East Beach Corridor Vulnerability Study

May 2021

PREPARED FOR:
Town of Westport, MA
816 Main Road
Westport, MA 02790

PREPARED BY:
Woods Hole Group, Inc.
A CLS Company
107 Waterhouse Road
Bourne, MA 02532 USA

East Beach Corridor Vulnerability Study

FINAL REPORT

May 2021

Prepared for:
Town of Westport, MA
816 Main Road
Westport, MA 02790

Prepared by:
Woods Hole Group
A CLS Company
107 Waterhouse Road
Bourne, MA 02532 USA
(508) 540-8080

Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

East Beach, in the Town of Westport, Massachusetts, is a low cobble dune segment of a geologically complex barrier beach system, separating the ocean from the important Westport River estuary. The barrier beach system is home to residents, water-dependent businesses, recreational areas, and priority habitat. East Beach serves multiple community lifeline, recreational, and ecological functions and is highly vulnerable to coastal flooding hazards, both historically and at present.

Westport residents are concerned that the impacts of coastal hazards on East Beach are going to worsen over the coming decades due to sea level rise and storm intensification caused by climate change. The Town of Westport held a workshop in 2018, funded by a Municipal Vulnerability Preparedness (MVP) grant from the State, to identify priorities for building community resilience to climate change impacts. Workshop attendees unanimously identified East Beach Road as a priority concern.

The Town obtained another MVP grant in 2019 for the East Beach Corridor Vulnerability Study, to carry out a detailed assessment of the Corridor's vulnerabilities to coastal flooding hazards under a changing climate and identify potential adaptive actions for the Town to take, with the involvement of local stakeholders. This report documents the results of this project and the process by which they were developed.

This project had three primary goals:

1. Develop a probabilistic assessment of coastal flood vulnerability within the East Beach Corridor, based on a foundational understanding of past impacts and current conditions, and supplemented by advanced physical modeling.
2. Recommend a suite of adaptation alternatives, using the findings of the vulnerability assessment and in cooperation with the Town and stakeholders, to:
   - Maximize the useable life of East Beach Road (and utilities);
   - Address access in the event of a breach at the Let;
   - Protect property and infrastructure along East Beach Corridor; and
   - Protect seasonal trailer homes on East Beach.
3. With feedback from stakeholders and the Town, develop a coastal resilience implementation roadmap to guide incremental and flexible adaptation investments over time and provide science-based thresholds for action.

1.1 PROJECT TEAM

The Town of Westport contracted Woods Hole Group and its subconsultant, Kleinfelder, to conduct the vulnerability assessment and adaptation planning study. To ensure that the study was informed by local knowledge and guided by local priorities, Woods Hole Group staff worked closely with a Town Steering Committee throughout the analysis. People who participated in the Steering Committee are listed in Table 1.

Table 1 Steering Committee participants.

Name	Title
John Bullard	Planning Board, Member (Steering Committee Chair)
Brian Valcourt	Board of Selectmen, Member
James Whitin	Planning Board, Chair
Robert Daylor	Planning Board, Vice-Chair
Philip Weinberg	Board of Health, Vice-Chair; Conservation Commission, Member
Sean Leach	Beach Committee, Vice-Chair
Mike Sullivan	Resident, Cherry & Webb Lane
David Sprogis	Resident, Bridge Road
Jeffrey Bolton	Resident, East Beach Road
Tony Vivenzio	Resident, East Beach Road
Christopher Capone	Conservation Agent)
Jim Hartnett	Town Planner (Project Manager)

1.2 Public Outreach

As noted above, achieving the goals of the project was dependent on the involvement of local stakeholders, both to raise public awareness of the escalating flood risks posed by sea level rise and storm surge to the East Beach Corridor, as well as inform strategies for adapting the Corridor to these changes over time. Public outreach activities were scheduled at each project milestone to keep the public and the Town officials abreast of the latest findings, gather input at crucial junctures, and facilitate active engagement over the lifetime of the project. At public meetings, Woods Hole Group presented information on climate change, flood modeling, the vulnerability and risk of the East Beach Corridor, adaptation options and implementation recommendations. Table 2 lists the meetings and public outreach activities organized as part of the project.

Table 2 Summary of public outreach activities.

Date	Public Outreach Activity
February 5, 2020	Kick-off Meeting and interviews with Town staff and officials.
April 30, 2020	Steering Committee meeting to review findings from review of historical documents, prior studies, and coastal flood risk modeling.
June 30, 2020	Recorded webinar on findings from review of historical documents, prior studies, and coastal flood risk modeling; posted to Town of Westport project webpage and Vimeo account; mailed notification to 186 property owners.
July - September, 2020	Online survey (50 respondents) on impacts from past storms, public perceptions of future risk, level of support for action, and ideas for adaptation.
October 7, 2020	Virtual Public Meeting (52 attendees) on vulnerability assessment findings and general adaptation strategies; posted notice of meeting

	on Town website and events calendar; email notification to parties of interest.
November 9, 2020	Steering Committee Meeting to review conceptual adaptation alternatives.
December 2, 2020	Steering Committee Meeting to refine and prioritize conceptual adaptation alternatives.
April 21, 2021	Steering Committee Meeting to review draft report comments and discuss next steps.
May 13, 2021	Steering Committee Meeting to review the final report.
May 18, 2021	Planning Board Meeting to review the vulnerability assessment findings and present the final adaptation recommendations and implementation plan to the Board and public.

1.3 Acknowledgements

The Town would like to thank the MA Executive Office of Energy and Environmental Affairs for supporting this project with an MVP Action Grant, without which this project would not have been possible. The Town would also like to thank the contribution of the Massachusetts Department of Transportation (MassDOT) under the direction of Steven Miller, Project Manager, and the Federal Highway Administration related to the modeling associated with the Boston Harbor Flood Risk Model (BH-FRM). The methodology from the BH-FRM was utilized as the basis for the development of the Massachusetts Coastal Flood Risk Model (MC-FRM), which was used for this study. The Town would also like to thank the Westport Historical Society and David Jones for sharing historical records with the project team, some of which are used in this report. Finally, and most importantly, the Town would like to thank the Steering Committee, public forum attendees, and online survey participants for their valuable contributions of time, knowledge, and ideas that informed this project.

2.0 VULNERABILITY ASSESSMENT

The coastal climate change vulnerability assessment carried out for this project was focused on the East Beach Corridor, including the roadway, utility poles, and public and private properties located on East Beach between Horseneck Road and John Reed Road (Figure 1). The broader barrier beach system that East Beach is a part of, including its development, infrastructure, and natural resources, was considered contextually.

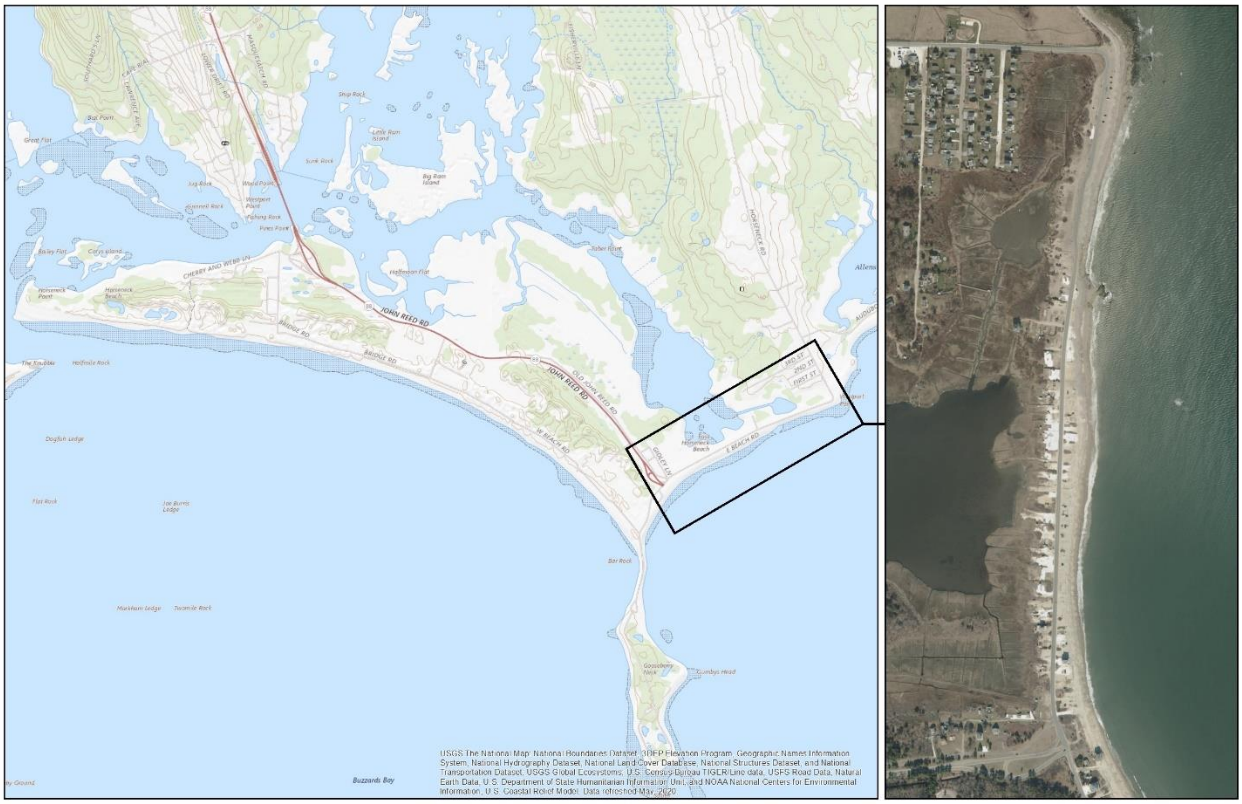


Figure 1 East Beach Corridor Vulnerability Study Area and Context.

The total barrier beach system has about 80 homes, a major boatyard, a restaurant, State and Town owned public beaches, and, on the East Beach segment, seasonal trailers. Horseneck Beach State Reservation, which hosts one of the largest public beaches in Massachusetts as well as campgrounds, is located on the barrier beach.

There are only two routes to access and evacuate the barrier beach in an emergency, the westerly Route 88 Fontaine Bridge (a drawbridge) across the Westport River and the historical easterly East Beach Road connection to Horseneck Road. All the electricity, telephone, and telecommunications services are routed from the mainland to the private and public properties on the barrier beach system through the East Beach Road right of way on utility poles.

The barrier beach system also plays significant roles in preventing storm damage and controlling flooding along the Westport River estuary and supporting and protecting natural resources of environmental, economic, and recreational significance.

The vulnerability assessment of the East Beach Corridor combines a foundational understanding of past impacts and current conditions with new insights from advanced physical modeling to estimate potential impacts of coastal hazards in the present as well in the near-term (2030-2050), medium-term (2050-2070), and long-term (2070-2100) future accounting for climate change. This section describes the data sources, modeling approaches, and findings of the vulnerability assessment, addressing the following hazards and impacts included in the scope of work:

- Historic storm impacts (Section 2.1)
- Historical and potential future erosion (Section 2.2)
- Sea level rise and storm surge inundation (Section 2.3)
- Nuisance overwash, major road damage, and breaching (Section 2.4)
- Utility pole undermining (Section 2.5)

A summary of the vulnerability assessment findings is provided in Section 2.6.

2.1 Historic Storm Impacts

The East Beach Corridor and residents, businesses, workers, and visitors of the broader barrier beach system have repetitively been impacted by damaging coastal storms. Figure 2 shows a timeline of some of the major historic storms that have impacted Westport, Massachusetts. This section of the report describes and illustrates the impacts on East Beach from a selection of the most historic storms in addition to ongoing nuisance flooding and overwash events.

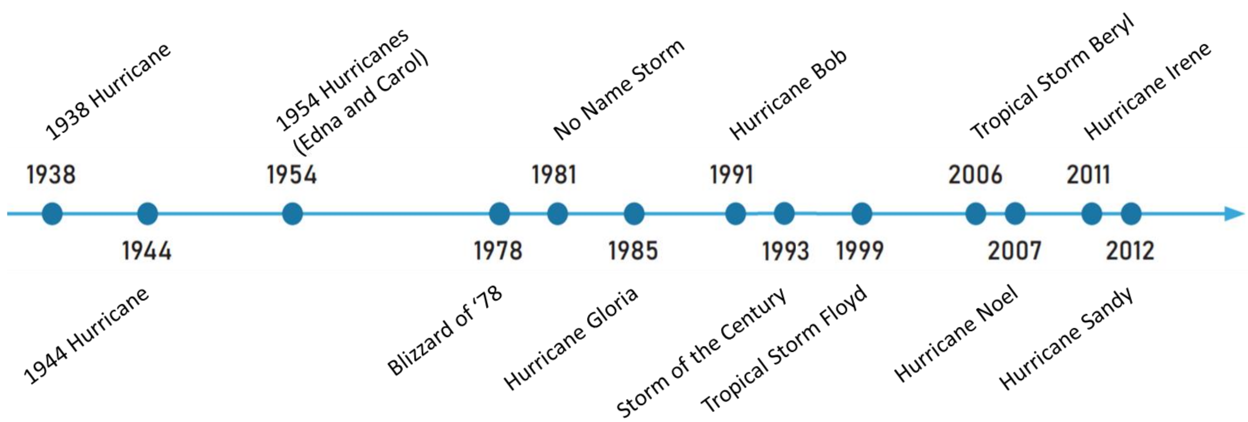


Figure 2 Timeline of significant historical storms that have impacted Westport.

2.1.1 Hurricanes of 1938, 1944, and 1954

Many people lost their lives, sustained physical and psychological harm, lost incomes, or had their properties destroyed and taken by eminent domain because of the historic hurricanes of 1938, 1944, and 1954. These impacts are memorialized in the Westport Historical Society (WHS) and private collection records and the collective memory passed between generations of residents.

Prior to the 1938 Hurricane, the Horseneck Beach and East Beach shorelines were highly developed with homes, hotels, stores, entertainment venues, houses of worship, stables, and other facilities. David Jones, a historian with ties to Westport, created a series of maps (Figure 3) showing the locations of buildings on East Beach pre-1938, based on historical insurance and property assessors maps, overlaid on recent aerial photos. Most of the structures on the ocean side were in beachfront areas that have eroded away over the past 80 years or so and are now submerged. The severe erosion has been caused by a combination of natural processes and human activities, according to past studies, but there is a lack of consensus on the degree of causation by each.

Figure 3 Map of East Beach development before the 1938 Hurricane.

The 1938 Hurricane is the "storm of record" for the area, resulting in the highest water levels in recorded history at more than 14 ft above mean high water. Almost all the pre-1938 structures were destroyed in the hurricane as shown in an aerial taken in 1938 after the hurricane (Figure 4), provided by David Jones, and other historical photos in the WHS and private archives. East Beach Road was covered with sand and debris 1-3 ft deep, according to the Town's 1938 Annual Report.

Figure 4 Aerial photo of East Beach after the 1938 Hurricane.

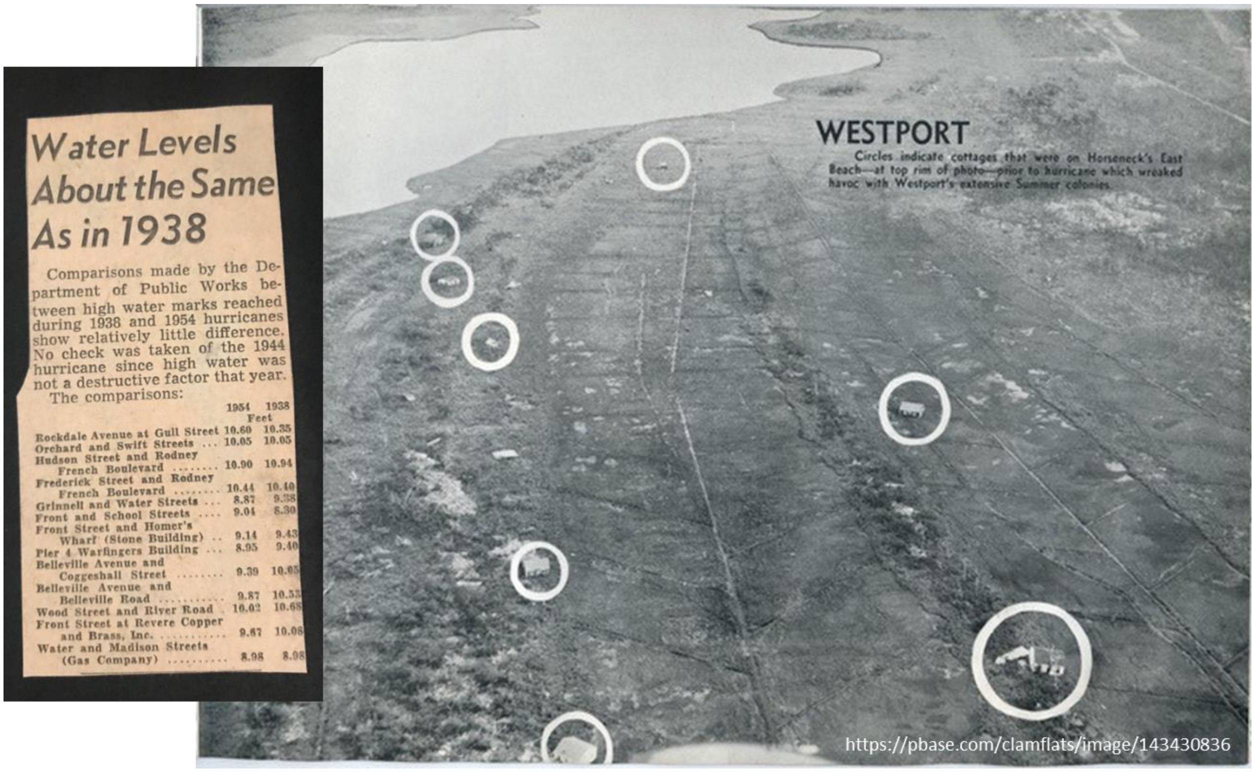
Figure 5 is an illustrative photo of the impacts on East Beach caused by the 1938 Hurricane's powerful storm surge, wind, and waves. It shows the rubble of structures that have been damaged or destroyed, toppled utility poles, and large berms of cobble and sand pushed onto land where East Beach Road would have been. More harrowing are the historical accounts of residents that survived the flood, archived at the WHS. Due at least in part to the lack of early warning about the danger of the impending hurricane's massive storm surge, 22 people drowned and died. According to an informational placard from a WHS exhibit "the youngest was two years old, the oldest 89 years old."

Figure 5 Photo of East Beach after the 1938 Hurricane.

After the 1938 Hurricane, some structures were rebuilt on East Beach. A few years later, the 1944 Hurricane came through the area and again resulted in damage to structures, East Beach Road, and utility infrastructure on East Beach (Figure 6).

Figure 6 Photos of East Beach after the 1944 Hurricane (WHS).

Two hurricanes impacted New England in 1954, Carol and Edna. Hurricane Carol was the more destructive for Westport, with similar water levels as the 1938 Hurricane and extremely powerful and destructive storm surge and winds. As shown in Figure 7, storm surge from Hurricane Carol lifted structures that had been rebuilt on East Beach, carried them into the Let, and deposited them on the marsh up to a mile upriver. After Hurricane Carol, most private properties on Horseneck Beach were taken by the State into public trust and the Horseneck Beach Reservation was created. This was highly controversial and consequential for Westport residents at the time. In interviews with Town officials, it was stated that the State intended to take properties on East Beach as well, but the Town negotiated to avoid the takings by limiting redevelopment of East Beach to only temporary seasonal structures, East Beach Road, and utilities. The few structures on East Beach that survived the hurricane were allowed to remain, and, of those that survived or have been rebuilt after subsequent storms, many have since been elevated on piles.



Water Levels About the Same As in 1938

Comparisons made by the Department of Public Works between high water marks reached during 1938 and 1954 hurricanes show relatively little difference. No check was taken of the 1944 hurricane since high water was not a destructive factor that year.

The comparisons:

	1954 Feet	1938 Feet
Rockdale Avenue at Gull Street	10.60	10.35
Orchard and Swift Streets	10.05	10.05
Hudson Street and Rodney French Boulevard	10.90	10.94
Frederick Street and Rodney French Boulevard	10.44	10.40
Grinnell and Water Streets	8.87	9.38
Front and School Streets	9.04	8.30
Front Street and Homer's Wharf (Stone Building)	9.14	9.43
Pier 4 Warfingers Building	8.95	9.40
Belleville Avenue and Coggeshall Street	9.39	10.05
Belleville Avenue and Belleville Road	9.87	10.53
Wood Street and River Road	10.02	10.68
Front Street at Revere Copper and Brass, Inc.	9.67	10.08
Water and Madison Streets (Gas Company)	8.98	8.98

Figure 7 Newspaper clipping (WHS) and aerial photo of impacts after Hurricane Carol (1954).

2.1.2 Hurricanes Bob (1991) and Irene (2011)

Many residents have living memory of more recent hurricanes, like Bob in 1991 and Irene in 2011, which caused significant destruction to infrastructure and private property, but for perspective produced water levels only half and one third the height of the record 1938 Hurricane. East Beach Road and utilities were particularly impacted, leaving the community without or with diminished lifeline services and access to recreational resources for extended periods of time. People's daily routines and quality of life were impacted according to online survey results, and businesses, like the Bayside Restaurant that relies on access from Horseneck Beach to attract visitors, suffered economically according to interviews with Town staff and officials.

Figure 8 shows destroyed structures, East Beach Road completely covered by cobble and sand, and utility poles toppled by Hurricane Bob. According to interviews with Town staff and officials, after Hurricane Bob, the barrier beach was without electricity for 6 to 8 weeks and East Beach Road had to be entirely reconstructed. As in Hurricane Carol, structures from East Beach were carried into the Let by storm surge and wind.

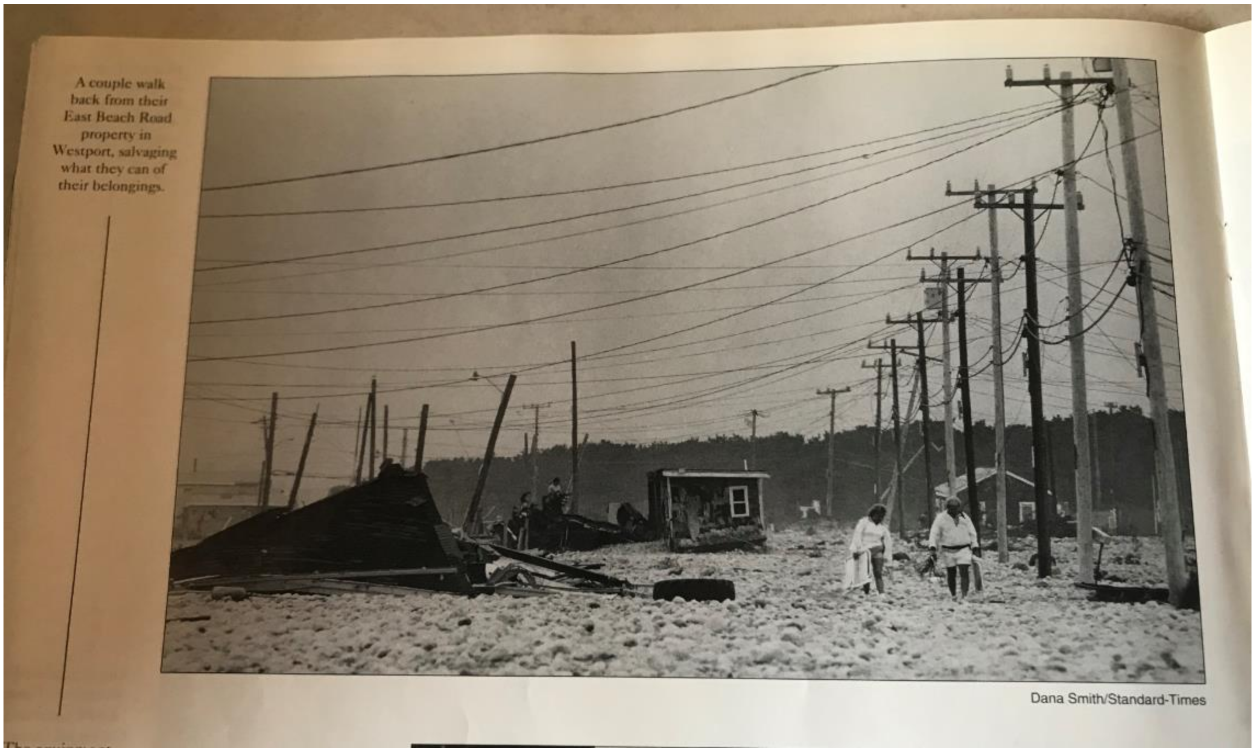


Figure 8 Photo of East Beach Road after Hurricane Bob in 1991 (WHS).

The most recent storm to have highly destructive impacts on East Beach was Hurricane Irene in 2011. Figure 9 shows a large section of East Beach Road, about 750 ft long, that was destroyed by the combined impacts of storm surge and waves. The road remained unpaved for over 2 years after the storm. The Town proposed to add revetment stones to the shoreline along the vulnerable section that was damaged, but the State denied the proposal on environmental grounds. The Town moved the alignment of the road in the damaged section about 30-40 ft back towards the Let and reconstructed the road at a cost of about $95,000, but the utility poles (not owned by the Town) were left in place and are now on the ocean side of the road. According to a September 1, 2011 interview with South Coast Today, the Westport Board of Health estimated that 40 to 60 septic tight tanks were compromised on the Ocean side of East Beach Road, resulted in releases of untreated sewage. Figure 10 shows exposed tight tanks and damage left behind after Hurricane Irene, taken from the Town's 2014 grant application to the MA Office of Coastal Zone Management Coastal Resilience Grant Program.

Figure 9 East Beach Road damage from Hurricane Irene.

Figure 10 Exposed and damaged septic tight tanks on East Beach after Hurricane Irene.

2.1.3 Ongoing Nuisance Flooding and Overwash

In addition to less frequent but more impactful storms, East Beach is frequently flooded in less intense southerly storms and nor'easters. The combination of moderate storm surge and waves results in ongoing coastal erosion and property loss; temporary road closures due to flooding, overwash sediment, and occasional debris; public and private maintenance costs; and emergency management costs. Recently, this has been occurring about twice a year in particularly low areas of the roadway, typically in winter, according to interviews with Town staff. The Highway Department and public safety staff work together to close the road at both ends during storms, and, after water levels subside, to clear the roadway of overwashed sediment. In past practice, the sediment removed from the north end of East Beach Road would be deposited on the south end of the Town Beach, where erosion is most acute. However, the State determined that this practice was not an officially permitted maintenance activity and the practice was stopped. Property owners impacted by the erosion caused by frequent storms have sought and obtained permits for nourishment of sediment on their lots.

2.2 Historical and Potential Future Erosion

As demonstrated in Section 2.1, the East Beach Corridor has historically been subject to both acute and chronic erosion caused by storm events. However, other natural coastal processes and human interventions have also influenced how the shoreline has changed over time. Woods Hole Group analyzed recent historic rates and patterns of erosion on East Beach to inform potential future projections of shoreline change. This section describes the available studies reviewed and historical shoreline change data analyzed to estimate the short- -term historical rates of erosion for the East Beach Corridor. It then provides results and analysis of potential future erosion impacts on infrastructure and private property under a scenario in which short-term historical erosion rates continue.

2.2.1 Data Sources

The primary source of shoreline change data available for the state of Massachusetts is the Massachusetts Office of Coastal Zone Management Shoreline Change Project (MSCP). The MSCP includes digitized historic shorelines depicting the local high-water line at approximately high tide. The historical shorelines are digitized from a variety of sources including Coast and Geodetic Survey (now the National Geodetic Survey) T-sheets, aerial and satellite imagery, and Lidar topographic surveys. The project demonstrates how the shoreline of Massachusetts has evolved from the early 1800s up to 2014. Rates of shoreline position change (the average distance the shoreline has moved in any year) are calculated along transects spaced approximately 50 meters apart along the entire coastline of the state.

Long-term and short-term rates are calculated covering the last approximately ~150 years of change and ~30 years of change respectively. The rates are calculated using a linear regression methodology, and uncertainty values are available for each rate. The project was originally created in 1989 to identify erosion prone areas along the Massachusetts Coastline (Benoit, 1989). The project was then updated in 2001 and 2013 (Thieler et al., 2001 and USGS 2013) to update the original analysis with shoreline position data created using more recent orthoimagery and Lidar datasets. In 2019, an additional project update was conducted to add two additional shoreline position datasets from Lidar data collected between 2010 and 2014 (Himmelstoss et al., 2019).

2.2.2 Results and Analysis

Figure 11 presents the digitized 1978, 1994, 2000, 2009, 2010, and 2013 shoreline positions for the East Beach Corridor project area from the latest iteration of the MSCP (Himmelstoss et al., 2019). Additional shorelines are available from 1844, 1895, and 1934. However, due to concerns with the accuracy of the 1844 shoreline position in the project area and the large time gaps between these and other years during which potentially significant historical storms (e.g., hurricanes of 1938, 1944, and 1954) and human interventions (e.g., Gooseberry Island Causeway construction) took place in the project area, the older shorelines and long-term rates are not included in this report. A member of the steering committee identified and notified the State of an issue with the accuracy of the 1844 shoreline in the project area, and USGS plans to exclude this segment of the 1844 shoreline from future data releases.

