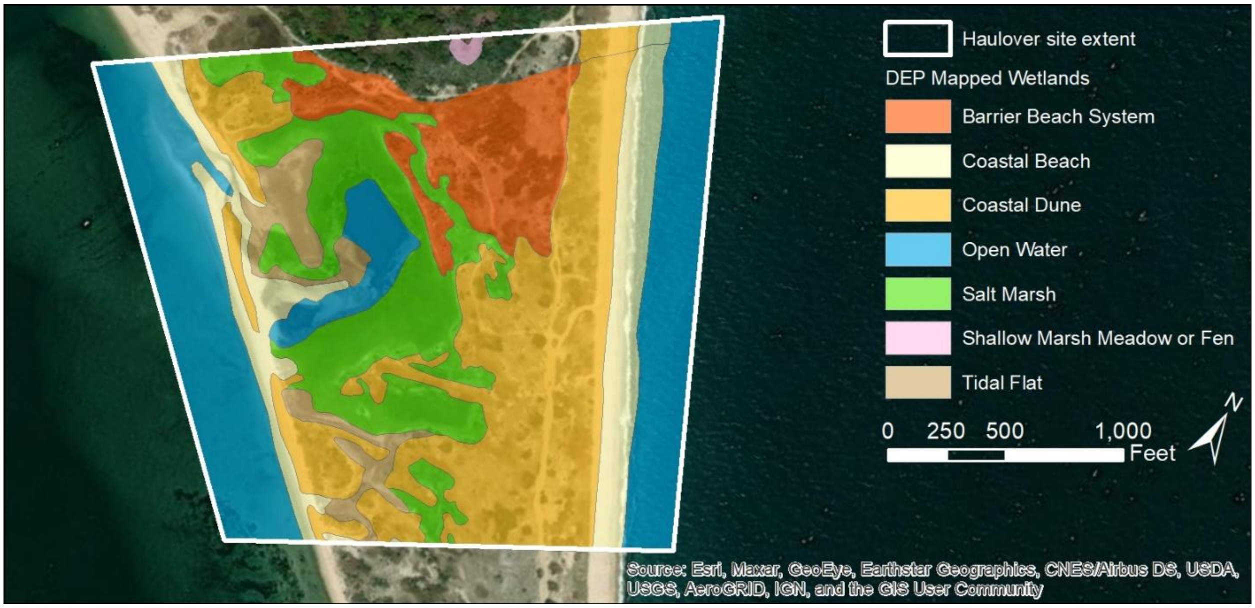
Along the northern extent of The Haulover, the site transitions from a barrier beach coastal dune system to a maritime forest, dominated by oaks (Figure 44 left) and eastern red cedar. There is a small freshwater wetland (Figure 44 right) just south of the maritime forest. In addition, a corrugated plastic pipe runs under the road that circles the southern boundary of the maritime forest (Figure 45). The flow from this pipe drains into a relatively large salt marsh (Figure 46) surrounding Haulover Pond on the Harbor side of the barrier beach. American oystercatchers regularly use the Nantucket Harbor shoreline in this area for nesting.

Figure 44. Other habitats present at The Haulover include: a maritime forest (left) and a freshwater wetland (right).

Figure 45. Existing corrugated plastic pipe under road.

Figure 46. Existing salt marsh on the Nantucket Harbor side of the barrier beach at The Haulover.

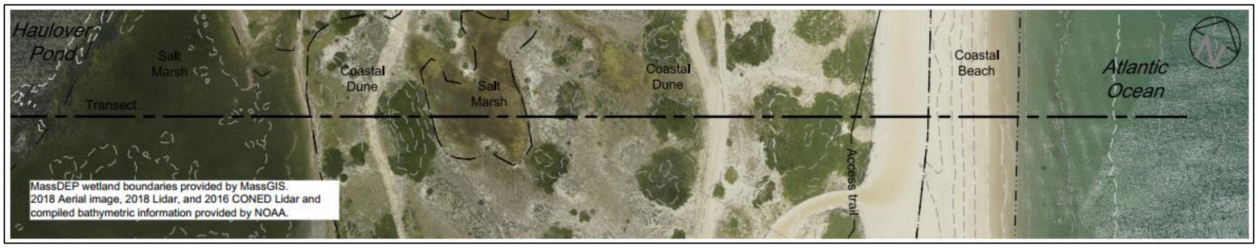
The extent and distribution of the existing wetland areas (as mapped by DEP) can be seen in Figure 47. Coastal beach extends along both Atlantic Ocean and Nantucket Harbor shorelines, with an extensive barrier beach and coastal dune system in between. As noted above, there is an extensive salt marsh surrounding Haulover Pond, which is separated from Nantucket Harbor by a smaller barrier beach spit; a narrow inlet provides tidal flow to and from the pond. The map in Figure 47 also shows a small freshwater wetland at the northern part of The Haulover site (labeled "Shallow Marsh Meadow or Fen" in the DEP mapping). Finally, as noted above, there is an upland maritime forest at the northern end of this site; the dense vegetation in this area can be seen at the top of Figure 47.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 47. Existing wetland resource areas, as mapped by MassDEP, at The Haulover.

Although there is currently no connection between the Atlantic Ocean and Nantucket Harbor at this location, the central area of The Haulover breached in 1896 and remained open for nearly a decade, cutting off the remaining Coskata-Coatue Point from the rest of Nantucket, but also providing easier boat travel between the Harbor and the open ocean to the east. The ocean-facing coastal beach eventually accreted enough to close the breach and the dune system has since grown to protect the area. Haulover Pond formed along the edge of the Harbor during the breach closure. The primary coastal dune serves to protect the inner over sand vehicle (OSV) access trail, salt marshes, and the pond from coastal storm waves with the lower, narrower secondary dunes providing additional protection. Figures 48 and 49 show resource area delineations and LiDAR elevations along a cross section through The Haulover.



MassDEP wetland boundaries provided by MassGIS. 2018 Aerial image, 2018 Lidar, and 2016 CONED Lidar and compiled bathymetric information provided by NOAA.

Figure 48. Plan of transect showing LiDAR topography and MassDEP resource areas.

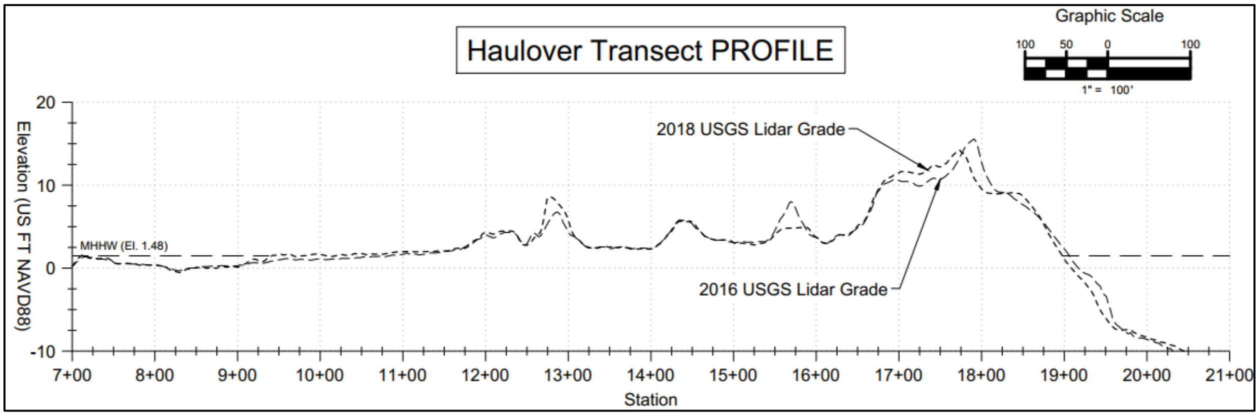


Figure 49. Profile showing LiDAR topography.

4.2 COSKATA POND

Coskata Pond is bordered by the thick maritime oak forest of Coskata Woods to the southeast, a barrier beach that separates it from the Atlantic Ocean to the east, and the low marshland of the Glades to the northwest (Figure 50). The Pond is connected via a circuitous channel to the Head of Nantucket Harbor to the south.

The area surrounding the south and southeast of the Pond, Coskata Woods, consists of mature maritime forest which is home to a variety of cedars, maples, tupelo, and oaks. Along the northwest border of the Pond are a series of well-defined parallel dune ridges, which are thought to be some of the oldest dunes on the Island and have been studied by many scientists and geologists over the years. Figure 50 shows these dune ridges as visible stripes or striations in the landscape. The Pond is separated from the Atlantic Ocean by a low barrier beach and coastal dune (Figure 51). Coskata Pond is largely open water, but it is fringed with salt marsh cord grass and abuts a larger salt marsh system (i.e., the Glades) to the west (Figure 52). The Pond is also home to an abundance of shorebirds, including herons, egrets, osprey, and American oystercatchers, as well as clams and striped bass.

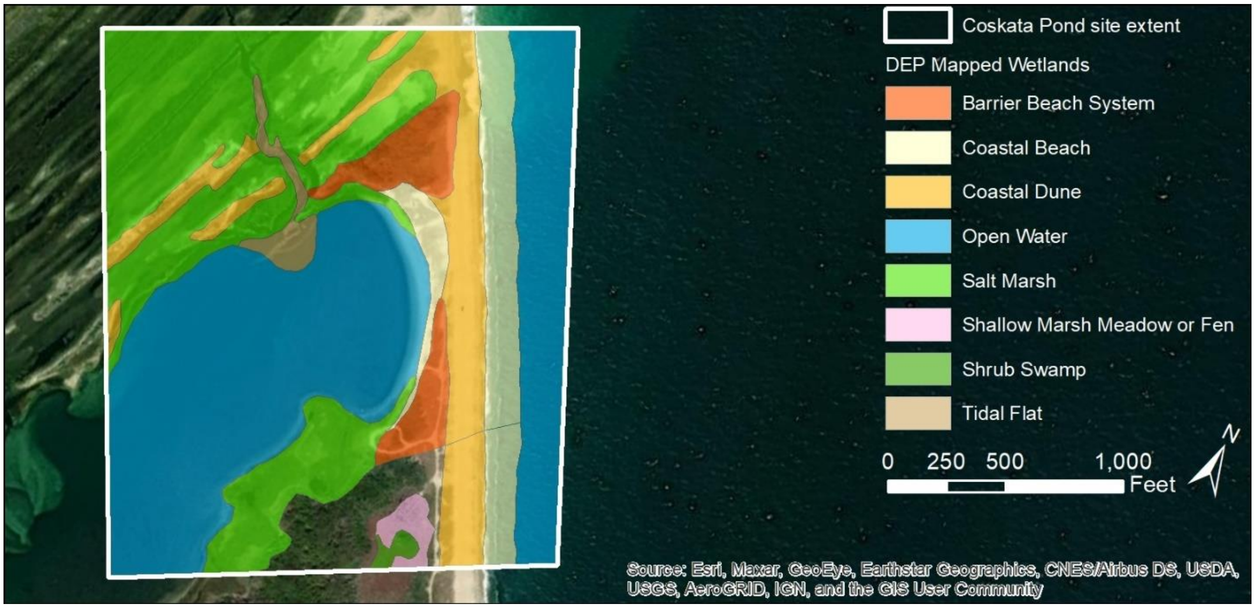
The wetland resources present around the northeastern portion of Coskata Pond, in the vicinity of the barrier beach, as mapped by MassDEP, are displayed in Figure 53. The barrier beach and coastal dunes dominated the eastern side of the site. Extensive salt marsh is displayed in green to the northwest of the Pond, with narrower fringing marsh present along the southeastern shore.

The historic dune ridges within the Glades (i.e., the salt marsh area) are also evident from DEP's wetland mapping.

Figure 50. Google Earth image of Coskata Pond showing the maritime forest to the south and the distinct parallel historic dune ridges within the Glades to the west of the Pond.

Figure 51. Barrier beach between the Atlantic Ocean and Coskata Pond - looking north.

Figure 52. Extensive salt marsh northwest of Coskata Pond.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 53. Existing wetland resource areas, as mapped by MassDEP, at Coskata Pond.

The barrier beach separately Coskata Pond from the Atlantic Ocean is approximately 350 feet wide at MHHW (based on the 2018 LiDAR), with a dune crest elevation 9 feet NAVD88 (Figure 54).

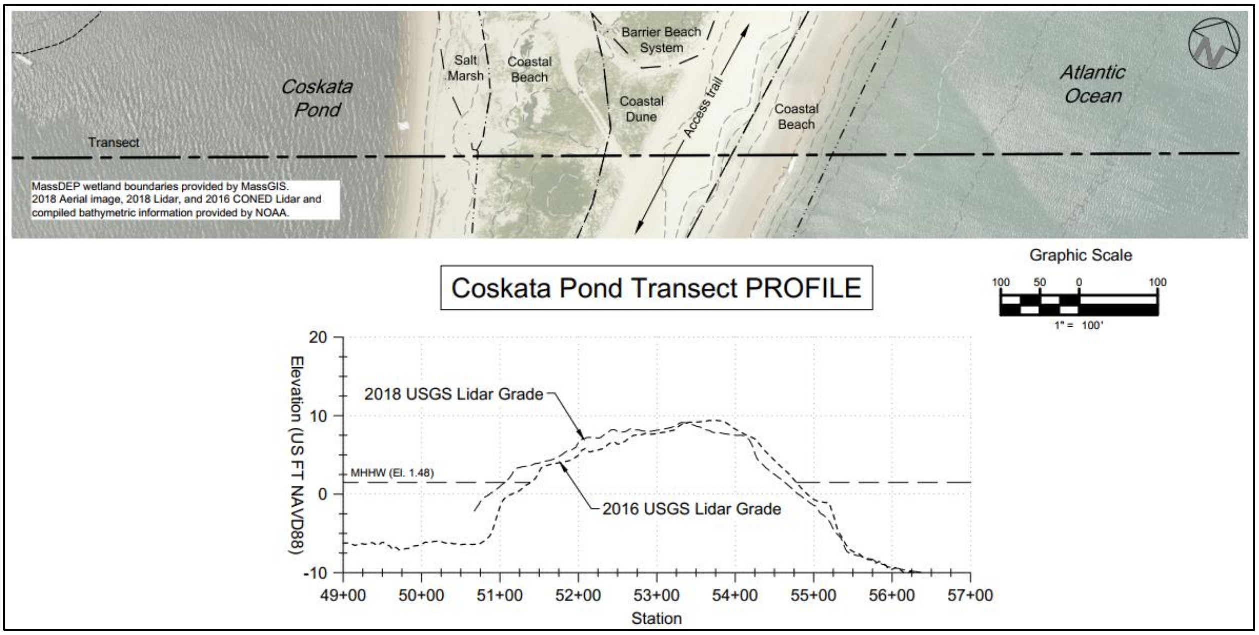


Figure 54. Plan and profile showing LiDAR topography and Mass DEP wetland resources.

4.3 THE GALLS

The Galls is a section of narrow, low lying coastal beach (Figure 55). The Galls divides the Atlantic Ocean to the east and Nantucket Sound to the west and connects the area around the Great Point Lighthouse to the north with the elbow of Coskata-Coatue. The wide, gently sloping beach is often over washed during even moderate coastal storms and occasionally breaches during larger storms (e.g., 1984 and 1991). Figure 55 shows views looking southeast at the dune crest (right) and north at the large overwash fan that developed during a storm (left). Figure 56 provides the DEP wetland mapping of this area, which shows only a single wetland resource type across the entire subsite: coastal beach. Healthy and robust coastal dunes with an approximately crest elevation of 16 feet NAVD88 (based on the 2018 LiDAR) extend northwest and southeast from The Galls.

The overwash area of The Galls is approximately 450 feet wide with a maximum elevation of 7 feet (NAVD88) based on the 2018 LiDAR (Figure 57). This significant westward migration that has occurred between 2016 and 2018 is shown in the LiDAR comparison of the Gall beach transect profile in Figure 57. For comparison, Figure 57 also provides a cross-section of the coastal dune to the south of the overwash area. Although the barrier beach landform is slightly narrower in this location, the crest elevation of the coastal dune is approximately 16 feet (NAVD88).

Figure 55. South and north-facing views from The Galls looking at the remaining dune crest (left) and a large overwash fan that developed during a storm (right).

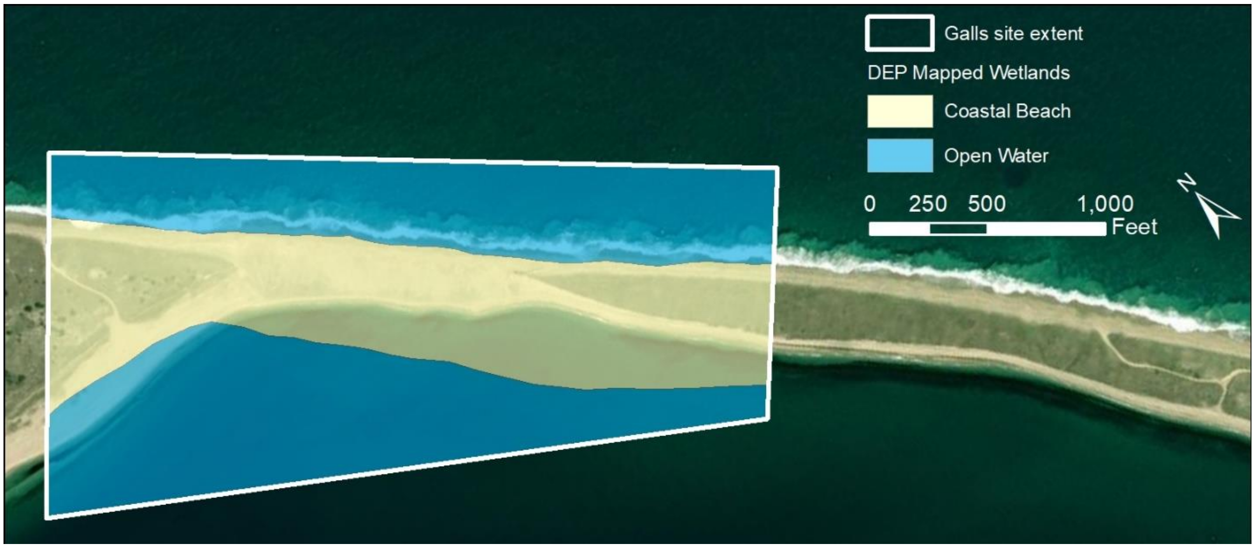


Figure 56. Existing wetland resource areas, as mapped by MassDEP, at The Galls.

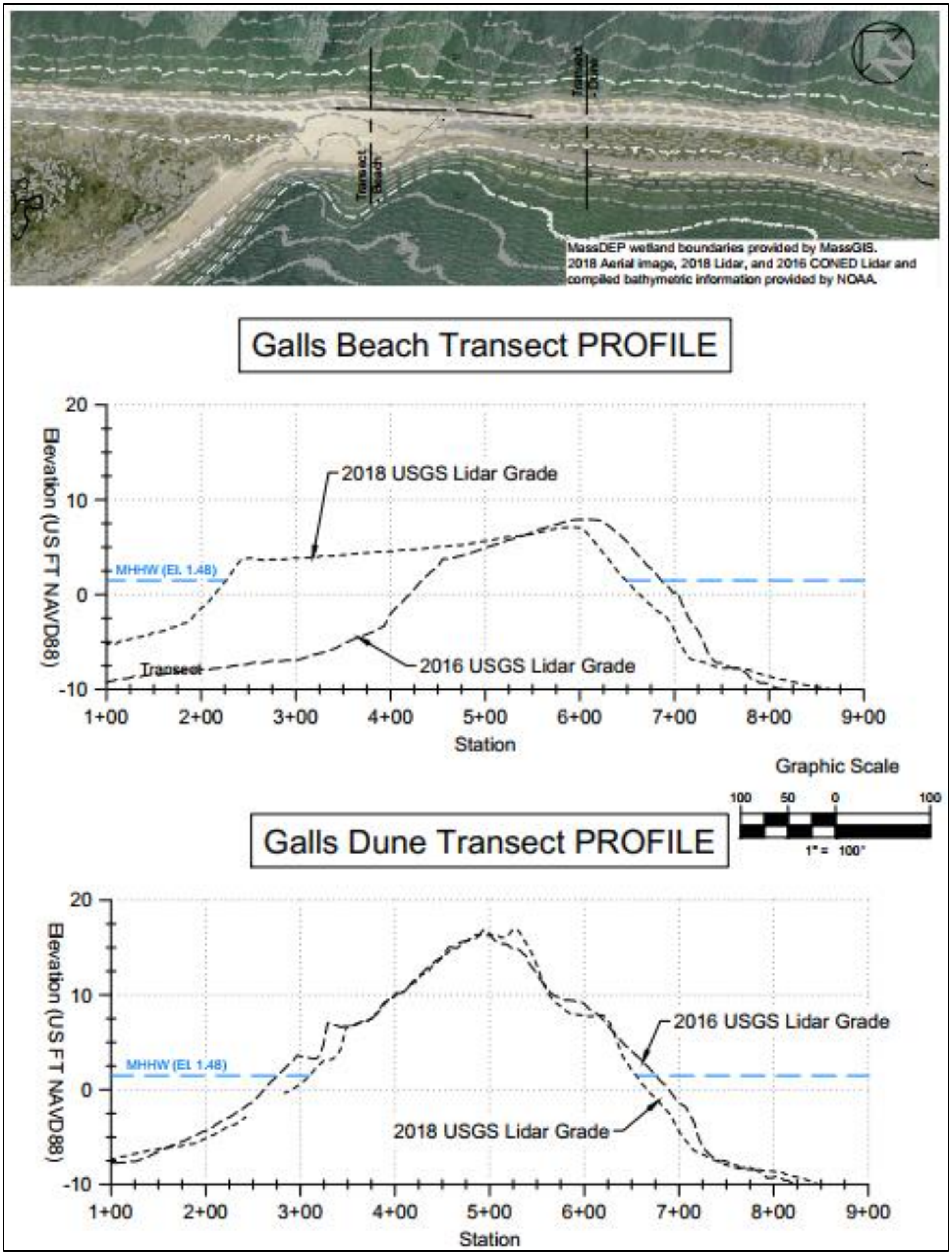


Figure 57. Plan and profile showing LiDAR topography at overwashed beach and remaining dune.

4.4 BETWEEN 1ST AND 2ND POINT

The cuspate spits along the southerly shore of Coatue are a unique landform system that is thought to have formed from the perfect combination of dominant winds, waves, and longshore currents post-glaciation. These six cuspate spits that extend as much as a half mile into the Harbor, have beautifully preserved recurve dune ridges, providing protection to inner marsh lagoons, and are the home to an abundance of terrestrial, avian, and marine wildlife. Piping plovers and American oystercatchers are known to nest in this area. Eastern prickly pear (*Opuntia humifusa*) can also be found throughout the barrier beach in this location. The area between 1st and 2nd Point is between two of these cuspate features, with a landform consisting of barrier beach, coastal dunes, tidal flats, and salt marsh. The vegetation in the coastal dunes includes beach grass, cedars, and other low lying salt tolerant shrubs (Figure 58).

Figure 58. Vegetated coastal dunes between 1st and 2nd Point (looking southwest).

A sandy over sand vehicle trail that originates in Wauwinet extends all the way to 1st Point and provides public access to this remote and beautiful spot in the wildlife refuge. A small sandy parking area is situated between 1st and 2nd Point (Figure 59) and provides a place for the public to park while exploring Coatue.

Figure 59. Low-lying dirt parking area between 1st and 2nd Point.

The wetland resource area mapping produced by MassDEP shows the range of wetland habitats present between 1st and 2nd Point (Figure 60). Coastal beach and coastal dune are found along the northern (Nantucket Sound) side of the barrier beach. Forest- and shrub-dominated areas of the barrier beach are classified as "barrier beach system". There is also significant salt marsh area in a lagoon connected to Nantucket Harbor through various circuitous inlets. Note that the dirt parking area mentioned above is classified by DEP as "tidal flat".

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 60. Existing wetland resource areas, as mapped by MassDEP, between 1st and 2nd Point.

The classification of the parking area as tidal flat is because it has a maximum elevation of 2.4 (NAVD88) based on the 2016 USGS LiDAR (Figure 61) and is frequently flooded. This limits access, which will likely get worse soon. The rest of the barrier beach is also relatively low-lying. The dunes have a maximum elevation of 9.4 feet NAVD88 (Figure 61) and are prone to erosion and overtopping.