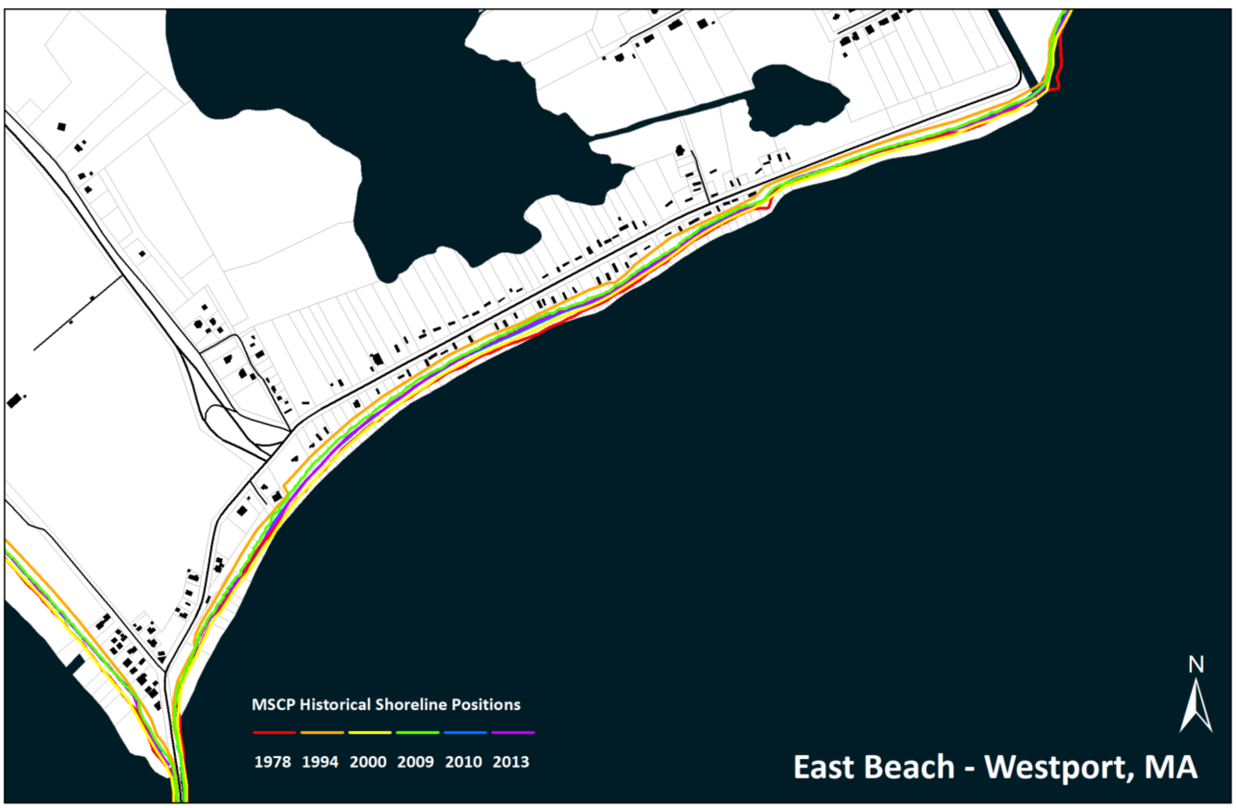


Figure 11 MSCP short-term historical shoreline positions for East Beach, Westport, MA.

Figure 12 shows short-term (1978-2013) rates of shoreline position change calculated by MSCP. The transect lines are colored to indicate relative rates of erosion or accretion, with reds and oranges indicating erosion, and greens indicating accretion. Rates of change in units of average distance (in feet) of change per year are also labeled on every fourth (on the overview figure) or second (on the zoomed-in inset figure) transect in the figure. Positive rates of change indicate accretionary shorelines, while negative rates of change indicate erosion.

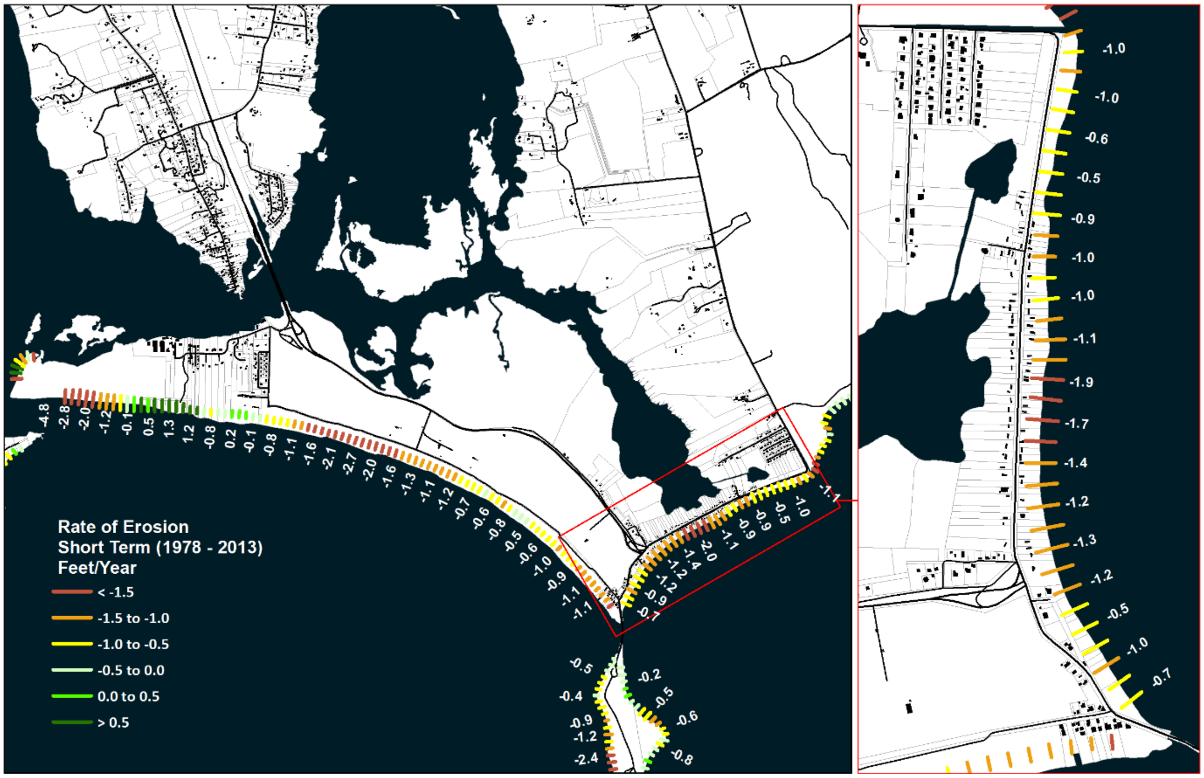


Figure 12 MSCP short-term historical shoreline change transects (1978 to 2013).

2.2.2.1 East Beach

As can be seen in Figure 11, East Beach has been erosional since at least 1978, with the shoreline moving landward over time. The MSCP analysis in Figure 12 shows that over the short-term period all transects along East Beach are erosional (negative rates of change) at a short-term average rate of change of -1.0 ft/yr (maximum -2.0 ft/yr and minimum -0.5 ft/yr). The highest rates of erosion in the short-term period of observation are at the center of the beach (red transects in Figure 12). These rates of erosion are similar to others seen throughout the region, but not as high as those seen in other southern facing shorelines in Massachusetts, likely due to the larger grain size material that makes up the barriers in the region, as well as how the barrier is anchored in place. However, due to the thin width of East Beach and the importance of lifeline infrastructure located on it, any erosion is important.

There is some uncertainty with the analysis presented by the MSCP that should be considered when evaluating the short-term shoreline change at East Beach. As seen in Figure 11, the 1994 shoreline exists landward of all the other historical shoreline positions presented in the figure. This anomaly in the 1994 shoreline has been noted across the state for numerous projects. On a "perfectly" erosional beach, one would expect the most recent shorelines to be the most landward, and the oldest to be most seaward. However, in reality, beaches move back and forth seasonally, as well as through time. For this specific case, however, it is possible that the extreme landward position of the 1994 shoreline is actually due a poor-quality aerial photograph, or because of one or more extreme storm events drastically altering the position of the shoreline for a short period of time, such as Hurricane Bob and the Perfect Storm in 1991. The 2013 MSCP update states that the 1994 shoreline has “larger positional uncertainty [than the other shorelines] due to source photography, registration errors, potential influence of storm events, and poor image contrast” (Thieler et al., 2013). The 2013 MSCP update did not address whether the 1994 shoreline may have a statistical impact on the short-term rates of change analysis.

2.2.2.2 Horseneck Beach

While not the focus of this study, shoreline change on Horseneck Beach was reviewed at a high level. Figure 12 shows that recently (1978 to 2013) the majority of Horseneck Beach, excluding a limited area in front of Mullin’s Way, is erosional with an average rate of change of -1.0 ft/yr (or -1.3 ft/yr if excluding the limited accretional transects seaward of Mullin’s Way).

Steering Committee members have shared the following anecdotal observations:

- Cobbling on Horseneck Beach has increased from the easterly end of the beach westerly.
- In the 1970’s and 1980’s, Horseneck Beach in front of the westerly parking lot had no cobbles, but now DCR has to plow a path so that bathers can reach the water.
- This year the cobbles extend westerly to Bakers Beach.

2.2.2.3 Gooseberry Island Causeway

In Steering Committee meetings, the Public Forum, and online survey, several residents have expressed a long-held concern that the construction of the causeway to Gooseberry Island in 1922, and subsequent upgrades through 1943, have disrupted natural sediment supply to the East Beach shoreline (and possibly also to Horseneck Beach) and are a primary cause of the erosion that has occurred since its construction.

A member of the Steering Committee independently reanalyzed and modified the 1844 MSCP shoreline, which is inaccurately placed in the MSCP data, and plotted the adjusted position with the others shoreline positions from a sample of MSCP transects. Based on their analysis and interpretation, the East Beach shoreline was relatively stable prior to the causeway’s construction (1844-1934), the shoreline eroded significantly after the causeway’s construction (between 1934-1978), and the shoreline has recently been in a new period of relative stability (1978-2013). It is important to note that the hurricanes of 1938, 1944, and 1954, which are known to have transported significant quantities of sediment across shore, also occurred between the 1934-1978 data gap in the MSCP shorelines. Woods Hole Group did not reanalyze the 1844 MSCP shoreline, disaggregate pre- versus post-causeway historical shoreline change, or create new shorelines for intermediate years in the 1934-1978 period, as such analysis were not included in the scope of the East Beach Vulnerability Study.

A 1997 study by Aubrey Consulting posited that the long-term historical erosion on East Beach is primarily the result of natural erosional processes and sediment supply starvation, especially the depletion of shoal sediment that was historically supplied by Gooseberry Island before it became naturally armored. The study did not disaggregate the shoreline change pre- versus post-construction of the causeway. The study found that sediment starvation was exacerbated by the causeway and development on East Beach, but that the west-to-east sediment transport blocked by the causeway "would supply no more than 10-20% of the sediment lost from East Beach annually".

The degree to which the Gooseberry Island causeway and natural processes have respectively contributed to erosion on East Beach and Horseneck Beach is the subject of ongoing debate and cannot be definitively answered without additional analyses that are beyond the scope of the East Beach Vulnerability Study. What is undisputed is that the erosion that has occurred on East Beach over the long-term and short-term has increased the vulnerability of East Beach Road to flooding and storm damage.

Understanding the historical impact of the causeway on sediment transport dynamics and shoreline change and evaluating the potential impact (positive or negative) of removing or modifying the causeway in the future can be gained through a modern coastal processes study. Creating advanced physical models of the type needed to evaluate the causeway's impact in this area may also be valuable for evaluating a variety of adaptation options for East Beach including beach nourishment and offshore wave attenuation.

2.2.2.4 Potential Future Erosion

To assess the potential vulnerability of property and infrastructure in the East Beach Corridor to future erosion, the short-term historical rates (1978-2013) shown in Figure 12 were used to estimate the future positions of the shoreline. Figure 13 shows the 2013 MSCP shoreline (blue) along with estimated shorelines in 2030 (green), 2050 (red), and 2070 (yellow). This analysis assumes that future average rates of erosion on East Beach will be the same as recent historical rates. The short-term rate used for this analysis includes the uncertain 1994 shoreline. Future sea level rise acceleration and storm intensification caused by climate change, which are not included in short-term historical rates, may lead to higher future rates of erosion than shown. In other words, this analysis assumes the contemporary erosion rate continues into the future without any acceleration due to potential sea level rise or increasing storm frequency or intensity. This also assumes the recent historic sediment source (or lack thereof) is relatively consistent over future time frames. Therefore, this is a simplified approach, but provides a reasonable first-order estimate of potential future shoreline position.

Figure 13 Future shoreline position based on MSCP short-term (1978 to 2013) historical rates of erosion.

The following potential impacts to properties on the ocean side and East Beach Road are observed:

- In 2030, no encroachment of the shoreline onto East Beach Road or areas seasonally occupied by structures are observed, but a few parcels could be severely eroded relative to their narrow existing across shore width.
- In 2050, East Beach Road (just west of the bend), 10 or more parcels and areas within them that are seasonally occupied by structures, and four existing utility poles could be severely encroached.
- In 2070, East Beach Road (just west of the bend and in the middle of East Beach), 20 or more parcels and areas within them that are seasonally occupied by structures, and 13 existing site utility poles could be severely encroached.

2.3 Sea Level Rise and Storm Surge Inundation

As shown from the Town's past and ongoing experiences, coastal flooding and related hazards can cause chronic inconvenience, like the minor flooding that shuts down East Beach Road every winter, and acute devastation, like the 1938 and 1954 hurricane storm surges that swept away entire neighborhoods. Climate change is expected to cause more frequent and intense coastal flooding in the coming decades, though the exact speed and magnitude is uncertain and the impacts will differ based on local conditions.

In an online survey of Westport residents conducted for this study, 76% of the 50 respondents indicated that they think East Beach will be highly impacted (rating 4 or 5 out of 5) by sea level rise and coastal storms in the next 10 years (Figure 14). When considering the longer-term horizons of 30 and 50 years, expectations of high impacts grew and became nearly unanimous.

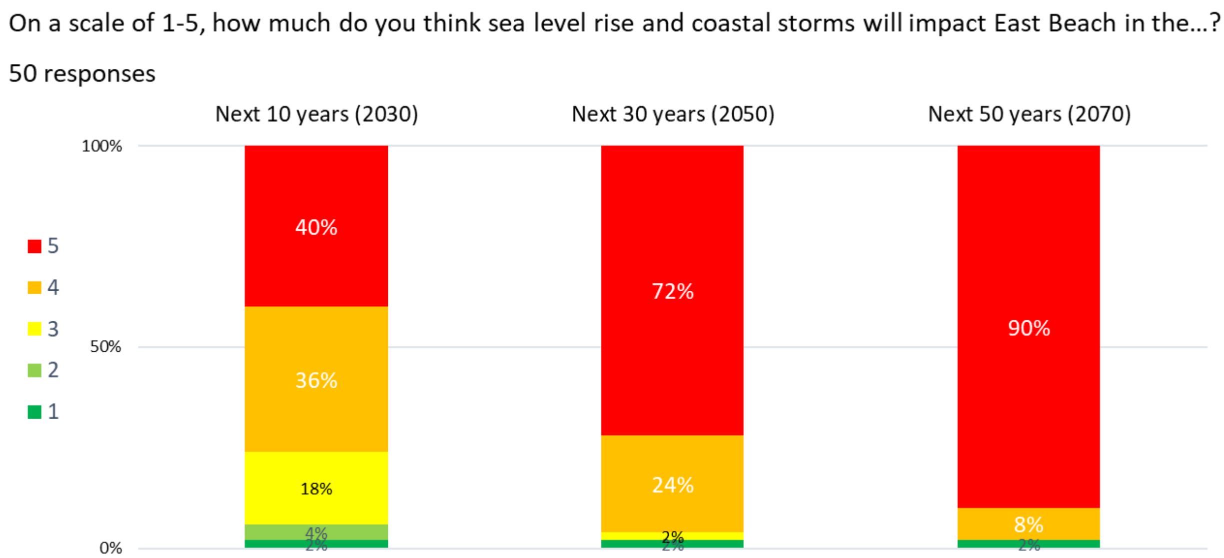


Figure 14 Online survey results - concern about sea level rise and coastal storms.

A key objective of the East Beach Corridor Vulnerability Study was to evaluate the likelihood, potential timing, and scale of impacts from tidal inundation caused by sea level rise and episodic inundation resulting from the combined effects of sea level rise and storm surge. This section describes how these vulnerabilities were assessed, including the models, data, and climate change projections used. It then provides results and analysis of potential impacts to East Beach Corridor infrastructure and properties under projected future daily high tide and probabilistic storm scenarios. Aligned with the assessment of potential future erosion in Section 2.2.2.4, vulnerabilities were assessed in the present, 2030-2050, 2050-2070, and 2070-2100 time horizons.

2.3.1 Model Description and Data Sources

Woods Hole Group used the Massachusetts Coast Flood Risk Model (MC-FRM) to develop probabilistic projections of future coastal inundation exposure. The MC-FRM simulates a full suite of processes that affect coastal water levels, including tides, waves, winds, storm surge, sea level rise, and wave set-up at a fine enough resolution to identify site-specific locations that are at risk under future climate conditions. Water surface elevations were modelled using the ADvanced CIRCulation (ADCIRC) software to predict storm surge flooding coupled with the unstructured version of Simulated WAves Nearshore (UNSWAN) software, a wave generation and transformation model. MC-FRM was developed for the Massachusetts Department of Transportation (MassDOT) to assess potential flooding vulnerabilities to coastal highways and other transportation infrastructure throughout the state of Massachusetts. Since the MC-FRM domain includes the entire Massachusetts coastal area, including the Town of Westport, this model was ideally suited to assess the vulnerability of the East Beach Corridor to tidal and storm surge flooding and to inform additional coastal modeling analyses (see Sections 2.4 and 2.5).

The spatial resolution of MC-FRM is generally on the order of 10 meters (~33 feet) or less between nodal points in offshore areas, and is minimized to as low as 2-3 meters (~7-10 feet) in inland and populated areas to capture important changes in topography and physical processes related to storm dynamics. Figure 15 shows the MC-FRM model mesh, which incorporates the baseline topographic model (2016 USGS CoNED Topobathymetric Model), in the vicinity of the East Beach Corridor up to elevation 8 meters (approximately 26.2 feet) NAVD88. This high-resolution model offers more accuracy than other storm surge models, such as the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model developed by the U.S. Army Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration (NOAA). The MC-FRM is also superior to a more rudimentary, elevation-based “bathtub” approach, since the latter does not account for critical physical processes that occur during a storm event, including waves and winds, nor can it determine the limited volume of water that may be able to enter certain areas, particularly those with narrow entry points.

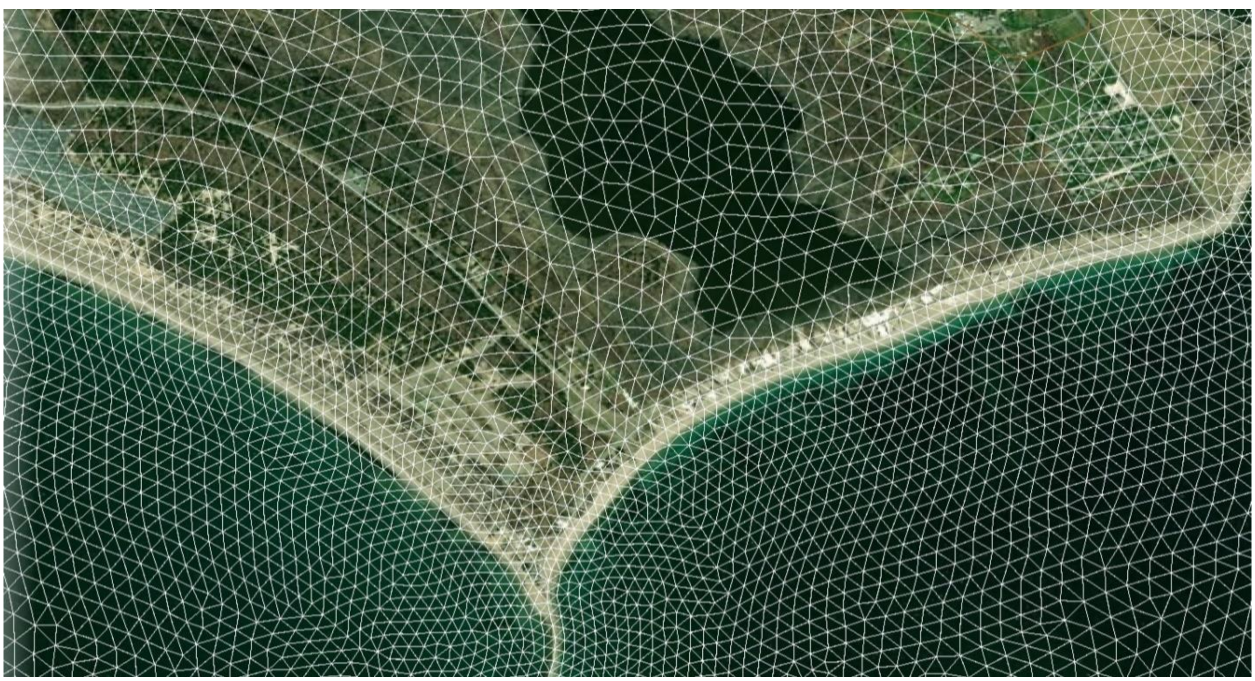


Figure 15 MC-FRM mesh in East Beach Corridor Study Area.

The MC-FRM quantitatively incorporates sea level rise (“High”) and climate change influences on tides, waves, storm track, and storm intensity for 2030, 2050, and 2070 time horizons, providing discrete risk estimates in those future years to assist with both near- and long-term planning. To do so, it evaluates a statistically-robust sample of storms, including hurricanes, tropical storms, and nor'easters, based on the region's existing and evolving climatology (using 5 various global climate models). Using this storm set, the model then calculates resulting water elevations to estimate the probability that different flood depths will be exceeded at each nodal point within the model boundary. The resulting flood risk maps and probability curves can then be interpreted using geographic information systems (GIS) to identify the estimated annual probability, or likelihood, that any node within the model will experience flooding, and if so, up to what elevation and depth.

This probability-based approach is beneficial for assessing the vulnerability of infrastructure and property, developing adaptation strategies to mitigate future flooding damage, and conducting benefit-cost analyses. It also produces information that can be used to inform regulatory boundaries and engineering design criteria since it provides the probability of an event occurring in this changing regime, such as the future 1% annual chance flood zone or elevation (equivalent to a 100-year recurrence water level). In particular, an accurate and precise assessment of the exceedance probability of combined sea level rise and storm surge enables the identification of areas of existing and near-term vulnerability requiring immediate action, as well as areas that will benefit from long-range planning for future preparedness and risk reduction.

The science of climate change is an evolving field that is constantly being updated. As such, projections made within this report based on MC-FRM provide guidelines for investment decisions based on the current state of the practice and knowledge to date. For example, the sea level rise projections utilized in MC-FRM are directly aligned with the state standards and therefore consistent with the values being used consistently across the Commonwealth. As such, the flood level predictions made in this report are based on some of the most recent developments in the science of climate change. However, they are not guaranteed predictions of future events. It is recommended that these results be updated over time as science, data, and modeling techniques advance.

2.3.1.1 Relative Mean Sea Level Historical Data

Westport and the East Beach Corridor have already experienced a significant amount of relative sea level rise (RSLR), a term that encompasses both sea level rise and changes to the local land movement (e.g., long-term land subsidence or rebound). Historical RSLR estimates are available from the local NOAA tidal gage at Woods Hole (station ID 8447930), which has recorded an increase in relative mean sea level of 2.95 mm (+/- 0.17 mm) annually based on monthly mean sea level data from 1932 to 2020 (Figure 16). This equates to approximately 10.2 inches of mean sea-level rise over the last 88 years. Over that same period, the global rate of sea level rise was about 1.7 mm annually (approximately 5.9 inches over the last 88 years). This significant difference between the RSLR experienced locally and the global trend highlights the importance of accounting for local conditions. The RSLR rate at Woods Hole has been accelerating over the last several decades, with an annual increase in 7 of the past 10 years that was large enough to increase the prior long-term (78- to 88-year) average rate (Figure 17). This indicates that the long-term trend over the observed time period (88 years) is not representative of the current sea level rise conditions, and that more recent contemporary rates of observed sea level rise far outpace the long-term historic trend. As such, using the long-term trend of historic sea level rise as a prediction of future water levels is an inaccurate approach.

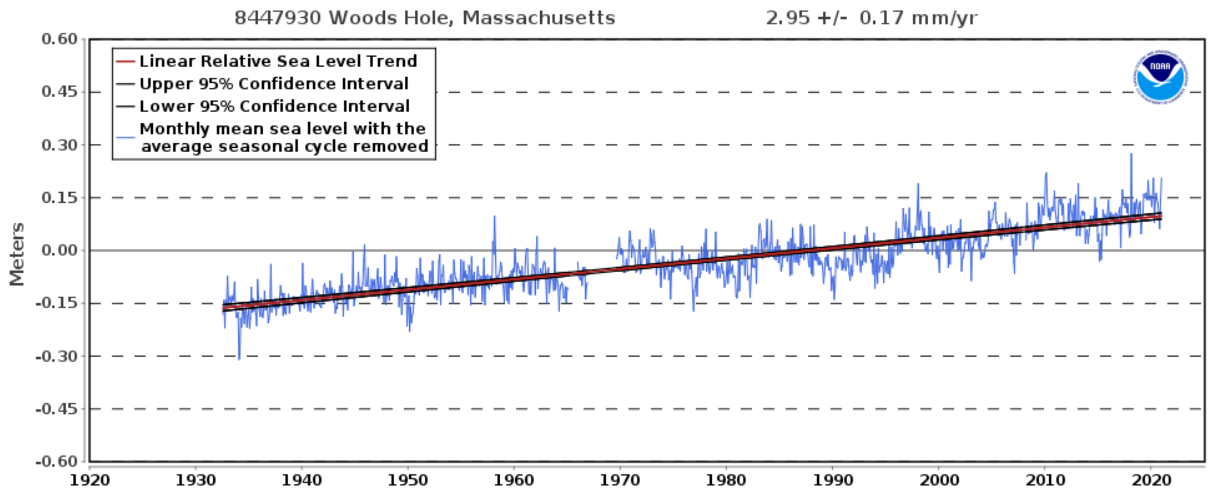


Figure 16 Mean sea-level rise trend at the Woods Hole tide gage (#8447930).

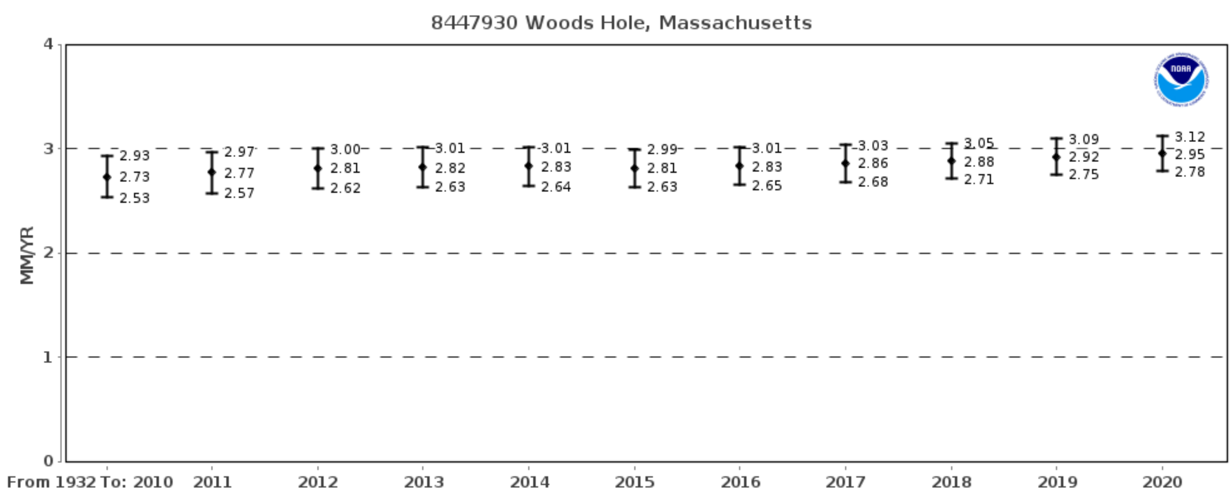


Figure 17 Previous mean sea-level rise trends at the Woods Hole tide gage (#8447930).

To compare "present day" to future projections of mean sea level, a starting elevation for mean sea level must be calculated. A tidal-epoch, a 19-year time period, is traditionally used to calculate tidal datums. For the MC-FRM, the 19-year tidal-epoch with a mid-point year of 2008 (i.e., 1999-2017) was used to calculate a present day elevation for mean sea level. Based on this methodology, the mean sea level in Woods Hole in the year 2008 was at an elevation of -0.17 feet (NAVD88). This 2008 starting elevation of -0.17 feet (NAVD88) can then be compared to projected relative mean sea level elevations discussed in the next section.

2.3.1.2 Relative Sea Level Rise Projections

The State has developed probabilistic climate change projections and made them available on the Massachusetts Climate Change Clearinghouse (resilientMA.org) for use by communities in the MVP program. Resilient MA provides projections for relative mean sea level elevation at the Woods Hole tide gage under "Intermediate," "Intermediate High," "High," and "Extreme" RSLR scenarios (DeConto et al., 2016; DeConto et al., 2017). As summarized in Table 3, these scenarios account for a range of assumptions regarding how much global greenhouse gas concentration[1], ocean thermal expansion, and melting of glaciers and ice sheets will occur and when. All four scenarios anticipate continued acceleration of RSLR.

Table 3 Relative mean sea level (ft-NAVD88) projections for Woods Hole, MA.

Scenario	Cross-walked probabilistic projections	2030	2050	2070	2100
Intermediate	Unlikely to exceed (83%) under RCP8.5	0.6	1.3	2.3	4.0
	• Extremely unlikely to exceed (95%) under RCP 4.5 • About as likely as not to exceed (50%) under RCP 4.5 when accounting for possible ice sheet instabilities				
Intermediate-High	Extremely unlikely to exceed (95%) under RCP 8.5	0.8	1.7	2.9	5.1
	• Unlikely to exceed (83%) under RCP 4.5 when accounting for possible ice sheet instabilities • About as likely as not to exceed (50%) under RCP 8.5 when accounting for possible ice sheet instabilities				
High	Extremely unlikely to exceed (99.5%) under RCP 8.5	**1.1**	**2.4**	**4.2**	7.7
	• Unlikely to exceed (83%) under RCP 8.5 when accounting for possible ice sheet instabilities • Extremely unlikely to exceed (95%) under RCP 4.5 when accounting for possible ice sheet instabilities				
Extreme (Maximum physically plausible)	Exceptionally unlikely to exceed (99.9%) under RCP 8.5	1.3	3.1	5.4	10.3
	• Extremely unlikely to exceed (95%) under RCP8.5 when accounting for possible ice sheet instabilities				
2008 (1999-2017 epoch) mean sea level at Woods Hole tide gage was -0.17 feet (NAVD88)					

The MC-FRM incorporates the "High" scenario projections provided by the State, outlined in dark red in Table 3. The "High" SLR scenario was recommended by the MA Office of Coastal Zone Management (CZM) and chosen by MassDOT for the MC-FRM because of the critical infrastructure at stake and the interest in planning for inundation risk probabilities that were unlikely to be exceeded (there is a 99.5% confidence level that the "High" scenario chosen will not be exceeded).

[1] Relative Concentration Pathway (RCP) 4.5 represents an aggressive emissions reduction scenario like the Paris Accords, while RCP 8.5 represents a very high emissions scenario.

Selecting the “High” scenario reduces the risk of under-preparing and under-designing for the future, while providing flexibility to move the timeline for adaptation actions further into the future if observed RSLR follows lower trajectories. As highlighted in Table 3 color coding, the “High” results in 2030 are similar to “Intermediate” results in 2050 (blue), the “High” results in 2050 are similar to the “Intermediate” results in 2070 (dark teal), and the “High” results in 2070 are similar to the “Intermediate” results in 2100 (bright red).

Note that the values in Table 3 are elevations of the projected mean sea level in future years relative to a vertical datum of NAVD88, not the magnitude of change in elevation. For comparison, the baseline (i.e., year 2008) mean sea level elevation, is -0.17 feet (NAVD88). Based on the projected sea level elevations presented in Table 3, this means the projected change in mean sea level is 1.27, 2.57. 4.37 and 7.87 feet between the year 2008 (present) and 2030, 2050, 2070 and 2100, respectively, based on the “High” SLR scenario. These projections were used to supply sea level rise information to MC-FRM and to develop tidal benchmark projections for future conditions at East Beach and are consistent with the approach being used across the entire state of Massachusetts.

The East Beach Vulnerability Study Steering Committee, after comparing recent observed mean sea level data to the “High” scenario projections, decided to treat the modeling results for specific future years in MC-FRM as representing ranges of years based on both the “High” and Intermediate” projections. Standard MC-FRM time horizons of 2030, 2050, and 2070 are therefore referred to as 2030-2050, 2050-2070, and 2070-2100, respectively, throughout this report.

2.3.1.3 Storm Events and Wave Run-up

The storm climatology parameters in MC-FRM include, but are not limited to, wind directions and speeds, radius of maximum winds, storm forward speed, pressure fields, and tracks. MC-FRM requires storm input data to run storm surge and wave run-up simulations and generate flooding results. Without input data, MC-FRM cannot determine the coastal flood levels that the East Beach Corridor will likely be exposed to in the medium- and longer-term future, as the Corridor’s flood risk profile is dependent on storms.

As part of the development of MC-FRM, a large statistically robust sample of storms, including tropical (hurricanes) and extra-tropical (nor’easters) storms, was developed specifically for the various coastlines of Massachusetts under existing and future climatologies. This storm data set includes historic storm events, as well as future storm conditions, and was used to assess coastal flooding risks in the present, 2030-2050, 2050-2070, and 2070-2100.

To generate future tropical storm conditions, the model utilizes five (5) different global climate models to produce dynamic frequency and intensity of tropical storms based on the changing climate. This means future tropical storms evolve with the predicted climate changes based on these global climate models. Of particular relevance to East Beach, given its southeasterly exposure, this future climatology includes powerful hurricanes similar to those experienced in the past, as well as reflecting projections that tropical storms will be more intense on average in the second half of the century. This set of tropical storm input data was created by MIT professor Dr. Kerry Emmanuel based on these five (5) global climate model projections.

Fully optimized Monte Carlo simulations were run in MC-FRM using the respective storm sets and RSLR projections for present and future conditions. Importantly, these simulations included the tide cycle as a dynamic element of the model. The same storm surge can result in very different flooding outcomes depending on whether it coincides with high, mid, or low tide. Results of the Monte Carlo simulations were used to generate cumulative probability distribution functions of the storm surge water levels at a high degree of spatial precision. In particular, they provide an accurate and precise assessment of the probability of water levels from combined RSLR and storm surge exceeding the elevation of the ground at each node in the model.

2.3.2 Results and Analysis

This section provides results and analysis of potential impacts to East Beach Corridor infrastructure and properties under projected future daily high tide and probabilistic storm scenarios.

2.3.2.1 High Tide Projections

High tide benchmark projections for future years, based on RSLR projections described above, were developed using MC-FRM, which includes non-linear effects associated with increasing water levels. The projected future tidal benchmarks in 2030-2050, 2050-2070, and 2070-2100 are reported in Table 4. Note that the tidal benchmarks provided in Table 4 are applicable for the Buzzards Bay shoreline of East Beach and may not be representative of tidal conditions in the Let or Westport River.

Table 4 Tidal benchmark elevations (ft-NAVD88) for East Beach.

Tidal Benchmark	Elevation (ft-NAVD88)		
	2030-2050	2050-2070	2070-2100
Mean High Water (MHW)	3.0	4.3	6.0
Mean Higher High Water (MHHW)	3.2	4.5	6.3

2.3.2.2 Future Daily High Tide Inundation

To assess the potential vulnerability of property and infrastructure in the East Beach Corridor to future daily tidal flooding, the MHHW tidal benchmark projections reported in Table 4 were mapped against the existing East Beach shoreline topography. Figure 18 shows the estimated shoreline positions in 2008 or present day (blue), 2030-2050 (green), 2050-2070 (red), and 2070-2100 (yellow). Areas located waterward of these lines could be exposed to flooding daily, on average, resulting in a loss of usability for transportation, seasonal trailers, and accessory uses.

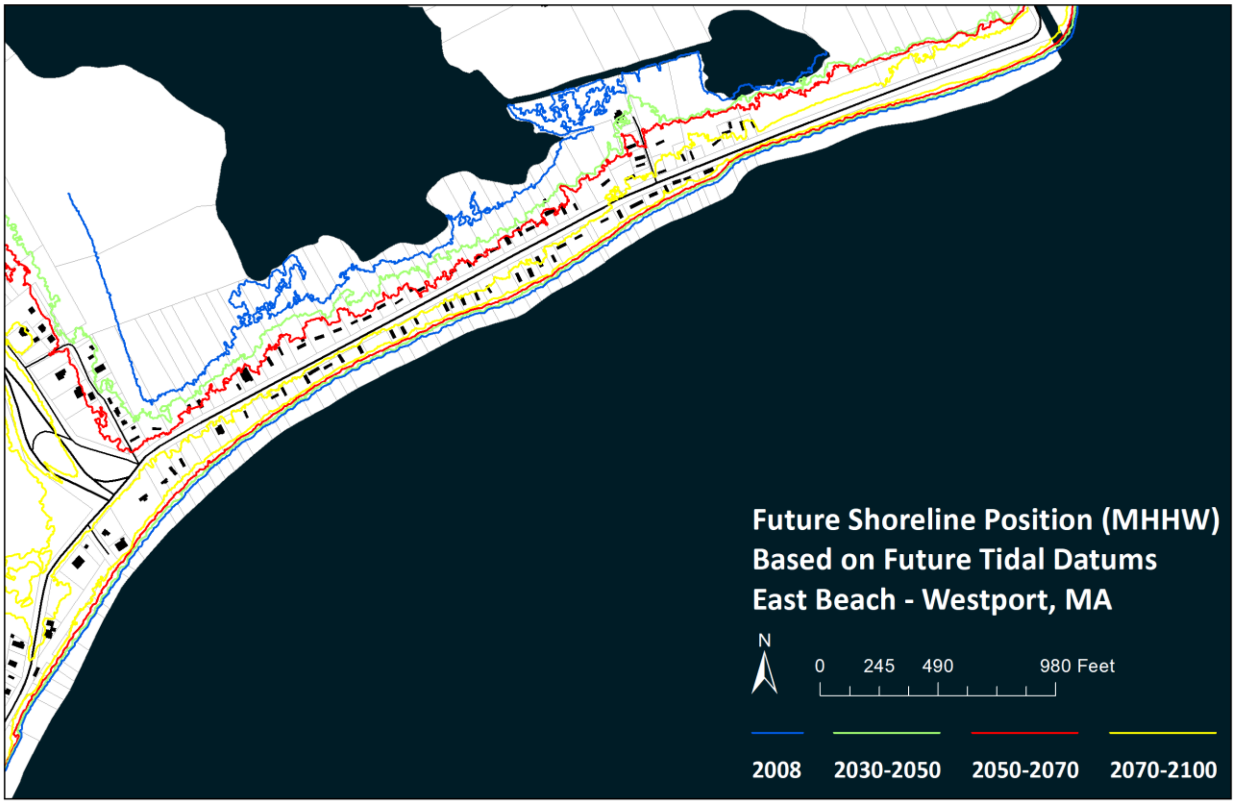


Figure 18 Future shoreline position at MHHW based on future tidal datums.

The observed scale of high tide flooding exposure for properties and roadways in the East Beach Corridor are summarized in Table 5.

Table 5 Potential exposure of properties and roadways to daily high tide flooding.

Areas Exposed	Scale of Exposure		
	2030-2050	2050-2070	2070-2100
Let side – current seasonal trailer locations	Few	30%	Almost all
Let side – parcel area presently dry at high tide	40%	60%	Almost all
East Beach Road	None	None	50%
John Reed Road connection	None	None	100%
Horseneck Road connection	None	None	Limited
Ocean side – current seasonal trailer locations	None	None	Few
Ocean side – parcel area presently dry at high tide	<10%	<20%	40%

The results indicate that properties on the Let side, and eventually the roadway, are sooner and more vulnerable to tidal flooding than properties on the ocean side. This is due to the natural topography of the barrier beach, with a higher elevation cobble dune on the ocean side and a lower and flatter overwash fan on the Let side. The risk of losing usable space on the ocean side is made more significant by potential future erosion (Figure 13), which is not accounted for in Figure 18 (i.e., the landscape stays in present day conditions).

There are a few important limitations of the future MHHW shoreline position map:

1. The projected future tidal benchmarks for Buzzards Bay were used to map the future shoreline positions in the Let. It is likely that tidal benchmarks in the Let may be slightly different than the tidal benchmarks along the Buzzards Bay shoreline due to tidal attenuation and other factors. This detail could be added in the future if needed for design purposes; however, for this assessment and due to the assumed fixed nature of the landscape, the tidal benchmarks applied here are reasonable.
2. The positions shown are based on a scenario in which the topography in future time horizons is the same as today. If the barrier beach is relatively stable, then this may be a reasonable assumption. However, the MSCP data suggest that ocean side has been eroding at an average rate of 1.0 ft/yr (see Section 2.1.2.1). If historical short-term rates (1978-2013) continue, the shoreline on the ocean side of East Beach may look more like Figure 13. As sediment from the ocean side is overwashed and deposited on the Let side, it may increase Let side elevations and mitigate some of the future vulnerability to high tide flooding.
3. Another important consideration is that MHHW is an average condition, and the highest tide on many days of a given year will be higher (and lower) than the average. “King” tides, for example, are extreme high tides that occur naturally.

Due to these limitations, Figure 18 and the vulnerability observations derived from it should be treated as a scenario planning tool, not as a precise prediction of what will occur or used for design purposes.

Because almost all of the occupied structures on the Let side are mobile trailers, property owners and seasonal residents could adapt to the encroaching tide by parking closer and closer to the roadway over time. This strategy could be effective through 2050-2070 according to the estimated future MHHW shorelines shown in Figure 18, though not for all properties. Existing permanent structures, elevated on piles, do not have the same flexibility.

2.3.2.3 Present and Future Coastal Flood Probability Maps and Impacts

Coastal flood risk maps showing the probability of flooding due to the combined effects of sea level rise and storm surge were created for present day (Figure 19), 2030-2050 (Figure 20), 2050-2070 (Figure 21), and 2070-2100 (Figure 22). The colors on the maps correspond with the annual coastal flood exceedance probabilities in the legends on the bottom left corners of the maps (e.g., a 1% annual probability corresponds to the 100-year return period flood elevation). Note that, while the MC-FRM is a high-resolution model, because the East Beach Corridor is so narrow, interpolation between points in the model mesh (Figure 15) that is performed to create the maps can mask some fine grain differences in elevations and flood risk. The tables that follow the time horizon maps provide more refined detail based on a comparison of Lidar elevation data with representative stillwater surface elevations at each probability level.

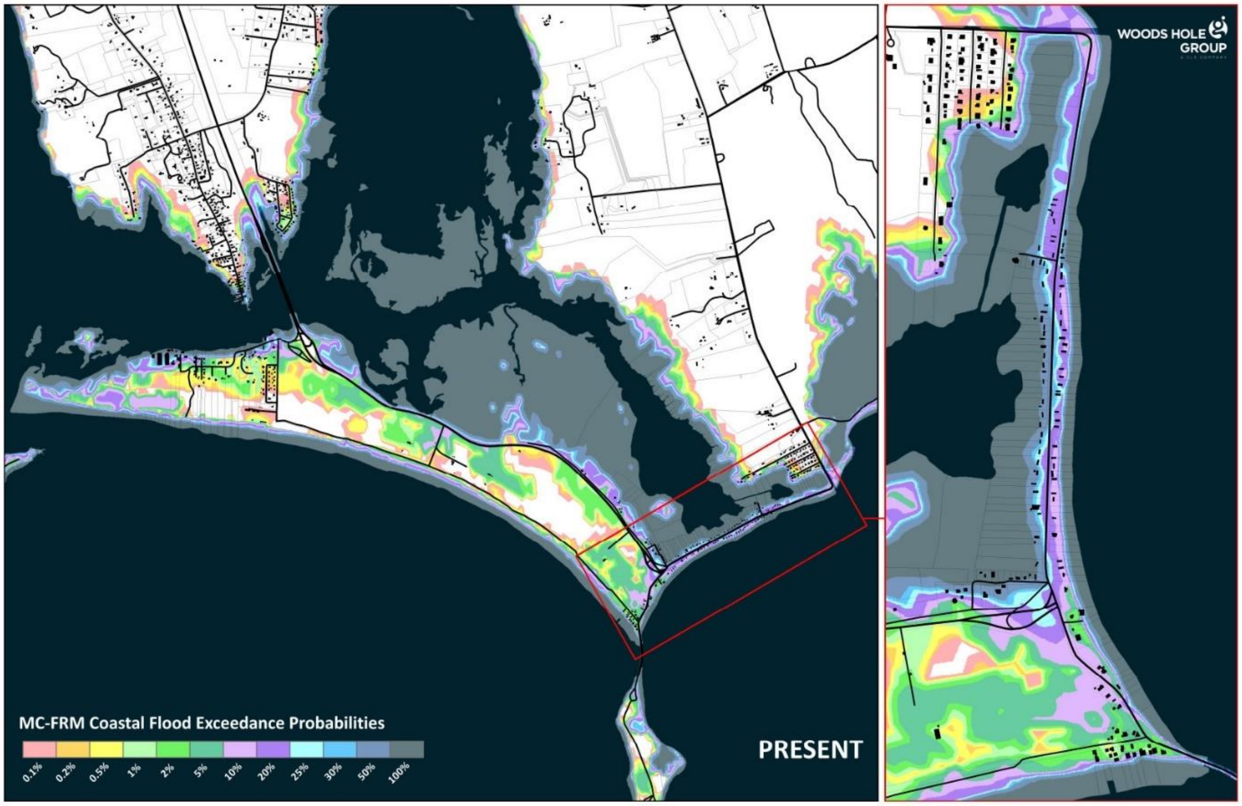


Figure 19 MC-FRM results for East Beach Corridor – Coastal Flood Probability (Present).

Flood probabilities for the Present time horizon represent the current risks faced within the study area. Figure 19 shows that the East Beach Corridor is already extremely vulnerable to coastal flooding, especially East Beach Road and properties on the Let side. Table 6 summarizes the potential flooding impacts to the East Beach Corridor in the Present time horizon at different storm return period and annual probability levels. It does not address other processes and impacts that may occur during coastal storm events (e.g., erosion- and wave-induced damage to private property and infrastructure).

Table 6 Present impacts to the East Beach Corridor in different storm scenarios.

Storm Scenario		Assets Exposed to Coastal Flooding
2-year	50%	Many current seasonal trailer locations on the Let side
~3-year	30%	About 30% of East Beach Road The interchange with John Reed Road Most current seasonal trailer locations on the Let side
10-year	10%	All of East Beach Road Horseneck Road All current seasonal trailer locations on the Let side About 20% of pole mounted electrical panels on the Let side Most current seasonal trailer locations on the Ocean side
20-year	5%	About 80% of pole mounted electrical panels on the Let side
50-year	2%	Almost all pole mounted electrical panels on the Let side All current seasonal trailer locations on the Ocean side About 20% of pole mounted electrical panels on the Ocean side
100-year	1%	All pole mounted electrical panels on the Let side About 50% of pole mounted electrical panels on the Ocean side

In addition to impacts to the East Beach Corridor, John Reed Road is presently exposed to coastal flooding at multiple locations starting at a 10% probability (10-year) level, West Beach Road is exposed at the 1% to 5% (20- to 100-year) level, and Cherry and Webb Lane is exposed at the 50% to 100% (1- to 2-year) level.

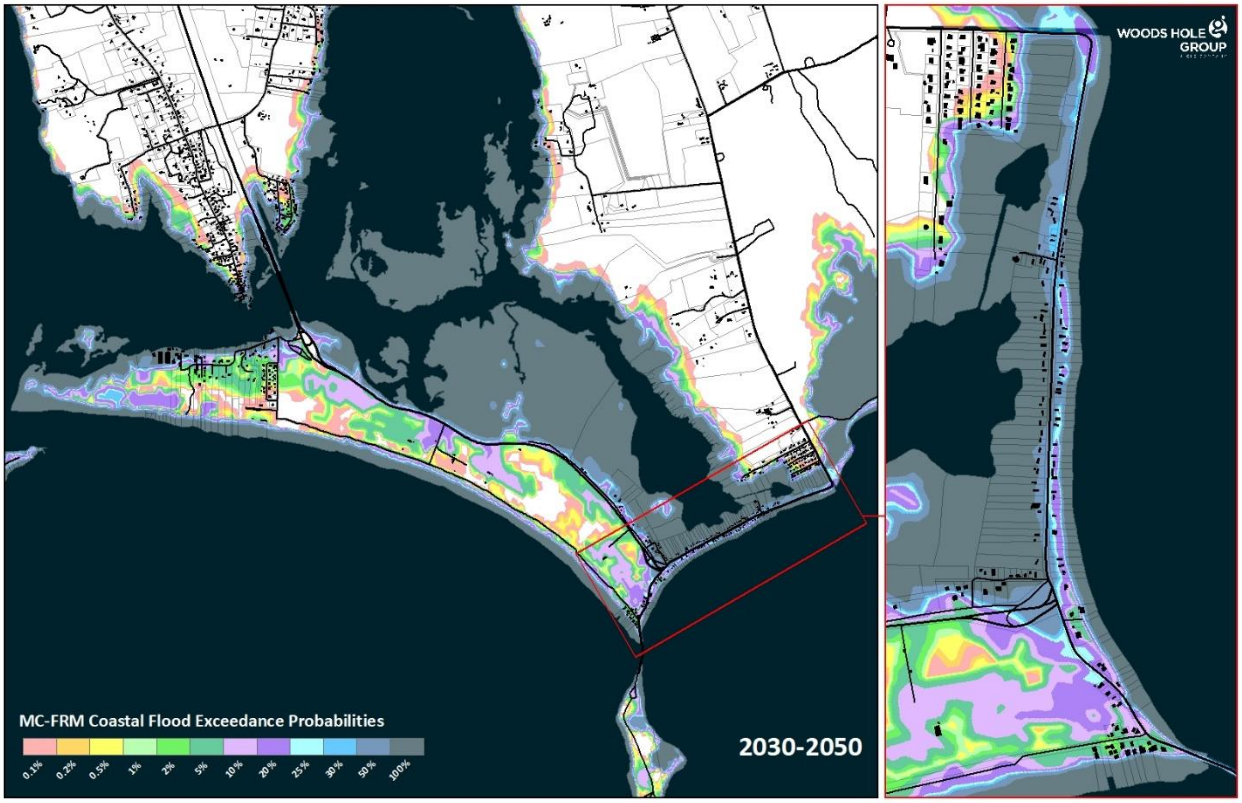


Figure 20 MC-FRM Results for East Beach Corridor – Coastal Flood Probability (2030-2050).

Flood probabilities for 2030-2050 represent a near to medium-term risk, depending on whether RSLR follows a "High" or "Intermediate" projection, respectively. Figure 20 shows that in this time horizon coastal flood risk on the East Beach Corridor will increase incrementally from present flood risk, with many areas shifting to the next highest probability level. Table 7 summarizes the potential impacts to the East Beach Corridor in the 2030-2050 time horizon at different storm return period and annual probability levels.

Table 7 2030-2050 impacts to the East Beach Corridor in different storm scenarios.

Storm Scenario		Assets Exposed to Coastal Flooding
1-year	100%	Few current seasonal trailer locations on the Let side
2-year	50%	About 35% of East Beach Road John Reed Road connection Most current seasonal trailer locations on the Let side
~3-year	30%	Horseneck Road connection All current seasonal trailer locations on the Let side Most current seasonal trailer locations on the Ocean side
5-year	20%	About 20% of pole mounted electrical panels on the Let side
10-year	10%	All of East Beach Road About 80% of pole mounted electrical panels on the Let side
20-year	5%	Almost all pole mounted electrical panels on the Let side All current seasonal trailer locations on the Ocean side
50-year	2%	All pole mounted electrical panels on the Let side About 50% of pole mounted electrical panels on the Ocean side
100-year	1%	About 75% of pole mounted electrical panels on the Ocean side

In addition to impacts to the East Beach Corridor in 2030-2050, John Reed Road is exposed to coastal flooding at multiple locations starting at a 20% to 25% probability (4- to 5-year) level, West Beach Road is exposed at the 2% to 10% (10- to 50-year) level, and Cherry and Webb Lane is exposed at the 50% to 100% (1- to 2-year) level.

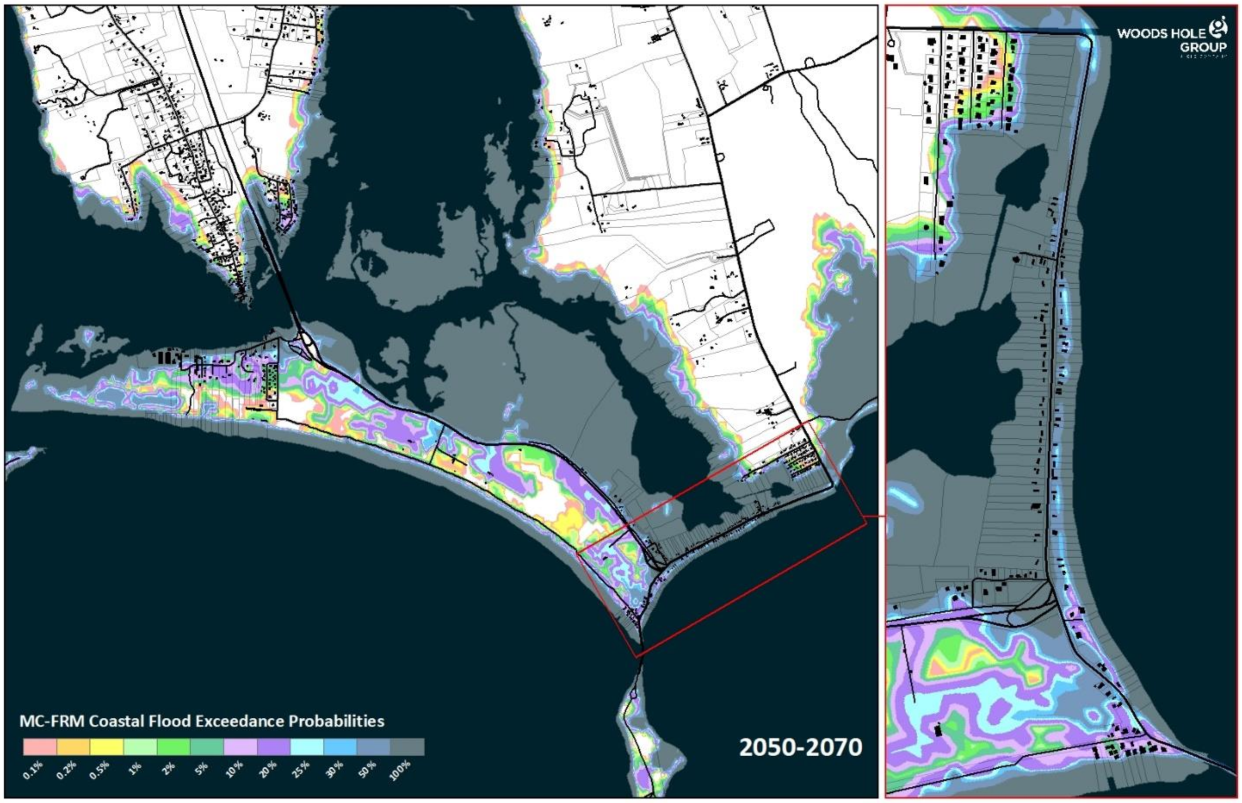


Figure 21 MC-FRM Results for East Beach Corridor – Coastal Flood Probability (2050-2070).

Flood probabilities for 2050-2070 represent medium to long-term risk, depending on whether RSLR follows a High or Intermediate projection, respectively. Figure 21 shows that in this time horizon coastal flood risk on the East Beach Corridor will increase incrementally from 2030-2050 flood risk, with most areas shifting to the next highest probability level. Some areas at around the 20% risk of flooding in 2030-2050 jump to the 50% risk level in 2050-2070. Table 8 summarizes the potential impacts to the East Beach Corridor in the 2050-2070 time horizon at different storm return period and annual probability levels.

Table 8 2050-2070 impacts to the East Beach Corridor in different storm scenarios.

Storm Scenario		Coastal Flooding Exposure Thresholds
1-year	100%	About 30% of current seasonal trailer locations on the Let side
2-year	50%	About 60% of East Beach Road John Reed Road connection Horseneck Road connection Most current seasonal trailer locations on the Let side Many current seasonal trailer locations on the Ocean side
~3-year	30%	All of East Beach Road All current seasonal trailer locations on the Let side About 60% of pole mounted electrical panels on the Let side Most current seasonal trailer locations on the Ocean side
5-year	20%	Almost all pole mounted electrical panels on the Let side
10-year	10%	All current seasonal trailer locations on the Ocean side About 20% of pole mounted electrical panels on the Ocean side
20-year	5%	All pole mounted electrical panels on the Let side About 60% of pole mounted electrical panels on the Ocean side
50-year	2%	Almost all pole mounted electrical panels on the Ocean side
100-year	1%	All pole mounted electrical panels on the Ocean side

In addition to impacts to the East Beach Corridor in 2050-2070, John Reed Road is exposed to coastal flooding at multiple locations starting at a 50% (2-year) level, West Beach Road is exposed at the 5% to 20% (5- to 20-year) level, and Cherry and Webb Lane is exposed at the 100% (annual) level.