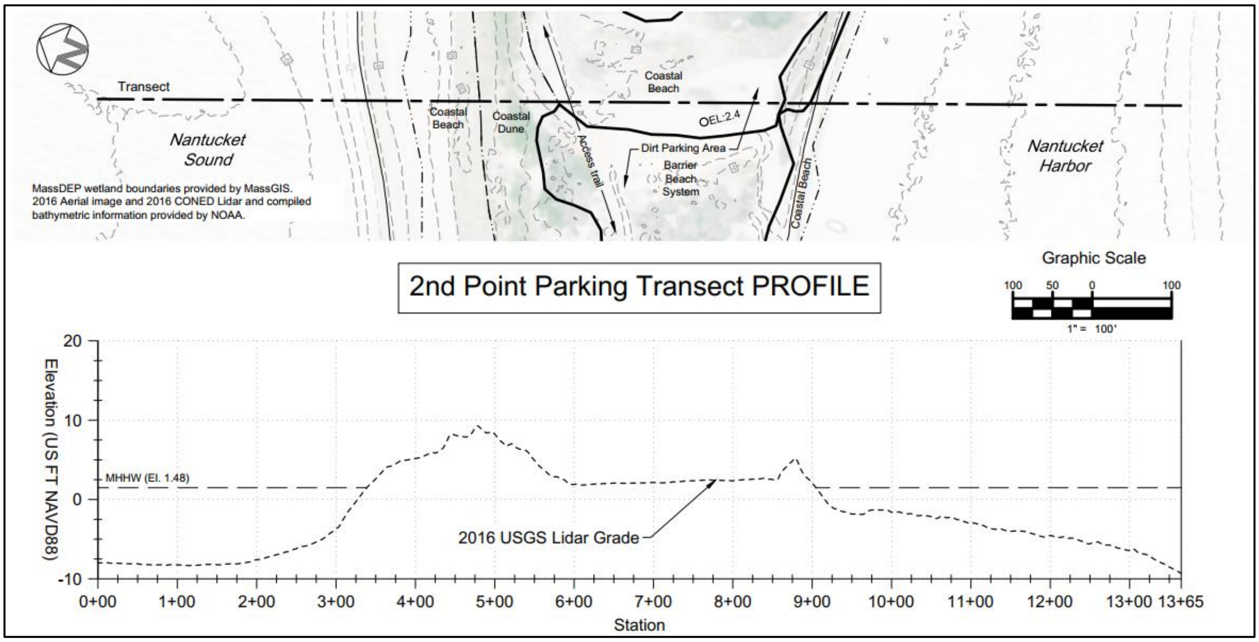


Figure 61. Plan and profile showing 2016 LiDAR topography and MassDEP wetland resources.

Figure 62. Photograph of Model A driving over timber roadway into the dunes (Image courtesy of the Nantucket Historical Association).

5.0 SLAMM RESULTS

Impacts to natural resources including beaches, salt marshes, and transitional wetlands were assessed on a semi-quantitative basis. Woods Hole Group utilized the Sea Level Affecting Marshes Model (SLAMM) results developed for the Massachusetts Office of Coastal Zone Management (CZM) to evaluate the effects of sea-level rise on coastal wetlands and natural resources at Coskata-Coatue. Final model results for the 2030, 2050 and 2070 out years for the "High" SLR projection for the project area are described below.

Natural resources provide numerous valuable ecosystem services, from fisheries habitat to carbon sequestration and storm damage protection. They are also an important component of the identity of the Town of Nantucket and a significant driver for the local tourism industry. However, they are also vulnerable to climate change impacts like sea level rise. For example, one of the major habitat changes that is projected to occur between Present Day and 2070 is an overall loss of salt marsh. In Present Day, the combined total area for regularly and irregularly flooded marsh is 230 acres, with the majority of that being irregularly flooded marsh (i.e., high salt marsh). By 2030, although the overall salt marsh acreage is projected to increase by approximately 7 acres, high marsh areas will start converting to low marsh as sea-level rises. This shift from high to low marsh will continue through 2050. By this time, overall salt marsh area will also decrease to 196 acres. By 2070, a significant overall loss of salt marsh area is expected, with the combined area of both regularly and irregularly flooded marsh predicted to cover only 123 acres, and with only approximately 3 acres of irregularly flooded salt marsh remaining. Figure 63 shows a quantification of the loss of salt marsh over this period, while Figure 64 provides a geographic overview of where these changes will occur.

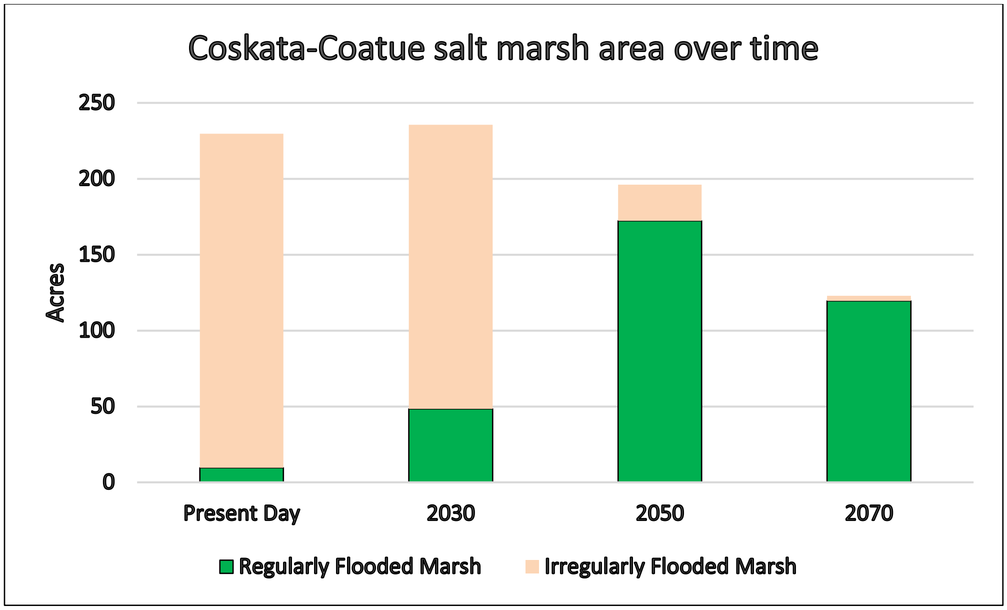


Figure 63. Quantification of salt marsh change between Present Day and 2070 for the entire Coskata Coatue study area.

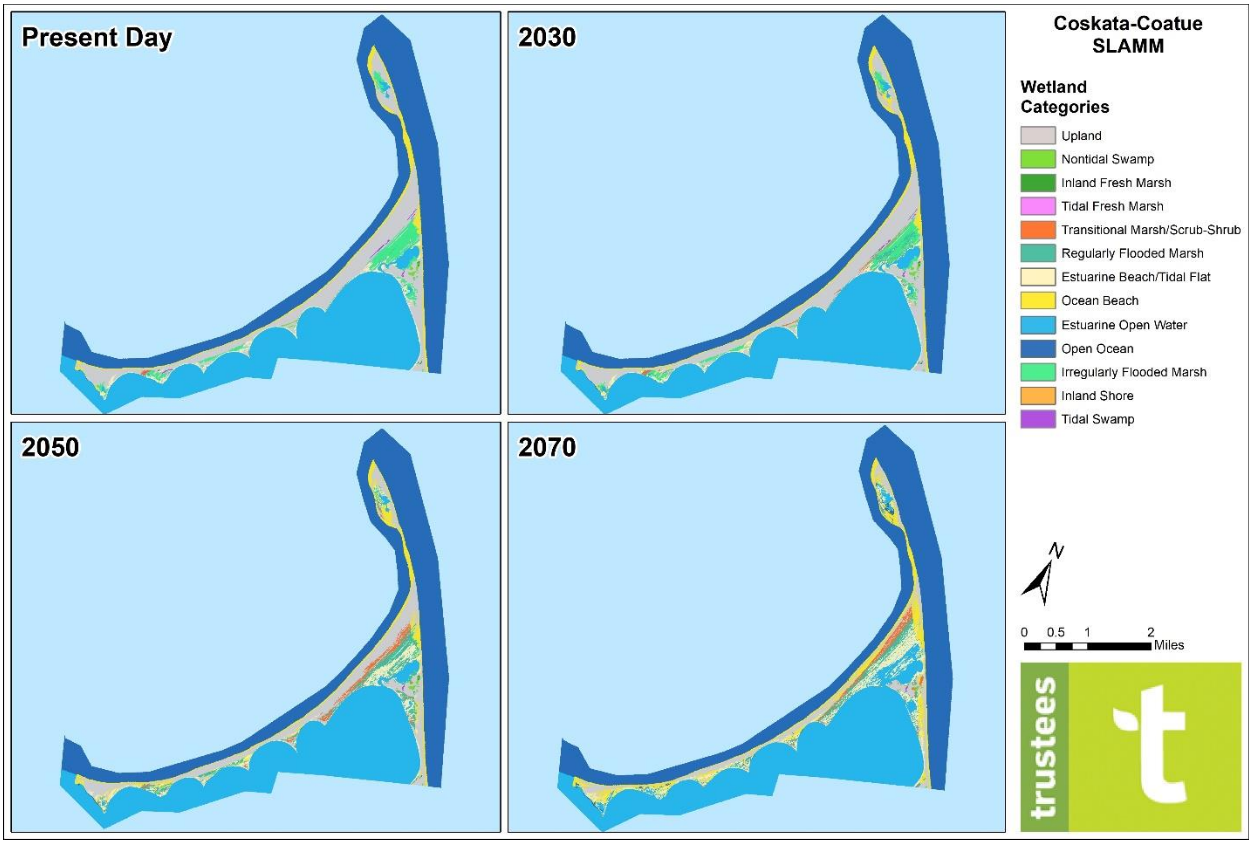


Figure 64. SLAMM results for the whole Coskata-Coatue study area.

5.1 THE HAULOVER

The major wetland changes at this site will occur around Haulover Pond, as shown in Figure 65. Presently, the Pond is surrounded by predominantly irregularly flooded marsh (i.e., high salt marsh). By 2030, no significant salt marsh loss is predicted, but the areas of the marsh closest to the pond will start to transition to regularly flooded marsh (i.e., low salt marsh) and areas around salt marsh will start to transition from upland to transitional marsh (i.e., the salt marsh will begin migrating to higher elevation areas). By 2050, salt marsh is expected to significantly expand into low-lying areas. Although there will be some salt marsh loss in the immediate vicinity of the pond, as lower elevation areas transition to tidal flat, overall, the total area of salt marsh may expand in 2050. It is worth noting, however, that much of this expanded salt marsh area will be regularly flooded marsh (i.e., low salt marsh), and will be vulnerable to continued sea level rise. Finally, by 2070, the open water area of Haulover Pond is projected to expand and almost all the salt marsh around the Pond is expected to disappear as that marsh converts to tidal flats and open water. There is some projected salt marsh migration north of the pond, but the success of any salt marsh in this area will be dependent on ensuring adequate tidal flow past the existing roadway.

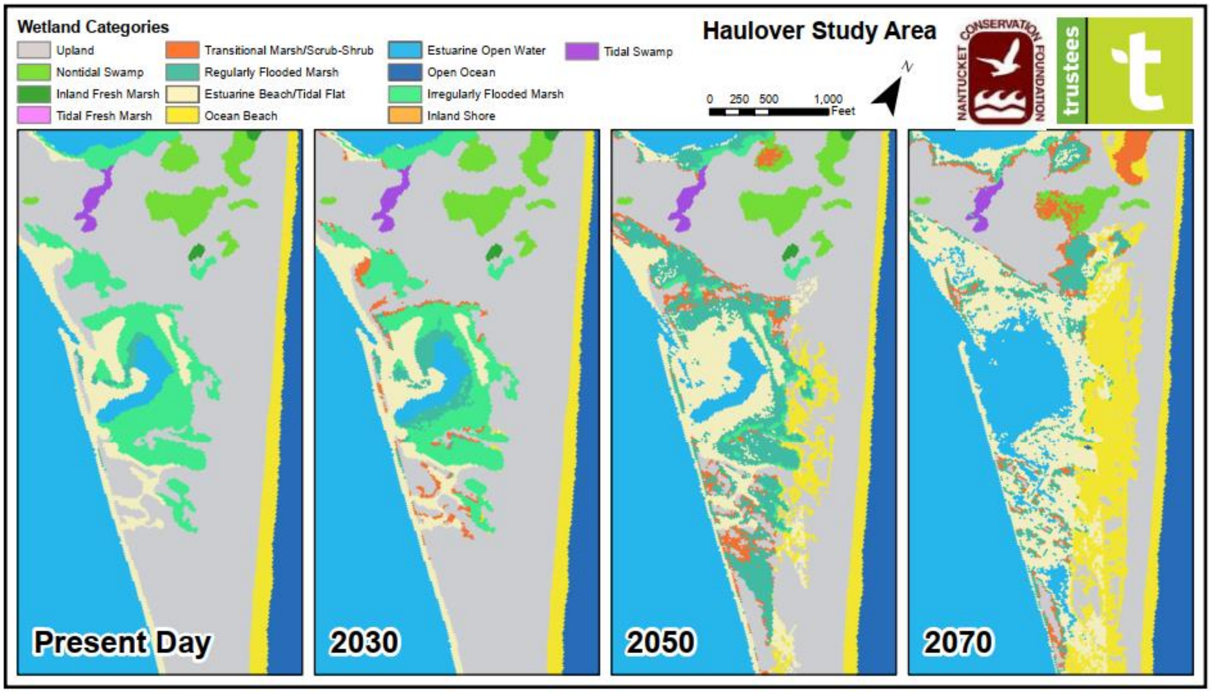


Figure 65. SLAMM results for The Haulover area.

5.2 Coskata Pond

The major wetland changes at this site will occur within the salt marsh areas around Coskata Pond, as shown in Figure 66. Presently, the Pond is bordered on the north and south by predominantly irregularly flooded marsh (i.e., high salt marsh). By 2030, no significant salt marsh loss is predicted, but lower elevation areas of the marsh within the Glades will start to transition to regularly flooded marsh (i.e., low salt marsh) and some areas around the historic dune ridges will start to transition from dune to transitional marsh (i.e., the salt marsh will begin migrating to higher elevation areas). By 2050, although salt marsh will migrate northwest within the Glades (see Figure 64), the salt marsh in the vicinity of the Pond will largely transition to tidal flat in the north (i.e., within the Glades) and to regularly flooded salt marsh in the areas to the south. Minor salt marsh migration into adjacent freshwater swamp to the south is also projected to occur. Finally, by 2070, the open water area of Coskata Pond is projected to expand into The Galls and almost all the salt marsh around the Pond is expected to disappear as that marsh converts to tidal flats and open water. There is some projected salt marsh migration south of the pond, but this area is relatively small. In addition, the isolated freshwater swamp/marsh to the southeast of the pond is expected to shift towards a transitional marsh community by 2070.

Although the changes to the salt marsh habitat are the most striking in this area, it is also important to note that SLAMM also projects that the barrier beach separating Coskata Pond from the Atlantic Ocean is expected to narrow overtime. This will increase the likelihood of overwash events or a breach in this location in the future.

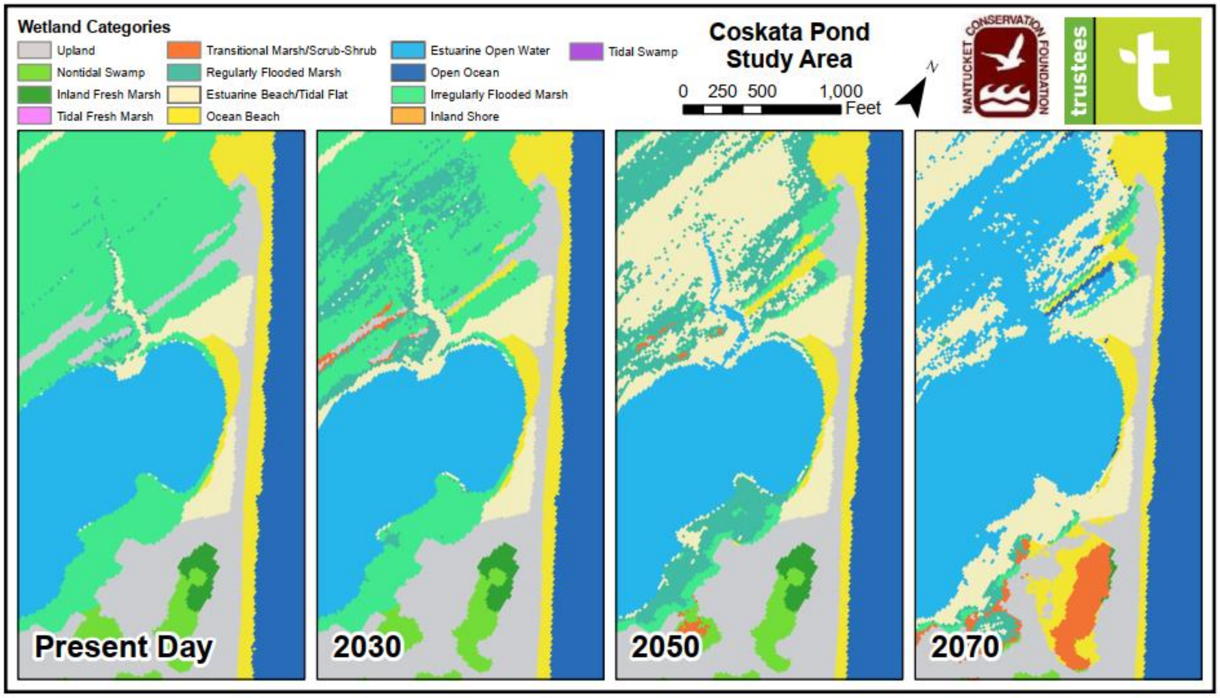


Figure 66. SLAMM results for the Coskata Pond area.

5.3 THE GALLS

Unlike other sub-sites within the larger Coskata-Coatue area, The Galls area does not have a diversity of wetland types. The Galls is a narrow barrier beach, with low lying, unvegetated beach habitat across its entire width. The SLAMM results in Figure 67 below show that this condition is likely to persist into the future. Although this barrier beach has largely managed to maintain its width historically, unless it is able to increase in elevation, it will likely narrow in width over time as sea level rises. It is also worth noting that SLAMM results do not incorporate potential storm damage (e.g., a breach in the barrier at this location); although this condition is not shown in Figure 67, a breach will become more likely as the barrier narrows.

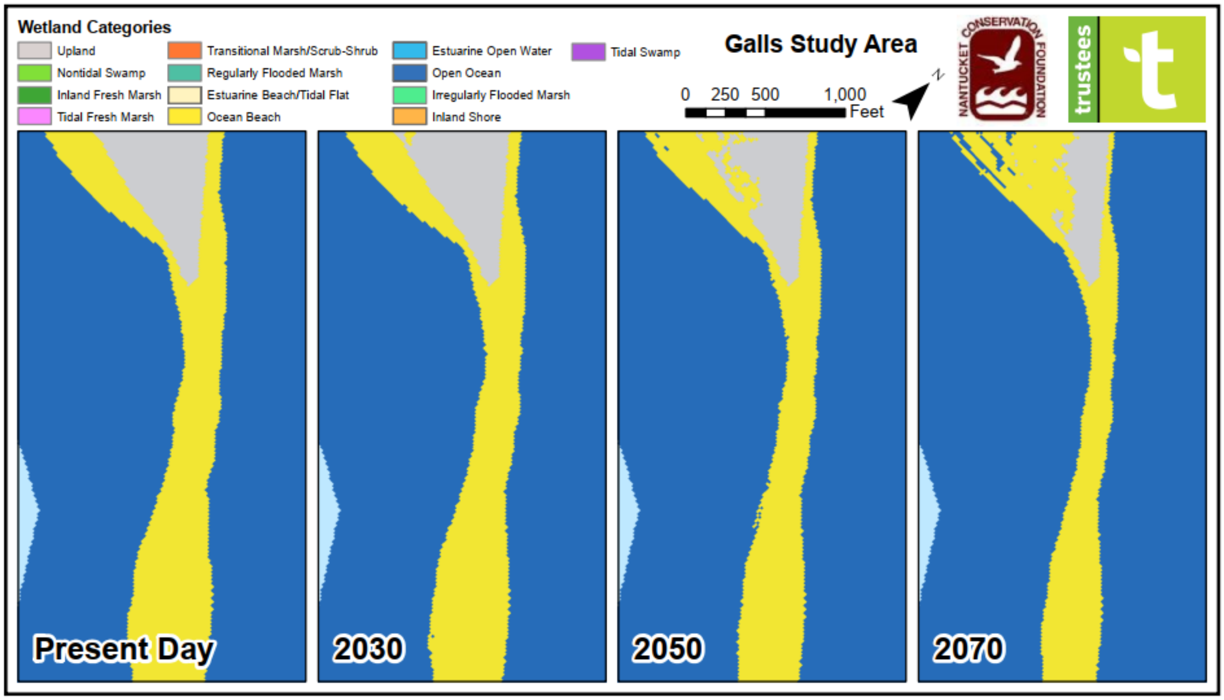


Figure 67. SLAMM results for The Galls area.

5.4 The Area Between 1st and 2nd Point

The SLAMM results for the area between 1st and 2nd Point are displayed in Figure 68. This area currently has a sandy coastal beach on the outer Nantucket Sound shoreline, and a mix of wetland habitats on the Nantucket Harbor side, including salt marsh, transitional marsh, and tidal swamp. By 2030 the marsh areas are projected to remained relatively stable, with only minor conversion of irregularly flooded marsh to regularly flooded marsh. The area of the existing dirt parking area, however, is expected to receive more regular tidal inundation and is classified as a tidal flat in the 2030 results. By 2050, much of the original salt marsh area will likely convert to tidal flat as daily inundation becomes more prolonged in those lower elevation areas. However, there is a good deal of salt marsh expansion into the surrounding low-lying areas, particularly in existing transitional marsh and tidal swamp. Finally, by 2070, much of the original area of salt marsh with convert to a predominantly open water area, and additional open water areas may develop in the low-lying area of the existing parking area. Salt marsh remaining at this location by 2070 will likely be relegated to the V-shaped area of what is transitional marsh and tidal swamp in present day.

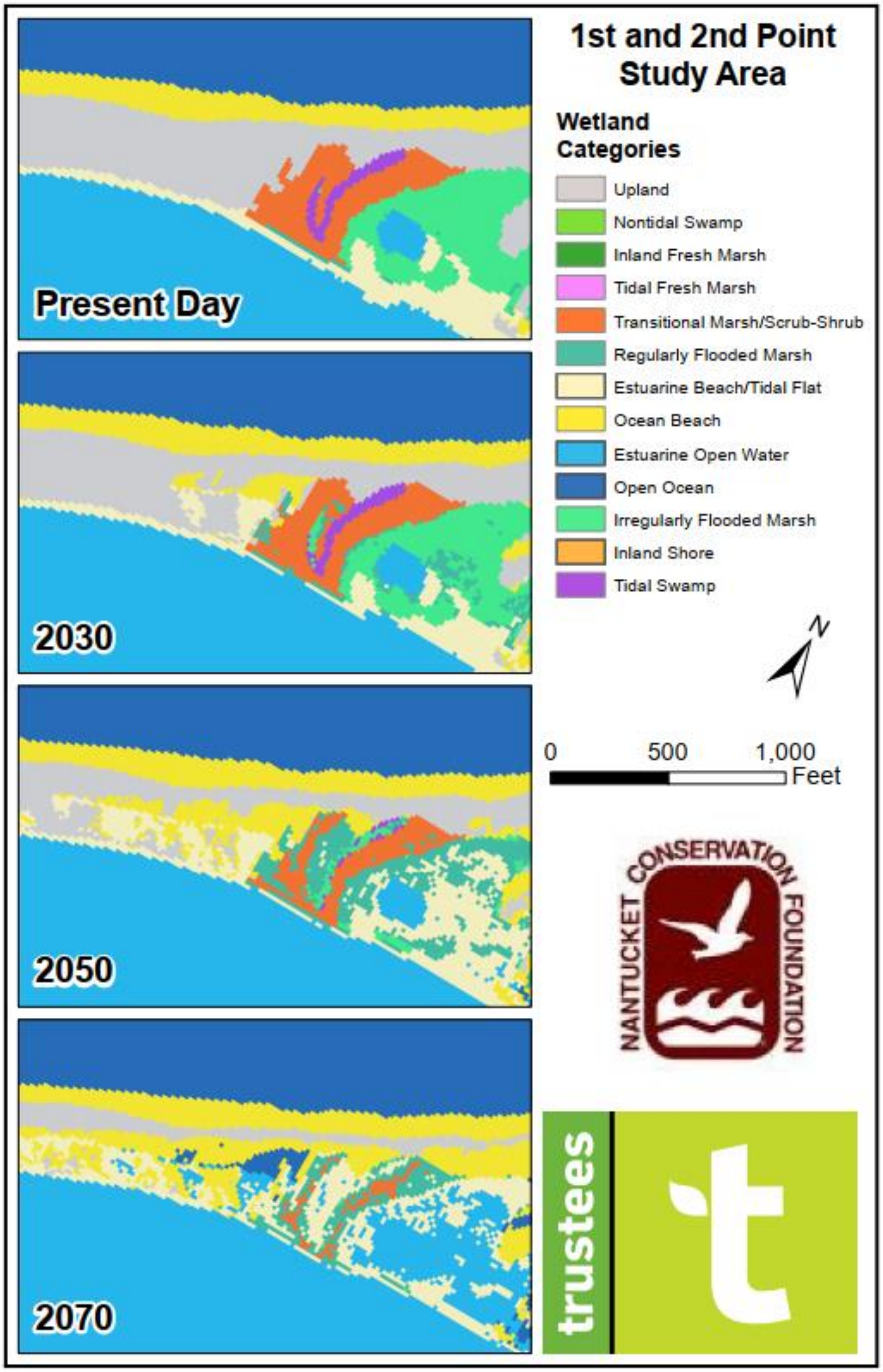


Figure 68. SLAMM results for the area between 1st and 2nd Point.

6.0 XBEACH COASTAL PROCESSES ANALYSIS

Modeling the effects of various intensity storms on a typical transect through each of the existing focus areas helps inform what the expected erosional probability is for a given site. The evaluation included cross-shore sediment transport modeling to determine if the existing dune would withstand a 1- or 2-year return period storm scenario. The storm scenario was defined using annual-exceedance-probability water levels and wave conditions from USACE's North Atlantic Coast Comprehensive Study (US Army Corps of Engineers, 2015). Cross-shore modeling was conducted using the process-based XBeach numerical model to determine morphological change along 1-dimensional profiles defined at each location.

The XBeach numerical model developed by Deltares focuses on wave propagation, long waves, mean flows, sediment transport, and morphological change. The surfbeat mode of XBeach, resolves long waves and short-wave variations at the wave group scale as waves enter the nearshore (Deltares, 2018). Waves are generated randomly along the offshore boundary by spectral analysis, capable of showing the escalation and de-escalation of a storm through the time-varying inputs of water level, wave height, and wave period. Associated sediment transport is calculated by depth-averaged computations that consider suspended load transport as well as bed load transport to determine storm-induced changes in bed level (Deltares, 2018).

6.1 XBEACH MODELING FOR EXISTING CONDITIONS

To determine the resiliency of the dunes or coastal beach at each of the four areas we chose five transects (Figure 69) throughout the four focus areas and used the most recent available LiDAR survey data to establish a snapshot of the existing topography. Laboratory analysis of sediment samples we collected during our site visit provided the effective grain size information to input an expected bed friction value to model the erosion. Haulover Pond and Coskata Pond were chosen to investigate what would happen at the narrow points of the coastal beach with the ponds behind. The Galls beach and dune transects were chosen to represent the large changes in height between the open coastal beach and adjacent coastal dunes along that portion of narrow barrier beach. The last transect was chosen on the western side of the Coatue spit. These profiles were run in XBeach for a 1- and 2-year storm to see how they will erode during these storm conditions.

Figure 69. Transect locations.

6.2 EXISTING CONDITIONS RUNS

The following graphics are outputs from the modeling that represent the expected erosion of the beach and dune profile after a given storm. The solid black line represents the existing topography, the dashed green line represents the peak storm tide elevation, the dashed blue line represents the peak wave crest elevation, and the solid red line represents the eroded profile immediately following the storm.

6.2.1 The Haulover Existing Conditions

The Haulover shows a maximum dune crest elevation of 14 feet NAVD88. Despite the higher elevation, the dune still experiences substantial erosion during the 1-year storm because of the narrow width of the dune (Figure 70). As expected, the results are even more dramatic following the 2-year storm where the entire dune is eroded and deposited on the seaward slope (Figure 71).

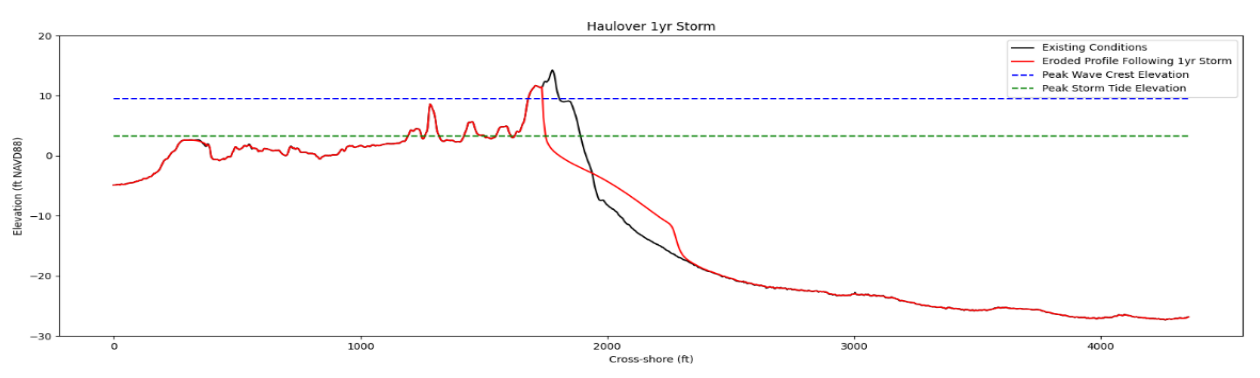


Figure 70. The Haulover profile after 1-year storm.

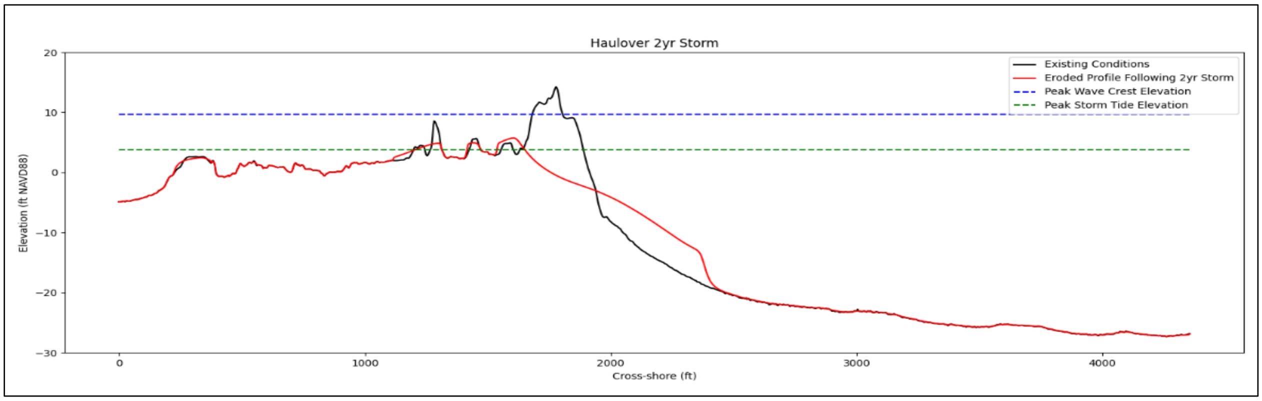


Figure 71. The Haulover profile after 2-year storm.

6.2.2 Coskata Pond Existing Conditions

The Coskata Pond transect shows a maximum dune crest elevation of 10 ft NAVD88. This low-profile dune experiences significant erosion during the 1-year storm, leaving little protection during subsequent storms (Figure 72). The 2-year storm exhibits a more severe eroded profile on the seaward slope, in addition to sediment being deposited on the landward slope and potentially into Coskata Pond. (Figure 73).

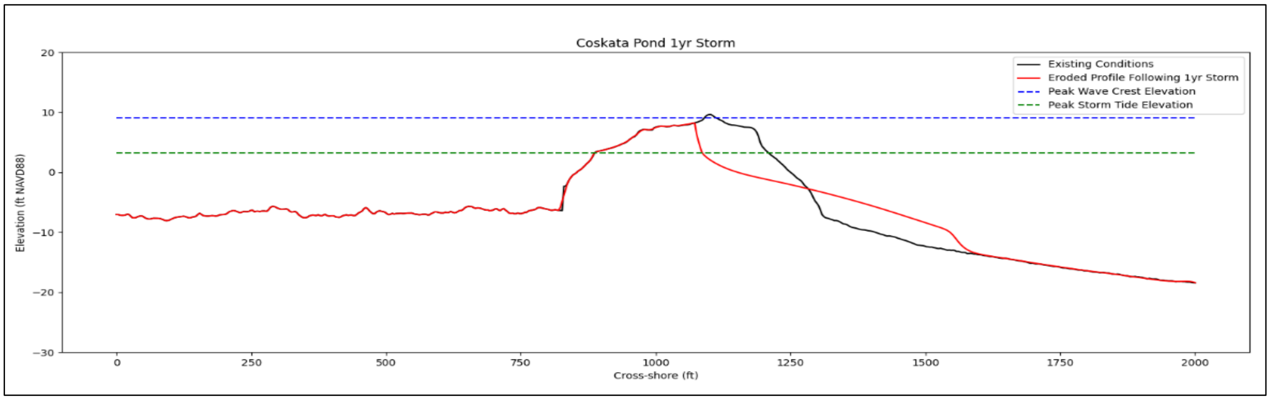


Figure 72. Coskata Pond profile after 1-year storm.

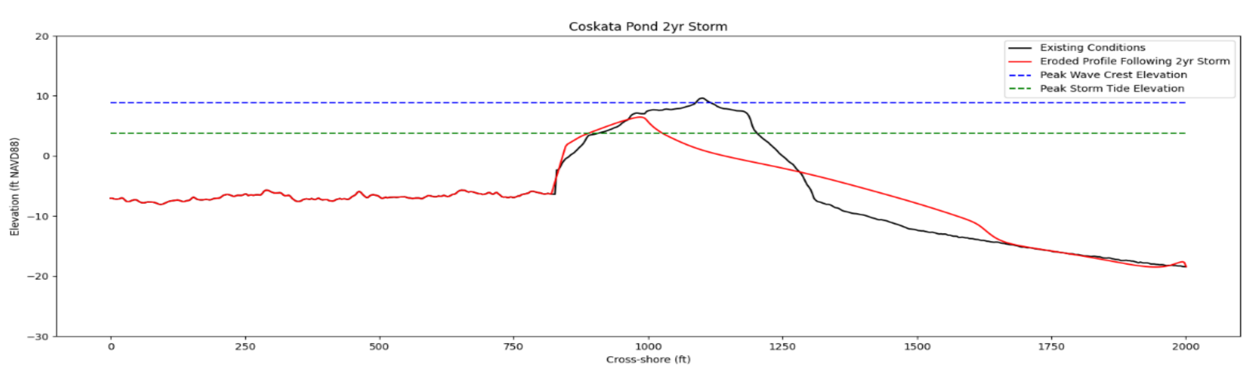


Figure 73. Coskata Pond profile after 2-year storm.

6.2.3 The Galls Beach Existing Conditions

The Galls beach has a lower profile dune system with a maximum crest elevation of 8 ft NAVD88 (Figure 74). During the 1-year storm, the dune experiences considerable erosion and the OSV trail on the landward side of the dune is likely to be impacted. The red line shows the final profile after the storm with a complete loss of the foredune ridge and little protection from future storms. The 2-year storm shown in Figure 775 shows the whole dune system is eroded and deposited on the western side of the spit as an overwash deposit.

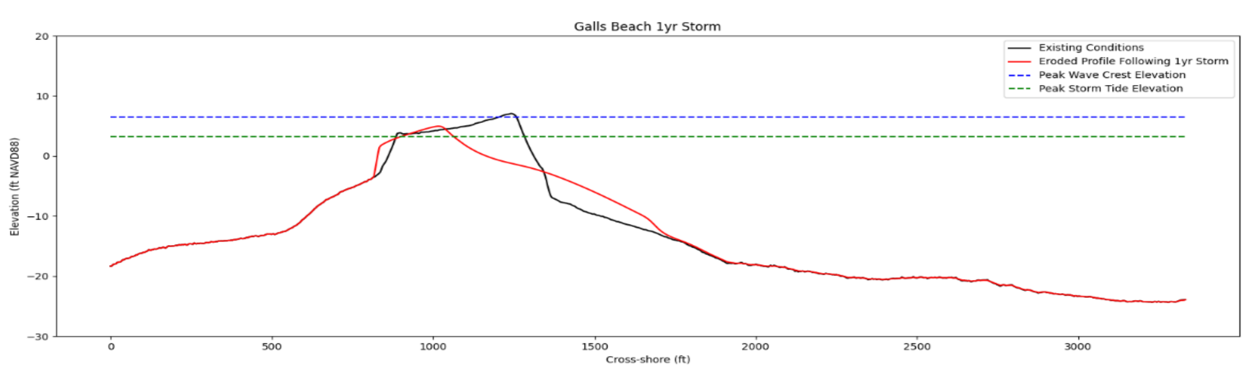


Figure 74. The Galls beach profile after 1-year storm.

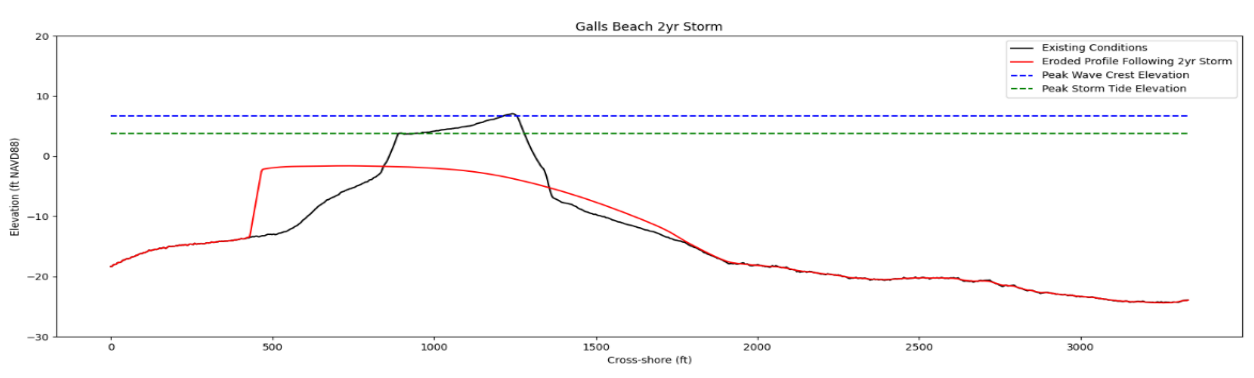


Figure 75. The Galls beach profile after 2-year storm.

6.2.4 The Galls Dune Existing Conditions

Adjacent to The Galls Beach overwash area, the dunes are substantial, having a maximum crest elevation of almost 18 ft NAVD88. The dune system performs moderately well during the 1-year storm. Following the storm, the dune crest is still intact and able to provide protection during a subsequent event. The sand that is eroded from the dune is deposited on the fronting beach slope (Figure 76). During the 2-year storm shown in Figure 77, the dune loses elevation and width, but remains intact.

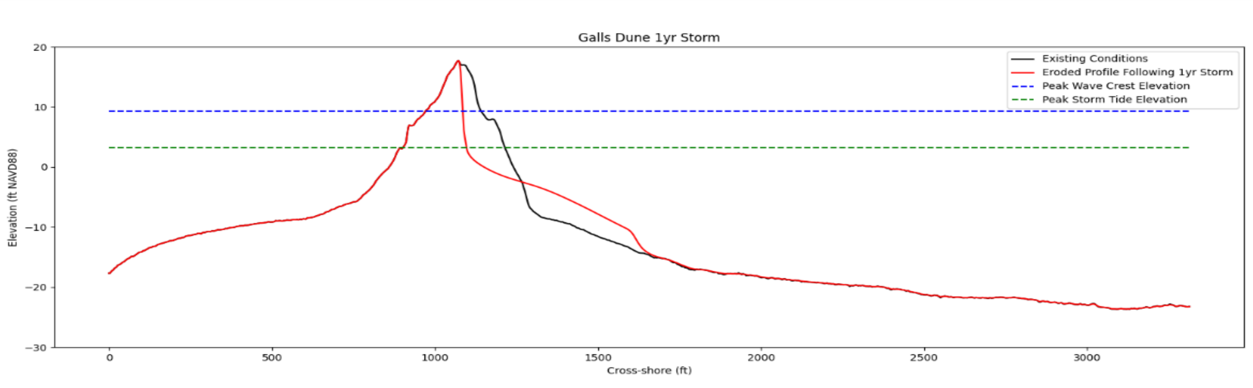


Figure 76. The Galls dune profile after 1-year storm.

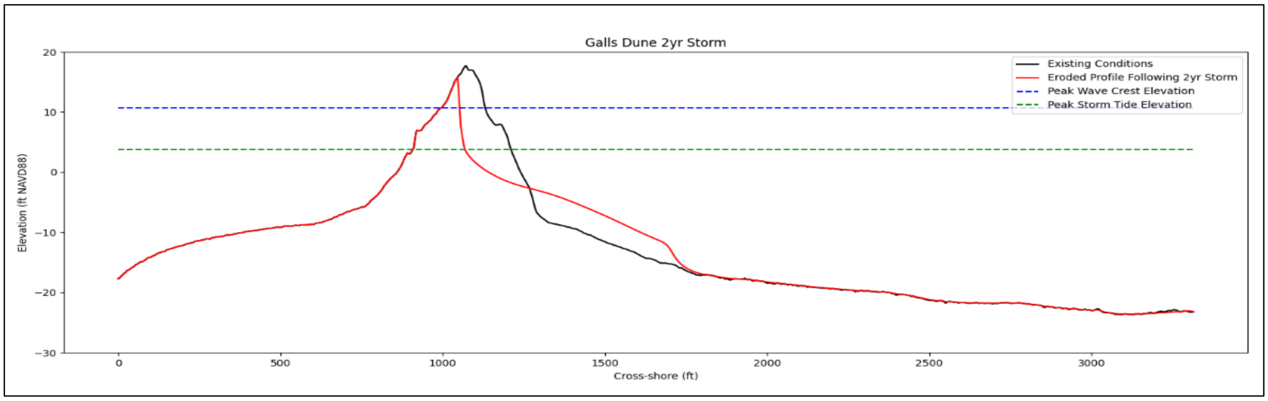


Figure 77. The Galls dune profile after 2-year storm.

6.2.5 Between 1st and 2nd Point Existing Conditions

The project site on the western side of Coatue is exposed to different wave conditions than those on eastern shoreline of Nantucket during a 1-year storm. The waves in Nantucket Sound are smaller compared to the other sites because the Sound is more protected. This, combined with a wide dune system means significantly less erosion of the dune during the same event. Even the larger, 2-year storm has minimal impact on the dune due to the smaller wave conditions. Figures 78 and 79 demonstrate the minimal erosion that takes places as a result of the one and two-year storm, respectively.

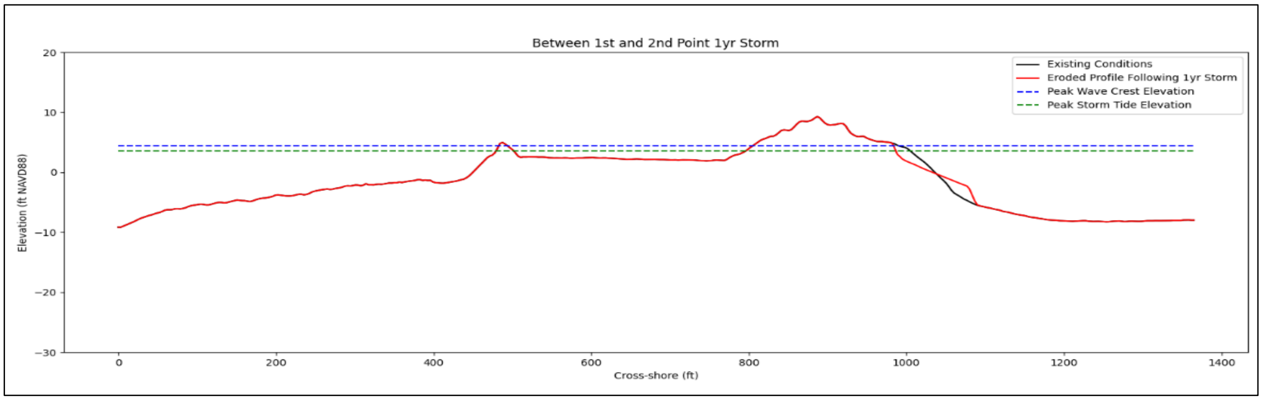


Figure 78. Between 1st and 2nd Point transect, existing conditions during a 1-year storm. Nantucket Harbor is to the left and the Sound is to the right.

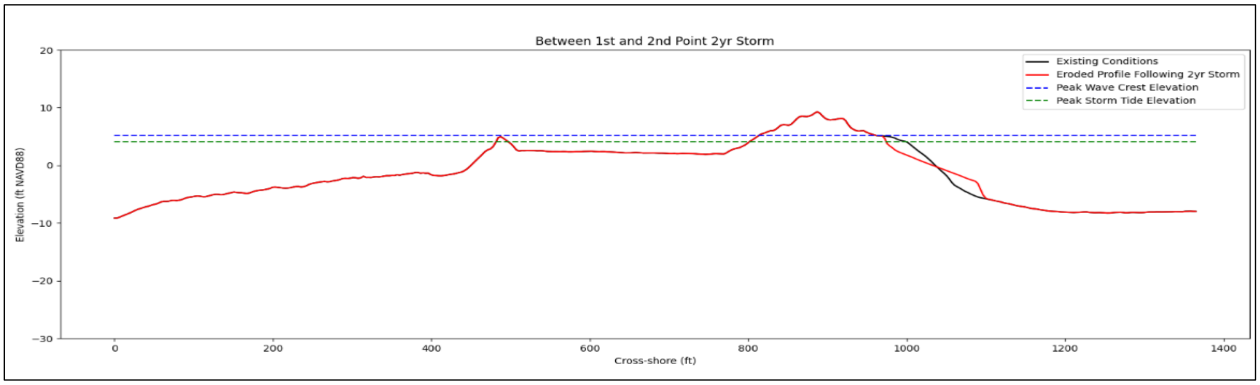


Figure 79. Between 1st and 2nd Point transect, existing conditions during a 2-year storm. Nantucket Harbor is to the left and the Sound is to the right.

7.0 ADAPTATION ALTERNATIVES ASSESSMENT, CONCEPTUAL DESIGN & MONITORING

Woods Hole Group utilized information from the existing conditions evaluation, coastal processes analysis and other in-house data to prepare an alternative analysis for each of the four focused areas of Coskata-Coatue. The specific goal of the alternative assessment was to identify and evaluate several practicable and feasible alternatives that would achieve the goals and objectives of the overall project, while minimizing short and long-term impacts at each site. Given the climate-related changes affecting coastal areas, any solution to the current challenges at any of these sites will necessarily have a finite lifespan. Possible considerations for alternatives included predominantly "soft" solutions such as the installation of native plantings, beach and dune nourishment, and a hybrid of such alternatives. Each of these alternatives is described below. Conceptual designs for selected adaptation alternatives at each site were developed and are presented to provide an approximate size and scale for planning purposes.

7.1 NO ACTION

Under the No Action alternative, a shoreline restoration project would not be implemented, and the natural processes of barrier beach and coastal dune erosion would continue, unimpeded. Coastal erosion is the natural process of shaping and reshaping the coastal environment over time by sediment transport associated with winds, waves, and currents. If the erosion is natural and not causing an immediate hazard to property or infrastructure, the No Action alternative is the least costly and often the environmentally preferable alternative. The properties would not be protected from future storms and ongoing erosion would continue along the shoreline. Consequently, the available habitat for listed threatened and endangered species would eventually degrade, and the recreational value created by the beaches would decrease. In evaluating the No Action alternative, the property owner must assess the level of risk they are willing to accept in conjunction with the existing and expected uses of the property.

The No Action alternative at Coskata-Coatue has the potential to negatively affect the properties, the environmental habitat and recreational value in the vicinity of the coastline. The current function of the primary coastal dunes to serve as a vertical buffer to storms will diminish. The trail system will be threatened, and public access will eventually be lost to coastal erosion. This will have secondary impacts on local tourism and the economy, as recreational beach space in Nantucket is highly utilized and valued.

7.2 BEACH GRASS

Common in New England, American Beach Grass is a vigorous, upright grass that grows in dense clumps, is capable of rapid lateral spread by runners and is considered the true pioneering plant of the sand dune environment. Beach grass stabilizes dunes by holding sand in place and changes the environment by retaining moisture and nutrients, allowing other plant species to then colonize an area because of these changes. Beach grass catches sand as the leaves slow the speed of wind, allowing wind-blown sand to be deposited and hence the accumulation of a sand dune. Once beach grass is established and a dune becomes more stable, other plants can gain a foothold, thereby creating greater diversity for wildlife habitat and reducing the potential for a loss of all vegetation to disease or pests. Ongoing management of a beach grass project involves occasionally planting additional culms to fill bare areas, and removal of invasive species, such as knotweed, with less desirable properties that can outcompete the beach grass. Beach grass is widely used in conjunction with dune restoration projects and would be a viable stabilization alternative at any of the Coskata-Coatue sites. Figure 80 is an excellent example of a successful beach grass installation that was done as part of a dune restoration project on Cape Cod.

Figure 80. Example of a hearty beach grass project on Cape Cod.

7.3 BEACH NOURISHMENT

Beach nourishment is sediment placement on the beach that temporarily provides protection to a coastal beach, coastal dune, or coastal bank by providing sacrificial material available for erosion during storms. Beach nourishment improves resiliency of the shoreline, provides a sediment source for downdrift beaches and dunes, and can enhance wildlife habitat. Beach nourishment also enhances public access by widening the area of dry sand and provides storm damage protection and flood control to upland areas by providing a buffer between the ocean and landward assets or resources.