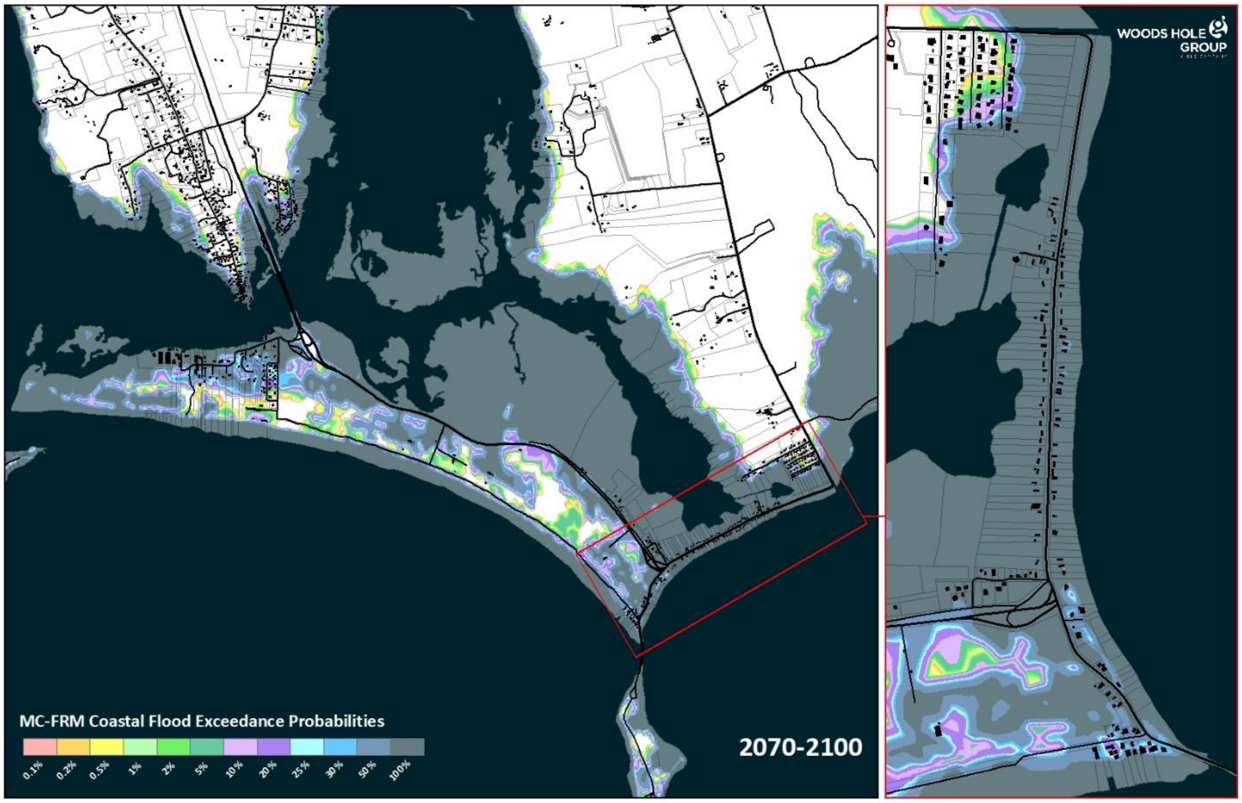


Figure 22 MC-FRM Results for East Beach Corridor – Coastal Flood Probability (2070-2100).

Flood probabilities for 2070-2100 represent long-term risk, either late or end of century, depending on whether RLSR follows a High or Intermediate projection, respectively. Figure 22 shows that in this time horizon coastal flood risk on the East Beach Corridor will jump multiple risk levels from those in 2050-2070 due to the combination of rapid RSLR acceleration and changes in storm climatology. Table 9 summarizes the potential impacts to the East Beach Corridor in the 2070-2100 time horizon at different storm return period and annual probability levels.

Table 9 2070-2100 impacts to the East Beach Corridor in different storm scenarios.

Storm Scenario		Coastal Flooding Exposure Thresholds
1-year	100%	Almost all current seasonal trailer locations on the Let side About 75% of pole mounted electrical panels on the Let side About 50% of East Beach Road John Reed Road connection Horseneck Road connection
2-year	50%	All of East Beach Road All current seasonal trailer locations on the Let side Almost all pole mounted electrical panels on the Let side Almost all current seasonal trailer locations on the Ocean side
~3-year	30%	All current seasonal trailer locations on the Ocean side About 30% of pole mounted electrical panels on the Ocean side
5-year	20%	All pole mounted electrical panels on the Let side About 60% of pole mounted electrical panels on the Ocean side
10-year	10%	Almost all pole mounted electrical panels on the Ocean side
50-year	2%	All pole mounted electrical panels on the Ocean side

In addition to impacts to the East Beach Corridor in 2070-2100, John Reed Road is widely exposed to coastal flooding at a 100% (annual) level, West Beach Road is exposed at the 20% to 50% (5- to 2-year) level, and Cherry and Webb Lane is exposed at the 100% (annual) level.

2.3.2.4 Present and Future Coastal Flood Depth Maps

Depth of inundation is also useful for planning and communication purposes. Depth of inundation maps are available in MC-FRM for the 1%, 0.5%, and 0.1% event flood levels. For the East Beach Corridor Vulnerability Study, the 1% and 0.1% event flood levels (equivalent to the 100-year and 1000-year recurrence water levels, respectively) are presented in Figures Figure 23 through Figure 26 and Figures Figure 27 through Figure 30, respectively.

The 1% probability level is the benchmark for the Federal Emergency Management Agency's (FEMA's) Flood Insurance Rate Maps (FIRMs). Although FEMA FIRMs are not forward-looking and do not incorporate sea-level rise into the mapping, FEMA does periodically update their modeling to account for increased sea level rise that has occurred (as well as other changes, such as changes in topography or armoring of particular areas). Though FEMA and MC-FRM modeling methodologies are different, the 2030-2050 and 2070-2100 1% probability of inundation extents may provide a reasonable proxy projection for future FEMA flood zones. Additionally, the 1% probability level corresponds to a 39.5% cumulative probability over a 50-year period, and a 63.4% cumulative probability over a 100-year period. Thus, the 1% event flood level is highly relevant to the design and assessment of infrastructure that may have a design life of 50 to 100 years.

The 0.1% probability level represents a very extreme and rare storm probability. The 0.1% probability level corresponds to a 4.9% cumulative probability over a 50-year period, and a 9.5%

cumulative probability over a 100-year period. The 0.1% probability level provides perspective on severe flood levels that may inform present and future planning.

Due to the East Beach Corridor's high degree of vulnerability to floods significantly less severe than a 1% or 0.1% probability level, the following maps are provided without further analysis. Flooding impacts at the 1% probability level are included in Tables Table 6 through Table 9.

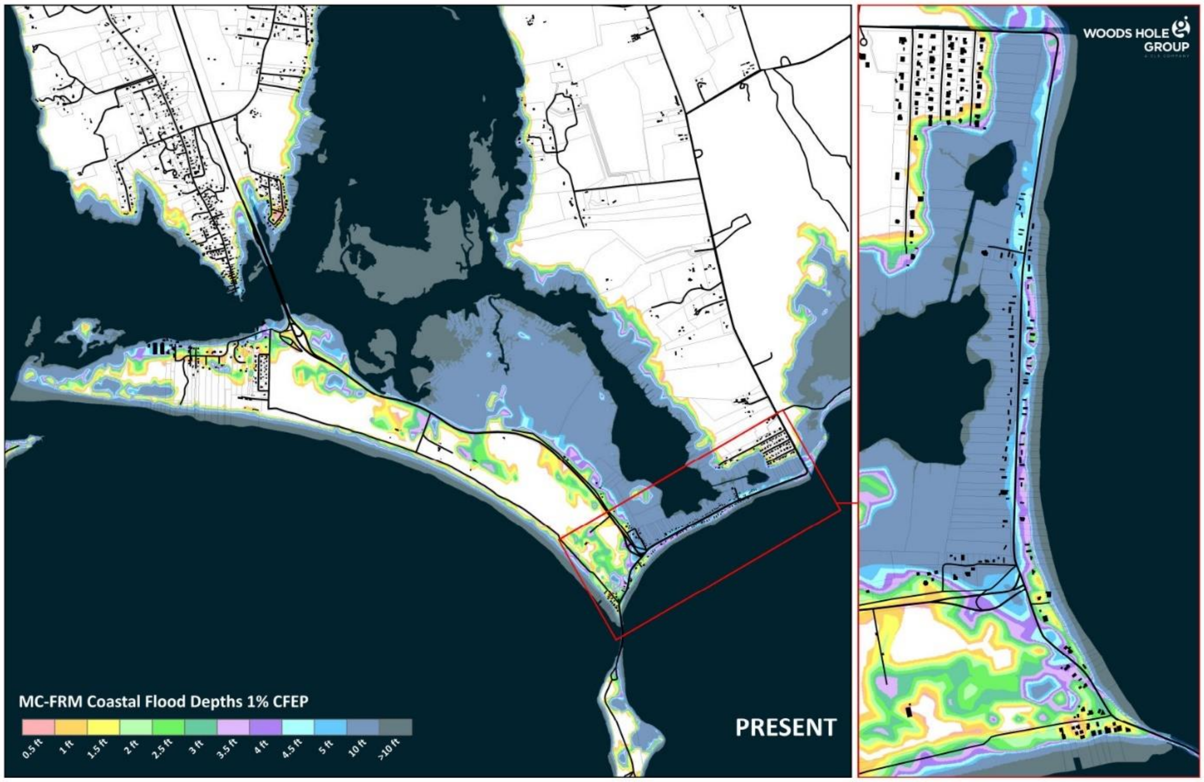


Figure 23 MC-FRM Results for East Beach Corridor – Flood Depth at 1% CFEP (Present).

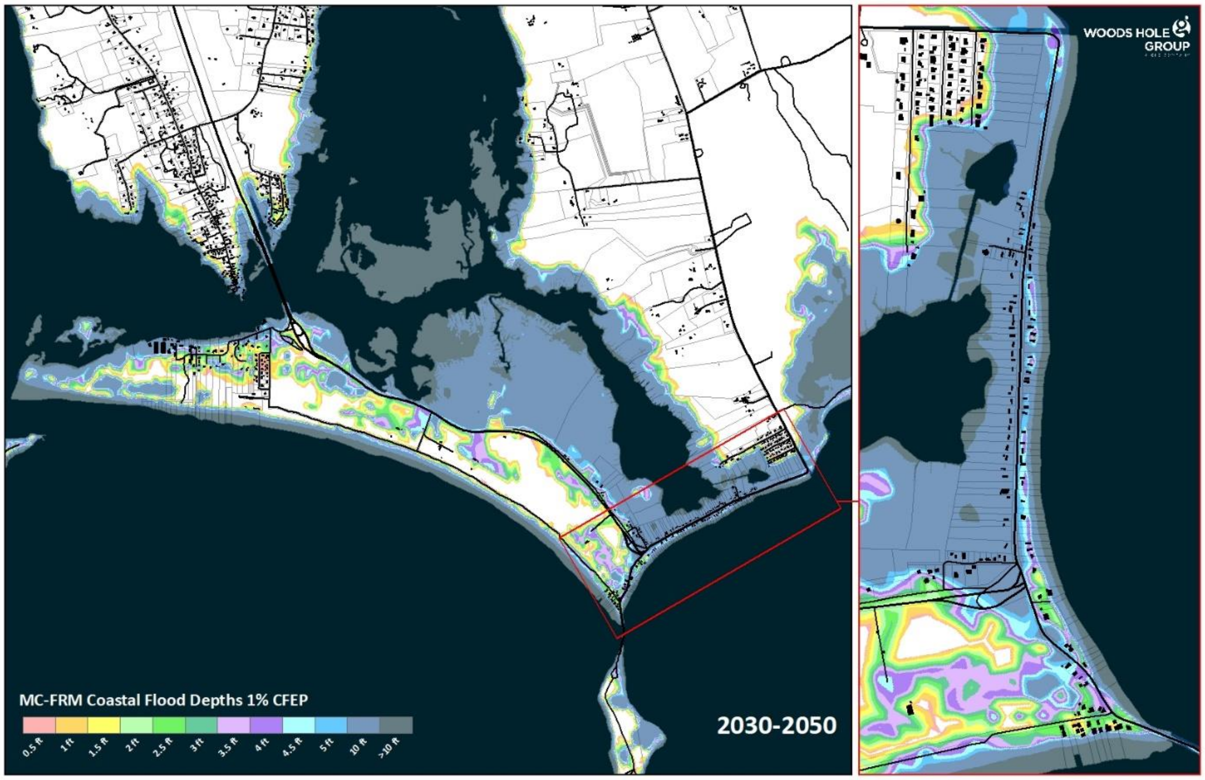


Figure 24 MC-FRM Results for East Beach Corridor – Flood Depth at 1% CFEP (2030-2050).

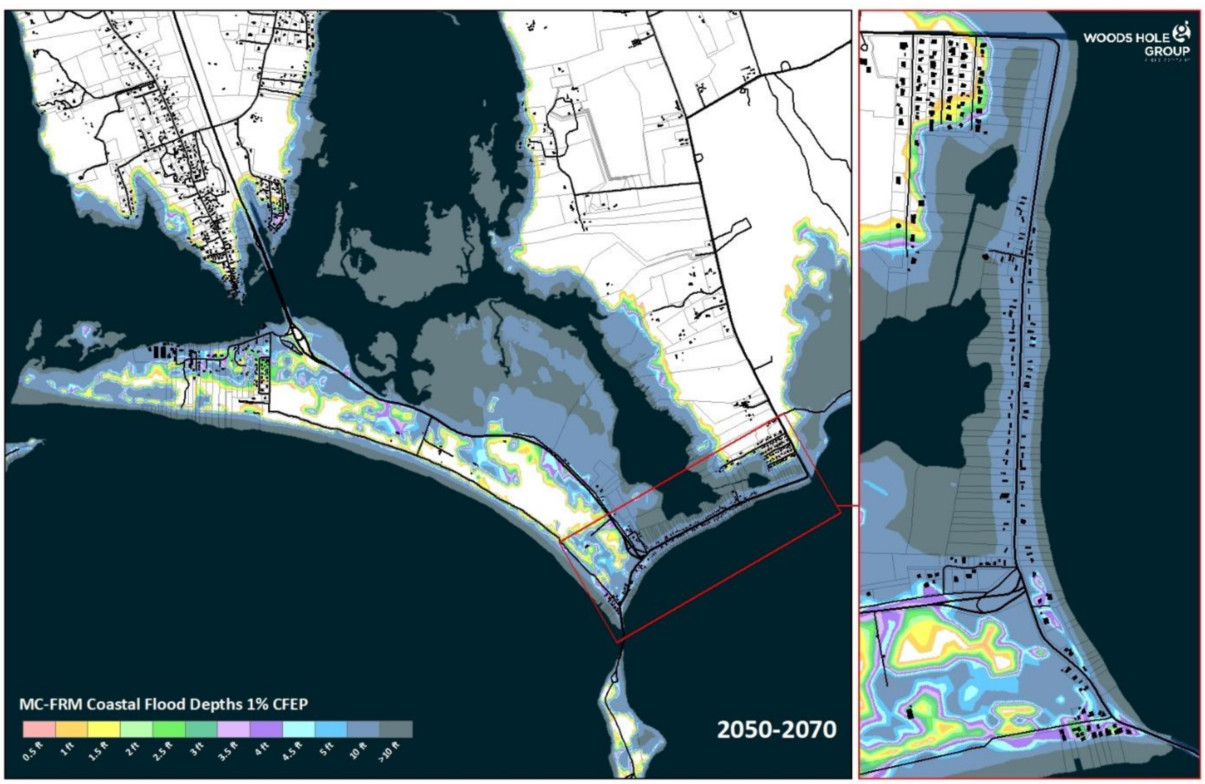


Figure 25 MC-FRM Results for East Beach Corridor – Flood Depth at 1% CFEP (2050-2070).

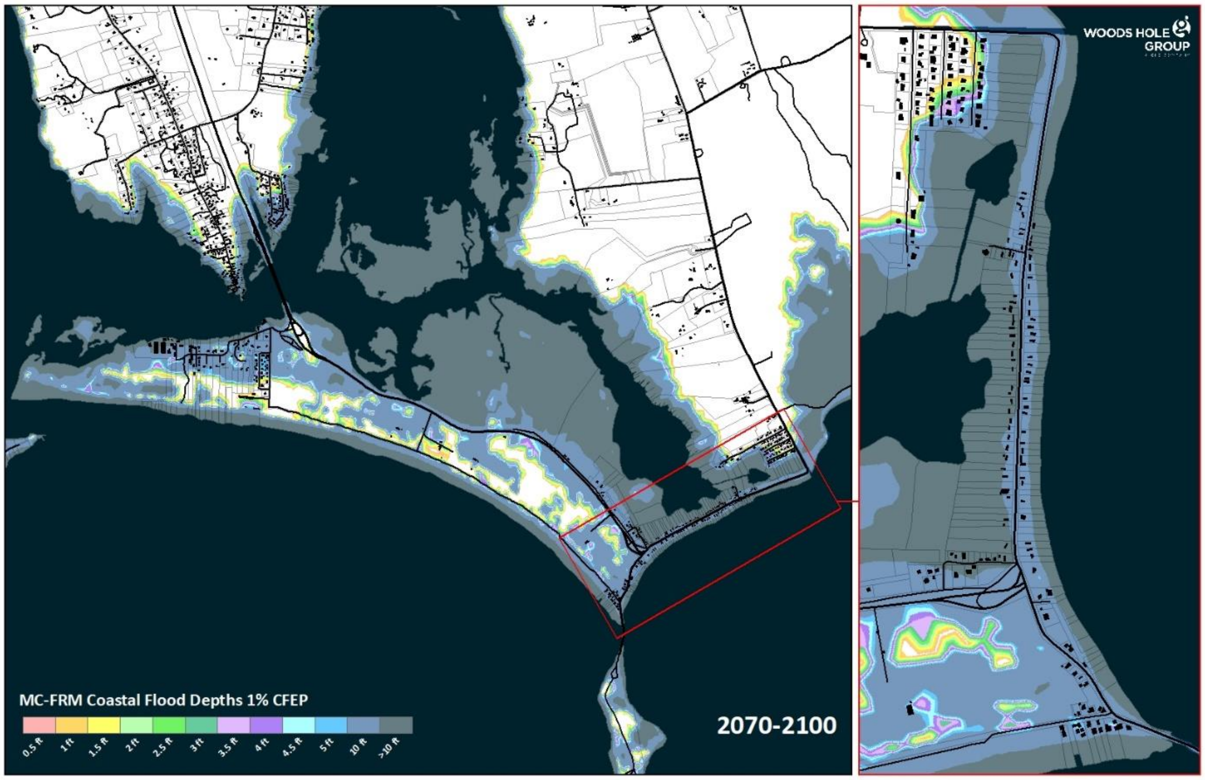


Figure 26 MC-FRM Results for East Beach Corridor – Flood Depth at 1% CFEP (2070-2100).

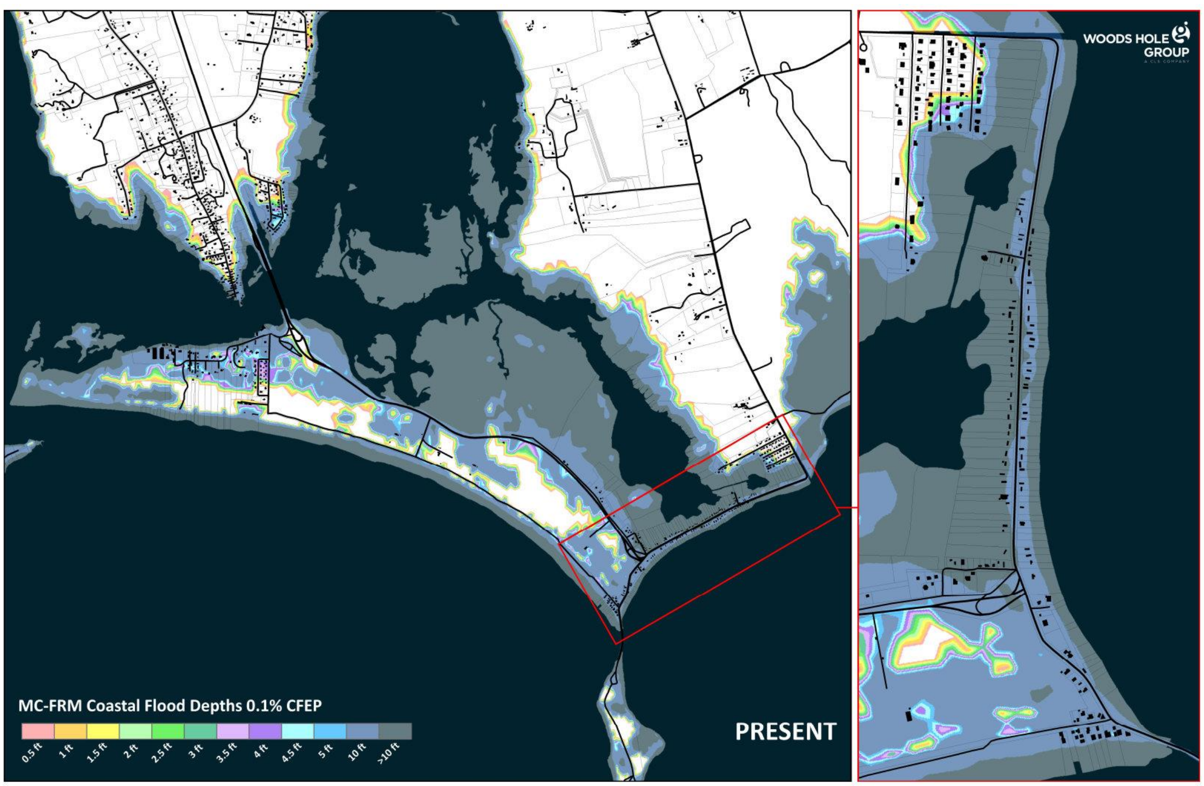


Figure 27 MC-FRM Results for East Beach Corridor – Flood Depth at 0.1% CFEP (Present).

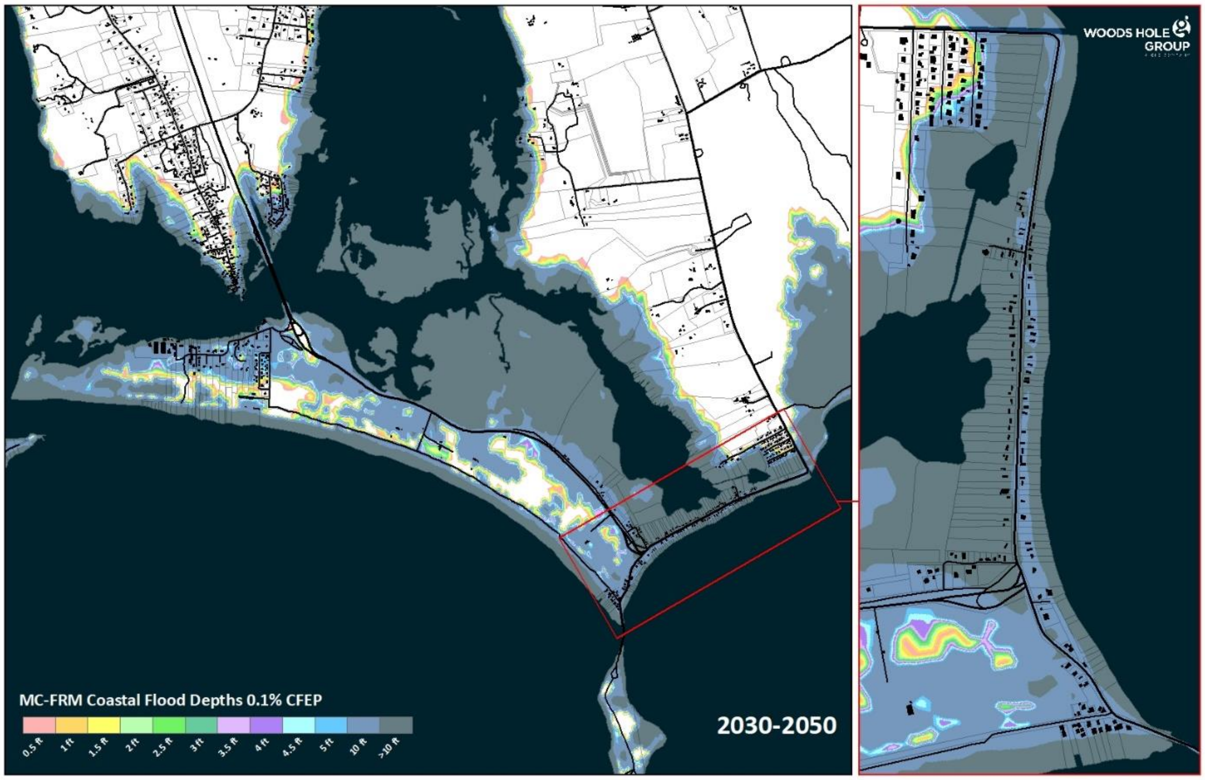


Figure 28 MC-FRM Results for East Beach Corridor - Flood Depth at 0.1% CFEP (2030-2050).

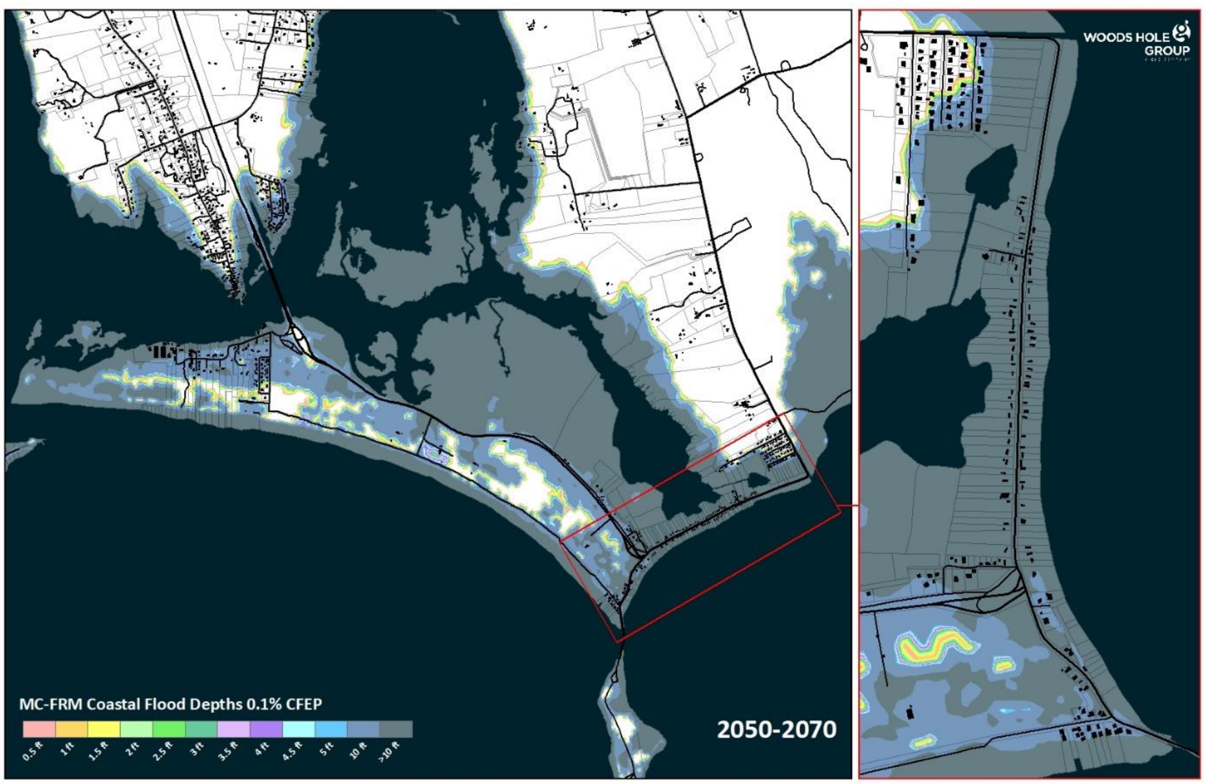


Figure 29 MC-FRM Results for East Beach Corridor - Flood Depth at 0.1% CFEP (2050-2070).

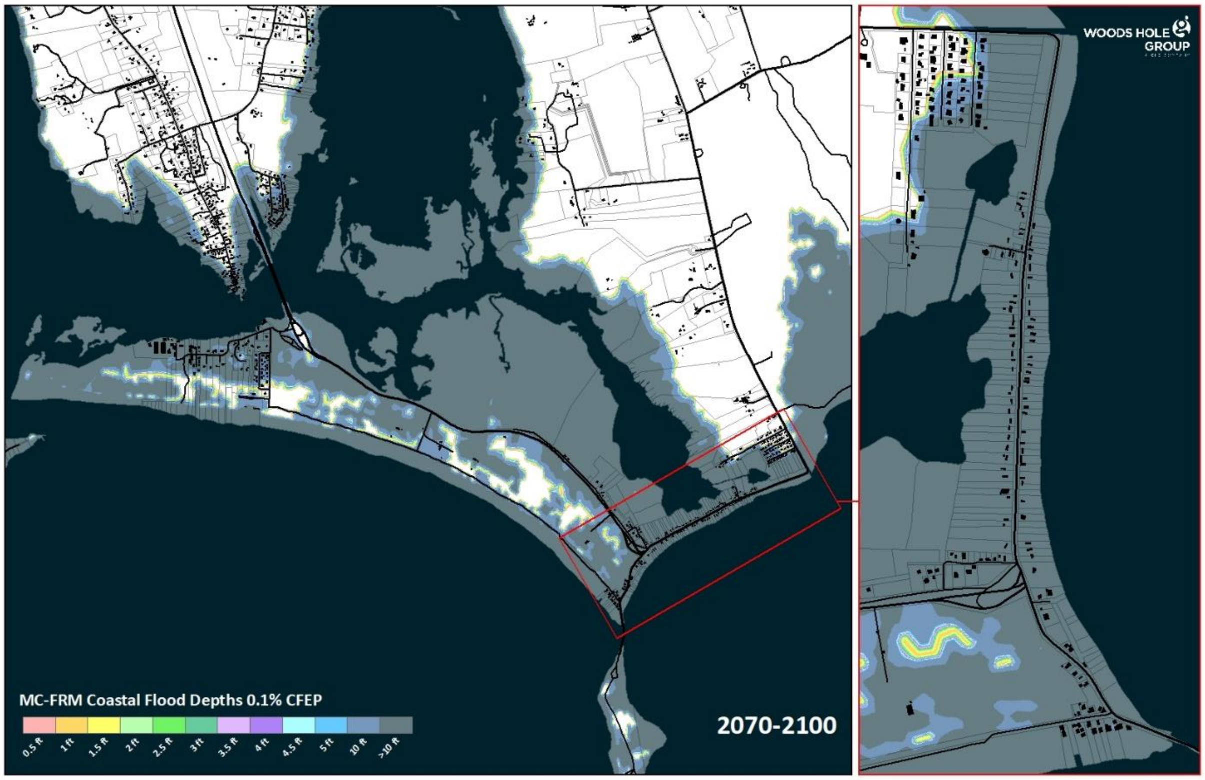


Figure 30 MC-FRM Results for East Beach Corridor - Flood Depth at 0.1% CFEP (2070-2100).

2.4 Nuisance Overwash, Major Road Damage, and Breaching

Woods Hole Group evaluated the present and future risk of nuisance overwash, major road damage, and a breach of the barrier beach at East Beach Road. As storms become more frequent and more intense, East Beach Road will be increasingly subject to sediment being transported onto the roadway surface. The probability of overwash was evaluated for current-day storms and in future time horizons by extracting specific return-frequency surge levels for storms from the MC-FRM. In other words, specific storms from the over 1,000 simulated were identified and used to provide specific storm assessments. The storm surge and associated wave conditions were used as inputs to a wave transformation and sediment transport model to determine what events would lead to sediment deposition and potential scour of East Beach Road. Additionally, the sediment transport model was used to determine what probability storm events would potentially cause a breach at East Beach to the Let, and at what point in the future.

2.4.1 Model Description and Data Sources

To evaluate the potential overwash, damage, and breaching of East Beach Road, a cross-shore sediment transport model (XBeach) was utilized. XBeach is an open-source numerical model developed to simulate wave, hydrodynamic and morphodynamic processes. It has been developed with support of various agencies including the US Army Corps of Engineers, Rijkswaterstaat and the EU, together with a consortium of UNESCO-IHE, Deltares (formerly WL|Delft Hydraulics), Delft University of Technology, and the University of Miami. The newest version of the model (XBeachX) was utilized for the purposes of this study. XBeach was originally designed to assess hurricane impacts on sandy beaches. However, with funding from the Dutch Public Works Department the model has been extended, applied and validated for storm impacts on dune and urbanized coasts, and with further support from the European Commission, XBeach has been validated on a number of dissipative and reflective beaches throughout the EU.

For its original purposes, XBeach was designed as a short-wave averaged, wave group resolving model (surf-beat mode) but has since been updated to allow for a variety of hydrodynamic options. XBeach now allows for a variety of different sediment transport formulations. These options, as well as others included in the model, allow for flexibility in the types of scenarios in which XBeach may be used for simulation purposes.

For the purposes of this study two different formulations of the model were utilized. For simulating beaches where sand is the dominant material, the default surf-beat mode wave formulation with the Van Thiel-Van Rijn transport equations (van Rijn, 2007) is appropriate for sediment transport calculations. For gravel dominated beaches, the XBeach-G formulation is utilized. XBeach-G is a branch of the main XBeach development that was designed to simulate storm impacts on gravel beaches. The development of XBeach-G is a collaboration between Plymouth University and Deltares. XBeach-G uses the non-hydrostatic wave model included in XBeach (wave-resolving) and the bed load transport equation included in van Rijn, 2007 excluding coefficients for silt for the calculation of sediment transport on gravel dominated beaches.

The surfbeat module of XBeach includes the hydrodynamic processes of short-wave transformation (refraction, shoaling and breaking), long wave (infragravity wave) transformation (generation, propagation, and dissipation), wave-induced setup and unsteady currents, and overwash and inundation. The non-hydrostatic wave model used in the XBeach-G formulation includes all wave processes included in the surfbeat module, in addition to including short wave motions (not averaged as is the case with the surfbeat module). The non-hydrostatic module is utilized for gravel beaches because due to the steep slopes typical at gravel beaches, swash motion is mainly at incident wave frequencies, and infragravity wave motion, which dominates the inner surf and swash zone on sandy beaches during storms, is of secondary importance.

The morphodynamic processes included in the XBeach formulation used for sandy beaches includes bed load and suspended sediment transport, dune face avalanching, bed update and breaching. In addition, XBeach-G includes a groundwater dynamics model to correctly account for upper swash infiltration losses and exfiltration effects on lower swash hydrodynamics. Interaction between swash flows and the beach groundwater table are considered particularly important on gravel beaches due to the relatively large hydraulic conductivity of the sediment, while on sandy beaches this process is of significantly less importance. Additionally, the XBeach-G formulation does not include suspended sediment transport. Further details of both the general XBeach model as well as the XBeach-G formulation and the theory behind the model can be found in the XBeach Technical Reference (Deltares, 2018).

2.4.1.1 Elevation and Grain Size Data

To assess potential overwash, road damage, and breaching at East Beach, a cross-shore profile of existing conditions was evaluated using both the standard XBeach and XBeach-G formulations to account for the variable and dynamic nature of sediment grain size at the beach both seasonally and spatially. A one-dimensional (1-D) representation of existing conditions was created for simulation in the model. The 1-D transect was defined through a representative segment of the shoreline (Figure 31).

Figure 31. Cross-shore transect used in wave transformation model.

Elevations along the transect were extracted from available bathymetric and topographic data. For the bathymetry and topography, the most recent USGS topo-bathymetric DEM (USGS, 2017) was utilized (available through NOAA's Digital Coast Data Access Viewer). The location of the transect evaluated is shown in Figure 31.

The 1-D grid utilized in XBeach for the standard formulation simulations was created with a resolution ranging from 10-meter grid spacing at the offshore portions of the transects down to 1-meter grid spacing at the more nearshore portions of the transects. For the XBeach-G formulation a more resolved grid spacing of 1-meter spacing at the offshore portions of the transect, down to 0.1-meter spacing at the more nearshore portions of the transect was utilized. The topography and bathymetry used to define the model grid was based on the most up-to-date available data. The model transect extended from the project site, approximately perpendicular to the beach, offshore to approximately -31 feet elevation relative to NAVD88. Site specific grain size information collected by the University of Massachusetts – Amherst (Woodruff et al., 2020) were utilized to define model sediment parameters.

2.4.1.2 Offshore Storm Surge and Wave Data

Boundary conditions for a set of storm simulations were created to be applied at the offshore boundary of the XBeach grid (Table 10). Storm still water levels were extracted from the MC-FRM for the present-day, and with future climate projections for the time horizons 2030-2050 and 2050-2070. Longer time horizons (2070-2100) were not considered for this analysis as East Beach Road would be inundated in higher frequency events (i.e., daily high tides and annual storm events) and it is assumed other adaptations would be required to maintain East Beach Road by this point. Wave information offshore of East Beach was extracted from USACE's North Atlantic Coast Comprehensive Study (NACCS) for the same set of return-frequency storm events. Table 1 provides the water level and wave information for the storm scenarios including the still water level (SWL), the offshore significant wave height (H_{mo}) and peak wave period (T_p).

Table 10 Storm water level and wave parameters.

Storm/Wave Recurrence and Time Horizon	SWL (ft-NAVD88)	H_{mo} (ft)	T_p (sec)
1-year in present day	2.2	7.4	7.6
1-year in 2030-2050	3.5	7.4	7.6
1-year in 2050-2070	4.4	7.4	7.6
2-year in present day	4.6	8.8	9.9
2-year in 2030-2050	5.8	8.8	9.9
2-year in 2050-2070	6.7	8.8	9.9
5-year in present day	6.3	10.0	11.9
5-year in 2030-2050	7.4	10.0	11.9
5-year in 2050-2070	8.5	10.0	11.9
10-year in present day	7.1	10.7	12.9
10-year in 2030-2050	8.2	10.7	12.9
10-year in 2050-2070	9.5	10.7	12.9
20-year in present day	8.2	11.3	13.6
20-year in 2030-2050	9.1	11.3	13.6
20-year in 2050-2070	10.4	11.3	13.6
50-year in present day	9.4	12.3	14.2
50-year in 2030-2050	10.2	12.3	14.2
50-year in 2050-2070	11.6	12.3	14.2
100-year in present day	10.3	13.0	14.2
100-year in 2030-2050	11.1	13.0	14.2
100-year in 2050-2070	12.5	13.0	14.2

2.4.1.3 Model Simulations

Each storm case was simulated over a 72-hour period with the peak wave heights lined-up to correspond with the peak water levels, and with the wave and storm surge conditions gradually increasing and declining to normal conditions.

To simulate conditions at East Beach, a combination of XBeach model simulations with different parameters was required. Since East Beach is composed of a dynamic mixed sediment grain size (sand and gravel), both the default XBeach formulation (used for sand) and XBeach-G (used for gravel) were utilized. This was required because a single model appropriate for "mixed-grain" type beaches does not exist. The gravel/sand size threshold utilized as a definition for this project was defined as the threshold between sand and pebbles as defined by Wentworth (1922). Grain sizes for each simulation were calculated based on the D50 of the sand fraction / gravel fraction for the XBeach / XBeach-G formulation simulations, respectively. Additionally, XBeach does not allow for the simulation of the possible failure conditions for structures such as the road surface present at the project site. In order to simulate the range of possible conditions at the site, additional simulations were conducted for each formulation, for each storm condition both with and without the road structure being defined as "non-erodible" in the XBeach model parameters. Once all four simulations were conducted for each storm condition, the results were evaluated together to understand the range of eroded conditions possible at the site.

The model output from each of the simulations conducted consists of wave height, water surface elevation, and velocity along the profile for each model output timestep, along with changes in the bottom profile showing areas of erosion and deposition. The final profile for each storm case was extracted from the model simulations for comparisons with the initial profile to determine possible impacts to the beach from storm conditions under existing conditions.

2.4.2 Results and Analysis

Results from the XBeach simulations were utilized to inform the potential for overwash, damage, and breaching of East Beach Road. This section describes the results of the model simulations conducted.

2.4.2.1 Nuisance Overwash

As previously discussed, given the mixed grain size and road surface at East Beach multiple model simulations were conducted for both sand and gravel beaches to inform the potential for sediment mobility and potential overwash of the roadway. Figure 32 shows the results for a present-day 1-year return period (100-percent-annual-chance) storm event with the top panel showing the initial (blue) and final (orange) profiles for a sand beach and the lower panel showing the same for a gravel beach.

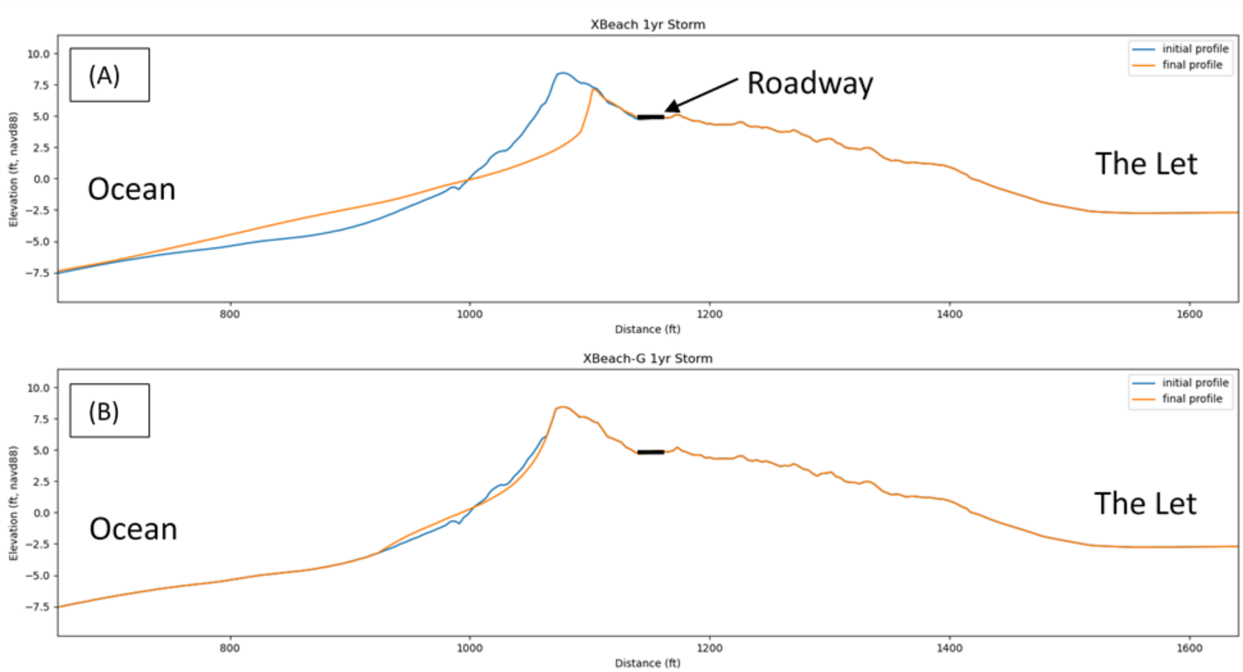


Figure 32 Sediment transport in a present 1-year storm event for a sand beach (A) and gravel beach (B).

The results in Figure 32 indicate there is erosion of the sand beach during a 1-year event. However, there is minimal overwash onto the roadway (as a majority of the sediment is mobilized seaward as the system attempts to build a protective offshore bar), with a small amount caused by wave run-up and overtopping of the cobble dune. For a gravel beach (lower panel of Figure 32), there is minimal erosion in a 1-year event, with a similar small amount of overwash onto the roadway from wave run-up and overtopping.

Figure 33 shows the sediment transport model results for a present-day 2-year return period (50-percent-annual-chance) event with the road being set as non-erodible. In this storm event, the roadway does experience overwash of sediment for both the sand and gravel beach cases. For a sand beach (top panel of Figure 33), there is significant overwash onto and landward of East Beach Road. For a gravel beach (lower panel of Figure 33), there is some mobility and minor deposition of gravel onto the roadway. Given the mixed grain size of East Beach, the actual deposition on the roadway is likely in between the sand and gravel beach results.

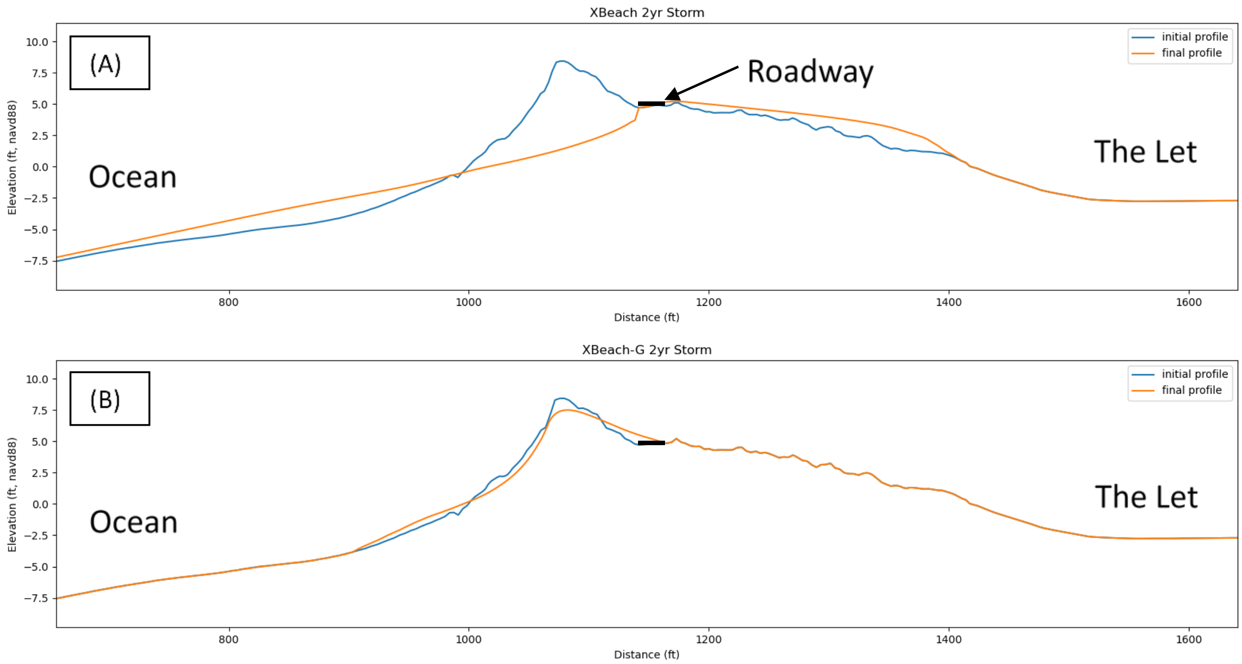


Figure 33 Sediment transport in a present 2-year storm event for a sand beach (A) and gravel beach (B).

These results suggest that small amounts of wave-run up and overtopping in a 1-year return period storm may cause nuisance flooding and overwash of the road, with more significant impacts being seen in a 2-year return period event. The return-period of these storm events refers to the probability of them occurring in any given year (with a 1-year event happening once a year on average), and as such multiple such events (or less) may happen in any given year. These results validate against the experiences shared by Highway Department staff in interviews, where they must temporarily close and clean off the road due to overwash flooding and sediment once or twice a year. Larger storms, like those described in Section 2.1, can bury the road in sediment and cause structural damage.

2.4.2.2 Major Road Damage

To assess the potential for scour at East Beach Road that could lead to major damage of the roadway, a set of XBeach model storm simulations were conducted again for both sand and gravel beaches. In these set of model simulations, the roadway was fixed or set as non-erodible in the model to determine when 2 feet of scour would occur at the edge of the roadway. The critical 2-foot scour threshold was set based on consultation with transportation engineers on when major damage of the roadway would be expected to occur. Under scenarios in which this critical threshold is reached, it is also likely that septic tight tanks on the ocean side of East Beach Road would be exposed and possibly damaged like in Hurricane Irene.

The sediment transport results from the seven (7) storm simulations are shown in Figure 34 for a sand beach and Figure 35 for a gravel beach. The results in Figure 34 indicate that, for a sand beach, storms having a present return period of 5 years or greater would scour the roadway edge and cause major damage to the roadway. However, the results in Figure 35 indicate that, for a gravel beach, damaging scour would not occur at the roadway edge even in up to a 100-year return period storm.

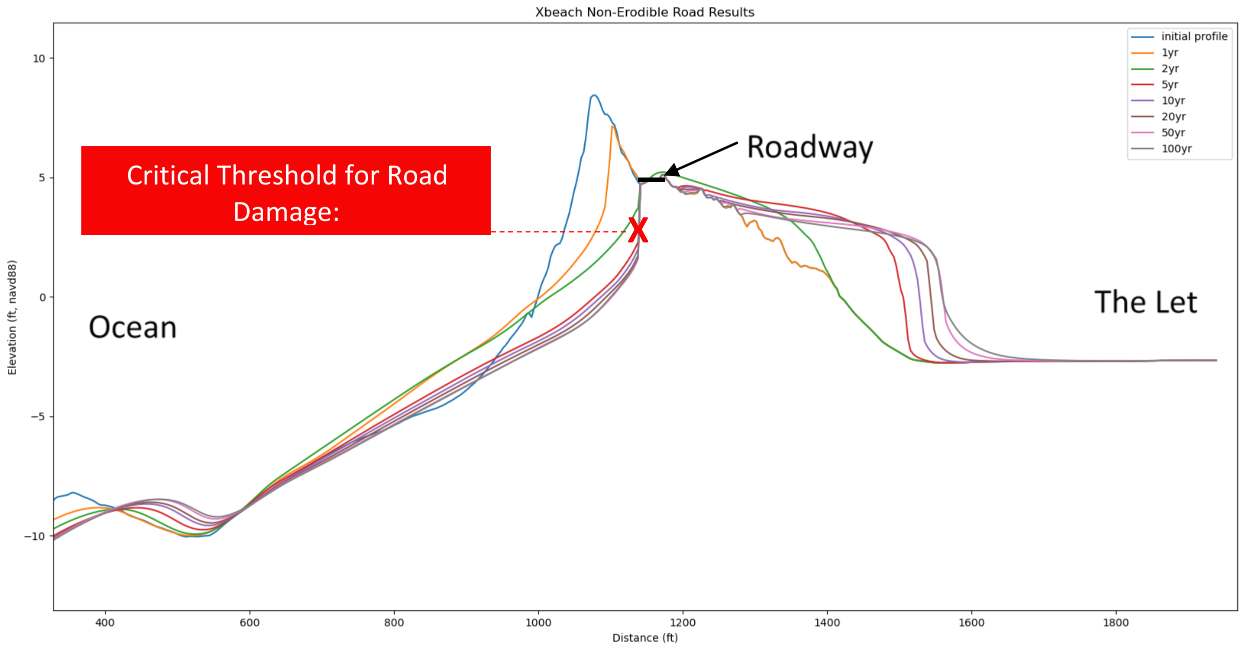


Figure 34 Sediment transport in present day storm events for a sand beach with a non-erodible roadway edge.

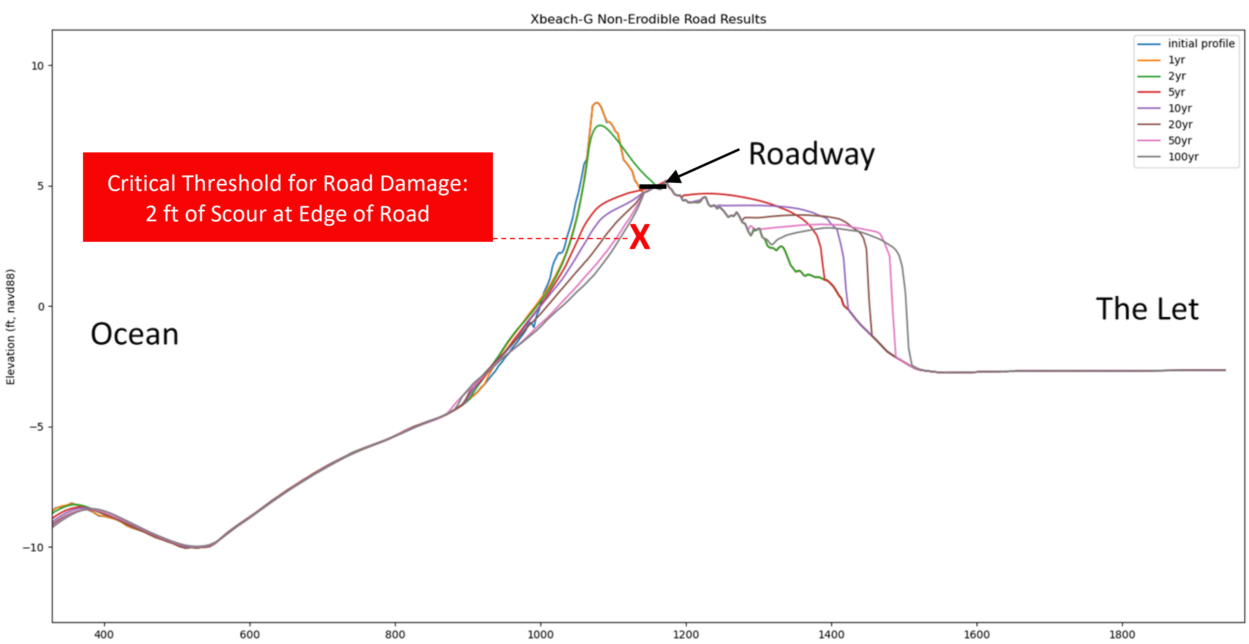


Figure 35 Sediment transport in present day storm events for a gravel beach with a non-erodible roadway edge.

Since East Beach is composed of a mix of sand and gravel, the scour, and subsequently road damage, results from the sand and gravel model simulations were tabulated and averaged in Table 11 to give a better representative estimate of predicted scour. Based on the averaged scour results in present-day storm conditions, assuming a 50%/50% mix of sand and gravel, the potential for roadway damage exists in the 50- and 100-year events (2% and 1% annual chance, respectively) given present sea level conditions. These risks may be lower or higher at locations where the beach and cobble dune conditions adjacent to the roadway are less or more robust than the transect modeled.

Table 11 Predicted scour at East Beach Road in present-day storm events.

Storm Recurrence (% Annual Chance)	Scour at Roadway (ft)		
	Sand Beach	Gravel Beach	Average
1-year (100%)	0.0	0.0	0.0
2-year (50%)	1.2	0.0	0.6
5-year (20%)	2.9	0.0	1.4
10-year (10%)	3.1	0.3	1.7
20-year (5%)	3.3	0.6	1.9
50-year (2%)	3.6	0.8	2.2*
100-year (1%)	3.6	0.9	2.2*

*Expected roadway damage, scour of 2 ft or greater.

Due to the rise in sea level projected to occur in the future, the risk of road failure due to scour is expected to increase as the base water level rises, and smaller storms cause wave action directly at or adjacent to the roadway. The present 1% - 2% risk of major roadway damage (based on an assumption of 1:1 sand/gravel fraction) is expected to increase to approximately 2% - 5% in 2030-2050, 5% – 10% in 2050-2070, and 20% – 50% in 2070-2100.

2.4.2.3 Breaching

Another set of XBeach model storm simulations were conducted for both sand and gravel beaches to assess the potential for a breach to the Let and at what storm frequency this may occur. In these set of model simulations, the roadway was allowed to erode to simulate rollover of the beach and determine when the beach elevation would lower below a critical elevation. The roadway was set to erodible because it is assumed that any storm that would cause a significant breach would cause a failure in the road surface. For the purposes of evaluating the potential for a breach, the critical elevations for the beach were assumed to be between mean high water (MHW) and the mean tide level (MTL). In other words, if the beach could erode to or below this elevation, significant quantities of water would be expected to be transported into and out of the Let even after storm passage since the elevation would be below the normal high tide level. This would result in significant ongoing velocities through the storm eroded breach location that would have the potential to keep the breach open, and may continue to erode the opening size and dimensions. Note that under a breach scenario, septic tight tanks and utility poles on both sides of East Beach road could be compromised. Salt marsh could be impacted by erosion from increased tidal velocities through the Let and increased exposure to storm surge. The sediment transport results from the seven (7) storm simulations are shown in Figure 36 for a sand beach and Figure 37 for a gravel beach.

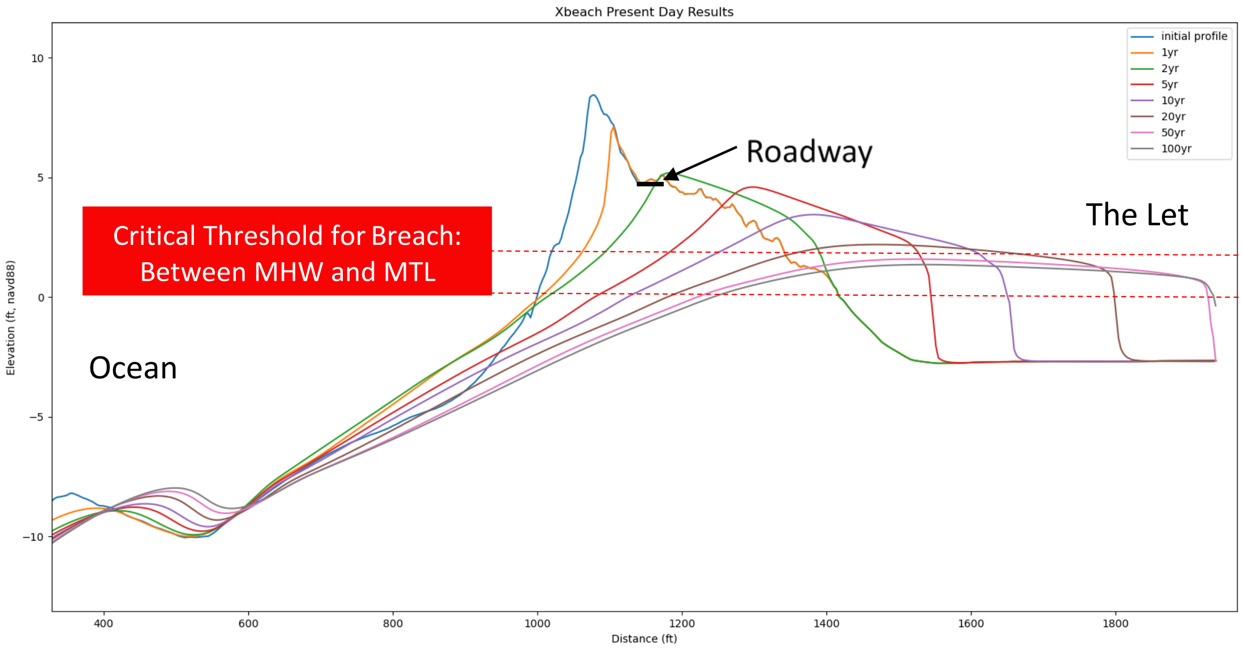


Figure 36 Sediment transport in a range of present-day storm events for a sand beach with an erodible roadway edge.