Localized beach nourishment is a reasonable solution that provides an increased recreational beach area and affords some protection to a coastal system if the appropriate length of beach is nourished with an adequate volume of sand. The effectiveness of any beach nourishment project is dramatically improved by a longer length of nourishment spread along the beach. The shorter the project the quicker the nourishment sand dissipates and spreads along- and off-shore. This decreases its ability to provide protection to an area, limiting the effectiveness and economics of a project and decreasing the longevity of the fill. Small-scale, localized beach nourishment projects provide added protection to an area but have a short life span, often being lost to one large storm. Larger scale nourishment projects are effective at reducing erosion for a greater period, depending on quantity of sand and length of project. Another contributing factor to the longevity of a nourishment project is the grain size of sediment placed. Sediment with a larger grain size than that of the existing beach, will hold its position better in the face of wind and waves. Conversely, sediment with a smaller grain size than that of the existing beach will more quickly erode and dissipate along- and off-shore.

A larger beach nourishment template would involve adding significant quantities of sand to expand the width and height of longer sections of the barrier beach. Beach nourishment would front the coastal dune to provide a wider and more resilient buffer from the effects of wind and waves during storms. A periodic and repeated addition of sand would be required to maintain the barrier. Strategies to regularly nourish the sites may include annual dredging and beneficial placement on the beach as nourishment, back passing of sand from elsewhere within the barrier system or import of an upland source to balance volumes throughout.

7.4 DUNE NOURISHMENT

Dune nourishment provides shoreline protection by adding compatible sediment to an existing dune, creating a reservoir of sand that can feed the beach during erosive storm conditions. With artificial dunes and dune nourishment, sediment is brought in from an offsite source, such as a sand and gravel pit or coastal dredging project to create a physical buffer between the sea and the land that can naturally shift during storms. As waves interact with a dune, the sediments move and shift and the wave energy is absorbed, protecting landward areas from the full brunt of the storm. Fortunately, sand that is eroded from a dune during a storm is not lost from the system but added to the surrounding beach and nearshore area where it further dissipates wave energy and provides protection from the next storm. The recommended size for an artificial or nourished dune depends on the required level of protection, exposure to storms, site limitations that include the width of the beach and proximity to protected resource areas, sediment availability and budget. Maintaining a nourished dune as an effective physical buffer, sediment must be added regularly to keep dune’s height, width, and volume at appropriate levels. Dune nourishment also typically requires periodic maintenance, including additional sand, plantings, sand fencing, etc.

A barrier beach with an adequate dune system of adequate height and width can shift over time due to regular storms and changing currents. Nourishing the dune with the placement of sand and installation of vegetation could help to balance the equilibrium and increase the long-term resiliency of the barrier beach. Figure 81 is an example of a similar and successful dune nourishment project along Popponesset Spit, a barrier beach in Mashpee, MA.

Figure 81. Dune nourishment at Popponesset Spit in Mashpee.

7.5 DUNE STABILIZATION USING BIOENGINEERED SOLUTION

Dune stabilization projects using a bioengineered solution provide enhanced toe protection to the coastal dune and inland assets while restoring and enhancing the recreational value of the coastal beach, which is highly desirable. This alternative involves the installation of fiber rolls or sand filled coir envelopes at the toe of the dune to prevent undercutting and installing compatible nourishment sand on top to protect the fragile bioengineered material that will quickly degrade with prolonged exposure to UV light. Figure 82 is an example of a bioengineered project on Cape Cod. The addition of coir envelopes for toe protection can bolster the beach and dune nourishment alternatives discussed above and are considered a “soft” solution, often permitted under the State Wetlands Protection Regulations, 310 CMR 10.00. This solution had been previously permitted and installed at many other locations on Cape Cod and Nantucket and is considered a viable alternative for coastal stabilization on properties where hard coastal engineering structures are undesirable or prohibited by the State or Town. Dune stabilization can be paired with dune restoration to increase protection of the dune and allow greater time for the establishment of dune vegetation.

Figure 82. Example of a coir project on Cape Cod, located in NHESP habitat.

7.6 SAND FENCE

Sand fencing creates areas of lower wind speed both in front of and behind a fence, which encourages the dune development by trapping wind-blown sand (Figure 83). Sand fencing also offers a low cost means of controlling foot traffic through sensitive dune areas. Two rows of zigzag sand fencing are typically recommended for installation along the seaward toe of an existing dune and can also be installed in low areas on the back side of a washover fan to help establish elevation is low areas. Sand fencing can effectively trap aeolian sand, providing an elevated base upon which American Beach Grass can colonize and establish a strong root system. Sand fencing provides a means to trap sand for dune building. The concept could be tested at less critical sites to gauge the effectiveness and ability to minimize beach erosion and overwash during storms. The elevation gains to the dune will be slow and will provide minimal resilience to higher sea level impacts. It is also not a long-term solution and will not prevent ongoing erosion of the beach and dune loss during storms.

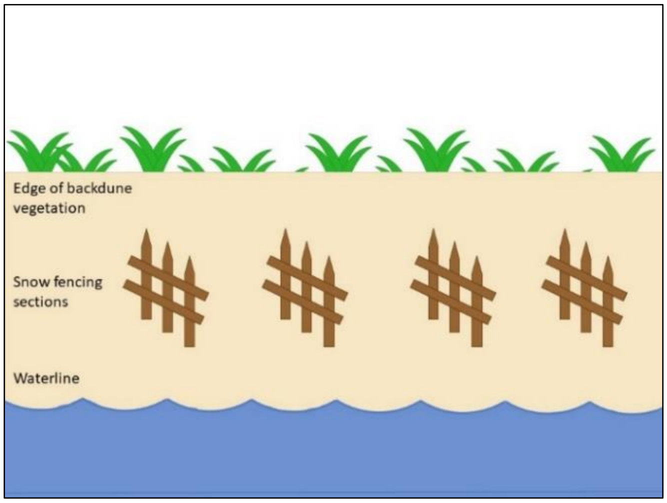


Figure 83. Schematic of possible sand fence installation.

Installation of sand fencing is relatively non-invasive, and the fencing is both removable and can direct foot traffic away from delicate dune resources. For these reasons, design and permitting are less involved than more aggressive measures. There can be drawbacks to the use of fencing on beaches. Fencing can become a perch for predators. Additionally, nesting shorebirds (such as plovers and terns) need to migrate from oceanfront beaches to protected bays and ponds, but young birds can be impeded by fencing. This can be mitigated by spacing sand fences with gaps. Figure 84 provides a photograph of sand fence installed locally.

Figure 84. Example of wind-blown accumulation at the base of drift fence in Edgartown.

7.7 THIN LAYER SEDIMENT PLACEMENT IN OVERWASH AREA

Thin-layer deposition of dredged sediment has been proposed in the literature and employed in several states as a management technique for increasing the resilience of low-lying coastal marshes to sea level rise. Thin-layer deposition typically is performed through the dredging of a shallow water area adjacent to the vulnerable wetland system, and the placement of the dredge material by spraying the sediment aerially in large swaths. The sediment "rains" onto the existing marsh and may be managed through haybales or coir logs to prevent the runoff of a slurry into the waterways. Thin-layer deposition is typically used for incremental increases in marsh elevation, on the scale of inches. Implementing thin-layer deposition will impact existing vegetation, however it would be designed to maximize elevation gains while promoting the natural revegetation through the deposited material. Planting and vegetation management procedures are likely necessary to ensure the longevity of the salt marsh habitat.

Thin-layer deposition can similarly be used in low-lying overwash areas on barrier beaches to improve resiliency and maintain a frequently overtopped nesting habitat. The application includes placing thin layers of compatible sediment in the low-lying area to raise the elevation and reduce the frequency of storm overtopping. Typically, the sediment placement would range from 6-12" and would be placed over a broad area with gentle side slopes. The intent of a thin layer sediment placement project is to raise the elevation of the overwash just enough to improve resiliency, while maintaining the function of the habitat. Figure 85 is an example of a thin layer sediment placement project in an overwash area at Fuller Street Beach in Edgartown that naturally colonized with native plants and remains a suitable nesting habitat. This alternative would require compatible sediment to the barrier beach system and provide protection for the habitat but would not resolve the issues associated with the OSV access.

Figure 85. Example of a successful thin layer sediment placement project in an overwash area at Fuller Street Beach, Edgartown.

7.8 COASTAL ENGINEERING STRUCTURE

Bulkhead, revetments, gabions and synthetic geotubes are all considered "hard" coastal engineering structures that provide protection to the toe of a coastal bank, which helps to stabilize the upper bank face. These structures are not allowed by regulatory agencies on a coastal dune and especially not on a barrier beach system. None of these alternatives are being considered for this location due to environmental considerations and permitting hurdles. There are no imminently endangered upland infrastructure assets that meet the criteria of being constructed before the promulgation of the Wetlands Protection Act Regulations (1978). Additionally, they are known for causing a lowering of the beach elevation in front of the structure, which is not advantageous for beach usage and would ultimately result in a narrowing of the recreational beach, which is not desirable. Coastal engineering structures are also known for shifting erosion to downdrift properties because of end effect erosion. This is especially undesirable on this site where adjacent privately owned residential properties are already susceptible to erosion within close proximity to the southern end of this focus area. Coastal engineering structures are also very expensive to construct. Given these permitting, environmental, and cost issues, none of the sites at Coskata-Coatue warrant this level of protection.

7.9 VEGETATION MANAGEMENT

Coastal vegetation habitats include maritime forests, scrub thickets, grassy upland prairies, fresh-water swamps, fresh-water marshes, mangrove swamps, salt-water marshes, and grassy or forested dunes. Each type of coastal vegetation has its own unique features that can retard land loss during storms or over time. Native vegetation in coastal areas also play an important role in stabilizing the surface against wind and surface water runoff erosion. The vegetation breaks the impact of raindrops and slows and diffuses overland flow which promotes the infiltration and absorption of water. Salt-tolerant plants can provide the same value in the face of wave splash as well.

Coastal dunes provide a buffer against coastal hazards such as wind erosion, wave overtopping and tidal inundation during storms. Vegetation plays a vital role in maintaining the integrity of those dune systems by acting as a wind break and trapping sand particles migrating along the coastline. Salt tolerant dune plants send out roots and rhizomes that further trap and stabilize the sand, helping to make the dune stronger and more resistant to erosion. Dune grasses also help stabilize blowing sand and can assist in dune enlargement. However, the roots of grasses and trees are generally too shallow to reduce erosion from large storm waves that lower the backbeach and undercut the dunes or uplands. Vegetation also provides added habitat value for wildlife.

Vegetation management aims to maintain and enhance the habitat and protective value afforded by the above habitats. Management would begin with a planting effort of native vegetation. The vegetation management protocol would then include ongoing monitoring and maintenance to ensure the plants thrive and are not outcompeted by less desirable invasive species that would not provide the same stabilization and habitat potential. Additional planting may be performed to fill the areas. Routine maintenance and monitoring would be required less frequently once the areas become fully established. Development of an adaptive management plan would benefit decision makers, providing background and guidance on monitoring changes, and determining the triggers for action. Vegetation planting and management could and should be used in conjunction with other management options such as sand fencing, thin layer sediment deposition, and others.

7.10 PATRON MANAGEMENT

The best efforts of any land manager can easily be thwarted by individuals who choose not to follow guidelines or ignore signage. Delicate resources can get trampled through misuse by a small minority of guests. A balance of protective measures and freedom of enjoyment needs to be found. Continuing to enact thoughtful management methods with educational signage (Figure 86) that explains the damaging effects of misuse may reduce destruction of resources in those areas. Erecting structural or vegetative barriers to block unintended pathways will allow areas to rebound from prior use. This can be done using sand fencing or post and rope to delineate pedestrian pathways and mark off sensitive areas. A Mobi-mat, or similar beach surface path, can be used to encourage visitors to stay in designated pathways as these mats make walking on the sand easier. Additionally, during king tide or storm scenarios which cause flooding, patron management may encompass access road closures to ensure public safety and minimize the risk that guests travel over sensitive resources to avoid flooded or eroded areas.

Figure 86. Patron Management signage.

7.11 MANAGED RETREAT

Managed retreat involves the planned relocation of assets out of a vulnerable area to an inland, upland, or protected area where function is not as threatened by coastal hazards. The assets along Coskata-Coatue mainly include inner trails and beach access roadways that could be relocated to higher areas, but their relocation could be inhibited due to constraints from bordering resources. Relocations would need to be dictated by the erosion rate with consideration for the assets purpose. Access roadways could be relocated onto other assets, such as the existing dune system. The existing habitat areas will be lost and will likely not be replaced by converted resource areas. Although this alternative may prove to be part of an acceptable overall consideration, there are opportunities to reduce the flooding frequency in key areas and potential for erosion with nourishment to reduce the frequency and/or distance of retreat.

7.12 SALT MARSH RESTORATION

Salt marsh restoration involves the dredging or grading (cutting/filling) of landforms and planting of vegetation to create and/or restore salt marsh habitats. Marsh habitats are primarily determined by elevation, and include subtidal, mudflat, low marsh, high marsh, transitional, and upland habitat. Native marsh vegetation, such as native low (*Spartina alterniflora*) and high marsh (*Spartina patens*) species, can be planted along the shoreline to hold soil in place, dampen wave energy, create habitat, and increase sedimentation. Salt marshes also provide water infiltration, uptake of nutrients, filtration, denitrification, and carbon sequestration. Planting only projects are a minimally invasive approach, while projects which require dredging or grading have a larger, though temporary, environmental impact.

Salt marsh restoration is most appropriate in coastal areas with low to moderate wave and current energy, often where erosion rates are low to moderate. Additionally, the area should have, or be graded to have, gentle slopes. Implementation of a project can be difficult should sensitive resources be nearby, such as protected avian species, shellfish beds, or essential fish habitat.

Marsh restoration projects often benefit from toe protection to assist with stabilization. Toe protection materials may include natural fiber rolls, shell bags, or stone. The toe protection may also allow the design to achieve the appropriate grade in lieu of seaward fill, thereby decreasing the project footprint (Figure 87).

Maintenance is typically required of salt marsh restoration. Plants that are removed or die during the early stages of growth must be replaced immediately to ensure the undisturbed growth of the remaining plants. The removal of debris and selective pruning of trees is also a good maintenance practice to ensure that sunlight reaches plants. Protection measures, such as fencing, must be taken to keep waterfowl from eating the young plants; and roughened surfaces such as scattered rock can help break up ice in winter. Ongoing maintenance of invasive species is also important to long-term success. After significant vegetative growth is established, only periodic maintenance/inspections may be needed.

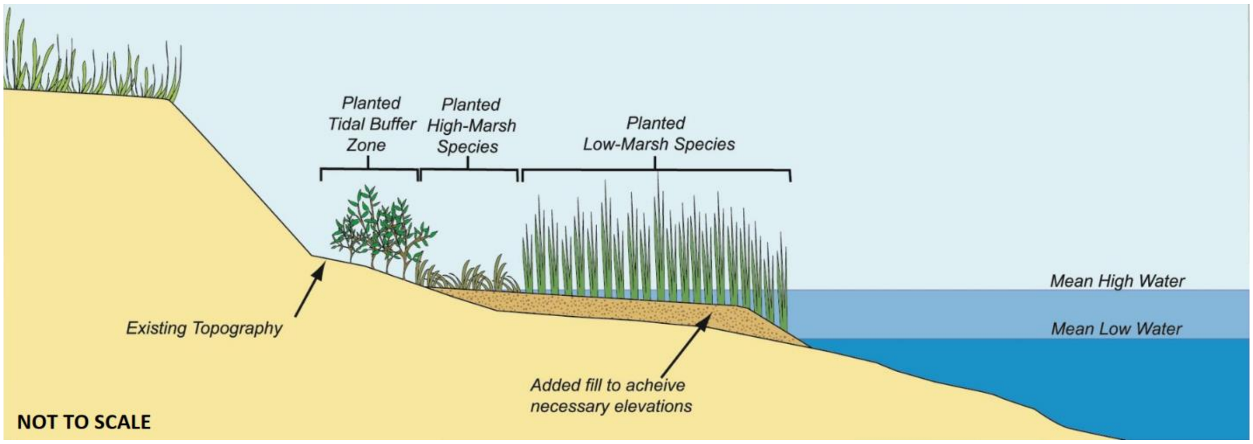


Figure 87. Salt marsh creation/enhancement schematic

7.13 LIVING BREAKWATER

Living breakwaters are constructed nearshore to break waves on the structure rather than on the shoreline to reduce erosion and promote accumulation of sand and gravel landward of the structure (Figure 88). They are typically larger than sills and constructed in deeper water in more energetic wave climates and have the potential to enhance habitat. Living oyster/mussel reefs can be constructed in various ways to provide similar erosion control benefits as rock sills. Additional benefits provided include a substrate for marine organisms, shelter and habitat for benthic and fish species, and water quality improvements through the filtering mechanisms of shellfish. Although breakwaters are often considered coastal engineering structures, a gapped living breakwater allows habitat connectivity and greater tidal exchange and can be used in combination with other living shorelines practices to reduce the wave energy allowing the establishment of a beach or vegetated (typically marsh) shoreline in its lee. The following characteristics constitute the optimal oyster restoration site (NOAA and NMFS 2017):

- Oyster reef elevations should lie in shallow subtidal and intertidal areas.
- Reef height should be at least an average of 12 inches higher than the surrounding substrate with no portion of the reef less than six inches.
- Oyster restoration sites should be in areas where shellfish populations have historically existed.
- If oyster recruitment rates are low at the restoration site, the transplanting of seed oysters or oyster spat may be necessary.
- Water should be brackish waters with an average salinity concentration between 23 and 35 parts per thousand (ppt). For reference, open ocean salinities typically range between 32 and 37 ppt.
- Sites should have adequate water circulation. The ideal flow of water over an oyster bed is steady and non-turbulent.
- Sites should not be selected if they exhibit extremely low dissolved oxygen concentrations or periods of hypoxia.

Oyster reefs can be designed with several material types including reef balls, bagged or loose oyster shells (i.e., cultch), and/or stone:

- Reef balls – Oyster reef balls can provide a living breakwater and shoreline protection. Reef ball modules are concrete structures designed to be a foundation for oysters. Use of reef balls is prominent on the East Coast and has been implemented in one location on the West Coast in San Francisco Bay. For reference, a reef ball breakwater was constructed in Stratford, CT, along a 1,000-foot reach. This project was designed in conjunction with salt marsh restoration on the landward side of oyster restoration.

- Oyster Shells – Oyster shells are another common material for oyster reef construction. Oyster shells can be implemented in many forms including caged cultch, bagged cultch, or loose cultch.

    - Caged cultch – Cages are similar in design to lobster/crab traps. Cages are filled with cultch to form oyster reef building blocks that can easily be anchored. This technique is especially beneficial in areas of high wave energy and has been used where shoreline protection is a project goal.

    - Bagged cultch – Bagged cultch uses aquaculture grade mesh (≤1 inch mesh size) or coconut fiber bags to create bags that are filled with cultch material. This design is often used in softer sediments and can remain stable in areas with higher wave velocities.

  - Loose cultch – Loose cultch is placed either directly on the seabed or on top of core reef material to create a cultch veneer. This method is used most for oyster reef enhancement for large subtidal oyster reef restorations. Loose shell may not be suitable in areas with moderate to high wave energy where cultch can easily be redistributed or in areas where there is a high risk of burial. Large volumes of shell are typically distributed from a barge but may also be placed by hand for smaller projects.

- Stone – Stone, i.e., rip rap, material can function not only as shore protection but as a base for oyster recruitment. However, the introduction of stone to a natural environment is very difficult to permit through the resource agencies.

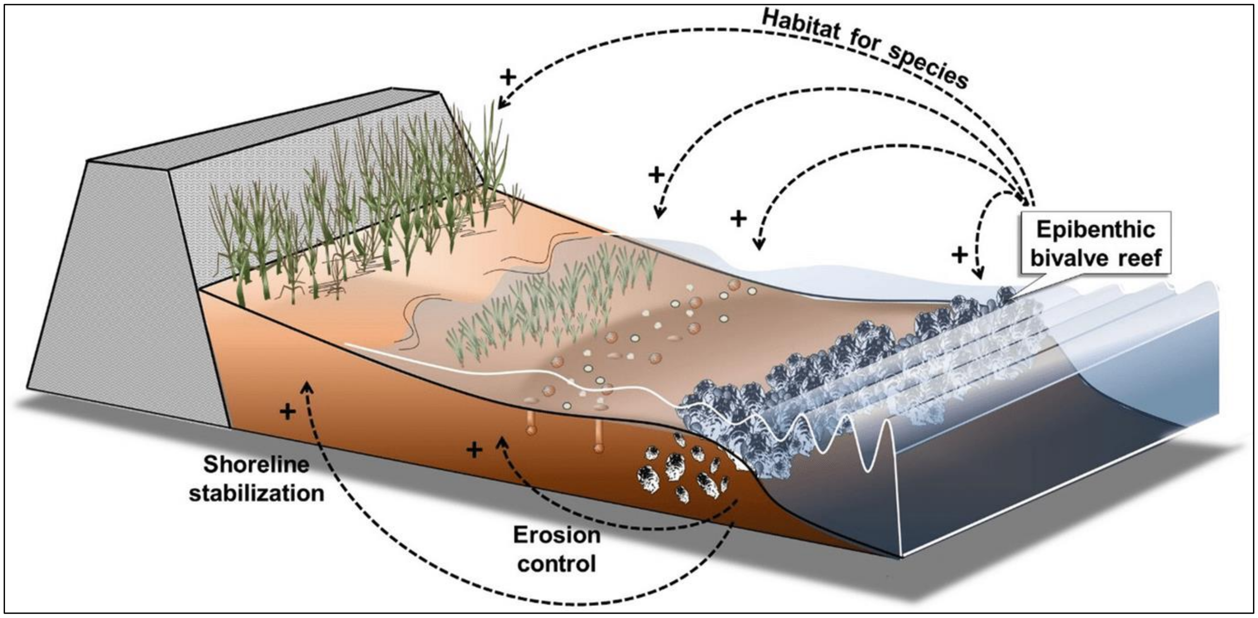


Figure 88. Oyster restoration effects schematic (Nantucket Conservation Foundation)

8.0 THE HAULOVER ALTERNATIVES

The narrow barrier beach system north of Wauwinet known as The Haulover contains a variety of resources and habitats for visitors and species alike (Figure 89). The OSV trail network separates into an inner and outer beach trail at this point. Access disruption at this point would be detrimental to travel through the rest of the properties farther north. Nuisance flooding currently disrupts vehicle and foot traffic over the OSV routes. As sea level rises these flooding events will become more frequent and thereby more disruptive. The existing resource areas will also be affected as they adapt to the new conditions or disappear as indicated in Figure 90.

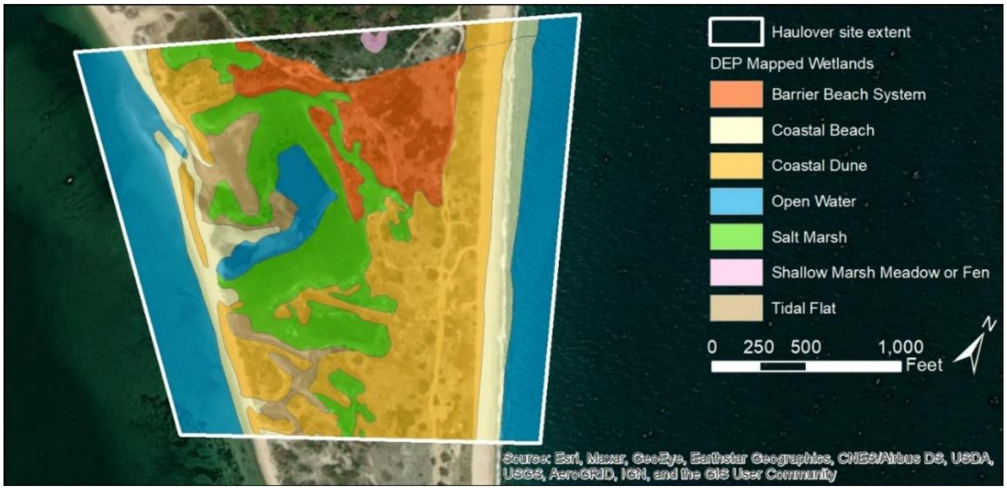


Figure 89. DEP Mapped Wetland Resources at The Haulover (MassGIS).