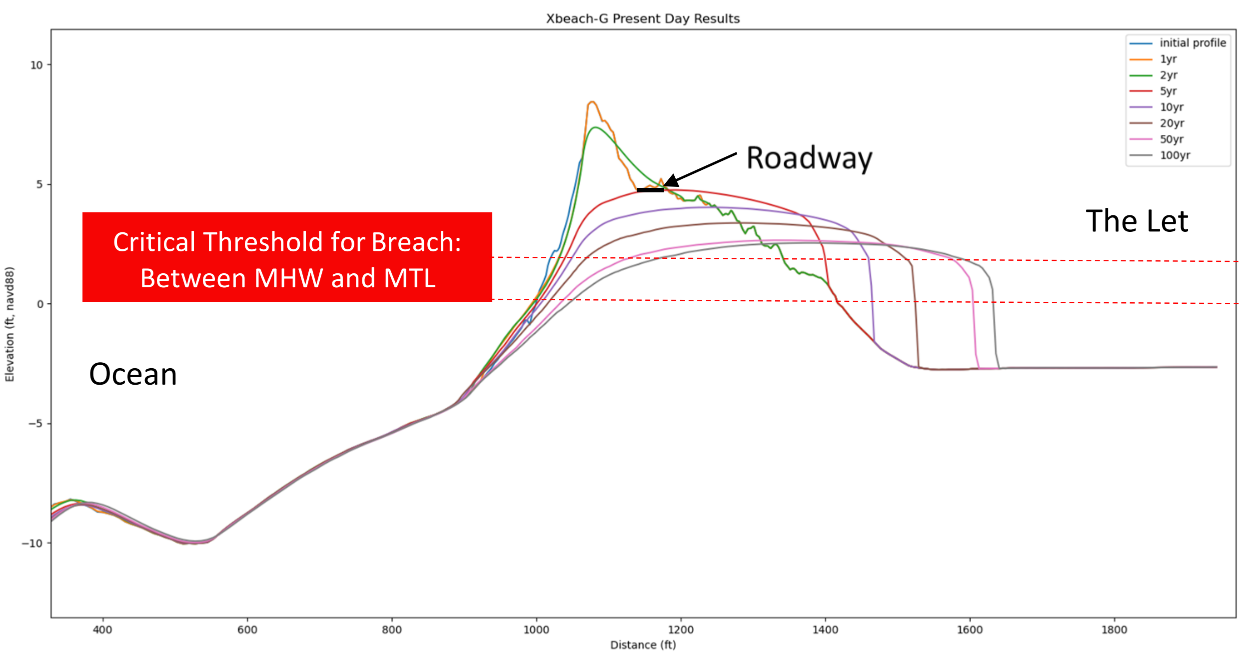


Figure 37 Sediment transport in a range of present-day storm events for a gravel beach with an erodible roadway edge.

Again, since East Beach is composed of both sand and gravel, the erosion results from the sand and gravel model simulations were tabulated and averaged in Table 12 to give a better representative estimate of the lowering of the beach and potential breach in the storm scenarios. The table presents the high point of the beach along the 1-D transect expected after storm-based erosion. The combined results indicate it is unlikely to have a breach occur that would be able to maintain a stable opening after the passage of a storm in present-day storm conditions up through a 100-year event. So, while present day storms will certainly cause water to flow from the Bay side of the barrier beach to the Let, and may even temporarily form a flow pathway, it is unlikely that any type of stable inlet would be able to form.

Table 12 Predicted erosion/lowering of East Beach Road in present-day storm events.

Storm Recurrence (% Annual Chance)	Post-Storm Ground Elevation (ft-NAVD88)		
	Sand Beach	Gravel Beach	Average
1-year (100%)	7.1	8.4	7.8
2-year (50%)	5.2	7.4	6.3
5-year (20%)	4.6	4.8	4.7
10-year (10%)	3.4	4.0	3.7
20-year (5%)	2.2	3.4	2.8
50-year (2%)	1.6	2.7	2.1
100-year (1%)	1.4	2.5	1.9

**Expected breach, elevation between present MHW and MTL (1.8 and 0.1 ft-NAVD88)*

The same analysis was conducted for 2030-2050 storm levels with the results presented in Table 13. The 2030-2050 results based on the assumption of a 50%/50% mix of sand and gravel indicate there is a potential for a breach to the Let in in the 10- to 100-year events (10%–1% annual chance in any given year), however due to the armoring of the beach by the roadway and other structures, as well as the potential for coarser material within the barrier beach, larger 2% to 1% storm (50 to 100 year events) appear more likely to present the risk of breach in 2030-2050. As sea levels rise, less erosion would need to occur to lower the barrier beach below the critical threshold for a breach to be created. Based on projected sea level rise rates, this risk could be expected to rise to 5%-10% by 2050-2070 and 20%-50% by 2070-2100.

Table 13 Predicted erosion/lowering of East Beach Road in 2030-2050 storm events.

Storm Recurrence (% Annual Chance)	Post-Storm Ground Elevation (ft-NAVD88)		
	Sand Beach	Gravel Beach	Average
1-year (100%)	5.5	7.9	6.7
2-year (50%)	4.6	5.6	5.1
5-year (20%)	2.5	4.0	3.2
10-year (10%)	2.0	3.5	2.7*
20-year (5%)	1.6	3.0	2.3*
50-year (2%)	1.4	2.6	2.0*
100-year (1%)	1.3	2.6	1.9*

**Expected breach, elevation between 2030-2050 MHW and MTL (3.0 and 1.4 ft-NAVD88)*

The Town has repeatedly in the past advocated for creating a stabilized inlet at the Let for navigation, harbor development purposes, environmental quality, and flood mitigation purposes. Opening the Let was studied and planned from 1955 to 1963, and an Act of the Massachusetts Legislature in 1957 authorized the State Department of Public Works to conduct the work, but it was never funded. In 1969, the Town, led by its Harbor Development Commission, submitted a "Proposal for a study on opening the Let" to the US Army Corps of Engineers. That proposal states that, in addition to the navigation and harbor development reasons, "the desired study would seek to preserve and improve the ecology of the Westport River, prevent further silting of the river, increase the salinity of the upper reaches of the river without materially lowering water temperatures [increasing the shellfish productivity], preserve the marshlands, and raise the height of East Beach to prevent washovers." Opening the Let was also identified in the Town's 2016 Master Plan as an action to "mitigate destruction of East Beach Road during storm events by seeking permanent improvements," specifically Action 1.3.b "Coordinate with the State to study options to alleviate existing flooding problem, including raising roadway and providing equalization culverts to allow flow between ocean and River or excavating the Let and constructing the roadway on a filled causeway with a bridge over the opening." This idea has persisted for 65 years, being raised by residents during this study's public outreach process. Woods Hole Group cannot substantiate any of the potential environmental or flood benefits or risks associated with potential breach formation, as this was outside the scope of the present study.

2.5 Utility Pole Undermining

Woods Hole Group evaluated the potential for utility poles to become undermined due to predicted scour and wave forces acting on the poles along East Beach Road, especially those located on the ocean side. Poles on the ocean side are primarily for site service, except for the main distribution poles seaward of the bend in East Beach Road which are of greater importance. As storms become more frequent and more intense, the vulnerable utility poles will be increasingly exposed to inundation, wave attack, and scour. The probability of pole washout and collapse was evaluated for current-day storms and in future time horizons by extracting return-frequency surge levels for storms from the MC-FRM. The storm surge and associated wave conditions were used as input to a scour analysis for the utility poles to determine a critical depth of exposure. Additionally, wave forces acting on the poles were calculated to determine what probability storm events would cause the poles to be undermined, and at what point in the future.

It should be noted that wind and water-borne debris are more common causes of utility pole failure than erosion and waves. Vulnerability of East Beach utility poles to wind- and debris-induced failure was not evaluated as part of this study.

2.5.1 Methods and Data Sources

Storm surge, wave, and elevation data were used to estimate parameters, which were then used along with utility pole information in empirical equations to calculate scour depths and wave forces under present and future scenarios.

2.5.1.1 Storm Surge and Wave Data

Parameters for the localized scour and wave force analyses were created for the 10-year and 100-year return period storm events in present-day, and with future climate projections for the time horizons 2030-2050 and 2050-2070. Longer time horizons (2070-2100) were not considered for this analysis as East Beach Road would be inundated in high frequency events (i.e. daily high tides and annual storm events) and it is assumed other adaptations would be required to maintain East Beach Road. The selected return period storm stillwater levels from the MC-FRM and offshore wave information from USACE's NACCS, extracted for the XBeach analyses described in Section 2.4, were used as inputs for wave transformation modeling.

Local wave setup for each of the storm events was evaluated using the 1-D Simulating Waves Nearshore (SWAN) model. Wave transformation modeling was conducted for a representative cross-shore transect and extracting elevations from the USGS (2017) topo-bathymetric DEM. The transect evaluated and underlying topography and bathymetry data are shown in Figure 38. This transect is located slightly northwest of the transect used for the XBeach analyses described in Section 2.4.

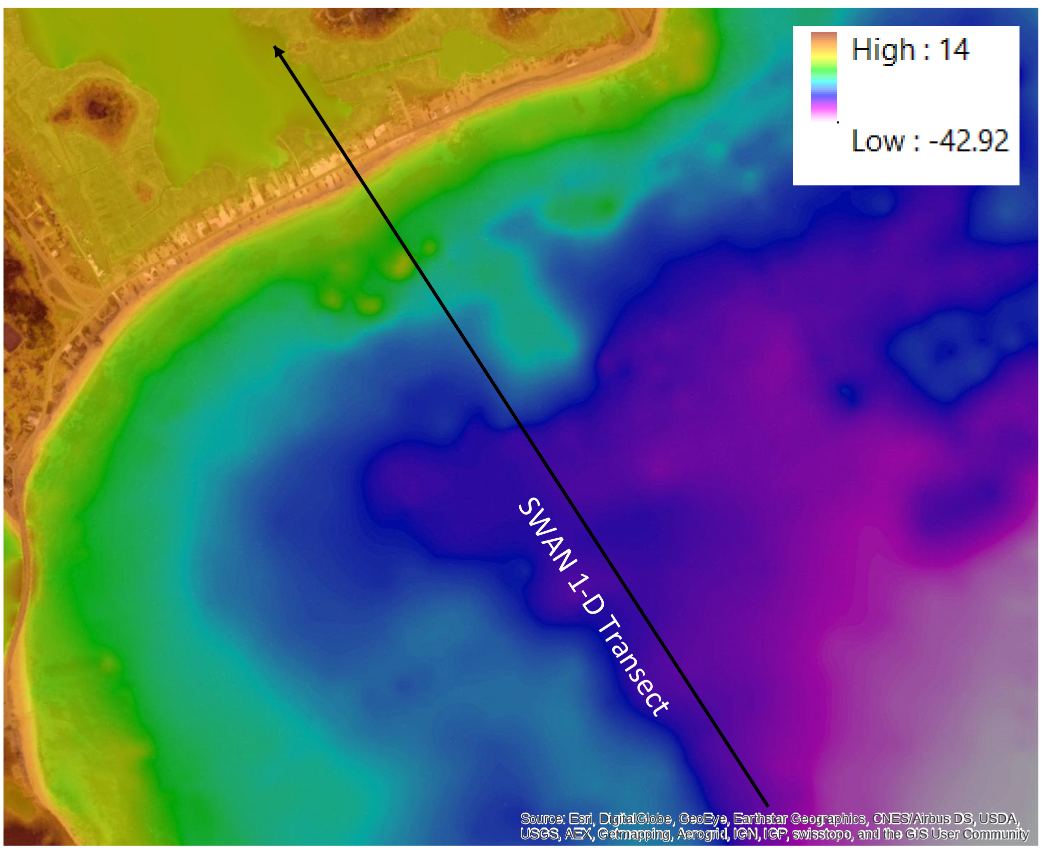


Figure 38 Cross-shore transect used in wave transformation model with bathymetry and topography data.

Table 14 provides the water level and wave information for the six (6) storm scenarios including the still water level (SWL), the wave setup computed using SWAN, the total water level (TWL), the significant wave height (H_{mo}) at the shoreline from SWAN, and the peak wave period (T_p).

Table 14 Storm water level and wave parameters.

Storm Scenario	SWL (ft-NAVD)	Wave Setup (ft)	TWL (ft-NAVD)	H_{mo} (ft)	T_p (Sec)
10-year in present day	7.1	1.9	9.0	6.8	12.9
10-year in 2030-2050	8.2	1.7	9.9	7.4	12.9
10-year in 2050-2070	9.5	1.3	10.8	8.3	12.9
100-year in present day	10.3	1.1	11.4	9.4	14.2
100-year in 2030-2050	11.1	1.1	12.2	9.8	14.2
100-year in 2050-2070	12.5	0.8	13.3	10.6	14.2

2.5.1.2 Utility Pole Information

The timber utility poles that are located seaward of East Beach Road were evaluated as part of this analysis to assess the potential for undermining. Three (3) utility poles now sit seaward of the recently rerouted portion of East Beach Road. The poles in question are shown in plan view in Figure 39 and in ground level view in Figure 3.

Figure 39 Plan view of utility poles located seaward of East Beach Road.

Figure 40 Ground level view of utility poles located seaward of East Beach Road.

Table 15 lists the utility pole parameters that were used for the scour analysis and calculations of wave forces. The ground elevations at the poles were taken from the latest 2018 USACE NCMP Topobathy Lidar data collected between May and August of 2018 by the USACE Joint Airborne Lidar Bathymetry Technical Center of eXpertise (JALBTCX). The utility poles were assumed to be 45-feet long (Class 4) with a typical embedment of 10% of the pole length plus 2 feet (total embedment depth of 6.5 feet).

Table 15 Utility pole parameters.

Parameter	Value
Length	45 ft
Embedment	6.5 ft
Diameter	1.0 ft
Type of wood	Southern Pine
Ground Elevation	8.5 to 9.1 ft NAVD88

2.5.1.3 Potential Scour Estimation

Estimates of potential scour for the timber poles were calculated using accepted empirical equations from literature. For circular piles with diameter, D, the maximum scour, S, that could occur for a normally incident breaking wave was calculated using the following equations from Sumer and Fredsoe (2002) and ASCE 7-16:

$$S/S_c = \left[1 - e^{-0.03\,(KC-6)}\right]$$

where *S = predicted scour*

S_c = scour in steady current alone

KC = Keulegan-Carpenter Number = V T / D

V = water velocity

T = wave period

D = pile diameter

with

$$S_c/D = 1.3 + 2\sigma_{\frac{S}{D}}$$

where $\sigma_{\frac{S}{D}} = 0.7$

The water velocity was specified as the wave orbital velocity, Uw, calculated using the following expression from Nielson (1985).

$$Uw = 0.5H(\tfrac{g}{h})^{0.5}\left[1 - 1/3(\tfrac{2\pi T_n}{T}\right]$$

where *H = wave height*

g = acceleration due to gravity

h = water depth

T = wave period

$T_n = (h/g)^{0.5}$

The depth-limited wave height at the utility poles was calculated using the shallow water approximation where

$H_b = 0.78\ d_s$ *(ASCE 7-16 Eqn. 5.4-2)*

Results are reported in Table 16 in Section 2.4.2.1, below.

2.5.1.4 Wave Force Calculation

The storm water levels and waves were used to determine the wave forces acting on the utility poles. The analysis included the calculation of the resulting hydrostatic and hydrodynamic forces of drag, inertia, and wave impact forces, where applicable, for each of the three utility poles for each storm scenario.

Since the pole diameter is much smaller than the wavelength of the storm waves, the slender pile equations can be used for analysis according to the USACE Coastal Engineering Manual (CEM) and the scour for each utility pole can be evaluated separately. The equations for the horizontal forces of drag (F_D) and inertia/momentum (F_M) acting at the stillwater point on the pole can be written as:

$$F_D = 0.5\ \Upsilon_w\ C_D\ D\ h_b^2 \qquad \text{(ASCE 7-16 Eqn. 5.4-4)}$$

and

$$F_M = 0.25\ \pi\ \Upsilon_w\ C_M\ D^2\ h_b \qquad \text{(CEM Eqn. VI-5-285)}$$

where

Υ_w = *unit weight of sea water = 64 lb/ft*^{3}
D = *pole diameter*
h_b = *breaking wave height*
C_D = *Coefficient of drag = 1.75 for round poles*
C_M = *Coefficient of inertia/momentum = 1.5 for turbulent flow*

In addition to wave induced current forces, the poles are also subject to short but more intense horizontal impact forces due to breaking waves at the base of the pole. These impact forces can be orders of magnitude larger than the wave current forces. Irschik et al. (2007) formulated the following equation for breaking wave impact forces on cylinders based on previous work and laboratory experimentation work:

$$F_{Impact} = 0.5\ C_s\ \Upsilon_w\ D\ h_b\ \lambda\ \eta_b\ \cos^2\alpha$$

where

C_s = *reflection coefficient*
λ = *curling factor*
η_b = *height of breaking wave above the stillwater line*
α = *pile angle (*$\alpha = 0$ *for vertical)*

The total horizontal, ΣF_H is simply the summation of each component:

$$\Sigma F_H = F_D + F_M + F_{impact}$$

The results of the total horizontal force calculations are report in Table 17 in Section 2.4.2.2, below.

2.5.2 Results and Analysis

The scour and wave force analysis results were used to evaluate the vulnerability of utility poles to failure under present and future storm scenarios.

2.5.2.1 Scour-Induced Failure

Table 16 includes the predicted scour for the different storm scenarios evaluated. Results show that in a 10-year storm, potential scour at the poles is up to 1-foot in present day conditions which then increases to 1.5 feet in 2030-2050, and 1.8 feet in 2050-2070. In a 100-year storm, potential scour at the poles is 2.1 feet in present day conditions which then increases to 2.2 feet in 2030-2050, and 2.3 feet in 2050-2070. It should be noted that with 2.2 feet of scour, approximately 1/3 of the pole embedment depth is eroded with an initial assumed embedment depth of 6.5 feet. However, the depths of scour in all of the scenarios evaluated do not appear to be sufficient to cause failure alone, without considering other factors such as wave, wind, or debris forces.

Table 16 Present day and future scour estimates for the utility poles at East Beach Road.

Storm/Wave Recurrence and Time Horizon	Depth at Poles (ft)	Orbital Velocities (ft/s)	Pole Scour (ft)
10-year in present day	up to 0.6	Up to 1.6	Up to 1.0
10-year in 2030-2050	0.8 – 1.4	2 – 2.7	1.2 – 1.5
10-year in 2050-2070	1.7 – 2.3	2.8 – 3.4	1.6 – 1.8
100-year in present day	2.3 – 2.9	3.3 – 3.8	1.9 – 2.1
100-year in 2030-2050	3.1 – 3.7	3.9 – 4.2	2.1 – 2.2
100-year in 2050-2070	4.2 – 4.8	4.5 – 4.8	2.2 – 2.3

2.5.2.2 Wave-Induced Failure

The horizontal wave force components and total horizontal forces (pounds) acting at the stillwater location of the pole are shown in Table 17. Of note, the impact forces, F_{impact}, start to exceed the sum of the drag and inertial forces, $F_D + F_M$, in the more extreme events, which is to be expected with increased water levels allowing for the propagation of higher breaking waves.

Table 17 Total horizontal wave forces (lb) acting on a single utility pole.

	Horizontal Forces			
Storm	F_D (lb)	F_M (lb)	F_{impact} (lb)	ΣF_H (lb)
10-year in present day	10.3	32.4	7.1	49.8
10-year in 2030-2050	70.7	84.7	127.8	283.2
10-year in 2050-2070	181.8	135.9	527.7	845.4
100-year in present day	288.5	171.1	1055.1	1514.7*
100-year in 2030-2050	469.0	218.2	2186.3	2873.5*
100-year in 2050-2070	794.8	284.1	4824.2	5903.1*

****Exceeds maximum allowable working load***

The maximum allowable lateral working load for the utility poles was determined using Brom's method as detailed in the Timber Pile Manual (Collin, 2016). The allowable working load was then compared with the computed total horizontal forces acting on the poles due to surge and waves, considering the predicted scour. This revealed that in a 100-year storm event, both in present-day and future climate conditions, the utility poles have the potential to washout and collapse. The horizontal loading increases by a factor of 2 in 2030-2050, and by a factor of 4 in 2050-2070.

In a 10-year storm event out to the time horizon 2050-2070, the poles do not appear vulnerable to failure and collapse, however, the wind forcing acting on the utility poles and power lines and potential debris impact forces on the poles were not evaluated which would pose additional loading on the poles and could contribute to failure. While potential failure is not predicted in a 10-year event (excluding wind forcing), the horizontal loading increases by a factor of 6 in 2030-2050, and by a factor of 17 in 2050-2070.

2.6 Summary of Vulnerability Assessment Findings

The vulnerability assessment provides a detailed understanding of the past, present, and future impacts on the East Beach Corridor. Based on the climate projections and methods in this study, the Town of Westport and East Beach stakeholders can anticipate significant impacts to unfold over the coming decades if no action is taken.

2.6.1 Lifeline Infrastructure Damage and Service Disruption

The barrier beach community's transportation, electricity, and telecommunications services will be increasingly disrupted due to vulnerabilities of the East Beach Corridor.

2.6.1.1 Short-Duration Disruptions

Short-duration disruptions to barrier beach access and egress via East Beach Road already occur a couple of times per year due to overwash or storm surge:

- As sea level rises in the future, the number of temporary road closures per year is expected to increase, though how frequently was not evaluated in this study.
- As the frequency increases, so will the likelihood that closures coincide with beach and camping season or emergency events.

2.6.1.2 Longer-Duration Disruptions and Degradation

Longer-duration disruption and degradation of community lifelines, like resulted when East Beach Road was damaged in Hurricane Irene or when utilities were damaged in Hurricane Bob, are highly consequential but relatively low probability risks in the near-term:

- At present, a 50- to 100-year return period storm would cause major roadway damage (Table 11). For context, roadways are typically rebuilt every 20-years under normal conditions.

- A present day 100-year storm would topple utility poles (distribution and service) on the ocean side (Table 17) and inundate electrical service panels on the Let side (Table 6).
- A breach is extremely unlikely in present climate conditions (Table 12).
- In 2030-2050, a 20-year storm would cause major roadway damage (Table 11) and inundate almost all electrical panels on the Let side (Table 7).
- A 50-year storm event in 2030-2050 could cause a breach (Table 13), undermine utility poles, and damage about 75% of all electrical service panels on both sides of the road (Table 7).

In the mid-to-late century, East Beach Road, its utilities, and connections to John Reed Road could face a combination of impacts that would threaten their viability if not mitigated:

- A 10-year storm in 2050-2070 and 2-year storm in 2070-2100 could cause major roadway damage (Section 2.4.2.2) and a breach (Section 2.4.2.3), meaning the roadway and utility poles would need to be almost continuously rebuilt.
- Erosion of the ocean side shoreline, just west of the bend, is projected to encroach upon the eastbound lane of East Beach Road in 2050-2070 and both lanes in 2070-2100 (Figure 13). Shoreline encroachment on the eastbound lane around the middle of East Beach is also projected in 2070-2100.
- The western half of East Beach Road and its intersections with John Reed Road are projected to be inundated by daily high tide in 2070-2100 (Figure 18).

2.6.2 Private Property Impacts

The amount of usable dry land on private properties abutting both sides of East Beach Road will shrink over time, as erosion and daily high tides encroach. Due to their mobility, seasonal trailers will likely migrate closer to the roadway over time as the shorelines encroach. However, other coastal flooding impacts will also make maintenance and seasonal occupancy of these properties more challenging over time.

2.6.2.1 Shoreline Erosion

Shoreline erosion will impact all properties on the ocean side of East Beach Road, at least at historical rates and patterns:

- Acute impacts will occur in events classified in sections above as resulting in major road damage (Figure 34 and Figure 35) or breach (Figure 36 and Figure 37). Though accretion will likely occur following such events, the net effect over multiple decades will be a relatively steady recession of the shoreline towards East Beach Road (Figure 13).
- Properties will not be affected equally. Those around the middle of East Beach, where historical rates of erosion are highest and the cobble dune width is narrowest (Figure 12), are likely to be impacted more and sooner (Figure 13).
- Future scenarios show that the shoreline in particularly vulnerable areas could encroach through presently unoccupied cobble dune areas in 2030, through areas where utility

service poles are located and trailers are currently parked for the season in 2050, and more so in 2070 (Figure 13).

2.6.2.2 High Tide Inundation

Daily high tide inundation will impact the usability of Let side properties more and sooner than ocean side properties.

- Daily tidal flooding could affect some rear yards on the Let in 2030-2050, about a third of areas where trailers are currently parked for the season in 2050-2070, and almost all Let side property area in 2070-2100 (Figure 18).
- The higher elevation areas between Farley Lane and the bend in East Beach Road will be affected the least and latest (Figure 18).

2.6.2.3 Property Damage and Indirect Impacts

Direct property damage from increased coastal flooding hazards will likely be limited to accessory structures, tight tanks, electrical service panels, landscaping, etc. Limited permanent physical structures and contents are allowed on seasonal parcels, and trailers and other property are moved to a high ground location off-beach in advance of named storms under existing emergency management practices.

Potential indirect impacts from increased coastal flooding hazards include:

- Seasonal residents may experience disruption or reduction in the quality of lifeline services due to impacts to East Beach Road, utilities, and privately-owned infrastructure (i.e., electrical service panels and septic tight tanks).
- Property owners may have to spend more time and money to maintain a usable area on their lots or to move or redesign property features due to erosion and high tide inundation.
- As storm surge and overwash frequency increases, the frequency with which evacuations and post-storm cleanup are required may become a significant nuisance.

3.0 ADAPTATION RECOMMENDATIONS

The adaptation recommendations for the East Beach Corridor respond to the findings of the vulnerability assessment and the ideas and interests expressed by the Town and community through the stakeholder engagement process. They are also grounded in considerations of technical, financial, political, and regulatory feasibility. Finally, they are guided by specific objectives laid out by the Town in the scope of work for the development of adaptation recommendations, including to:

- Maximize the useable life of East Beach Road (and utilities);
- Address access in the event of a breach at the Let;
- Protect property and infrastructure along East Beach Corridor; and
- Protect seasonal trailer homes on East Beach.

This section describes the general types of adaptation strategies and then provides specific recommendations for near-, medium-, and long-term actions. Each recommendation builds on or responds to ideas gathered from Westport residents through the public survey conducted during the study in which they were asked open ended for ideas that should be considered. After the narrative describing each recommendation, all relevant quotes from Westport residents are listed.

3.1 General Adaptation Strategies

There are generally four types of adaptation strategies that may be applicable to adapt to the risks of flooding from sea level rise and storm surge. While in some cases they can be used alone, in other situations a combination of approaches may be most appropriate. The four adaptation strategies are:

- Avoid,
- Accommodate,
- Protect, and
- Retreat.

These types of strategies are conceptually illustrated and described in Figure 41, from CoastAdapt (NCCARF, 2019).

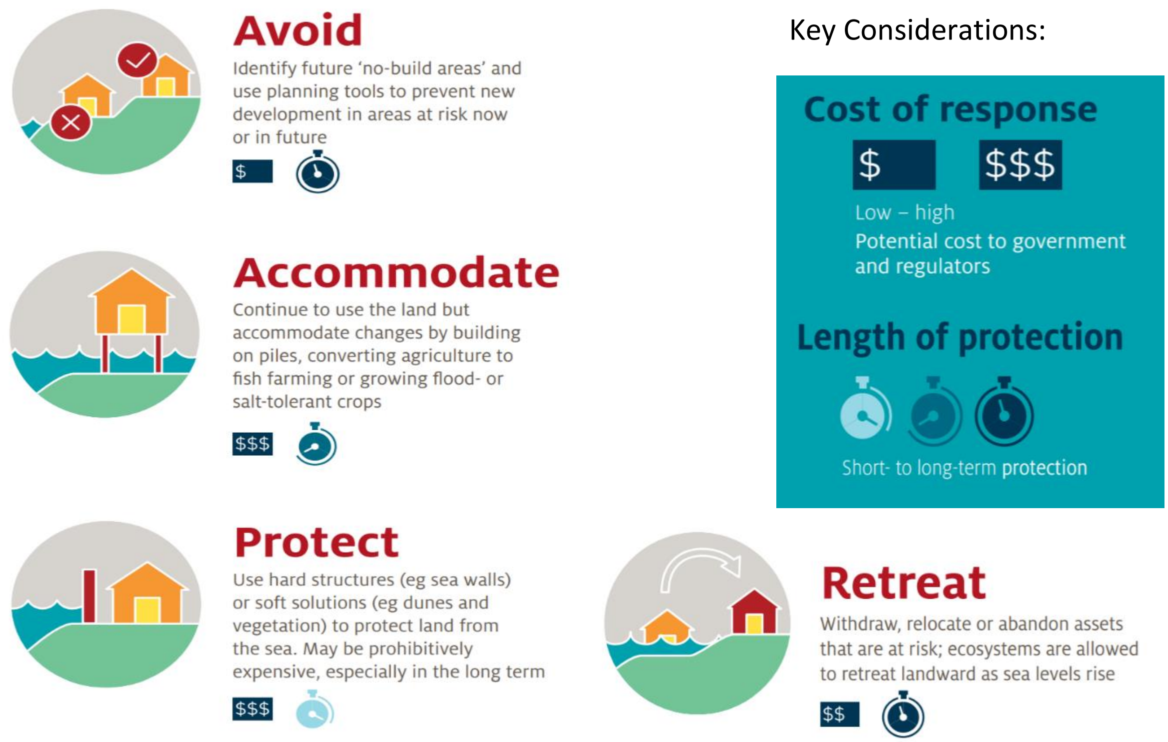


Figure 41 Conceptual illustrations of adaptation options (from NCCARF, 2019).

Avoid: Risk avoidance strategies typically involve planning level activities to prohibit future development in areas subject to coastal hazards, such as sea level rise and storm surge impacts, or in areas where the current level of risk is low but will increase over time. This may involve identifying "no-build" areas and the adoption of by-laws or regulations to limit development in these areas.

Accommodate: Accommodate strategies allow continued use of the land or assets within a higher risk area by implementing changes to human activities and/or the buildings and infrastructure to improve resiliency to occasional flooding. This strategy does not stop flood waters from reaching essential infrastructure, but takes action to minimize and control the damage that would be caused during such an event. Accommodation strategies may include physical, operational, or regulatory actions. Physical measures may include raising roads or buildings above flood elevation and retrofitting structures with floodproofing measures. Operational measures may include improved evacuation or emergency planning, additional training for first responders, or providing education and resources to residents and business owners in high risk areas. Finally, regulatory measures may include updates to zoning bylaws or design standards.

Protect: Protect strategies utilize hard (e.g., revetments, seawalls, flood barriers) and soft (e.g., beach nourishment, dune enhancement, living shorelines) infrastructure to protect an area and its assets from exposure to flooding. Shoreline infrastructure may need to be raised incrementally to continue providing adequate protection in the future, given projected sea level rise and increased storm intensity.

Retreat: Retreat strategies involve withdrawing infrastructure and development from high risk areas and relocating them to low risk areas. These strategies acknowledge that it may be too costly or technically infeasible to accommodate or protect an area or asset against escalating flood risks. As hard infrastructure is relocated, previously developed areas along the coast can be restored to healthy ecosystems, which can provide valuable ecosystem services. Retreat strategies could also allow ecosystems, such as salt marshes, to migrate landward as sea level rises. Municipalities can implement retreat adaptation strategies through property buyouts, relocation of roads, utilities and other infrastructure, and implementation of new zoning or other regulations limiting new development or reconstruction.

3.1.1 Public Support for Adaptation Strategies

There appears to be a high level of support among Westport residents for the Town to act in the next 10 years to address sea level rise and coastal storms (Figure 14). In an online survey of residents conducted for this study (Figure 42), 84% of the 50 respondents favor the Town taking gradual, incremental actions to increase protection. Taking immediate, aggressive protective action and living with/relocating are each favored by half of respondents. Only about 1 in 6 respondents favor doing nothing.

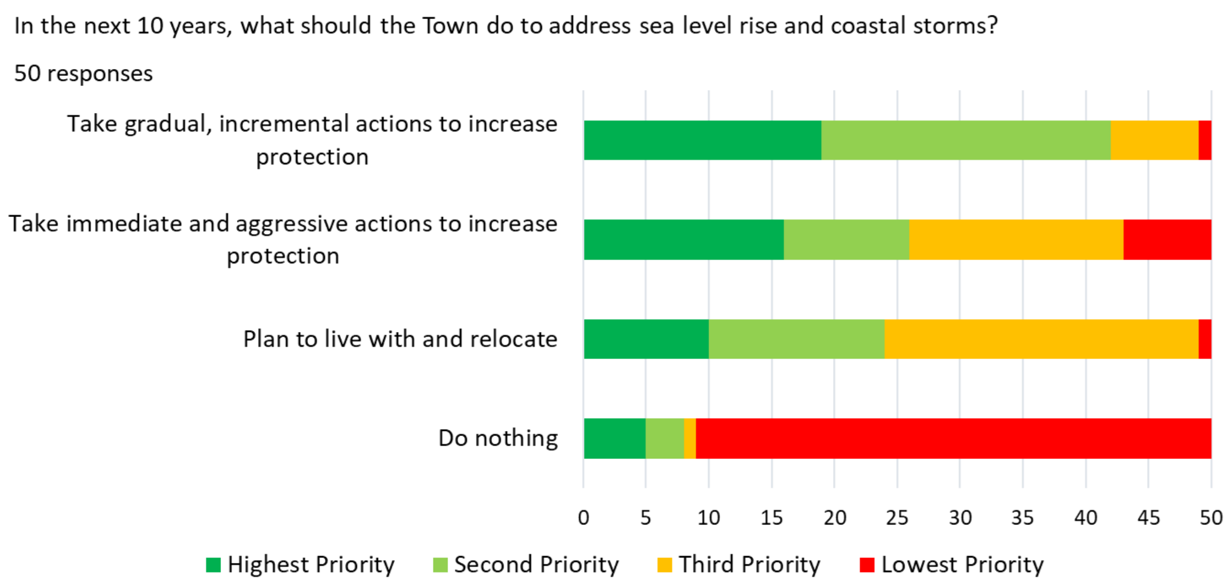


Figure 42 Online survey results – priority strategies to address coastal risks.

3.2 ESTABLISH AND SUSTAIN A COASTAL OR CLIMATE RESILIENCE COMMITTEE

Climate change and the Town's adaptation to it will be a continuous process, and there is no single project that will solve these challenges indefinitely. Planning for future risks and implementing appropriate adaptation strategies requires ongoing engagement of the community, leadership, and coordination between all of the municipal departments and committees. Because it will be important for all municipal departments to keep climate change at the forefront of their planning, the Town of Westport should consider creating a local committee dedicated to thinking about and providing recommendations to the Board of Selectmen or Planning Board on how to manage risks from coastal flooding, erosion, and sea level rise. East Beach residents should be included in the committee membership.

This committee should meet regularly (e.g., quarterly) with department heads and the municipal administration to further discuss the findings presented in this report and future studies, and advance actions and plans for implementing recommendations. The committee could also address other priority climate change risks, including impacts from changes in temperature and rainfall. Responsibilities could include monitoring sea level rise and other coastal or climate changes, recommending priorities for implementation, pursuing grant and Town funding, providing oversight on future projects, identifying opportunities to integrate climate resilience in other planning processes or capital improvements, and engaging with stakeholders in an ongoing dialogue.

Ideas from Westport Residents:

- *"Keep all property owners in the discussion as the plan goes forward"*
- *"More information should be available to all residents and seasonal residents preferably via internet"*
- *"More active public involvement… More engagement with government officials."*

3.3 Raise Awareness of Permittable and Non-Permittable Property Protection Strategies on the Barrier Beach

Through various public outreach activities, residents have expressed support for armoring East Beach, particularly in its most eroded and steep shoreline areas. The Town should work to increase public awareness that coastal armoring, including engineering structures like seawalls, groins, jetties, or revetments, is not permittable under current environmental regulations, while strategies such as dune and beach nourishment are potentially permittable. The Town has been unsuccessful in obtaining authorization from State regulators for constructing even a limited revetment along the portion of East Beach Road that was damaged by Hurricane Irene, despite its importance as a secondary evacuation route for a large State Reservation. However, property owners on East Beach have been successful obtaining permits to carry out dune restoration (adding sediment above the High Tide Line and Mean High Water) and beach nourishment (adding sediment below the High Tide Line and Mean High Water). Beach nourishment involves more permits, including from federal agencies.

East Beach is identified as a barrier beach under the US Coastal Barrier Resources Act, MA Wetland Protection Act (WPA), and MA Executive Order 181 (EO 181). Barrier beaches and the coastal beaches, coastal dunes, and tidal flats that comprise them are highly regulated environmental resources areas. As examples, WPA prohibits any alteration or structure on a coastal dune or within 100 feet of a coastal dune that has an adverse effect by "affecting the ability of waves to remove sand from the dune" or "interfering with the landward or lateral movement of the dune" among other restrictions. EO 181 explicitly states that "Coastal engineering structures shall only be used on barrier beaches to maintain navigation channels at inlets and then only if mechanisms are employed to ensure that downdrift beaches are adequately supplied with sediment." Only an Act of the State Legislature, signed by the Governor, circumventing these and possibly other regulations could authorize such coastal armoring on East Beach.

The Town should create informational material (e.g., fact sheet, Frequently Asked Questions page, presentation slides) summarizing the major federal, state, and local regulations affecting coastal engineering structure permittability on the barrier beach, including the limited conditions under which such structures may be permitted. The material should also summarize under what conditions dune and beach nourishment can be permitted, the process to be followed to seek such permits, and local examples of permit applications and permit conditions that have been approved in the past. This informational material should be made readily available on an appropriate page of the Town's website and in print at Town Hall, and proactively distributed and disseminated to residents either through mailings or relevant future public meetings. With an understanding that coastal armoring is not feasible, and that dune restoration and beach dune nourishment are potentially permittable, residents can turn their focus to non-structural strategies that are permittable on barrier beaches to protect from flooding and erosion and enhance property value.

Ideas from Westport Residents:

- "Shore up edges of East Beach Road with natural materials (large boulders)"
- "Build a sea wall"

3.4 Develop an Emergency Access/Egress Contingency Plan

The Town of Westport should work with partners to develop a post-flood emergency access and egress contingency plan for the barrier beach. This effort should be led by the Fire Department (Emergency Management) in cooperation with EMS, Police Department, Harbormaster, Highway Department, DCR, MassDOT, MEMA, US Coast Guard, DHS/FEMA, and other mutual aid and volunteer partners. Technical assistance could be sought to supplement staff capacity. The plan should identify the actions and resources needed to address scenarios in which the barrier beach does not have roadway access to the mainland during the immediate post-flood period. This is the period when search and rescue, emergency medical, and firefighting services are critical for lifesaving. A tabletop exercise should also be conducted to test and improve the plan.

The Fontaine Bridge (Route 88) is the official emergency evacuation route, and East Beach Road is the secondary route. The inaccessibility of East Beach Road is reasonably foreseeable based on the vulnerabilities identified in this report. Under existing procedures, the Route 88 drawbridge is opened in advance of major storms to allow boats to enter Westport River for safe harbor. The bridge then closes to traffic. Following a disaster like a hurricane, MassDOT would require bridge inspection to ensure it is safe prior to reopening for vehicular traffic. In addition, because the drawbridge relies on electricity routed via East Beach Road, it should be assumed that the drawbridge will not be able to open to allow taller vessels through. During this extended period of time, the only means of access or egress may be by water or air.

The plan should include:

1. Hurricane search and rescue safety training refresher material
2. Key contacts
3. Command structure
4. Communications systems and emergency power
5. Suitable landing and launching points for vessels, assuming the drawbridge is closed
6. The locations, types, sizes, and availability of vessels that could be used to land or launch
7. Capacity of those vessels to carry personnel and equipment
8. Additional restrictions on vessel-based access and egress due to tidal range, bathymetry, and bridge clearance
9. Suitable helipad locations for medical evacuation
10. Suitable (low flood risk) locations for emergency response vehicles to be pre-staged and first responders to be sheltered-in-place on the barrier beach, and conditions in which it is not safe to do so
11. Post-flood muster points for members of the public seeking medical attention or evacuation assistance, accessible by foot from pre-identified boat landings and helipads
12. Other actions and resources identified by the cooperating partners

Ideas from Westport Residents:

- *"Emergency egress plans for Horseneck Beach State Park would clearly need modification"*
- *"Working with the state to provide access to West Beach Road in the likely event that East Beach Road gets washed out in the future"*
- *"Prepare for the eventuality of there being no connection between Horseneck Road and Rt. 88"*
- *"Systems need to be in place to protect residents and natural resources during a worst case scenario"*

3.5 Establish a Dune and Beach Monitoring Program

East Beach and Horseneck Beach have seen significant changes to the shoreline profile and grain size over the last century. Within the body of specific adaptation recommendations above, monitoring local conditions will be key to developing, refining, and advancing timely and appropriate solutions for the East Beach Corridor in the future. Transect-based topographic cross-shore surveys, grain-size analyses, and water level monitoring have been recommended to support a range of adaptation recommendations, including as a baseline for the coastal processes study (Section 3.7.1), to support design and permitting of the elevation of East Beach Road and dune system (Section 3.8.3.1), and to inform long-term retreat and relocation (Section 3.9).

To support future adaptation initiatives, the Town, in partnership with the DCR, should establish a network of long-term cross-shore transects, down to low tide, regularly spaced along East Beach and Horseneck Beach for periodic monitoring of elevation profiles. Surveys should be conducted annually, either once a year in the late spring, or twice a year in different seasons to capture seasonal variability. Year-to-year the survey(s) should be conducted at the same time(s) as the initial survey(s). These transects could be set up independently or initiated with the coastal processes study.

The Town could contract these services or carry out the surveys in-house. Contract would cost about $20,000 per year. At this cost, data could be collected using a drone equipped with LiDAR plus ground controls, processed by a professional technician, and reported on including analysis of year-to-year changes observed. Using drone LiDAR for data collection would allow for many transects to be monitored at limited marginal cost, plus the LiDAR could be used for other purposes. Using a drone would also avoid the need for right of entry permissions to be obtained from each property owner on which a survey is conducted. Alternatively, the Town could purchase an RTK GPS rover for about $30,000 up front plus approximately $5,000 per year in subscriptions, warranties, and O&M costs, and use professional staff from the Highway Department with support from volunteers to manually conduct ground surveys and process and analyze their own survey data. This work should ideally be conducted, and at a minimum be supervised, by professional staff familiar with surveying methods and equipment to minimize data quality issues. If conducting ground survey, the number of transects would be more limited by available labor. It would be reasonable for a professional team to survey 5-10 transects on East Beach and 5-15 transects on Horseneck Beach in one to two days. Additional in-house staff or volunteer time would be needed to process and analyze the data. The Town would need to obtain right of entry permissions from each property owner on which a survey is conducted. The survey equipment could also be used by the Town for other purposes. The data should be made publicly available with metadata including any limitations on liability and intended use by private parties. If Town and volunteer labor is not included in the calculation of costs, then the cumulative cost of the in-house option is cheaper than the contractor option starting in year 3.

Grain size should be sampled a minimum of twice in the first year to capture seasonal variability and then once every few years or if there is a specific project for which grain size data is required. The cost to have samples analyzed by a laboratory is approximately $100 per sample. Assuming 10 samples are taken twice per year, the cost would be $2,000 in year 1 and periodically in years thereafter.

Additionally, one or more water level sensors could be installed to track sea level rise locally, as well as tide range differences between the Let and the open coast. For a water level sensor that can be attached to a fixed dry structure above water, such as the Fontaine Bridge, the cost would be approximately $3,000 for the install and survey controls and $3,800 per year for hardware, data telemetry, and web posting. Depending on the Town's ability to inspect and maintain the sensor, contractor field support could cost up to $2,000 per year.

Informed by the coastal processes study and the results of this vulnerability assessment, points of action could be established and keyed into various stages of the recommended adaptation actions. For example, local annual average MHHW elevation within a set difference from East Beach Road could trigger design and construction of a road elevation increment, or a known vulnerable beach profile and grain size composition would initiate planning for nourishment activities to reduce the chance of roadway undermining.

3.6 Model Coastal Processes to Evaluate the Impact of the Causeway and In-Water Adaptation Strategies

There are several questions, some longstanding (65-100 years) and some new, that could not be answered within the scope of the present study. Answers to these questions are needed to facilitate consensus building on what type(s) of medium- to long-term strategies the Town should invest in:

1. What scale of beach nourishment would meaningfully mitigate overwash and erosion risks on East Beach under present and future scenarios, and how frequently would renourishment be needed?
2. How would removal or modification of the Gooseberry Island Causeway, to reestablish historic alongshore sediment transport, affect the frequency with which beach renourishment would be needed?
3. Though permitting would be a significant challenge with uncertain outcomes under current regulations, are wave attenuation strategies, particularly nature-based/ecological strategies, technically feasible and effective in the East Beach offshore environment?
4. How would opening the Let or allowing a permanent breach to form affect coastal flooding, storm damage, and habitat in the Westport River estuary?

The modeling and analyses developed for the East Beach Corridor Vulnerability Study were designed to answer specific questions about the progression of sea level rise and storm surge, and the current and future probabilities of various coastal flooding impacts along East Beach. To answer the questions identified above, a more detailed understanding of coastal processes along East Beach and Horseneck Beach would need to be developed through data collection, research, and numerical modeling.

Coastal processes govern the dynamic nature of these beaches, interact with barrier beach processes, affect the Westport River and Let side hydrodynamics, and ultimately shape Westport's coastline. Developing a detailed understanding of these governing physical processes, and how coastal infrastructure such as the Gooseberry Causeway may impact sediment supply and transport, or how features like East Beach may affect upstream coastal flood risks and ecology is critical to refining the alternatives identified in this study and identifying community-supported, feasible, sustainable, and cost-effective solutions to the present and future stressors that the East Beach Corridor faces. Additionally, an updated evaluation of existing conditions will not only provide necessary information and data to the coastal processes study, but also serve as a touchpoint for evaluating the feasibility of any proposed solutions.

To develop a workable long-term barrier beach management plan to make the East Beach Corridor resilient to rising sea levels and extreme storm events, it is first necessary to understand the dynamics of the coastal processes that affect the beach. This proposed study would provide the scientific and technical basis for developing a comprehensive resiliency plan for this critical part of Westport's shoreline that balances the protection of property and infrastructure with habitat restoration and natural processes.

The scope of the coastal processes study should include the collection of site-specific wave height and direction data, water surface elevation data, sediment grain size sampling, shoreline change analysis, and the application of computer models to simulate the coastal processes. With properly applied models, backed by real world observations, the performance of various project alternatives (i.e., “what-if?” scenarios) can be predicted and used to make educated decisions about the most cost-effective solution or combinations thereof. The models – including hydrodynamic, wave, and sediment transport models – will provide planning and engineering decision support tools to identify and select projects for implementation, and will enhance understanding of the potential influence of actions in one area of the East Beach Corridor on inter-connected areas. Potential scope elements to be refined in the development of a future study are provided in Sections 3.7.1-3.7.5. The order-of-magnitude cost of completing such a study is $200,000 (if limited to the Buzzards Bay and Rhode Island Sound) to $275,000 (if the Westport River and Let are included).

Ideas from Westport Residents:

- *“Restoring the beach”*
- *“Shift the current or build a barrier against storm surge to protect the beach”*
- *“Replace the Gooseberry Causeway with a raised roadway to allow historical longshore sand flow to resume”*
- *“Alter causeway to Gooseberry with replacement culvert sections to allow flow through”*
- *“Removal or adjustment of the Gooseberry Point causeway”*
- *“Remove causeway to Gooseberry”*
- *“Removing the causeway to restore balance to the currents”*
- *“Study whether installation of culverts between the Let and the ocean across East Beach would help preserve the remainder of East Beach”*
- *“Opening up the let to flow and storm surge”*
- *“The river should be allowed to flow through the inlet as it did in the past… Build a small bridge over the inlet”*
- *“Build a small bridge over the inlet”*
- *“Putting a culvert or some opening beneath the road from the ocean to the river”*

3.7.1 Site Specific Data Collection

The following field data collection and literature research activities are potential elements of a coastal processes study that form the foundation for model development, analysis, and interpretation. The types of data and analyses include, but may not be limited to:

- *Wave Data Observations:* The primary driver for sediment movement and shoreline modifications is the wave energy that impacts the coastline. Therefore, any coastal evaluation must include a good understanding of the waves that are influencing the site-specific coastal location. Site specific wave data in the local regions offshore of East Beach and Horseneck

Beach should be collected to provide an understanding of the wave conditions in the near-shore vicinity of the area, as well as to validate the wave transformation modeling.

- *Tide Data Observations:* Water surface elevation, salinity, and temperature data should be collected and used to calibrate the hydrodynamic model.
- *Grain Size Sampling:* In order to determine the sediment characteristics of the native (beach) material, samples of the beach material should be obtained and analyzed for grain size. This data can be utilized for the sediment transport modeling to determine the anticipated erosion rates and equilibrium beach profile shape. After performing a grain size analysis, the beach sediment data can also be used to determine if future sediment sources are compatible for beach replenishment or other uses.
- *Historical and Geological Change:* In a physical system like that of the East Beach Corridor, the geologic and historical perspective is an important piece of understanding the past history of the region, as well as insight into the future. Regional geomorphic change is the evolution of depositional environments for coastal stretches over extended periods of time. Aerial photographs and topographic and hydrographic surveys of coastal and near-shore morphology provide data for quantifying regional geomorphology and change. Coastal shoreline change and digital bathymetric data for the same region, but different time periods, produce a method for calculating potential sediment movement within a region. This information can then be used for estimating magnitude and direction of sediment transport and "ground-truthing" of the numerical sediment transport models. If sufficient historical data are available, shoreline change analysis may be focused on pre- and post-construction epochs for the Gooseberry Causeway to contribute to the understanding of that coastal structure's impacts.

3.7.2 Hydrodynamic Modeling

A hydrodynamic model of the East Beach Corridor study area will summarize the overall coastal process in the region, and can be used to assess existing conditions along the beaches and in the Let. Model development includes model setup and defining inputs, model calibration and validation, and then simulation of how the system and hydrodynamics interact with the beach and sediment transport patterns. Results of the modeling effort provide insights on erosion and deposition, shoaling concerns, and circulation patterns behind the barrier beach. The model can be run for normal tidal conditions, storm conditions, and potential sea level rise scenarios, and used to develop conceptual alternatives affecting the Westport River and Let environments.

3.7.3 Wave Transformation Modeling

The impact of waves on near-shore processes and shoreline change is highly dependent on the offshore wave climate and transformations to the shoreline. Wave modeling is required to simulate wave and current processes that drive coastal sediment transport. One of the primary advantages of wave modeling is the ability to simulate multiple scenarios (e.g., evaluation of various restoration configurations, initial evaluation of varying beach nourishment or structural templates, etc.). The wave input can also be modified to simulate a wide range of wave conditions (e.g., storm events, seasonal variations, etc.) and therefore determine the changing impacts on the shoreline.

3.7.4 Sediment Transport Modeling:

From the wave modeling results, wave-induced currents, and sediment transport fluxes (rates and directions of sand movement) can be developed to indicate the net sediment transport potential along East Beach and Horseneck Beach. Areas of convergence and divergence (patterns of erosion and accretion) can be determined to identify spatial variations in sand movement. The sediment transport model can provide a physically-based representation of alongshore currents and sediment transport driven by breaking waves in the surf zone. The existing movement of sediment can be identified, and subsequently the influence of various alternatives on the sand movement can be determined.

3.7.5 Conceptual Resilience Alternatives:

A flexible approach to the evaluation of alternatives is essential. Field data collection and modeling, such as those described above, can provide a comprehensive picture of the coastal processes in the East Beach Corridor. Using these informational pieces, conceptual alternatives can be developed that intend to provide increased resiliency to the East Beach Corridor (in general) and East Beach Road (specifically), while also enhancing coastal resources and habitat. Once developed, other alternatives can be evaluated cost-effectively. Stakeholders should collaborate to ensure the resilience alternatives developed are consistent with community goals and are feasible to implement from both a regulatory and construction standpoint. Based on the findings of the East Beach Corridor Vulnerability Study and stakeholder input received during the public engagement process, resilience alternatives to be evaluated could include (a) the various roadway elevation and beach nourishment configurations for East Beach Road, (b) offshore wave attenuation designs such as an offshore berm or breakwater, (c) the removal or modification of the Gooseberry Island Causeway, and (d) the opening or breach of the Let. These – and potentially other – alternatives should be tested with the model to evaluate their effectiveness at achieving desired coastal resiliency goals.

3.7 ELEVATE EAST BEACH ROAD AND COASTAL DUNES ON ABUTTING PROPERTIES

There is substantial support among the Town and local stakeholders for incrementally raising East Beach Road and portions of abutting private properties as a feasible and acceptable strategy to mitigate future increases in coastal flooding risks due to climate change. The goal of this strategy is to mitigate future increases in exposure of the roadway to coastal flooding hazards and associated impacts, while maintaining the viability of seasonal trailer uses on private properties that abut the roadway. Other indirect benefits include mitigation of future increases in flood-related risks to public safety, emergency access and egress, utility services, recreational resources, small business income, and tax revenue.

Implementing this strategy can help mitigate increases in exposure and impacts from storm surge inundation and tidal inundation over time. However, assuming that the existing barrier beach profile and subsequent incremental changes are maintained, either naturally or through ongoing intervention, the risk of overwash, major erosion, and breach will likely continue to increase over time but at a slower rate than if no action is taken. To mitigate overwash and erosion further, this strategy would need to be paired with others such as beach nourishment, wave attenuation, or property acquisition to enable roadway realignment and a wider and higher cobble dune (with associated tradeoffs in the objective to maintain existing uses). Additional study is recommended to enable more detailed evaluation of the feasibility and efficacy of the former two strategies in Section 3.7.

Ideas from Westport Residents:

- *"Protect the road"*
- *"Move the road north on the west end"*
- *"Consider raising height of road if feasible"*
- *"Increase elevation of Cherry & Webb and East Beach"*
- *"Coordinate a private/public beach nourishment project with East Beach residents"*
- *"Planting more vegetation along the road"*

3.8.1 Conceptual Adaptation Alternatives

Conceptual adaptation alternatives were developed that can be used as a guide for future implementation of this strategy. Project-specific engineering design and environmental permitting will be required for these concepts to be realized through construction.

3.8.1.1 Existing Conditions

Cross-shore topographic transects, oriented approximately perpendicular to the East Beach Road centerline, were taken in GIS using the latest publicly available Lidar elevation data. Transects were taken at several locations between Horseneck Road and John Reed Road. Two transects, representative of typical conditions in low-lying roadway sections on East Beach Road, were selected for developing alternative corridor elevation concepts. In addition to these typical conditions, different conditions prevail around the bend in East Beach Road, along Horseneck Road, and at the intersections with John Reed Road.

Figure 43 and Figure 44 shows the cross-shore elevation profiles and land classifications for the selected transects. Transect 1, shown in Figure 43 in brown, was selected from an area where the roadway layout runs close to the center of the barrier beach landform. Transect 2, shown in Figure 44 in gray, was selected from an area where the roadway layout runs closer to the ocean shoreline. Mean High Water (MHW) elevations under present conditions (2008) and projected future sea level rise time horizons (2030-2050, 2050-2070, and 2070-2100) are superimposed in red for reference. The elevations, slopes, and land classification boundaries shown in these and all diagrams that follow are approximate and for illustration only.

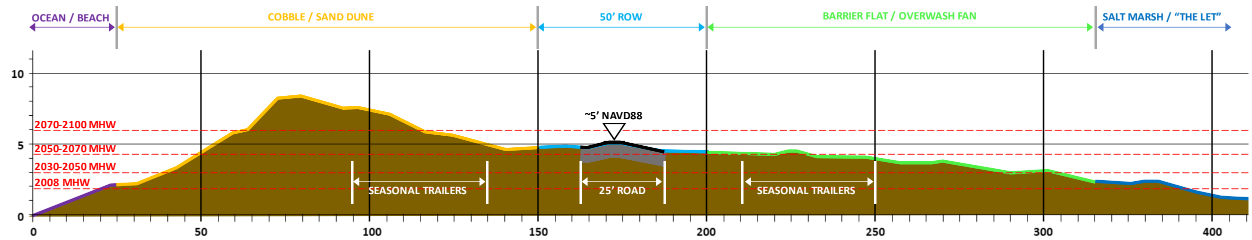


Figure 43 **Existing elevation profiles and land classifications for Transect 1.**

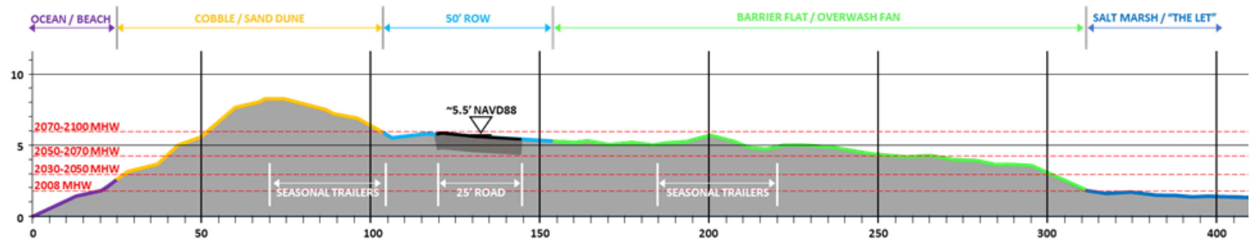


Figure 44 **Existing elevation profiles and land classifications for Transect 2.**

3.8.1.2 Design Guidelines

The following design guidelines were applied to develop a set of reasonable conceptual alternatives for incrementally raising the East Beach corridor over time:

- Except for the roadway surface, base, and subbase, all fill material should be within the range of existing barrier beach sediment characteristics. (See later sections for additional considerations for a buried roadway erosion protection gabion)
- No fill should be proposed below the mean high water line or areas with existing salt marsh vegetation to avoid triggering more complex, lengthy, and costly permitting processes with more uncertain outcomes.
- The roadway pavement should be no more than 25 ft wide, including two 10 ft lanes, and be located within the existing Town-owned roadway layout property boundaries.
- The roadway pavement should have a minimum cross-slope of 1.5-2% from the centerline to each edge-of-shoulder for drainage.
- The unpaved roadway shoulders should not exceed 25 ft in combined width and be located within the existing Town-owned roadway layout property boundaries.
- The roadway shoulders should have cross-slopes of no less than 1.5% for drainage and no more than 10% to avoid creating hazards for trailer towing.
- A minimum 30- to 40-ft wide set-aside on each side of the roadway, measured from the roadway layout property boundaries, should be reserved for the siting of trailers and accessory structures within which cross-slopes should be within 1.5 to 4%.
- The trailer set-asides to be raised on properties abutting the Let should not be expansive to keep the project below 10 acres of alteration, avoid impacts to regulated habitat, and conserve space for future marsh migration due to sea level rise.