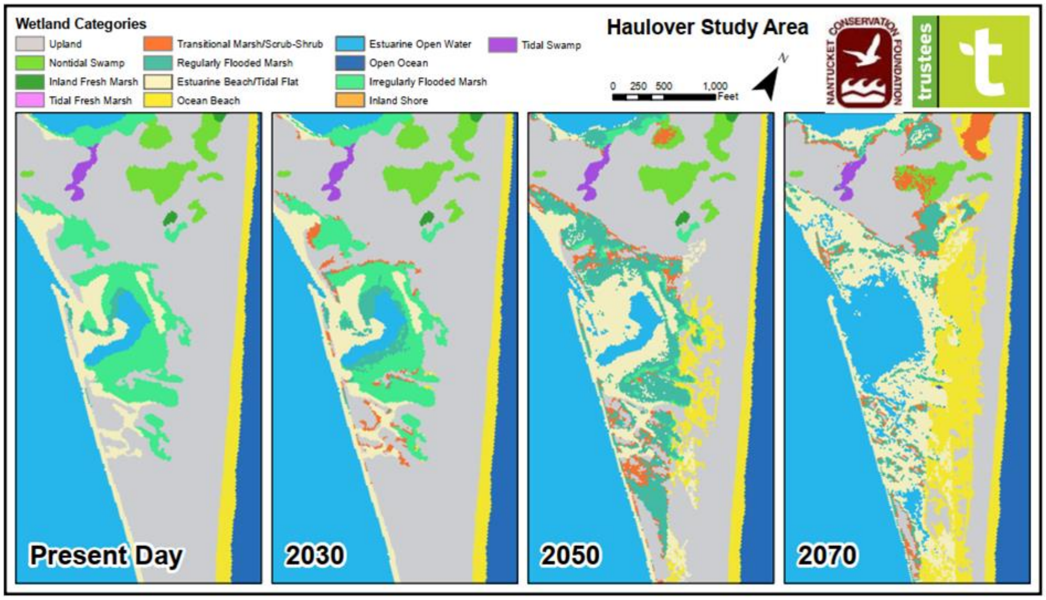


Figure 90. Graphic showing SLAMM results at The Haulover

Adaptation alternatives for improving resiliency at The Haulover involve raising portions of the OSV access road, nourishing and stabilizing the primary frontal coastal dune, and protecting the wetland resources. The primary dune is vulnerable to overtopping and storm damage, which can result in degradation of Harbor side habitats including those for state listed species as well as the inner OSV trail. Loss of the protective dune exposes the backdune assets to greater storm damage. Although the OSV rules prohibit drivers from leaving the trail to avoid puddles or flooded areas, this may still occur. Once an unintended alternate route is started it requires quick action to avoid additional use. Management of use will also help to reduce localized erosion and damage to the natural resources and help them perform their intended functions. Table 6 identifies possible alternatives for The Haulover area. Each of these alternatives is discussed in the following pages.

Table 6. Adaptation Alternatives for The Haulover.

Adaptation Alternatives	Result
No action	Continued erosion of dunes, loss of property and infrastructure, diminished public access, loss of inland habitat.
Vegetation Management – Beach grass and other plants	Lessen dune erosion, enhance wildlife habitat, invasive species control.
Patron Management	Less unintended disturbance/erosion, citizen scientist cooperation, educational opportunities.
Sand Fencing	Enhance sand capture and promote incremental dune growth. However, will not be sufficient as a stand-alone solution to prevent erosion/overwash during storms. Can serve to manage public traffic.
Dune Nourishment	Slow overall erosion, upland protection, raised OSV to reduce flooding of access.
Beach Nourishment	Temporarily provides protection to adjacent dune with sacrificial material for erosion.
Managed Retreat	Important assets relocated to avoid loss.
Salt Marsh Restoration	Implement on lee side of The Haulover, within existing salt marsh and open water area. Expand marsh habitat and potentially adapt to low levels of sea level rise. Continued erosion of dunes, loss of property and infrastructure, and diminished public access.
Living Breakwater	Open coast implementation would require stone breakwater. Lessen dune erosion, increase beach width, potentially enhance marine habitat. Implementation on lee side of The Haulover to provide shellfish habitat (with water quality improvement as secondary benefit), reduce wave energy incidental to salt marsh, and potentially increase sedimentation.
Combination of Efforts	Nourish coastal dune at weakest points, install sand fencing, manage vegetation, and relocate trails.

Adaptation Alternatives	Result
	Pair oyster restoration with salt marsh restoration on lee side of The Haulover to create marine habitat and salt marsh toe protection to reduce erosion.

Table 7 summarizes the pros and cons for considering each of these adaptation alternatives at The Haulover site. Careful consideration must be given to each alternative to weigh the benefits versus the impacts. Only by considering all alternatives and assessing them against the principal mission of the Trustees and NCF, can the best value for shoreline longevity and resource protection be determined. Alternatives may not be considered acceptable because of environmental concerns or adverse impacts, costs associated with engineering, permitting and construction, or opinions about short- versus long-term benefit.

Table 7. Adaptation Alternatives Pros & Cons for The Haulover.

Adaptation Alternatives	Pro	Con
No action	• Inexpensive • No permitting required • Natural processes allowed	• Loss of trail access to high tide flooding and erosion
Beach Grass	• Healthy root systems stabilize resources • Inexpensive • Improves habitat • Citizen scientist opportunities	• Not a long-term standalone project
Sand Fencing	• Encourages sediment accumulation • Controls foot traffic • Provides protection for beach grass	• Could inhibit wildlife function • Potential debris
Patron Management	• Inexpensive • Easy to accomplish	• Dependent on users complying
Beach Nourishment	• Enhances public access • Enhances habitat • Sediment source for downdrift beaches/dunes	• Costly • Sand source challenges • Long permitting process • Limited longevity
Managed Retreat • Relocate Trails	• Low cost • Opportunity to reconfigure trail system	• Loss of habitat and resources • Loss of alternative trails

Adaptation Alternatives	Pro	Con
Dune Nourishment	• Improves resiliency • Extends usability of assets • Sediment source • Enhances habitat	• Costly • Maintenance • Sand source challenges • Limited longevity
Salt Marsh Restoration	• Enhances habitat • Preserves longevity of marsh	• Does not address open coast erosion • Maintenance
Living Breakwater	• Enhances habitat and water quality • Reduces beach/dune or salt marsh erosion, depending on where it's implemented	• Costly • Relatively untested • Permitting challenges if using stone material
Combination of Efforts: • Relocate Trails • Dune Nourishment • Beach Grass Installation	• Cost efficiency focused on most valuable assets & resources • Maintains access • Builds resiliency	• Costly • Sand source challenges

8.1 THE HAULOVER INTERIM APPROACH

A short term, interim approach may be pursued at the Haulover to attempt to improve conditions while a longer-term solution is developed. Sand fencing can be installed relatively easily to provide a means to trap sand. Fencing could be installed in a zig-zag pattern along the existing OSV roadway to capture sand in the secondary dune area, with the goal of building dune and roadway elevation (Figure 91). Sand fencing can provide the secondary benefit of being a demarcation and barrier for pedestrians and vehicles from impacting sensitive resources. Planting and management of beach grass can accompany sand fencing to further enhance sand capture, and improve habitat conditions, especially in areas which have been previously overwashed and have relatively less vegetation than less-impacted adjacent dunes.

Sand fencing could be installed in the secondary dune area, as opposed to at the toe of the dune, because the high wave energy of the site would soon be likely to washout the fencing in a storm. While placement along the roadway will have a longer lifespan, it is not anticipated that fencing will be sufficient to prevent erosion or overwashing. Should there be a concern that fencing may impede young shorebirds from moving from beach to inland bay, the fencing could be installed with evenly spaced gaps. Additionally, monitoring should follow installation to see if fences become a perch for predators.

Figure 91. Conceptual sand fencing placement along roadway at The Haulover.

8.2 THE HAULOVER CONCEPTUAL DESIGN

Woods Hole Group was tasked with developing a robust, non-structural conceptual design for long-term resilience for the Haulover based on information gathered during the existing conditions evaluation, an assessment of the dominant coastal processes acting to shape the site, as well as the potential for shoreline change (accretion and/or erosion). Based on the gathered data, several alternatives were evaluated and a combination of dune nourishment with native plantings and asset relocation was determined to be the most appropriate alternative and a conceptual design was drafted for this alternative.

Figure 92 shows a conceptual dune nourishment design and Figure 93 shows a conceptual footprint for the dune alternative. This design includes adding nourishment to raise the elevation and increase the width of the primary dune crest, which would slope gently on landward side where additional nourishment would be placed to raise the elevation of the OSV trail. The conceptual design also includes the installation of native beach grass plantings to stabilize the nourishment, enhance wildlife habitat, and improve resiliency.

Approximately 1,700 linear feet of dune could be nourished along The Haulover barrier beach area using approximately 50,000 cubic yards (29 yd^3/linear foot) of compatible material. The sand would come from either a local dredging project or an upland source. Details for sand sourcing and construction methods would be determined during the permitting process.

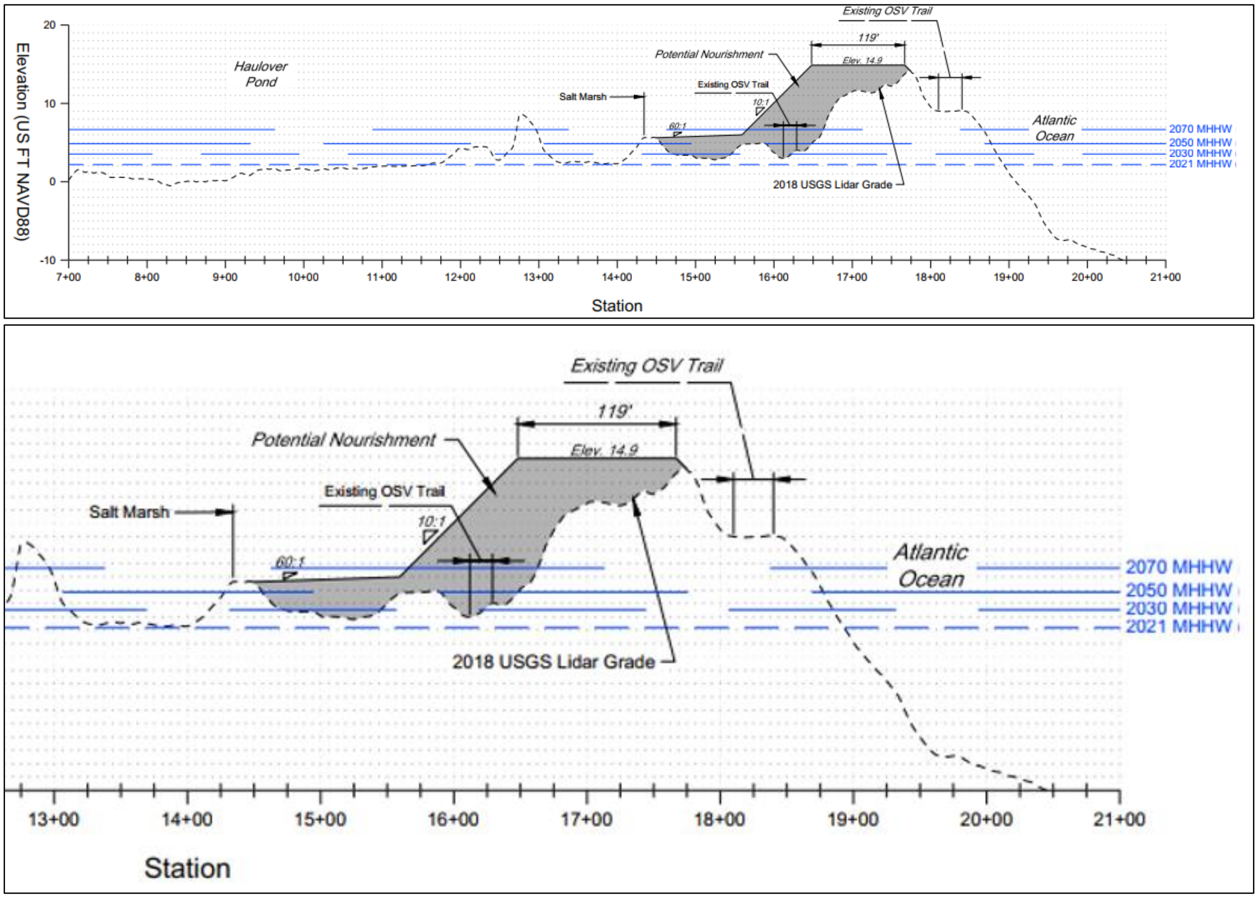
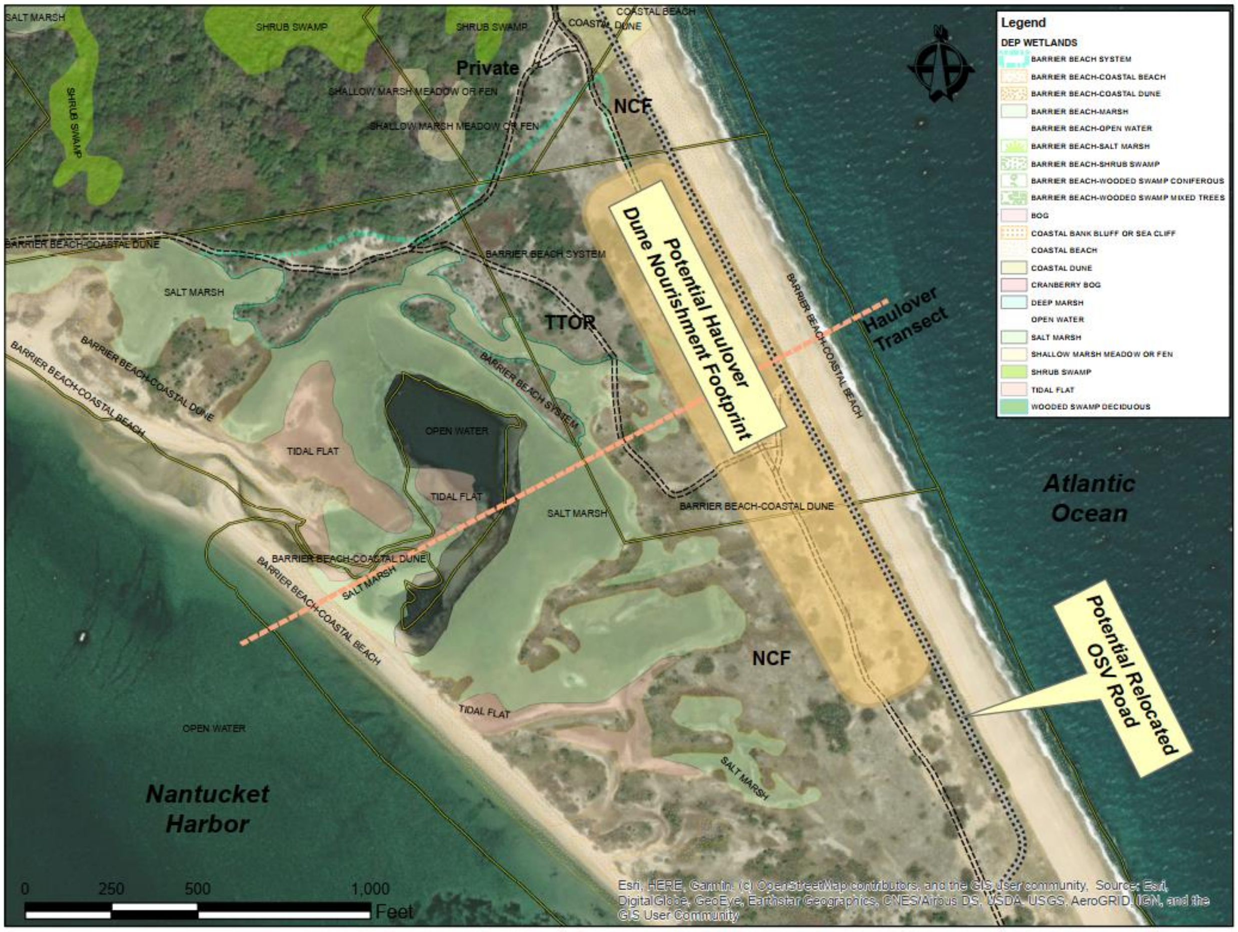


Figure 92. Conceptual design for a dune nourishment at The Haulover.



Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS User community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 93. The Haulover conceptual nourishment footprint and OSV relocation.

The conceptual nourishment profile was entered into the XBeach model and the 1- and 2-year Annual Return Period (ARP) storms were simulated to evaluate the cross-shore response to those storms. Figure 94 shows the conceptual nourishment profile (black line) and the eroded profile following the 1-year storm (red line). The conceptual nourishment profile includes a wider, taller dune that provides protection during this storm, but a considerable amount of sand is transported seaward. This process results in a gentler beach slope because of sand accumulation seaward of the dune and in essence, provides beach nourishment. The dune nourishment sand will redistribute along the beach following the storm and provide some level of protection to the dune.

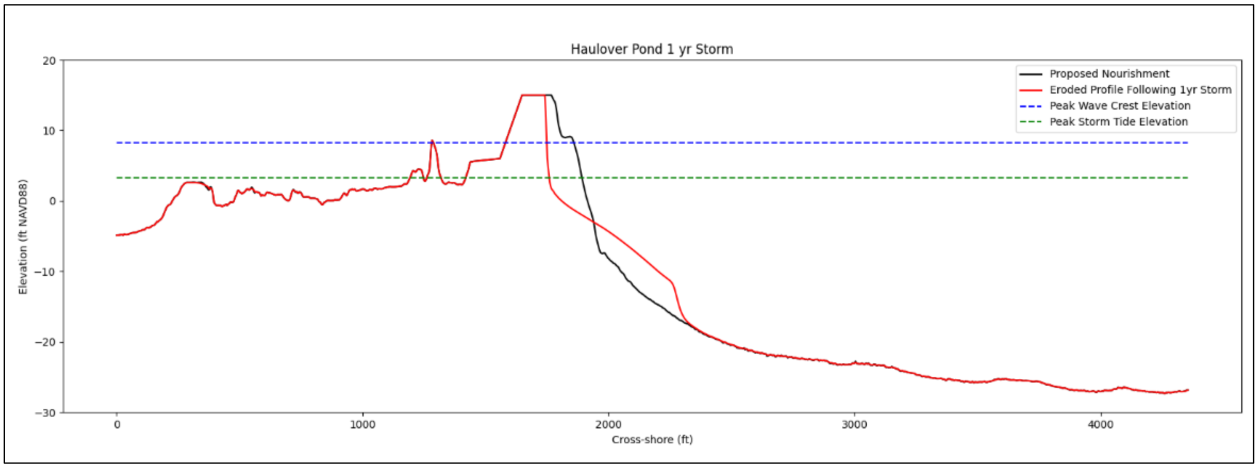


Figure 94. Conceptual nourishment and eroded profiles at The Haulover during a 1-year storm.

Figure 95 shows the design response at The Haulover following the 2-year ARP storm. The increased height and width of the nourished dune provides protection to landward areas of the dune, however, a significant amount of the nourishment is eroded and deposited on the seaward beach slope during the 2-year storm. While this post-storm, gentler beach slope will help to dissipate wave energy during future storms, renourishment would be necessary following larger storms. The model also indicates that the nourishment placed within on the OSV trail on the nourished backdune stays intact.

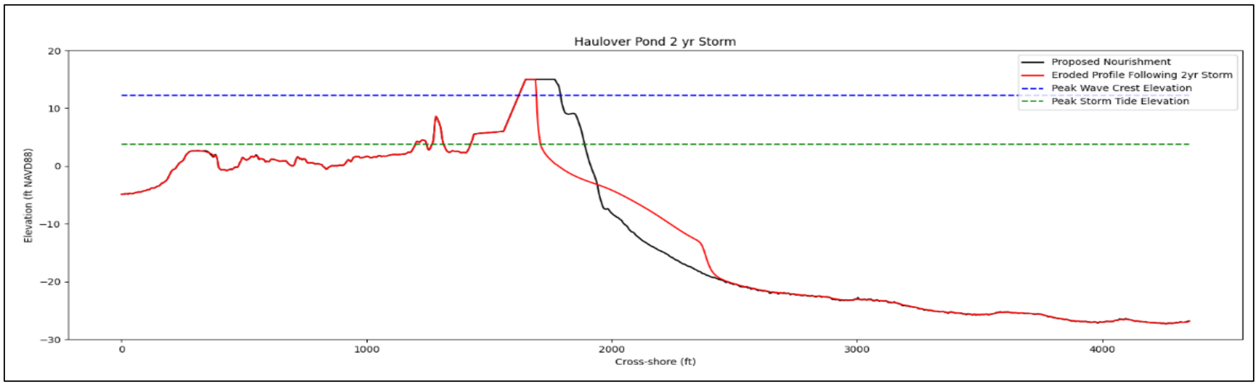


Figure 95. Conceptual nourishment and eroded profiles at The Haulover during a 2-year storm.

9.0 COSKATA POND ALTERNATIVES

Fundamentally, alternatives for improving resiliency at Coskata Pond involve adding sand to the barrier in the form of dunes and/or beach nourishment and installing sand fencing and beach grass. A key element of any nourishment strategy is identifying suitable and accessible sources of sand that are compatible with the beach and/or dune, affordable and consistent with environmental policy. The barrier in its present condition is vulnerable to overtopping and storm damage, which results in overwash of sand to the Coskata Pond system, loss of barrier functionality, degradation of habitat for listed species, and vulnerability of OSV access. Figure 96 shows the dramatic loss of coastal dunes in this area in a short period of time between 2012 and 2016 showing the vulnerability. Figure 96. LiDAR profiles at Coskata Pond between 2010 - 2018.

Table 8 identifies possible alternatives for the Coskata Pond area. Each of these alternatives is discussed in the following pages.

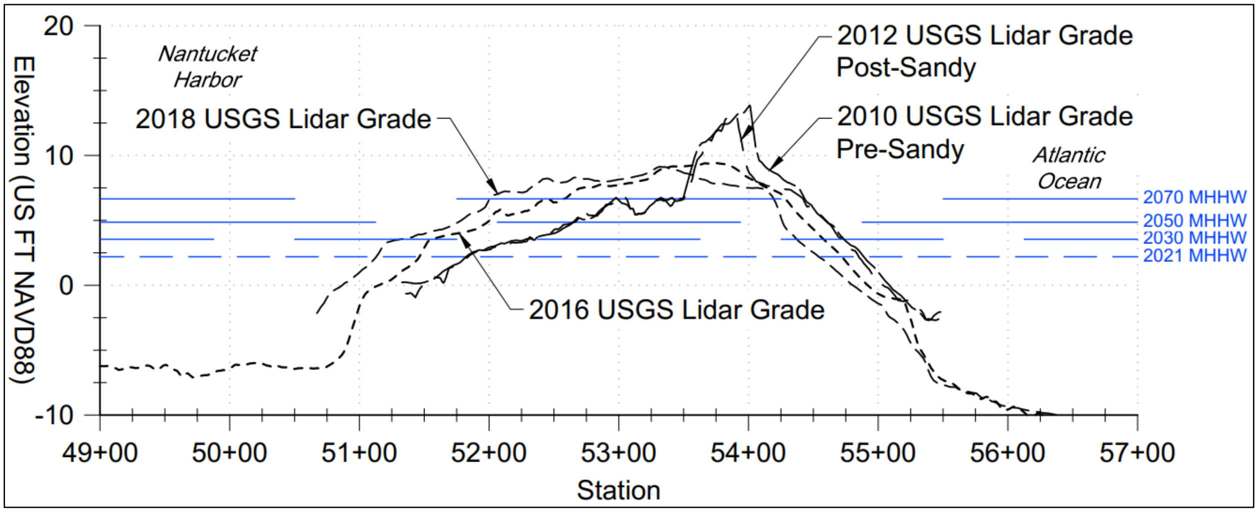


Figure 96. LiDAR profiles at Coskata Pond between 2010 - 2018.

Table 8. Adaptation Alternatives for Coskata Pond area.

Adaptation Alternatives	Result
No action	Continued erosion of dunes, loss of property and infrastructure, diminished public access, loss of inland habitat.
Vegetation Management	Lessen dune erosion, enhance wildlife habitat, invasive species control.
Sand Fencing	Enhance sand capture and promote incremental dune growth. However, will not be sufficient as a stand-alone solution to prevent erosion/overwash during storms. Can serve to manage public traffic.
Patron Management	Less unintended disturbance/erosion, citizen scientist cooperation, educational opportunities.
Dune Nourishment	Slow overall erosion, upland protection, raised OSV to reduce flooding of access.
Beach Nourishment	Temporarily provides protection to adjacent dune with sacrificial material for erosion.

Adaptation Alternatives	Result
Managed Retreat	Important assets relocated to avoid loss.
Salt Marsh Restoration	Implement within the pond and surrounding marsh. Expand marsh habitat and potentially adapt to low levels of sea level rise. Continued erosion of dunes, loss of property and infrastructure, diminished public access, loss of inland habitat.
Living Breakwater	Open coast implementation would require stone breakwater. Lessen dune erosion, increase beach width, potentially enhance marine habitat. Implementation in pond to provide shellfish/benthic habitat (with water quality improvement as secondary benefit), reduce wave energy incidental to salt marsh, and potentially increase sedimentation.
Combination of Efforts	Nourish coastal dune at weakest points, manage vegetation and relocate trails. Pair living breakwater with salt marsh restoration in pond to create marine habitat and salt marsh toe protection to reduce erosion.

Table 9 summarizes the pros and cons for each of the adaptation alternatives for the Coskata Pond site. Careful consideration must be given to each alternative to weigh the benefits versus the impacts. Only by considering all alternatives and assessing them against the principal mission of the Trustees\NCF, can you be assured of the best value for shoreline longevity and protection. Alternatives may not be considered acceptable because of environmental concerns or adverse impacts, costs associated with engineering, permitting and construction, or opinions about short- versus long-term benefit.

Table 9. Adaptation Alternatives Pros & Cons for Coskata Pond Site.

Adaptation Alternative	Pro	Con
No Action	• Maintains natural system • Breach provides connection between Pond & ocean • Barrier will likely continue shifting westerly	• Loss of property • Loss of access to/from Great Point

Adaptation Alternative	Pro	Con
Beach Grass Program	• Stabilizes dunes • Promotes sediment accumulation • Enhances habitat • Citizen scientist collaboration	• Not a long-term standalone project
Sand Fencing	• Encourages sediment accumulation • Controls foot traffic • Provides protection for beach grass	• Could inhibit wildlife function • Potential debris
Beach Nourishment	• Enhances public access • Improves barrier beach resiliency • Less likelihood of overwash/breaching • Enhances habitat • Provides protection to Coskata Pond • Sediment source for downdrift beaches/dunes	• Costly • Sand source challenges • Long permitting process • Limited longevity
Dune Restoration	• Enhances public access • Improves barrier beach resiliency • Less likelihood of overwash/breaching • Enhances habitat • Provides protection to Coskata Pond • Sediment source for downdrift beaches/dunes	• Costly • Sand source challenges • Long permitting process • Limited longevity
Salt Marsh Restoration	• Enhances habitat • Preserves longevity of marsh	• Does not address open coast erosion • Maintenance

Adaptation Alternative	Pro	Con
Living Breakwater	- Enhances habitat and water quality - Reduces beach/dune or salt marsh erosion, depending on where it's implemented	- Costly - Relatively untested - Permitting challenges if using stone material
Combination of Efforts: - Beach, Dune, & Grass	- Lessens erosion - Upland protection - Improves access reliability	- Very costly - Sand source challenges - Long permitting process - Limited longevity

9.1 COSKATA POND AREA INTERIM APPROACH

A short term, interim approach may be pursued at Coskata Pond to attempt to improve conditions while a longer-term solution is developed. Sand fencing can be installed relatively easily to provide a means to trap sand. Fencing could be installed in a zig-zag pattern along the existing OSV roadway to capture sand in the secondary dune area, with the goal of building dune, and potentially roadway elevation (Figure 97).

Figure 97. Conceptual sand fencing placement along roadway at Coskata Pond.

Sand fencing can provide the secondary benefit of being a demarcation and barrier for pedestrians and vehicles from impacting sensitive resources. Due to the low elevation of certain reaches by Coskata Pond, sand could be imported to pre-nourish the dune and sand fencing area. Planting and management of beach grass can accompany sand fencing to further enhance sand capture, and improve habitat conditions, especially in areas which have been previously overwashed and have relatively less vegetation than less-impacted adjacent dunes. Sand fencing could be used behind the foredune, as opposed to at the toe of the dune, because the high wave energy of the site would likely damage the fence on the seaward side in a storm. While placement along the roadway will have a longer lifespan, it is not anticipated that fencing will be sufficient to prevent erosion or overwashing. Should there be a concern that fencing may impede young shorebirds from moving from beach to inland bay, the fencing could be installed with evenly spaced gaps. Additionally, monitoring should follow installation to see if fences become a perch for predators.

9.2 COSKATA POND AREA CONCEPTUAL DESIGN

Woods Hole Group was tasked with developing a robust, non-structural conceptual design for long-term resilience at the Coskata Pond barrier beach area, based on information gathered during the existing conditions evaluation, an evaluation of the dominant coastal processes acting to shape the site, as well as the potential for shoreline change (accretion and/or erosion). Based on the gathered data, several alternatives were evaluated and beach nourishment and dune restoration with beach grass planting was determined to be the most appropriate alternative and a conceptual design was drafted for this alternative.

For the conceptual design, Woods Hole Group used an existing 2018 high-resolution LiDAR data set published by the Army Corp of Engineers, to generate profiles of the beach and dunes, in lieu of a traditional on-the-ground topographic survey. At the conceptual design phase, use of the LiDAR data is appropriate and reduced the budget required for surveys. If the Trustees/NCF decide to proceed with this alternative, a topographic survey by a Professional Land Surveyor (PLS) will be necessary, and the conceptual design will need to be refined in consideration of existing conditions.

To protect the site from future overwash and improve the physical integrity of the barrier beach, approximately 1,800 linear feet of dune could be nourished along the Coskata Pond barrier beach area using approximately 30,000 cubic yards (17 yd^3/linear foot) compatible material for the dune. The sand would need to be acquired from a local dredging project or an upland source. Details for sand sourcing and construction methods would be determined during the permitting process. For a project of this size, a designated borrow site would likely be necessary to acquire enough compatible sediment to fill the design template.

Figure 98 shows a conceptual design layout for a large-scale dune nourishment project and Figure 99 illustrates the concepts of dune restoration for the Coskata Pond area. The extent of the nourishment is restricted by the fact that the properties on either end are privately owned. While nourishment would benefit the private land as well, the owners' approvals would need to be obtained prior to performing any work there.

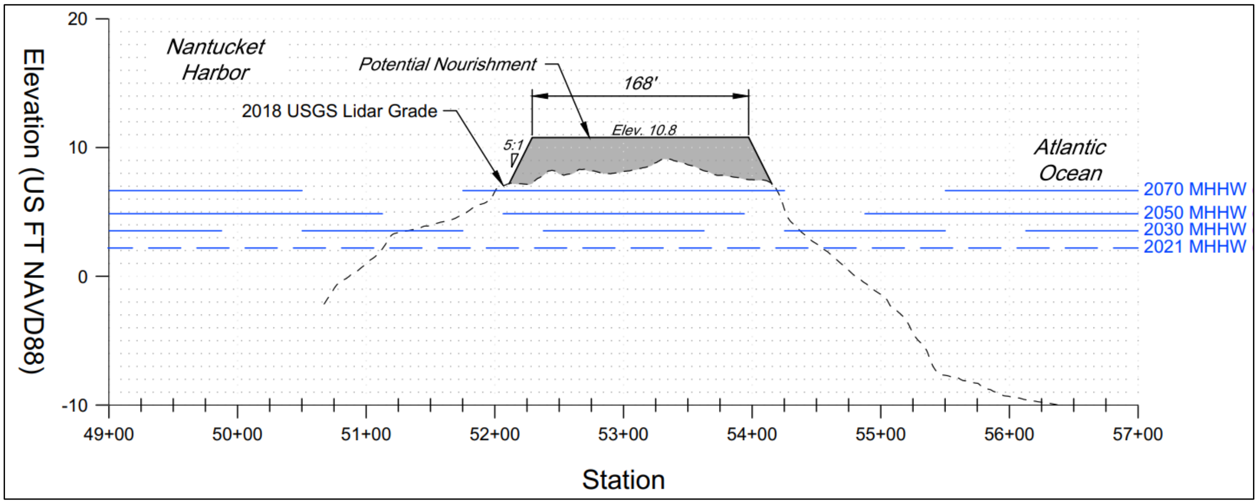


Figure 98. Conceptual dune nourishment design for Coskata Pond.

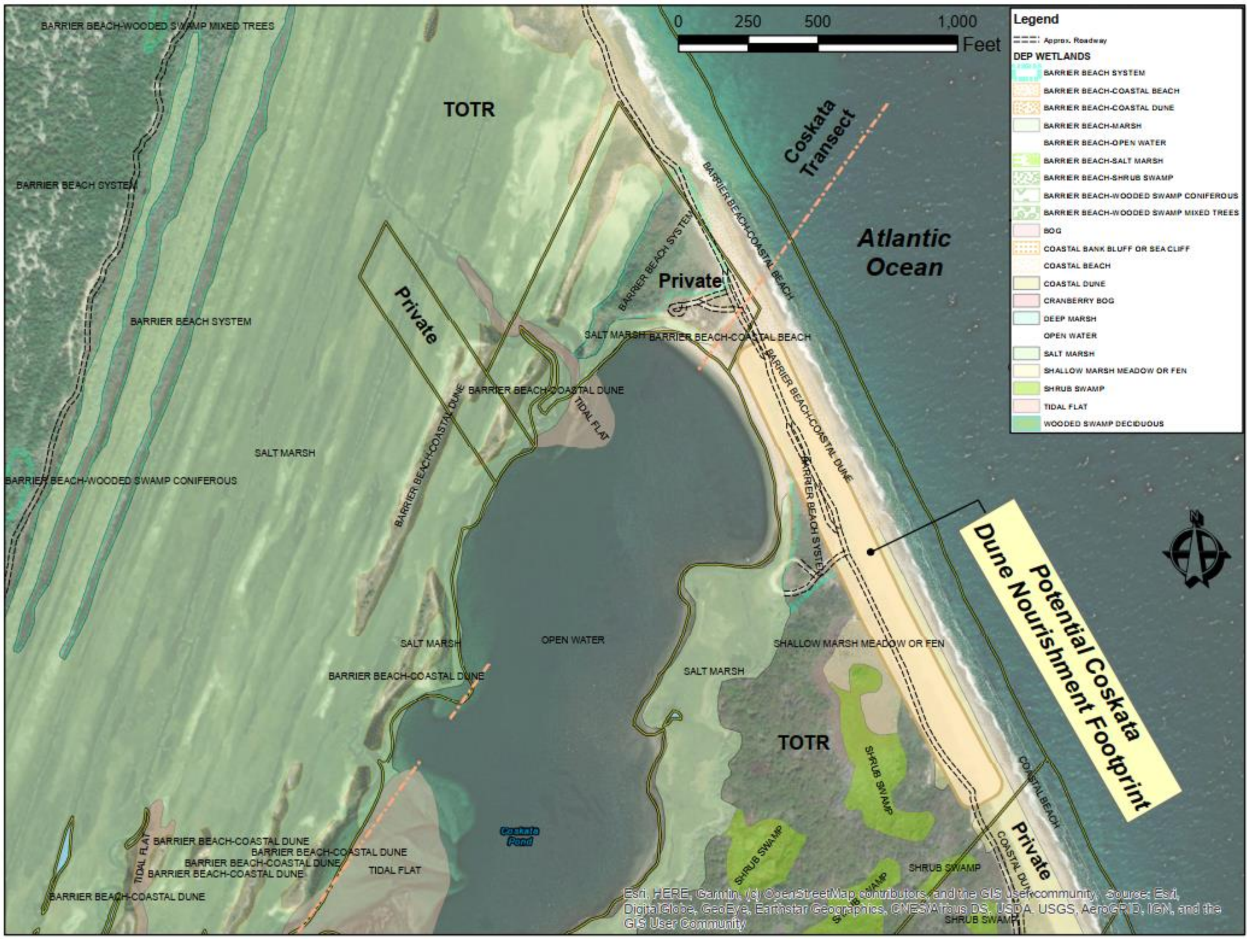


Figure 99. Potential Coskata Pond dune nourishment footprint.

The conceptual nourishment profile was entered into the XBeach model and two storms, the 1- and 2-year ARP, were simulated to evaluate design resiliency and storm response. Figure 100 shows the design profile before the 1-year ARP storm in black, and the profile response following the storm in red. During the 1-year storm, the seaward slope of the dune experiences fairly significant dune loss. However, sand removed from the dune is deposited on the seaward side of the profile, creating a gentler beach following the storm, which will help to dissipate waves energy during the next storm.

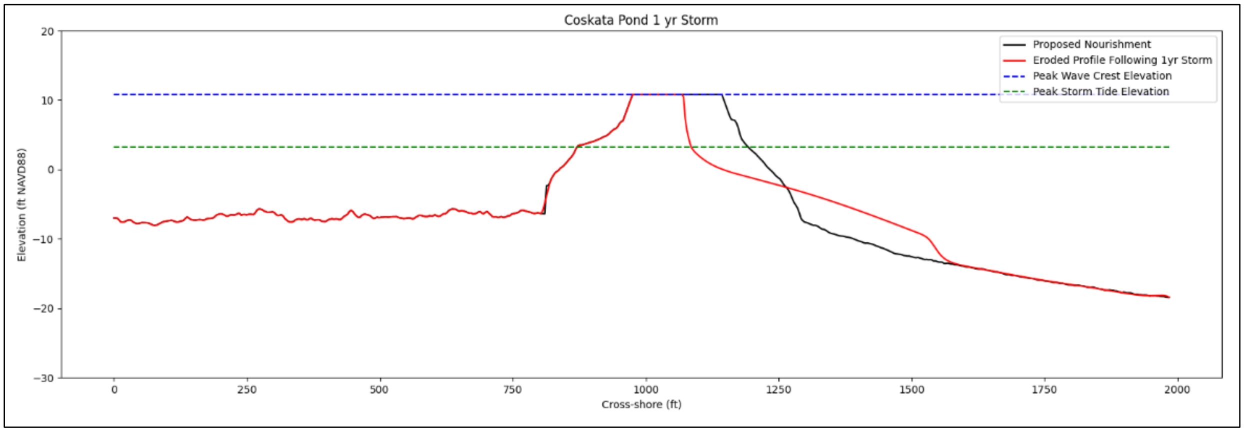


Figure 100. Conceptual nourishment and eroded profiles at Coskata Pond during a 1-year storm.

Figure 101 shows the conceptual design profile at Coskata Pond following the 2-year ARP storm. Similar to the 1-year storm discussed above, the seaward slope absorbs the wave energy, providing protection to areas landward of the dune. The higher water levels and increased wave energy from the 2-year ARP storm result in more dune retreat with approximately two thirds of the dune width removed. The eroded sand, however, provides for a gentler beach slope seaward of the eroded dune, allowing for larger waves to break farther offshore.

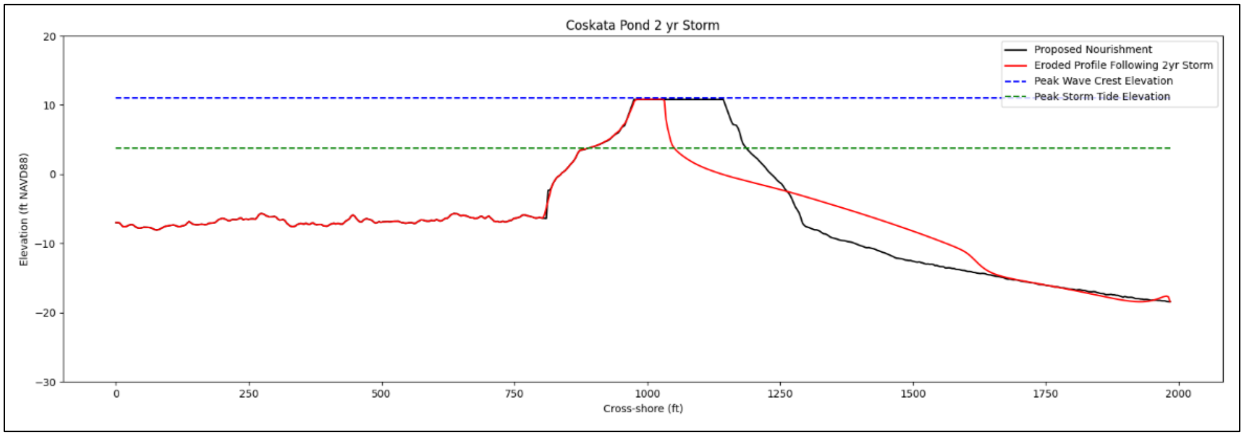


Figure 101. Conceptual nourishment and eroded profiles at Coskata Pond during a 2-year storm.

10.0 THE GALLS ALTERNATIVES

Woods Hole Group utilized information from the existing conditions evaluation, as well as other in-house data available to prepare an alternative analysis and a non-structural conceptual design for beach and dune stabilization for The Galls area. This project has identified and evaluated alternatives for the degraded dunes and overwash area in the narrow spit of sand just south of Great Point. The recommended conceptual design was based on guidance from the Trustees, and NCF, who utilize the area for access to their northerly properties and for visitors to the Great Point lighthouse. Table 10 identifies possible alternatives for The Galls area while Table 11 lists the pros and cons for each alternative. Salt marsh restoration is not included because no salt marsh habitat exists or is known to have existed at the site. A combination of alternatives was chosen to meet the needs of the stakeholders as the best protection alternative.

Table 10. Adaptation Alternatives for The Galls Area.

Adaptation Alternative	Result
No action	Continued erosion of adjacent dunes, loss of public access, higher potential for new breach, loss of habitat.
Vegetation Management	Lessen beach erosion, enhance wildlife habitat, citizen scientist cooperation.
Sand Fencing	Enhance sand capture and promote incremental dune growth. However, will not be sufficient as a stand-alone solution to prevent erosion/overwash during storms. Can serve to manage public traffic.
Patron Management	Educational opportunities to explain potential for further overwash.
Dune Nourishment	Slow overall erosion, upland protection, sediment source, increased overwash elevation.
Beach Nourishment	Temporarily provides protection to adjacent dune with sacrificial material for erosion, raised OSV to reduce inundation of access.
Living Breakwater	Open coast implementation would require stone breakwater. Lessen erosion, increase beach width, potentially enhance marine habitat.
Combination of Efforts	Nourish coastal beach at overwash and relocate trails.
Thin Layer Sediment Deposition in the Overwash Area	Increased resiliency to overwash due to increased elevations with minimal disturbance to habitat.

Table 11 summarizes the pros and cons for each of the alternative discussed for The Galls. Careful consideration must be given to each alternative to weigh the benefits versus the impacts. Only by considering all alternatives and assessing them against the principal mission of the Trustees/NCF, can you be assured of the best value for shoreline longevity and protection. Some alternatives may not be considered acceptable because of environmental concerns or adverse impacts, costs associated with engineering, permitting and construction, or opinions about short versus long-term benefit.

Table 11. Adaptation Alternatives Pros & Cons for The Galls Area.

Adaptation Alternative	Pro	Con
No Action	• Maintains natural system	• Diminished public access
Beach Grass Program	• Stabilizes dunes • Promotes sediment accumulation • Enhances habitat • Citizen scientist collaboration	• Costly for large area • Slow to establish in active overwash area • Permitting challenges in NHESP habitat
Sand Fence	• Encourages sediment accumulation • Controls foot and vehicle traffic • Provides protection for beach grass • Citizen scientist collaboration	• Possibly inhibit wildlife function • Potential debris • Permitting challenges in NHESP habitat
Beach Nourishment	• Enhances public access • Improves barrier beach resiliency • Less likelihood of overwash/breaching • Enhances habitat • Sediment source for downdrift beaches/dunes	• Costly • Sand source challenges • Long permitting process
Dune Restoration	• Protection of public access (OSV trail) • Improves resiliency of beach • Enhances diversity of wildlife	• Costly • Sand sourcing challenges • Permitting challenges in NHESP habitat

Adaptation Alternative	Pro	Con
	- Sediment source for downdrift beaches/dunes	- Conversion of resource area from coastal beach to coastal dune
Living Breakwater	- Enhances habitat and water quality - Reduces beach/dune erosion	- Costly - Relatively untested - Permitting challenges if using stone material
Thin Layer Sediment Deposition in the Overwash Area	- Improves resiliency - Enhances habitat - Lessens likelihood of overwash - Sediment source for downdrift beaches/dunes	- Costly - Sand source challenges - Long permitting process

10.1 THE GALLS INTERIM APPROACH

A short term, interim approach may be pursued at The Galls to attempt to improve conditions while a longer-term solution is developed. Sand fencing can be installed relatively easily to provide a means to trap sand. The Galls is a unique reach for sand fencing, and two potential alternatives may be considered:

1. Fencing could be installed in a zig-zag pattern along the lee side of the existing dunes. This would promote sand capture in the dune area but would leave the sandy overwash reach unimproved and exposed to erosion and potential breaching.
2. Fencing could be installed in the overwash area, with beach grass planting placed every 3 feet on center within the network of fences. This alternative would improve sediment capture in an area which currently has no means to capture windblown sand. Sand capture could raise existing elevations, and eventually create dune habitat. However, the overwash area is very exposed to storm waves, and it is very possible that fencing would quickly be destroyed and become debris, while providing no significant erosion protection. This alternative is additionally difficult, due to the occupation and potential resource conversion of sandy beach habitat.

Alternative 1 would provide some measure of sand capture improvement to The Galls (Figure 102). Sand fencing can provide the secondary benefit of being a demarcation and barrier for pedestrians and vehicles from impacting sensitive resources. Planting and management of beach grass can accompany sand fencing to further enhance sand capture and improve habitat conditions.

Sand fencing could be installed on the lee side of the dune, as opposed to on the open ocean side, because the high wave energy of the site would soon be likely to washout the fencing in a storm.

While placement along the leeside dune will have a longer lifespan, it is not anticipated that fencing will be sufficient to prevent erosion or overwashing.

Should there be a concern that fencing may impede young shorebirds from moving from beach to inland bay, the fencing could be installed with evenly spaced gaps. Additionally, monitoring should follow installation to see if fences become a perch for predators.

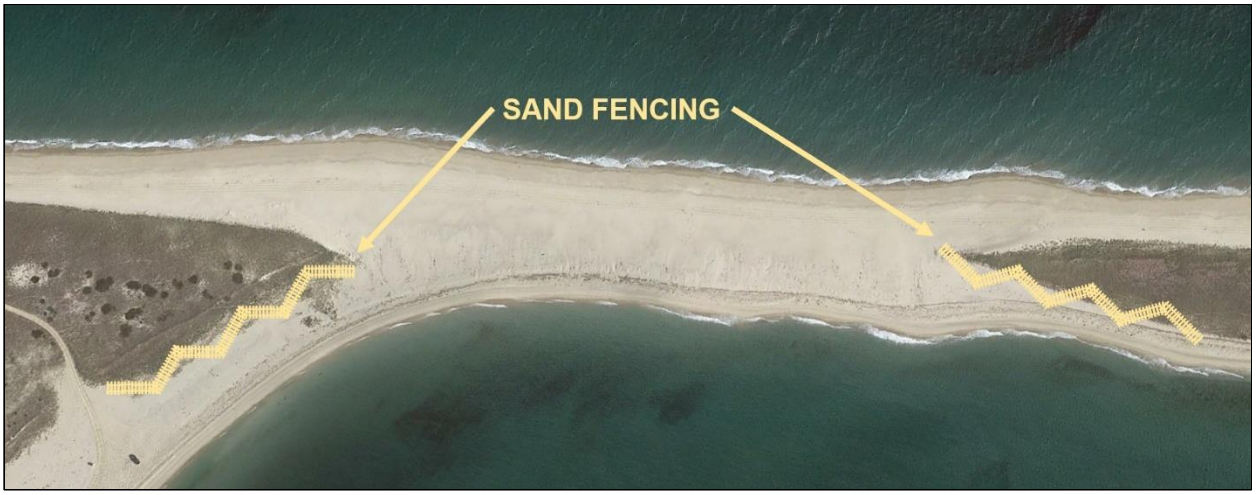


Figure 102. Conceptual sand fencing placement behind dunes at The Galls.

10.2 THE GALLS CONCEPTUAL DESIGN

Woods Hole Group was tasked with developing a robust, non-structural conceptual design for long-term resilience at The Galls. This conceptual design was drafted based on the existing conditions, an evaluation of local coastal processes and the potential for beach and dune erosion or accretion. Based on an evaluation of the data, several alternatives were considered, and beach nourishment was determined to be the preferred alternative to improve resiliency.

For the conceptual design shown in Figure 103, Woods Hole Group used an existing 2018 high-resolution LiDAR data set published by the Army Corp of Engineers, to generate profiles of the beach and dunes, in lieu of a traditional on-the-ground topographic survey. At the conceptual design phase, use of the LiDAR data is appropriate and reduced the budget required for surveys. If the Trustees/NCF decide to proceed with this alternative, a topographic survey by a Professional Land Surveyor (PLS) will be necessary, and the conceptual design will need to be refined in consideration of existing conditions.

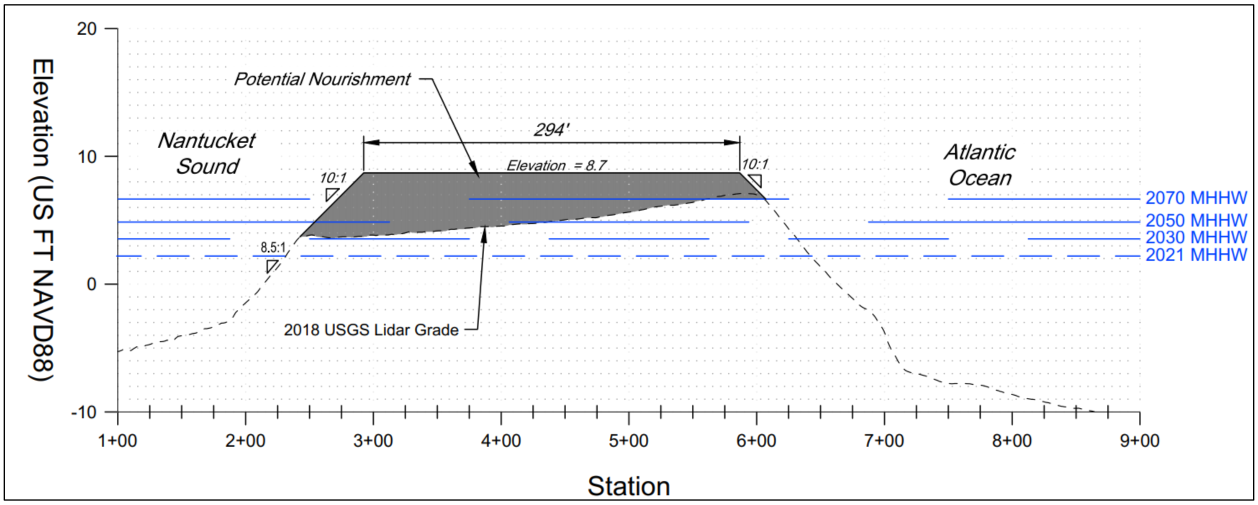
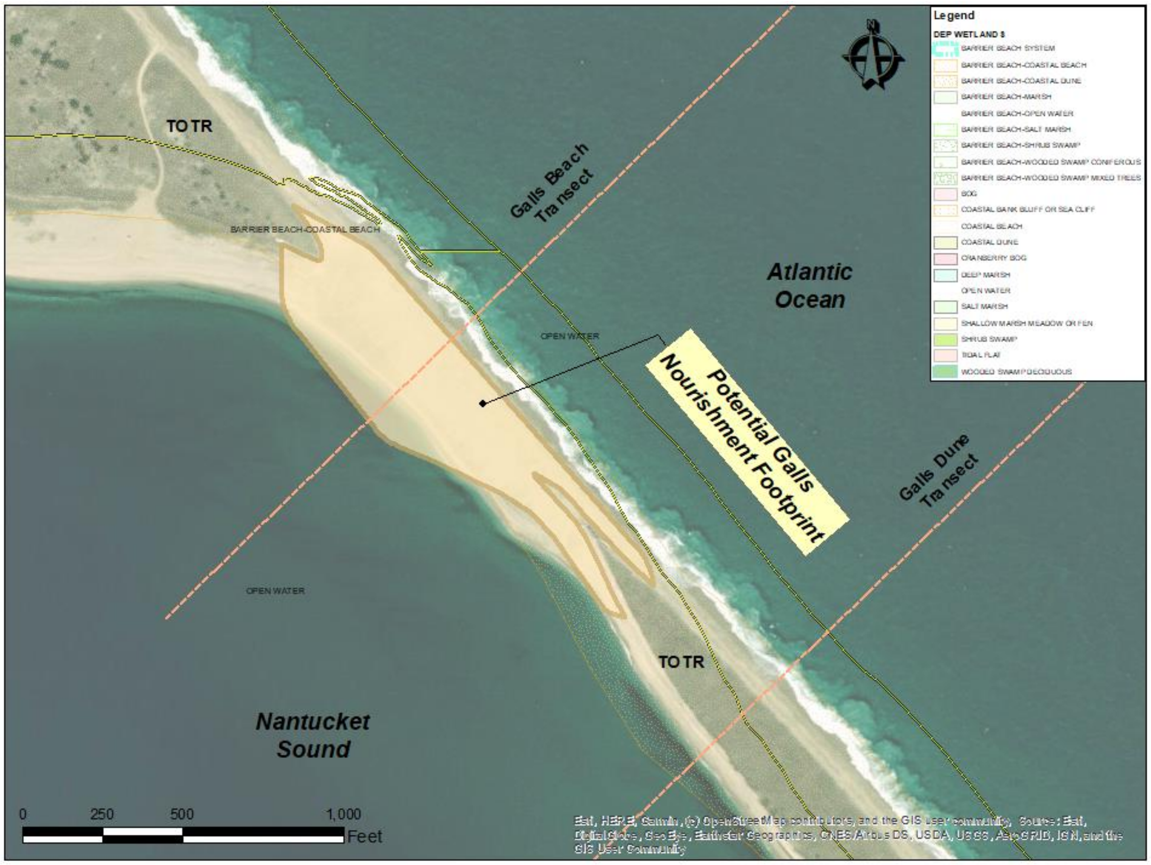


Figure 103. Conceptual design for the beach nourishment alternative at The Galls.

Figure 104 shows the footprint of a beach nourishment alternative that blends into the adjacent coastal dunes. The nourishment would extend along 1,600 linear feet of beach and would require approximately 65,000 cubic yards of beach compatible material. Details for sand sourcing and construction methods would be determined during the permitting process but could come from a local dredging project or an upland source.



Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community; Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 104. Potential beach nourishment footprint at The Galls.

Utilizing the XBeach model, this alternative was evaluated for the 1- and 2-year ARP storms. Figure 105 shows the conceptual design performance of beach nourishment before (black line) and after (red line) the 1-year ARP storm. During the storm, sand is removed from the dune and deposited on the beach resulting in a gentler foreshore slope.

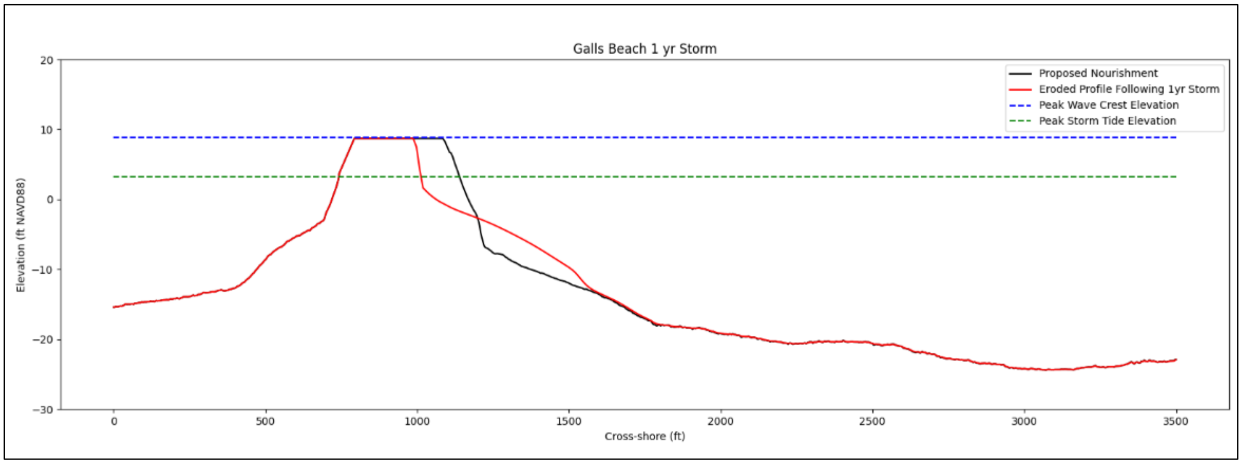


Figure 105. Conceptual nourishment and eroded profiles at The Galls during a 1-year storm.

Figure 106 shows the same conceptual design alternative at Gall's beach following the 2-year ARP storm. The red line on the figure shows the profile response following the storm. Like the 1-year storm shown in the previous figure, sand is removed from the dune face and deposited on the beach resulting in dune retreat but a gentler foreshore slope following the passage of the storm. The more energetic waves in the 2-year ARP storm result in approximately twice as much dune retreat, however the design profile provides sufficient protection during the storm to prevent breaching and potential wave exposure landward of the dune.

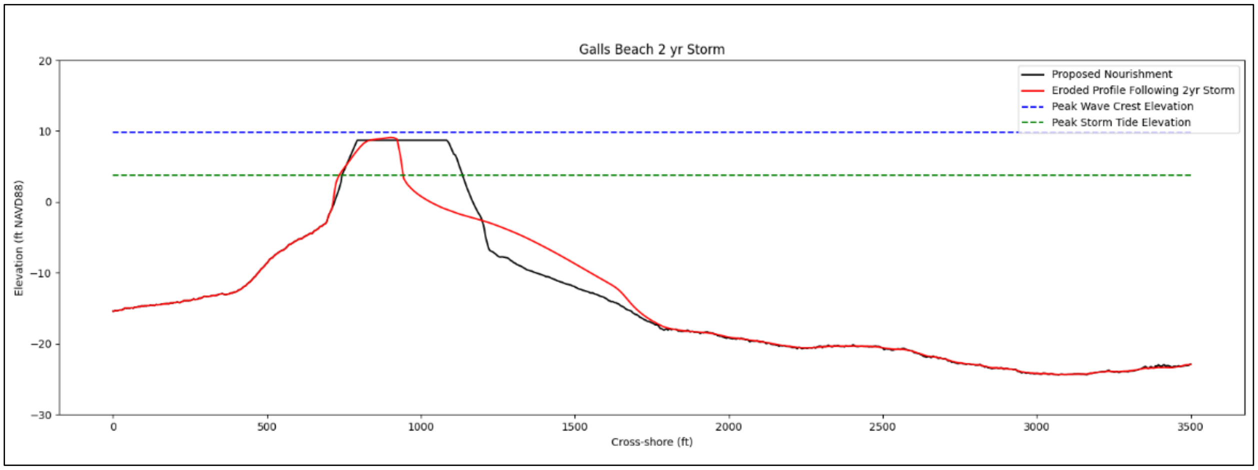


Figure 106. Conceptual nourishment and eroded profiles at The Galls during a 2-year storm.

11.0 HARBOR SIDE OSV BETWEEN 1ST AND 2ND POINT ALTERNATIVES

Another low-lying section of the OSV inside trail that experiences frequent flooding is along Nantucket Harbor between 1st and 2nd Point. The large open sandy plain in this area is sometimes used as an intermediate parking area, but the low elevation and lack of dunes along the Harbor here allows higher tides to impact the trail and restrict access to Coatue Point. Salt marsh habitat exists on the lee side of the OSV trail, closer to and within 2nd Point. The healthy dune system facing Nantucket Sound and the lower storm wave intensity from that direction caused us to consider the Harbor side impacts for more immediate adaptation opportunities with potential for future enhancement.

Tables 12 and 13 summarize the pros and cons for each of the alternatives discussed for the area between 1st and 2nd Point. Careful consideration must be given to each alternative to weigh the benefits versus the impacts. Only by considering all alternatives and assessing them against the principal mission of the Trustees/NCF, can you be assured of the best value for shoreline longevity and protection. Some alternatives may not be considered acceptable because of environmental concerns or adverse impacts, costs associated with engineering, permitting and construction, or opinions about short versus long-term benefit.

Table 12. Adaptation Alternatives for between 1st and 2nd Point.

Adaptation Alternatives	Result
No action	Loss of public access, loss\conversion of resources, loss of habitat, more frequent inundation.
Vegetation Management	Enhance wildlife habitat, citizen scientist cooperation.
Patron Management	Educational opportunities to explain potential for further inundation.
Dune Nourishment	Slow overall erosion, upland protection, sediment source.
Beach Nourishment	Raised OSV to reduce inundation of access.
Salt Marsh Restoration	Implement within the wetland area located on the cuspate foreland, east of the sandy parking area. Enhance marsh habitat and potentially adapt to low levels of sea level rise. Continued erosion of beach/dunes, loss of public access, loss\conversion of resources, loss of habitat, more frequent inundation.
Living Breakwater	Open coast implementation would require stone breakwater. Lessen dune erosion, increase beach width, potentially enhance marine habitat. Implementation in open water on lee side to provide shellfish/benthic habitat (with water quality

Adaptation Alternatives	Result
	improvement as secondary benefit), reduce wave energy incidental to salt marsh, and potentially increase sedimentation.
Combination of Efforts	Nourish OSV and relocate trails.

Table 13. Adaptation Alternatives Pros & Cons between 1st and 2nd Point.

Adaptation Alternatives	Pro	Con
No action	• Inexpensive	• Loss of trail access to high tide flooding
Patron Management	• Inexpensive	• Dependent on users complying
Managed Retreat • Relocate trails	• Low cost • Opportunity to reconfigure trail system	• Loss of habitat and resources • Loss of alternative trails
Dune Nourishment	• Improves resiliency • Extends usability of assets	• Costly • Maintenance
Salt Marsh Restoration	• Enhances habitat • Preserves longevity of marsh	• Does not address open coast erosion • Maintenance
Living Breakwater	• Enhances habitat and water quality • Reduces beach/dune or salt marsh erosion, depending on where it is implemented	• Costly • Relatively untested • Permitting challenges if using stone material
Combination of Efforts: • Relocate trails • Dune Nourishment	• Cost efficiency focused on most valuable assets & resources • Maintains access • Potential for transitional salt marsh habitat	• Costly • Sand source challenges

11.1 1ST AND 2ST POINT INTERIM APPROACH

A short term, interim approach may be pursued at 1st and 2nd point to attempt to improve conditions while a longer-term solution is developed. The seaward beach and dune at this site are considered relatively stable. Therefore, the interim approach would address the most pressing issues in the area, understood to be flooding on the backside of the barrier spit, where a low sandy parking area can be wetted by extreme tides, storm surge, and wind waves. Improvements to this section would be the import of a relatively small volume of sandy material to patch the low-lying areas and minimize future flooding of the parking area. While an elevated linear dune along the bay-side would provide some protection from overtopping, it would also create a potential risk for retaining stormwater. A more appropriate approach is to elevate the entire low-lying area above the king tide line and ensuring that the topography continues to slope towards the bay to promote drainage (**Figure 107**). Vegetation management with dune plantings and sand fencing could be implemented in areas where parking is prohibited to improve sand capture and stabilization and minimize the risk for trampling by visitors and drivers.

Figure 107. Conceptual footprint for elevation with import at 1st and 2nd Point – February 2018 Aerial

11.2 1ST AND 2ND POINT CONCEPTUAL DESIGN

Raising the elevation of the existing OSV trail above current and projected high water with sand nourishment and adding sand to the landward slope of the dune adjacent to the Harbor, provide several long-term resiliency benefits. First, raising the elevation of the low-lying sections of the trail between 1st and 2nd Point would reduce the occurrence of a flooded access. Nourishment could be performed in several phases to balance project costs with projected sea level rise timelines, although minimizing the mobilization efforts to the remote location are encouraged. As one of the lowest trail points along Coatue, nourishment here will provide much needed resiliency to flooding, but please make note that other OSV sections will eventually become exposed to higher tide levels also.

Second, increasing the width of the coastal dune will improve the barrier's resiliency to storms and decrease the likelihood of a breach between the Sound and Harbor. Each of the cuspate spit concavities create a weaker point in the barrier beach due to their narrow nature. Increasing the volume of sand and hence the width and elevation of the dune system, will provide much greater resiliency against future storms and sea level rise.

Third, the nourishment was designed with the notion that as sea level rises, this area could one day transition to salt marsh habitat, much like the adjacent marsh at 2nd Point. The Harbor side slope was designed to be very gentle so that salt marsh habitat could naturally migrate up the slope as sea level rises. To enhance the sites potential for future salt marsh, an oyster sill could be constructed in the shallow areas of the harbor, at the toe of the nourishment site. An oyster sill, constructed of reef balls, for instance, would help break wave energy, encourage sediment deposition, and enhance habitat value. This would improve conditions for the establishment of marsh grasses and other wetland habitat vegetation.

A potential dune nourishment cross section is shown in Figure 108. Creating a stepped nourishment allows the roadway to be raised in its current location and provides for a potential future relocation to higher ground as necessary. The 2.8-acre nourishment footprint would require approximately 7,200 cubic yards of fill and is shown in relation to the projected mean higher high water (MHHW) elevation for 2030 in Figure 109.

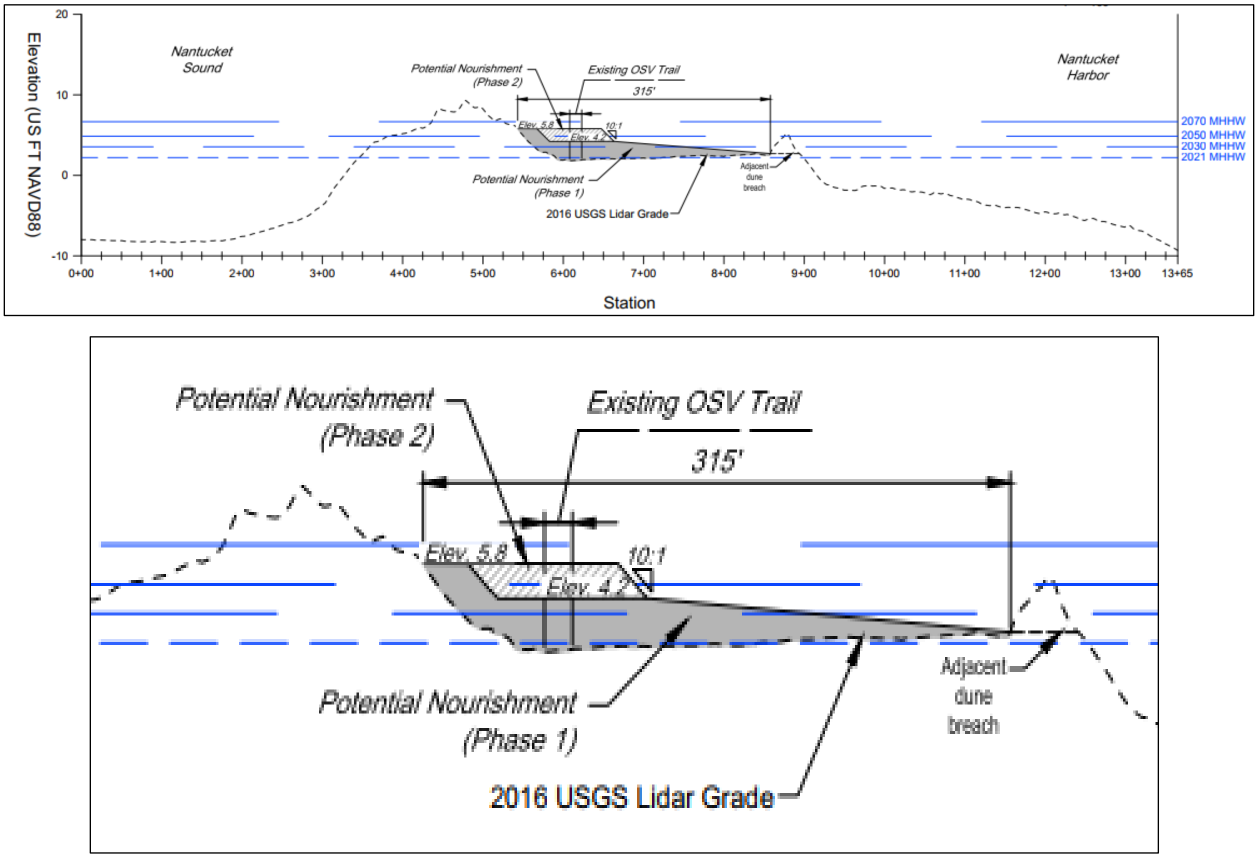
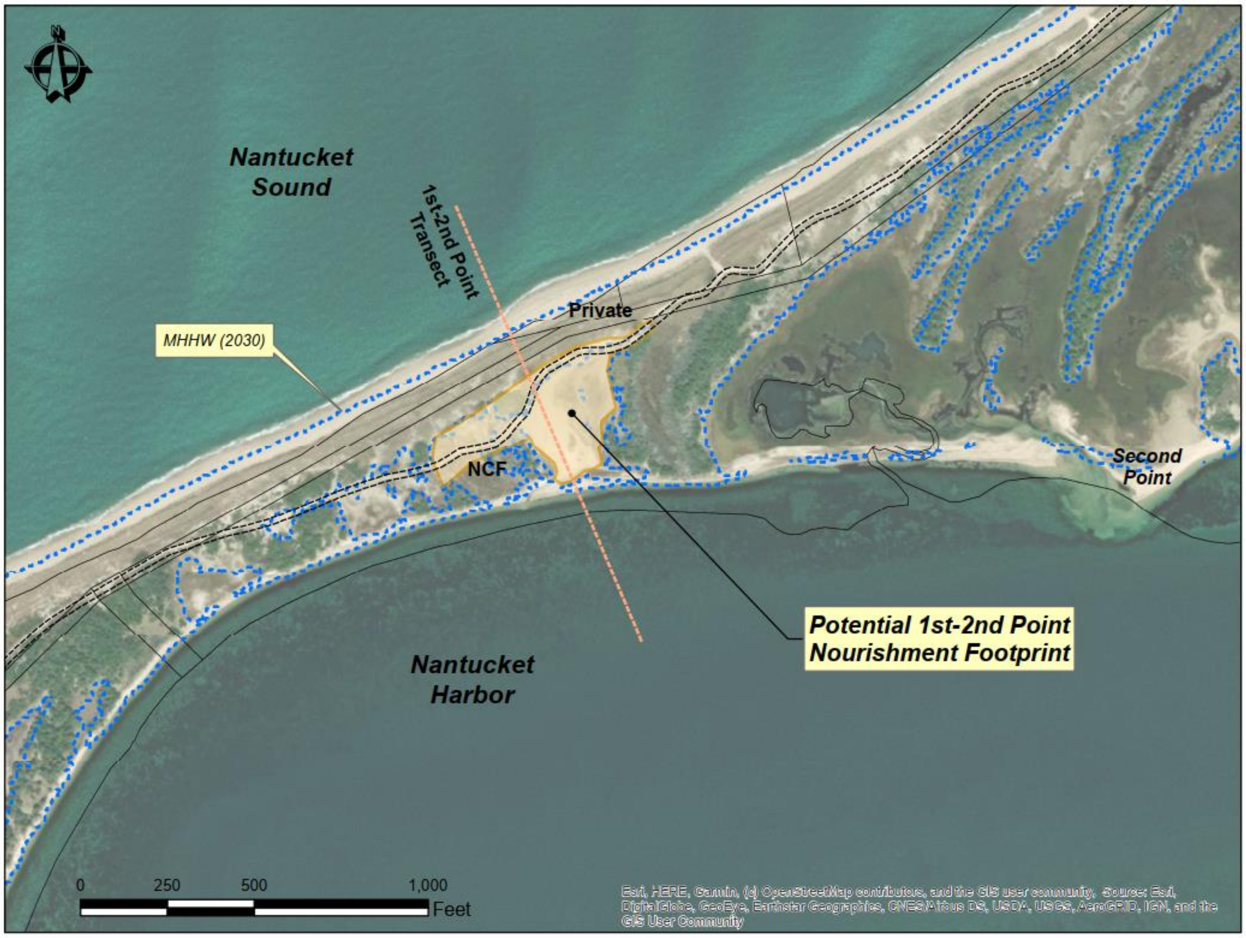


Figure 108. Cross-Section of Potential Nourishment between 1st and 2nd Point.



Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 109. Potential dune nourishment footprint between 1st and 2nd Point.

Utilizing the XBeach model, this conceptual design alternative was evaluated for the 1- and 2-year ARP storms and the results are shown in Figures 110 and 111, respectively. This project site, located on the western end of Coatue, is exposed to different wave conditions than those on eastern shoreline of Nantucket during a 1-year storm. The waves in Nantucket Sound are smaller compared to the other sites because the Sound is more protected. This, combined with a wide dune system means significantly less erosion of the dune during the same event. Even the larger, 2-year storm has minimal impact on the dune due to the smaller wave conditions. The small volume of sand that has eroded from the dune during both the 1- and 2-year storms is deposited directly on the beach.

The OSV trail located on the Harbor side of the dune system here, is not subjected to direct wave attack during the 1- or 2-year storms and the storm profiles in Figures 110 and 111 show no change. However, this area is subject to inundation from storm surge as shown in the MC-FRM data in Section 3.2.4. Increasing the elevation with sand nourishment will lessen potential flooding of the trail and increase resiliency here.

Overall, this location responded well to the projected, more frequent storms due to the northerly exposure to Nantucket Sound, shallower offshore water depths, and reduced wave heights. Even though the short-term shoreline change data indicates accretion of the beach at this site, larger storms are still likely to produce erosion and sand nourishment could be beneficial for long-term resiliency.

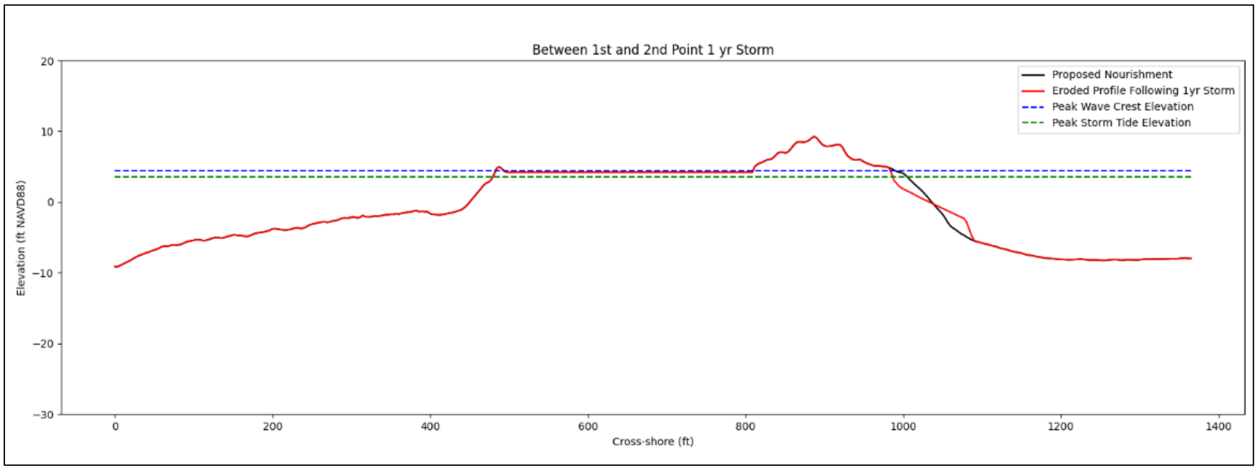


Figure 110. Conceptual nourishment and eroded profiles between 1st and 2nd Point during a 1-year storm.

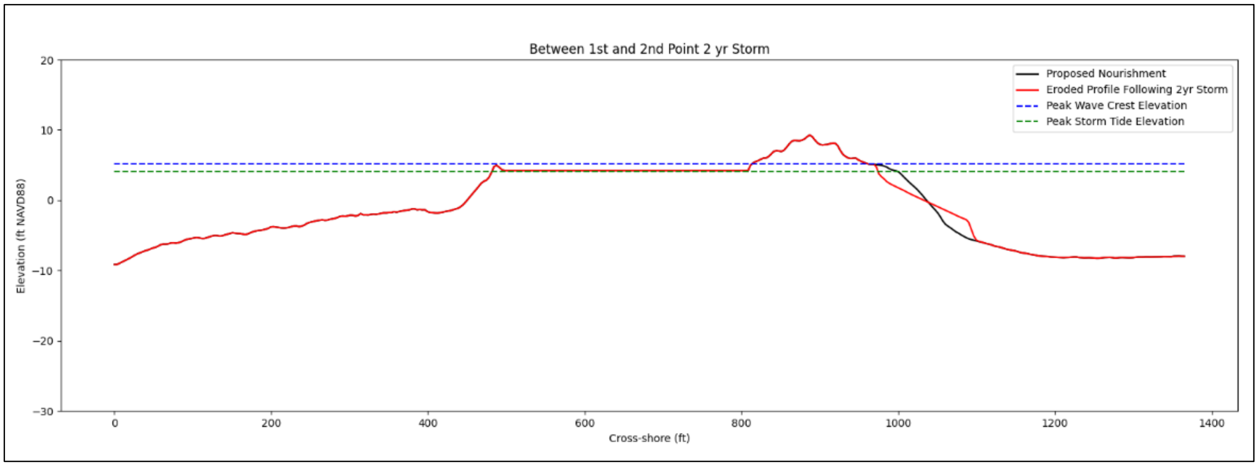


Figure 111. Conceptual nourishment and eroded profiles between 1st and 2nd Point during a 2-year storm.

12.0 PROJECT COSTS

Estimated costs for the alternatives at The Haulover, Coskata Pond, The Galls, and the area between 1st and 2nd Point are described below. Please note that these costs are estimates based on our knowledge of these types of projects on Cape Cod, Martha's Vineyard, and elsewhere. Nantucket, and especially Coskata-Coatue, present additional cost increases due to the additional ferry/barge travel for equipment and materials to reach the remote location. An expected cost increase factor has been included in the described values below. Costs presented are for planning purposes only and actual costs for different alternatives would have to be refined when an engineering design for an alternative is created. This information is shown in Table 14.

12.1 TYPICAL ADAPTATION ALTERNATIVE COSTS

12.1.1 No Action

The No Action alternative would allow nature to take its course and result in continued erosion and increased inundation of the access road. This no action alternative does not include direct costs but will represent a loss of revenue when the access road and walking trails are unusable due to flooding or lost to erosion and visitors no longer have access to the rest of the properties. In an unmanaged condition, public users may blaze their own trails should erosion remove existing trails. Managed retreat, discussed in Section 12.1.11, would be the most closely related alternative, with the plus of including organized public access.

12.1.2 Beach Grass

This adaptation includes the installation of Cape American Beach Grass in the backdune areas with exposed sand and/or sparse vegetation outside of the access roadway. Estimated costs for beach grass is $1.00 per square foot if installed by citizen scientists and $2.50 per square foot is installed professionally. Additionally, 2-gallon woody plants would cost $100.00 each installed.

12.1.3 Beach Nourishment

The beach nourishment adaptation includes the placement of compatible beach sand along the seaward toe of the coastal dune. A compatible source of sand could come from a local dredge project or upland source. Due to the remote location, upland sand could cost as much as $100 per cubic yard or more. Dredge sand would likely range between $45-50 per cubic yard if a local source is available.

12.1.4 Dune Nourishment

The dune nourishment adaptation includes the placement of sand for use as compatible nourishment along the coastal dune. A compatible source of sand could come from a local dredge project or upland source. Due to the remote location, upland sand could cost as much as $100 per cubic yard or more. Dredge sand would likely range between $45-50 per cubic yard if a local source is available.

12.1.5 Dune Stabilization Using Bioengineered Solution

Dune stabilization with a bioengineered core typically involves the installation of a series of coir rolls and\or envelopes placed along the face of the dune starting from an elevation below the existing toe and extending to a design height appropriate for the expected wave heights of a given storm. The stabilized core system is then covered with a quantity of compatible sand as nourishment along the coastal dune. The cost of constructing this adaptation with the combined core and nourishment components could cost approximately $5,000 per linear foot of dune depending on the components.

12.1.6 Sand Fence

The sand fence adaptation includes the installation of one or more rows of staggered sand fencing with posts aligned along the dune to aid in capturing windblown sand. Typical costs for implementing this alternative are $20.00 per linear foot of fence row.

12.1.7 Thin Layer Sediment Placement in Overwash Area

The cost of placing a thin layer of compatible sediment in the overwash area can be site dependent due to the placement range capabilities of different equipment. It may be possible to transport the material and a conveyor by barge that can anchor offshore in the Sound and transfer the sediment to the beach without disruption to the site by construction vehicles. Alternatively, that same conveyor equipment could be brought in over the access road but would require altering the beach access road slopes to accommodate the equipment. An approximate cost per cubic yard for this type of nourishment is $50.00 - $100.00.

12.1.8 Coastal Engineering Structure

This alternative is unlikely to be approved at these sites and is likely to be a higher cost than the other alternatives. Further costs analysis could be calculated if this alternative can be considered for another site that has a greater likelihood of being approved.

12.1.9 Vegetation Management

This alternative includes the installation of Cape American Beach Grass and other appropriate native plants. Estimated costs for beach grass is $2.50 per square foot and $100 per 2-gallon woody plant.

12.1.10 Patron Management

The Patron Management alternative includes protecting sensitive areas by corralling and redirecting foot traffic with the installation of split rail fence or other natural barriers and the installation of additional signage educating visitors on the importance of staying on the designated trails and acceptable property uses. There are no direct costs for this but $5,000 – $10,000 annually is an acceptable estimate for planning purposes.

12.1.11 Managed Retreat

This alternative includes relocating the access road to protect it from flooding due to rising sea level. There are minor direct costs, associated with relocating or demolishing infrastructure, presented for this alternative.

12.1.12 Salt Marsh Restoration

If salt marsh restoration only entails planting, typical costs are $5-7 per plug planting assuming *Spartina alterniflora* in low marsh and *Spartina patens* in high marsh installed at 12" on-center across the restoration area. While this cost includes labor and materials, there would be additional costs for mobilization in the range of $15,000. If the project requires regrading of marsh substrate and dredging, costs are significantly raised. This may be done at an estimated rate of $250,000 - $300,000 per acre of salt marsh restoration.

12.1.13 Living Breakwater

NCF has piloted a living breakwater project at Polpis Harbor. This experience found reef material and transportation to the island to cost approximately $450 per linear foot. Additional costs may arise given the determined implementation procedures. There will be additional costs depending upon final implementation procedures, such as should oysters be grown to seed the reef materials.

12.2 THE HAULOVER PREFERRED ALTERNATIVE

12.2.1 Dune Nourishment

The dune nourishment alternative includes the placement of approximately 50,000 cubic yards of sand for use as compatible nourishment along the coastal dune. A compatible source of sand could come from a local dredge project or upland source. Due to the remote location, upland sand could cost as much as $100 per cubic yard or more. Dredge sand would likely range between $45-50 per cubic yard if a local source is available. It is estimated that a minimum of 30 cubic yards per linear foot of dune would be required for the nourishment profile for a total volume of 50,000 cubic yards and a cost of $5,000,000.

12.2.2 Beach Grass

This alternative includes the installation of native Cape American Beach Grass throughout the nourishment areas and within existing dunes to improve density. If planted by citizen scientists, beach grass installation will cost approximately $1.00 per square foot for two plugs per hole. If planted by a professional landscaper, costs would be approximately $2.50 per square foot for the same density. Total square footage is approximately 200,000 for a total cost of $200,000 for citizen scientist installation and $500,000 if installed by a professional landscaper.

12.3 COSKATA POND PREFERRED ALTERNATIVE

12.3.1 Dune Nourishment

The dune nourishment alternative includes the placement of 30,000 of compatible sand for use as nourishment along the coastal dune. A compatible source of sand could come from a local dredge project or upland source. Due to the remote location, upland sand could cost as much as $100 per cubic yard or more, if not more. Dredge sand would likely range between $45-50 per cubic yard if a local source is available. It is estimated that approximately 1,800 linear feet of dune would be restored with a minimum of 17 cubic yards per linear foot of dune with compatible sand for a total volume of 30,000 cubic yards and a cost of $3,000,000.

12.3.2 Beach Grass

This alternative includes the installation of native Cape American Beach Grass throughout the existing dunes on Coskata Pond to stabilize the dunes and assist with the trapping of wind-blown sand. If planted by citizen scientists, beach grass installation will cost approximately $1.00 per square foot for two plugs per hole. If planted by a professional landscaper, costs would be approximately $2.50 per square foot for the same density. Total square footage is 280,000 per square foot of new grass. If planted by citizen scientists, beach grass installation will cost approximately $280,000 ($1.00 per square foot) for two plugs per hole. If planted by a professional landscaper, costs would be approximately $700,000 ($2.50 per square foot) for the same density.

12.4 THE GALLS PREFERRED ALTERNATIVE

12.4.1 Thin Layer Sediment Placement in Overwash Area

The thin layer sediment placement alternative includes placing thin layers of beach compatible sand in an area that is experiencing frequent overwash, to raise the elevation while preserving the function of the overwash as a suitable habitat. This is best achieved by pumping dredge material directly onto the overwash area but can also be accomplished with the deposition of upland sand. It is estimated that approximately 1,600 linear feet of coastal beach (overwash area) would be restored with a minimum of 40 cubic yards per linear foot of beach with compatible sand for a total volume of 65,000 cubic yards and a cost of $6,500,000.

12.5 BETWEEN 1ST AND 2ND POINT PREFERRED ALTERNATIVE

12.5.1 Dune Nourishment with Beach Grass

The dune nourishment alternative includes the placement of 7,200 cubic yards of compatible sand for use as nourishment along the back side of coastal dune. A compatible source of sand could come from a local dredge project or upland source. Due to the remote location, upland sand could cost as much as $100 per cubic yard or more. Dredge sand would likely range between $45-50 per cubic yard if a local source is available. It is estimated that a total volume of 7,200 cubic yards would be installed within a 2.8-acre footprint and a cost of $720,000.

12.5.2 Beach Grass

It is estimated that a total square footage of 122,000 per square foot (2.8 acres) of new grass would be installed in the area behind the existing dune. If planted by citizen scientists, beach grass installation will cost approximately $122,000 ($1.00 per square foot) for two plugs per hole. If planted by a professional landscaper, costs would be approximately $305,000 ($2.50 per square foot) for the same density. Whereas this area is now used for parking, we are unsure if grass installation would be desired here.

Table 14. Example Matrix for Comparison of Various Coskata-Coatue Alternatives Per Site.

Activity	Engineering Design Costs	Environmental Permitting Costs	Environmental Permitting Timeline and Difficulty	Construction Costs	Annual Monitoring and Reporting
No Action	N/A	N/A	N/A	N/A	$2.5K (visual inspections and reporting)
Coastal Engineering Structure	Not Determined*	Not Determined	Not Determined	Not Determined	Not Determined
Vegetation Installation and Management	$10K	$10-15K	4-6 months easy	$1.00 - $2.50 per square foot for beach grass, $100 per 2-gallon plant	$2.5K (visual inspections and reporting)
Sand Fence	$10K	$10-15K	6 months Moderate (NHESP approval)	$20.00 linear foot	$2.5K (visual inspections and reporting)
Patron Management – Education Signage, Symbolic Fence, Mobi Mats	$10K	$20k	4-6 months easy	N/A	$2.5K (visual inspections and reporting)
Dune Restoration	$20K	$20K (No ENF)	6-12 months Moderate (NHESP approval)	$50.00 cy (dredge sand) $100.00 (upland sand)	$7.5 - 10K (topo survey and reporting)
Beach Nourishment – above MHW	$20K	$25K (No ENF)	6 months moderate	$50.00 cy (dredge sand) $100.00 (upland sand)	$7.5 - 10K (topo survey and reporting)
Beach Nourishment – below MHW	$50-75K	$100 - 150K (ENF Required)	12-18 months difficult	$50.00 cy (dredge sand) $100.00 (upland sand)	$7.5 - 10K (topo survey and reporting)

Activity	Engineering Design Costs	Environmental Permitting Costs	Environmental Permitting Timeline and Difficulty	Construction Costs	Annual Monitoring and Reporting
Managed Retreat – relocation of OSV and walking	$20K	$10-50K	4-6 months easy	N/A	$1-2K (visual inspections and reporting)
Bank Stabilization with Bioengineered Solution	$20K	$50K (above MHW)	6 months moderate	$3,000 per linear foot (does not include sand or vegetation)	$10-15K (topo survey and reporting)
Salt Marsh Restoration (planting only)	$10K	$10-15K	4-6 months easy	$5.00 - $7.00 per square foot	$2.5K (visual inspections and reporting)
Salt Marsh Restoration (grading/dredging /planting)	$200K	$100 - 150K (ENF Required)	12-18 months difficult	$250K per acre	$7.5 - 10K (topo survey and reporting)
Living Breakwater	$100K	$100 - 150K (ENF Required)	12-18 months difficult	$450 per reef ball $2K - $20K per day of construction	$2.5K (visual inspections and reporting)

*Not Determined because coastal engineering structures are not anticipated to be feasible on a barrier beach system due to permitting constraints.

13.0 REGULATORY REQUIREMENTS

A large component of the environmental feasibility of the various alternatives revolves around securing the necessary permits and approvals for alterations within protected resource areas. The regulatory process within the Commonwealth of Massachusetts for obtaining permits can be lengthy and complex. Due to the smaller scale of some of the alternatives, and the expected support from Town officials, some of the issues should be more easily addressed. Permitting the small-scale alternatives such as installing sand fence or adding sand to the parking area between 1st and 2nd Point will likely take 3 to 6 months and only require a local permit. However, permitting the larger-scale alternatives such as beach nourishment from local dredging sources can take up to several years, and typically requires anywhere from 5 to 7 approvals from various local, state, and federal agencies. Below is a description of the various Local, State and Federal permits that could be required and Tables 15, 16, and 17 provide a list of the permits and approvals that will likely be required for each of the alternatives.

Certificate from the Secretary of Environmental Affairs on ENF - If applicable, this Certificate is required prior to the issuance of other permits. To receive the Certificate, an Environmental Notification Form (ENF) must first be filed with the Massachusetts Environmental Protection Act (MEPA) and reviewed by numerous state environmental regulatory agencies (e.g., Division of Marine Fisheries, Natural Heritage and Endangered Species Program, DEP, etc.), and the public. The purpose of the ENF filing is for MEPA to rule on whether the project will have significant environmental impacts and require filing an Environmental Impact Report (EIR). An EIR is a comprehensive document characterizing the existing environment, demonstrating the need for a proposed project, evaluating alternatives and environmental impacts, and making the case that a proposed project is the most acceptable alternative from an environmental standpoint. Depending on the size of the project, the MEPA regulations also include thresholds for mandatory EIRs. In these cases, the Secretary's Certificate on the ENF essentially provides the scope of work and issues to be addressed in the EIR.

Order of Conditions – The Town of Nantucket Conservation Commission would issue the Order of Conditions permit. A Notice of Intent (NOI) application must be filed with the Commission. The NOI is followed by a site inspection with the Commission, as well as public hearing(s). Once the hearing is closed, the Commission will issue an Order of Conditions for the project, if approved during the public hearing process. As some of the sites fall within the mapped habitat for endangered species, coordination with Natural Heritage and Endangered Species Program (NHESP) will also be required.

Water Quality Certification – The Massachusetts Department of Environmental Protection (DEP) Wetlands Division issues the water quality certification. The purpose of this DEP review is to ensure there are not adverse water quality impacts associated with a proposed project, or at least that water quality impacts are minimized.

Chapter 91 License/Permit – The Massachusetts DEP Waterways Division issues this permit/license, which provides permission to work in state-owned waters (e.g., below the high-water mark).

Consistency Determination – This approval is granted by the Massachusetts Coastal Zone Management (MCZM) Agency following the issuance of the Chapter 91 License/Permit. MCZM's role is to ensure consistency with their marine environmental policies and an appropriate level of coordination between the state and federal agencies.

General Permit (GP) – This permit is issued by the United States Army Corps of Engineers (USACE) once MCZM issues its Consistency Determination. The USACE process also requires input from the US EPA, US Fish & Wildlife Service (USFWS), and the National Marine Fisheries Service (NMFS).

Table 15. Regulatory Requirements for The Haulover and Coskata Pond.

Alternatives	Permits						
	Order of Conditions	DEP/ Chapter 91	DEP/Water Quality Certification	USACE General Permit	CZM Federal Consistency	MEPA Environmental Notification Form	MEPA Environmental Impact Report
No Action							
Beach Grass	√						
Beach Nourishment	√	√	√	√	√	√	
Dune Nourishment	√	√	√	√	√	√	
Dune Stabilization using Bioengineered Solution	√	√	√	√	√	√	
Sand Fence	√						
Thin Layer Sediment Placement above MHW	√					√	
Coastal Engineering Structure	√	√	√	√	√	√	
Vegetation Management	√						
Patron Management	√						
Managed Retreat	√						
Salt Marsh Restoration (planting only)	√	√	√	√	√	√	
Salt Marsh Restoration (grading/ dredging*/ planting)	√	√	√	√	√	√	
Living Breakwater	√	√	√	√	√	√	

*It must be noted that if an unpermitted borrow site is proposed for a sand source, an Environmental Impact Report for a dredging site would likely be required.

Table 16. Regulatory Requirements for The Galls.

Alternatives	Permits						
	Order of Conditions	DEP/ Chapter 91	DEP/Water Quality Certification	USACE General Permit	CZM Federal Consistency	MEPA Environmental Notification Form	MEPA Environmental Impact Report
No Action							
Beach Grass	√						
Beach Nourishment	√	√	√	√	√	√	
Dune Nourishment	√	√	√	√	√	√	
Dune Stabilization using Bioengineered Solution	√	√	√	√	√	√	
Sand Fence	√						
Thin Layer Sediment Placement above MHW	√					√	
Coastal Engineering Structure	√	√	√	√	√	√	
Vegetation Management	√						
Patron Management	√						
Managed Retreat	√						
Living Breakwater	√	√	√	√	√	√	

Table 17. Regulatory Requirements for the Area Between 1st and 2nd Point.

Alternatives	Permits						
	Order of Conditions	DEP/ Chapter 91	DEP/Water Quality Certification	USACE General Permit	CZM Federal Consistency	MEPA Environmental Notification Form	MEPA Environmental Impact Report
No Action							
Beach Grass	√						
Beach Nourishment	√	√	√	√	√	√	
Dune Nourishment	√	√	√	√	√	√	
Dune Stabilization using Bioengineered Solution	√	√	√	√	√	√	
Sand Fence	√						
Thin Layer Sediment Placement above MHW	√					√	
Coastal Engineering Structure	√	√	√	√	√	√	
Vegetation Management	√						
Patron Management	√						
Managed Retreat	√						
Salt Marsh Restoration (planting only)	√	√	√	√	√	√	
Salt Marsh Restoration (grading/ dredging/ planting)	√	√	√	√	√	√	
Living Breakwater	√	√	√	√	√	√	

14.0 SUMMARY

The Trustees and NCF identified several at-risk shoreline areas across the Coskata-Coatue Wildlife Refuge in northeastern Nantucket to evaluate potential strategies to increase the resiliency to climate change and storm erosion impacts. Woods Hole Group utilized information from existing conditions site evaluations and other available in-house data to prepare an alternative analysis for areas at The Haulover, Coskata Pond, The Galls, and the narrow reach between 1st and 2nd Point. The specific goal of the alternative analysis was to identify and evaluate several practicable and feasible green infrastructure/living shoreline alternatives that would build resiliency while minimizing short and long-term adverse effects at each site. Given the climate-related changes affecting coastal areas, it was known that any solution to the current challenges at these sites would have a finite lifespan. Possible considerations for alternatives included predominantly "soft" solutions such as the installation of sand fencing and native plantings, salt marsh and oyster restoration, beach and dune nourishment, or a combination of alternatives to meet the needs of the stakeholders as the best protection alternative.

The alternatives span a wide spectrum from minimally invasive to major construction projects. In the short-term, minimally invasive approaches, especially sand fencing, beach grass planting, and patron management, may be employed at a relatively low cost to promote habitat establishment, dune growth, and overall resilience. However, such short-term approaches are not anticipated to be protective under significant storm wave and erosion events and are at risk of being damaged or lost within a year. Major construction projects may include beach and dune nourishment, or salt marsh and oyster restoration, depending on the environment in question. Such approaches are anticipated to have a longer lifespan, providing storm protection and habitat value. However, these approaches require significant planning, permitting, and funding. The final approach to be considered is managed retreat. This approach allows nature to take its course, while relocating assets (i.e., OSV trails) to areas where they may continue to function. Managed retreat does not resolve problems associated with erosion and sea level rise, nor does it enhance habitat. However, it is the lowest cost alternative, and attempts to maintain public access if feasible without intervening in natural processes.

Using a generalized evaluation system (Low to High), a summary table of all alternatives (Table 18) benefits/drawbacks is provided. For example, a beach nourishment project is described has having a "High" storm protection value, meaning it provides relatively greater protection than other alternatives; a "Moderate" habitat value, because it maintains, but does not enhance, a necessary resource for birds and invertebrates; and, a "Low" construction/ implementation feasibility, because of the anticipated difficulty in obtaining and transporting large volumes of sands to the sites. A similar summary of the restoration sites' benefits/drawbacks is provided in Table 19. This is followed by a summary of the preferred alternatives at each of the four sites.

This report was produced to describe the site assessments, historical and future vulnerabilities, and adaption alternatives in detail. The primary goal of the alternatives analysis and conceptual design preparation was to sustain future public access and to provide ongoing habitat protection throughout the project area for future.

Table 18. Adaptation Alternatives Evaluation Criteria.

Alternative	Most Practical Environment for Implementation	Design Life	Storm Protection Value	Permitting Feasibility	Habitat Value	Recreational Value	Construction/ Implementation Feasibility	Project Cost
Dune Nourishment	Sand Dune	5-10 yrs	High	Moderate	High	Moderate	Moderate	$$$
Beach Nourishment	Beach	5-10 yrs	High	Low	Moderate	High	Low	$$$
Beach Grass Plantings	Sand Dune	<5 yrs	Low	High	High	Low	High	$
Vegetation Management	Sand Dune/Marsh	<5 yrs	Low	High	High	Low	High	$
Salt Marsh Restoration (planting in existing marsh only)	Sheltered Marsh	~1 yr	Low	High	High	Low	High	$
Managed Retreat	Undeveloped Area	>5 yrs	High	High	Low	Negative	Moderate	$
Patron Management	Sand Dune/Marsh	~1 yr	Low	High	Moderate	Low	High	$
Dune Stabilization with Core	Sand Dune	5-10 yrs	Moderate	Moderate	Moderate	Low	Moderate	$$
Living Breakwater	Sheltered Open Water	>5 yrs	Moderate	Moderate	Moderate	Low	Moderate	$$
Sand Fence	Beach/Sand Dune	~1 yr	Low	High	Low	Low	High	$
Salt Marsh Creation (grading/ dredging/ planting)	Sheltered Marsh/Open Water	>5 yrs	Low	Moderate	High	Low	Low	$$$
Engineered Structure	Developed Area	~25 yrs	High	Low	Low	Low	Low	$$$
Thin Layer Sediment Placement	Overwash Area	N/A	Low	Low	High	Low	Low	$$$
No Action	Areas without flooding/erosion	N/A	Low	N/A	Low	Low	N/A	$

Table 19. Restoration Site Evaluation Criteria.

Site	Preferred Concept	Design Life	Storm Protection Value	Habitat Value	Recreational Value	Approximate Project Cost
The Haulover	Dune Nourishment, Beach Grass, & Managed Retreat	5-10 years	Moderate	High	High – The Haulover must be accessible to reach Coskata Pond, The Galls, and 1st/2nd Point	$5.5 million
Coskata Pond	Dune Nourishment & Beach Grass	5-10 years	Moderate	High	Moderate – Coskata Pond must be accessible to reach The Galls and 1st/2nd Point	$3.7 million
The Galls	Dune Nourishment & Beach Grass	5-10 years	Moderate	High	Low	$6.5 million
1st to 2nd Point	Dune Nourishment & Beach Grass	5-10 years	High	High	Low	$1.0 million

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