- The foreslope and backslope of proposed cobble dunes on the Atlantic side and embankment tying back to existing grade on the Let side should not exceed 14.3% (1:7).

3.8.1.3 Incremental Concepts and Alternatives

Adaptation concepts were developed for three increments of roadway raising for each transect, shown in Figure 45 and Figure 46. The first increment of raising is approximately 1 to 1.5 ft higher than the existing roadway elevation, the second increment is 1 ft higher than the first increment, and the third increment is 2 ft higher than the first increment. Within each increment, two to three conceptual alternatives were developed representing low (white dashed lines and labels), high (no line and lighter colored labels), and in some cases medium (darker colored dashed lines and labels) levels of intervention on abutting properties.

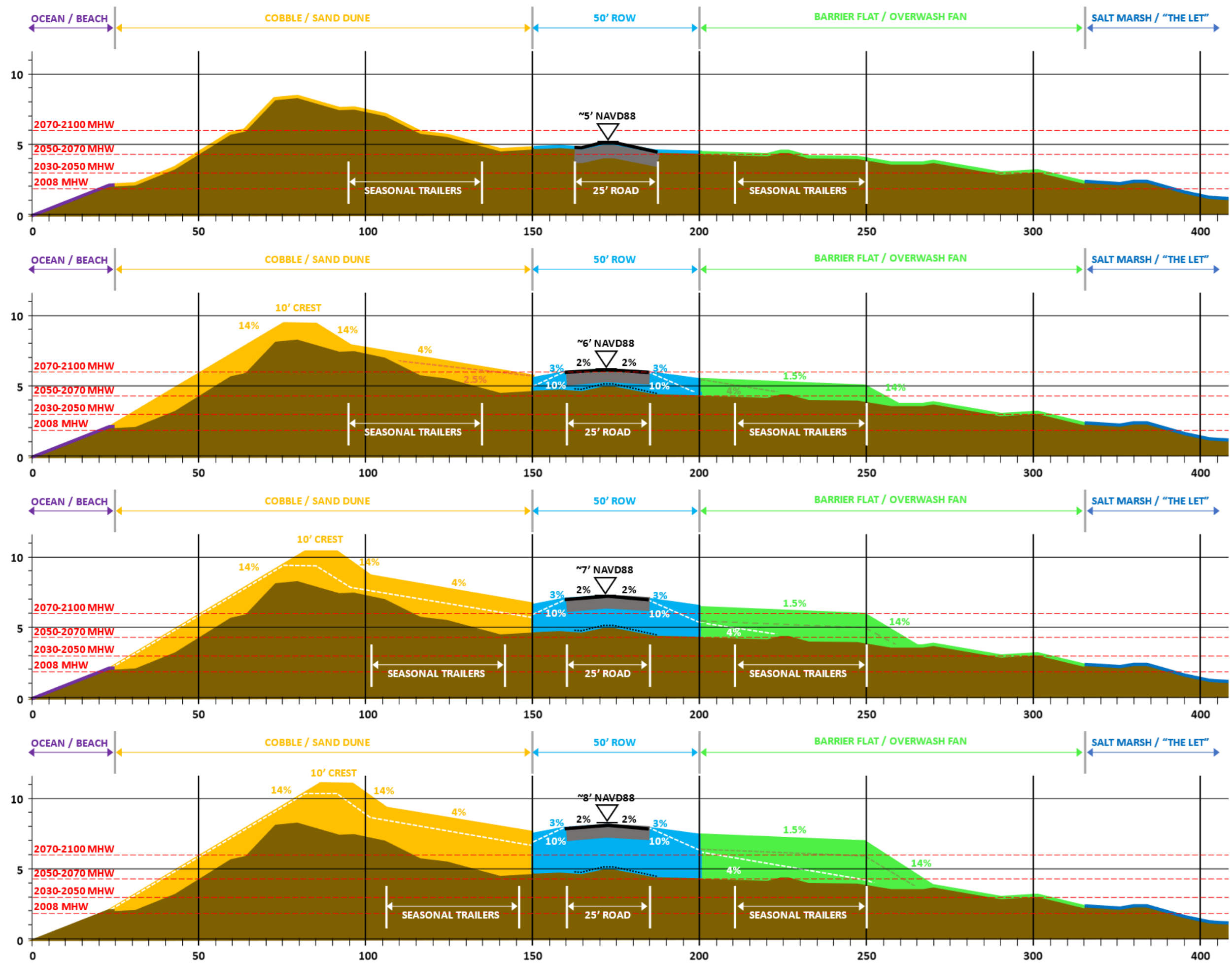


Figure 45 **Incremental dune and roadway raising concepts and alternatives for Transect 1.**

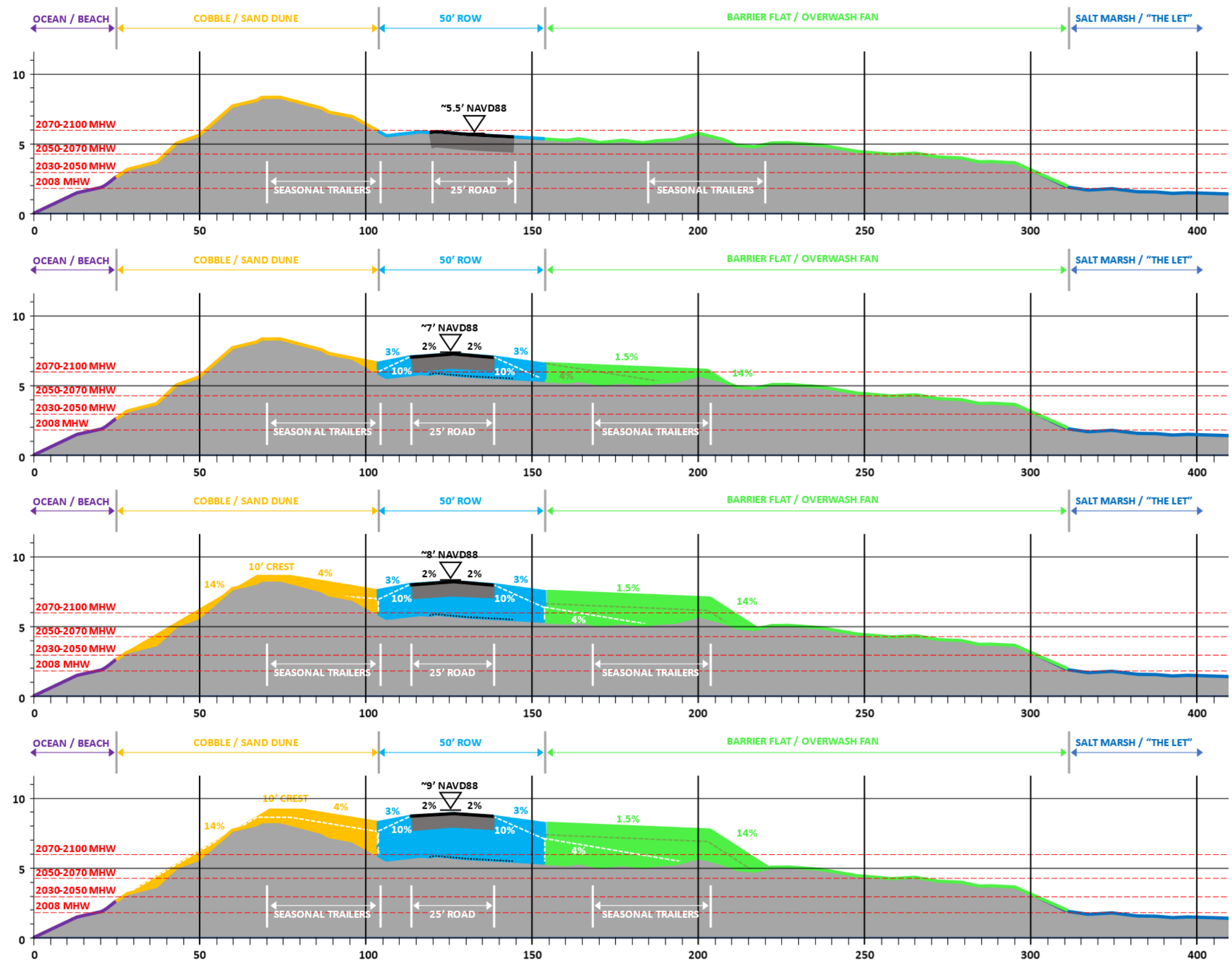


Figure 46 Incremental dune and roadway raising concepts and alternatives for Transect 2.

3.8.1.4 Implementation Phasing

Incremental corridor raising should be implemented through the natural capital cycle, meaning that it should become a part of ongoing road maintenance, planned capital improvements, and emergency repairs or reconstruction following coastal storm damage events. Leveraging the natural capital cycle is more cost-efficient than raising the corridor as a standalone hazard mitigation action because it leverages the base costs of designing, permitting, and constructing a normal road or property improvement project.

The increment to which the corridor should be raised and time between increments of raising should be based on 1) the severity and frequency of coastal flooding hazard exposure and impacts the Town and abutting property owners are willing to live with, 2) the ability and willingness to pay the associated costs of mitigating unacceptable risks, 3) the amount and speed of sea level rise and associated coastal hazard intensification, and 4) the willingness of the Town, private property owners, and other partners to cooperate on implementation. These factors should be periodically reevaluated as they evolve over time, and the incremental implementation strategy can adjust accordingly.

It is assumed for planning purposes that the increments would be implemented sequentially over time, with the first increment completed in the near future, the second increment completed around 2030-2050, and the third increment completed around 2050-2070. This assumes that RSLR follows a track between the Intermediate and High scenario. However, if monitoring indicates that RSLR is following a lower or extreme scenario, the time between increments could be extended or contracted.

3.8.1.5 Hazard Mitigation Benefits

The low level of intervention seeks to minimize costs and area of disturbance on private properties while still allowing for the roadway to be raised to an equivalent elevation (and achieve similar risk mitigation) as in the high level of intervention. Under the low level of intervention, coastal flooding risks on abutting properties are greater in the future time horizons than they are under present conditions, though not as high as they would be if no actions were taken.

The high level of intervention is intended to mitigate increases in storm surge and tidal flooding risks for the roadway and abutting properties over the 10 years (for the first increment) or 20 years (for the second and third increments) that follow implementation, such that the risks in 2030-2050, 2050-2070, and 2070-2100 are no greater than the present risks. If climate changes are slower or less intense than projected, the time between increments would be longer.

Based on the MC-FRM, the roadway and some seasonally occupied portions of the abutting properties on the ocean side are presently expected to be exposed to storm surge flooding at a 30-50% annual probability level (i.e., 2- to 3-year recurrence). Some seasonally occupied portions of the abutting properties on the Let side are expected to be exposed to storm surge flooding at a 30-100% annual probability level (i.e., 1- to 3-year recurrence). Assuming the implementation sequence at a high level of intervention described above, completion of each increment of raising would temporarily reduce the annual probability of flooding to 10-25% (i.e., 4- to 10-year recurrence) for the roadway and ocean side properties and about 25-50% (i.e., 2- to 4-year recurrence) for the Let side properties. These benefits would be reduced over the decades that follow, as sea level rises and storm frequency and intensity increase, until the roadway and abutting properties are eventually back at their present level of risk. This cycle of temporary reduction in risk and eventual return to present risk levels reoccurs after each increment of raising under the high level of implementation. This is a significant reduction in risk compared with the expected impacts if no action is taken, described in Section 2.3.2.3.

The roadway and abutting properties are presently above the projected daily high tide flooding elevation of 3.2 ft-NAVD88 for 2030-2050. Under the high level of intervention, implementation of the second increment of raising around 2030-2050 would mitigate the risk of daily flooding at elevation 4.5 ft-NAVD88 through 2050-2070, and implementation of the third increment around

2050-2070 would mitigate the risk of daily flooding at elevation 6.3 ft-NAVD88 through 2070-2100.

These benefits apply to storm surge and daily tidal inundation risks only. Evaluation of how the alternatives perform at mitigating overwash and major erosion risks is beyond the scope of the present study. Based on engineering judgement, it is reasonable to assume that the risk mitigation benefits of incremental raising will be less for overwash and major erosion than for storm surge and tidal inundation.

3.8.1.6 Conceptual Order-of-Magnitude Costs

High-level parametric cost estimates (i.e., dollars per linear foot) were developed for implementing the low and high conceptual adaptation alternatives under typical conditions shown in Figure 47 and Figure 48. Estimated quantities, based on GIS measurements and the conceptual illustrations, were multiplied by standard unit costs for roadway reconstruction and upland source fill material, delivery, and construction, based on RS Means and engineering judgement. Standard markups, including for General Conditions (15%), Overhead and Profit (10%), Insurance and Bonds (1.5%), Engineering Costs (15%), and Contingency (25%), were applied to estimated construction costs to calculate a total estimated cost per linear foot. Escalation factors were not applied, given the long range and uncertain planning horizons.

The parametric costs are cumulative to avoid double counting of costs associated with prior increments of raising. Figure 47 costs include the recurring cost of reconstructing the roadway as part of each increment. Figure 48 costs exclude the roadway reconstruction costs, which account for approximately 17-37% of the total cost per linear foot through the third increment, recognizing that the Town would reconstruct the roadway every 10-30 years under the normal capital cycle and following major damage events without the additional impetus of adapting to climate change.

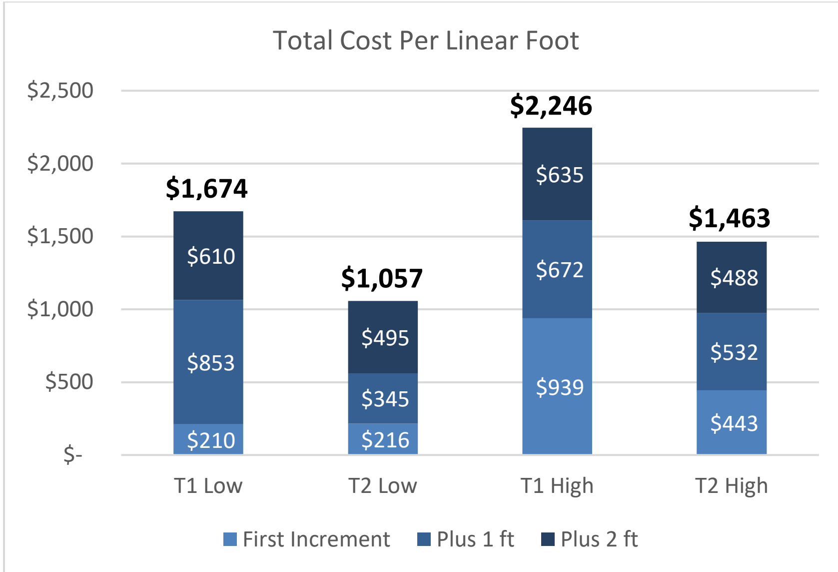


Figure 47 **Estimated costs per linear foot for incremental corridor raising with roadway reconstruction.**

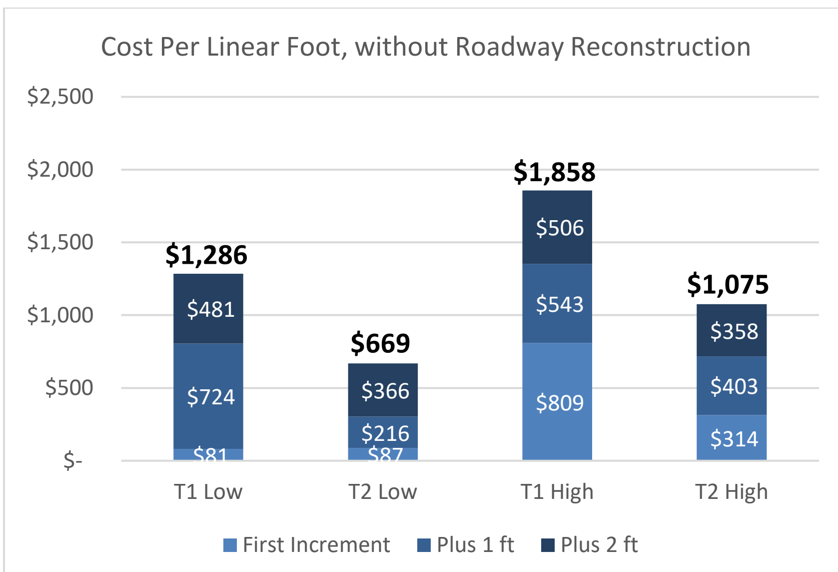


Figure 48 **Estimated costs per linear foot for incremental corridor raising without roadway reconstruction.**

Next, the order-of-magnitude parametric costs (including roadway reconstruction) were multiplied by the lengths of low-lying roadway to be raised on the East Beach corridor in each increment. The parametric cost applied to each length of roadway was based on judgement as to whether existing conditions more closely match Transects 1 or 2. For the second and third increments to be effective, low-lying portions of Horseneck Road would also need to be raised at an estimated parametric cost of $103 per linear foot for the second increment and $145 per linear foot for the third increment. Costs for raising the John Reed Road intersection are not included, as it is not owned by the Town.

Two methods were used to calculate a range of potential total project costs:

- In the first method, each increment of raising was tied to a target elevation to which low-lying sections would be raised (i.e., first increment raises low-lying sections to 6 ft. NAVD88, second the 7 ft NAVD88, third to 8 ft NAVD88). Judgement was applied in the calculation of fill quantities and costs to account for the fact that the road would need to be tapered down to meet existing grades abutting the low-lying sections to be raised, resulting in lower total costs.
- In the second method, each increment of raising was treated as absolute using the exact quantities and costs developed based on the typical transects, resulting in higher total costs.

The resulting total project cost estimates are shown in Table 18, rounded up to the next thousand dollars. The results show that pursuing the high level of intervention has a roughly three to four times higher cost in the first increment than the low level of intervention, but they have similar costs in the second and third increments. Due to this differential in first increment costs, total project costs through the third increment are approximately 20-30% higher for the high level of intervention compared with the low level. Importantly, the high level of intervention provides substantially greater flood mitigation benefits for the private properties abutting East Beach Road.

Table 18 Range of total project costs for increments of corridor raising.

Increment	Description	Total Length of Intervention	Costs by Level of Intervention	
			Low	High
First increment	Raise sections with roadway elevations lower than 6 ft. NAVD88 to 6 ft. NAVD88	2,265 ft.	$413,000	$1,396,000
Second increment	Raise sections with roadway elevations lower than 7 ft. NAVD88 to 7 ft. NAVD88	3,580 ft.	$1,819,000	$1,746,000
Third increment	Raise sections with roadway elevations lower than 8 ft. NAVD88 to 8 ft. NAVD88	4,945 ft.	$2,323,000	$2,342,000
Total Cost			*$4,555,000*	*$5,484,000*
First increment	Raise sections with roadway elevations lower than 6 ft. NAVD88 by first increment	2,265 ft.	$481,000	$1,780,000

Second increment	Raise sections with roadway elevations lower than 7 ft. NAVD88 by second increment	3,830 ft.	$2,000,000	$2,050,000
Third increment	Raise sections with roadway elevations lower than 8 ft. NAVD88 by third increment	4,295 ft.	$2,112,000	$2,134,000
Total Cost			*$4,593,000*	*$5,964,000*

Certain costs are not included in the order-of-magnitude estimates above, including but not limited to the following:

- *Utility poles:* The risks to the main line of utility poles from coastal flooding hazards were estimated to be low relative to other potential impacts, particularly in the near to medium-term. Additional investigation is required to determine whether existing utility poles could simply be left in place during the corridor elevation construction work or would need to be replaced, reset, or relocated. Burying the poles to greater depths would in concept make them less vulnerable to scour and erosion-based failure. Applying the same markups as used for the estimates presented above, the cost of replacing one electrical utility pole is estimated to be approximately $6,700, not including associated electrical work. If utility poles need to be altered, the utility company that owns the poles would produce their own authoritative estimate of the cost for the project, as they would be responsible for conducting the work.
- *Private property:* The cost of removing, storing, and returning existing accessory structures (decks, sheds, etc.), fences, mailboxes, bollards, and other assets located on private properties to be elevated are also not included. The costs of removing and reinstalling or making modifications to existing underground tight tanks and wells that may be required due to the addition of fill on private properties and the costs associated with any unknown hazardous material identification, management, and disposal are also not included.
- *Roadway erosion protection:* A non-erodible underground barrier on the ocean side edge of the roadway could substantially mitigate the risks of major damage to the roadway and a breach at the Let. One strategy that has the potential to pass regulatory scrutiny would be to construct a buried gabion, filled with barrier beach compatible cobble material, which would function as part of the roadway substructure. Dura-Guard™ is one of several gabion products that is advertised as being "constructed of durable, non-corrosive, and environmentally friendly" geotextile material, suitable for use in coastal erosion protection applications. The order-of-magnitude cost of constructing a 3 ft. wide by 6 ft. deep gabion is estimated as approximately $204 per linear ft, including the same markups as used for the estimates presented above. When applied to the total linear distances of each increment in Table 18, the project costs with the gabion would increase by approximately $461,000 for the first increment, an additional $268,000 to $319,000 for the second increment, and an additional $95,000 to $278,000 for the third increment, totaling $874,000 to $1,006,000 through the third increment. Costs could increase or

decrease from those provided here based on gabion sizing to be determined during design and permitting. Due to regulations prohibiting coastal engineering structures from being constructed on barrier beaches in Massachusetts, implementation of this strategy may not be feasible if the gabion is interpreted as a coastal engineering structure from a permitting perspective. Implementation of this strategy would depend on development of a sound rationale that complies with barrier beach and coastal dune performance standards, the interpretations of environmental regulators, and budgetary constraints.

- *Maintenance:* The life-cycle cost of maintenance of fill volumes and grading for each increment of raising, and potential increase in roadway clearing activities from any additional sediment overwashed in storms is not included. Cross-shore modeling of alternatives, proposed as part of the design process, should be used to estimate the recurrence of significant sediment loss and the associated volume and cost of fill that would be required to renourish to design levels. The majority of overwashed sediments are not likely to be lost from the barrier beach system and may result in a natural increase in elevation on the Let side of the barrier between incremental raising.

3.8.2 Governance

The most critical factor to successful implementation of the strategy described above and achievement of its potential benefits are the willingness of the Town, abutting private property owners, and other potential partners to cooperate on implementation.

To illustrate this point, consider that if the Town and private property owners work together, it would be technically feasible (setting financial and permitting constraints aside) for the roadway to be raised as high as 9 to 12 ft above existing grade while maintaining at least 30 to 40 ft of relatively flat land on both sides of the road for seasonal trailer parking. However, wherever abutting property owners decline to participate, the Town would be limited to making improvements within Town-owned roadway layouts and properties in the corridor. Where so limited, the Town can only implement the first increment of raising at a low level of intervention, raising the roadway by an increment of no more than 1.5 ft, while maintaining a reasonable 10% shoulder slope for vehicles towing trailers to cross onto abutting properties.

Raising the roadway without also raising the primary frontal dune on ocean side properties would leave the roadway exposed to greater risks of major damage from coastal storms, as the dune provides a first line of defense from wave-induced erosion. Not raising low-lying properties on the Let side would leave the roadway exposed to tidal inundation over the longer term. A vulnerable roadway would negatively impact abutting property owners, who rely on it for access and utilities. Without cooperation, both the roadway and private properties will be less resilient to present and future coastal hazards.

Prior to beginning design and permitting efforts in earnest, the Town Board of Selectmen and departmental leadership, all willing private property owner participants, and any other willing partners (e.g., DCR) should establish a Memorandum of Understanding (MOU) that will govern the process of cooperation through each phase of the project including design, permitting, legal agreements, construction, and monitoring and maintenance. To minimize transaction costs in negotiating and implementing the MOU, it would be ideal for private property owners to act through a single legal entity, such as the existing East Beach Improvement Association. The MOU should articulate the justification and conditions for the parties' agreement to cooperate, their shared goals, and the general design concept that the parties agree to advance (e.g., which increments and levels of intervention). It should also describe their respective expectations, rights, roles, and responsibilities, including how costs will be distributed amongst the parties. It should also anticipate and provide contingencies in the event that post-storm emergency repairs may be needed before the project is constructed. The MOU can be amended as needed to account for changes in conditions resulting from the design and permitting process or other external factors. An example of a similar type of agreement is the MOU and its Amendments between the Town of Nantucket and Siasconset Beach Preservation Fund, Inc. for the protection and/or relocation of Baxter Road, including scenarios where post-storm emergency repairs are needed.

Other forms of legal cooperation will be required as the project moves through implementation. As examples, parties to the MOU on whose land improvements are proposed will need to jointly or individually execute land access agreements to authorize survey, construction, monitoring, and maintenance activities to be carried out by others; environmental permitting applications and deed recordings; and any agreed upon easements or licenses required for construction.

3.8.3 Design and Permitting

Design and permitting will be an iterative process, conducted in advance of construction of each increment of corridor raising. The design and permitting process described below centers on a hypothetical near-term project to implement a single initial increment of corridor raising within the boundaries of property owned by parties to the MOU. It has been assumed that the Town and at least some abutting property owners will agree to cooperate on this project.

The framework for cooperation on design and permitting should be defined by the MOU. Therefore, no prejudgments have been made regarding which entity would be responsible for managing the design or permitting process, particularly for the portions of the project on private property. It has been reasonably assumed that the Town Highway Department would lead the roadway design components. Responsibilities for other elements of the scope described below would be subject to negotiations.

The design and permitting phases of the project are likely to be at least a 2-year effort, particularly if successive cycles of competitive State grant funding for municipal climate resilience initiatives are obtained to support the project. Litigation, including appeals of regulatory decisions, could extend this timeframe by up to 2 years. Each grant cycle typically has a 6- to 10-month working term tied to annual application cycles, fiscal year appropriations, and public bidding of resulting contracts. The granting agencies recommend that grantees do not propose to complete full design and permitting in a single grant cycle to ensure they can reasonably be completed by the end of the fiscal year. It would be beneficial for work to be conducted during the "dormant" periods between grant funding cycles to prime the process to maximize the value of limited grant funding and performance periods. An as-needed, non-State funded contract would also be beneficial as a contingency measure so that out of scope issues of importance that arise during the design and permitting process need not be delayed until future grant funding cycles.

The scope will be multi-disciplinary, including survey, environmental permitting; and geotechnical, coastal, and transportation engineering.

3.8.3.1 Survey and Wetlands Mapping

A basemap of the project area will be needed to document property boundaries, existing conditions, and wetland resource areas as a basis for the development of design, permitting, and legal documents.

The following activities should be included:

- Execute rights of access agreements with all participating private property owners for field survey and wetlands delineation to develop the basemap. The MOU should include commitment to and conditions for the granting of access rights for these purposes.
- Rights-of-way and property lines from assessor's plans, current deeds, and plans of record should be researched and located. Additional effort may be needed to resolve discrepancies between information sources as to the locations of these boundaries.
- Visible surface features, such as roadway centerline, edge of pavement, utility poles, fences, buildings and accessory structures on private properties should be located based on field survey.
- Utility locations, septic structures, and wells should be located based on record information and field survey.
- The condition of existing utility poles should be documented and assessed to inform replacement decisions.
- Vertical clearances of overhead utility lines should be measured and analyzed in coordination with utility owners to determine what level of land raising would reduce the clearances below minimum thresholds.
- Topographic data should be collected, including spot elevations in sufficient detail to map existing conditions and contour the project area and along cross-shore transects to inform coastal engineering.
- Sediment samples should be collected from the beach, primary coastal dune, and overwash fan and sent to a testing laboratory for grain size analysis. At least two rounds of sampling should be conducted, once in the summer and once in the winter, to account for seasonal variation. These samples are taken from the surface, in contrast with geotechnical borings taken to deep subsurface levels. Grain size information is necessary for refining coastal modeling inputs and identifying suitable sources of fill material.
- Wetland resource area types and locations (including buffers) should be delineated in conformance with the Massachusetts Wetlands Protection Act and associated regulations

and guidelines. A wetland delineation narrative should be prepared describing the vegetation types and characteristics of each coastal resource area encountered on site for use in future permitting applications.

- Identify and map Priority Habitat of Rare Species and Estimated Habitats of Rare Wildlife within the project area based on the 14th Edition of the MA National Heritage Atlas.

3.8.3.2 Geotechnical Investigation

Geotechnical borings within the Town-owned roadway layout(s) will need to be performed, tested, and analyzed to support the roadway design, due to the potential for settling or instability that could result from large volumes of fill material associated with the incremental design concepts. The Town can conduct this work prior to execution of the MOU.

The following activities should be included:

- For approval of the boring locations, a permit application with a boring locus map should be prepared and submitted to the Westport Conservation Commission and a Project Notification Form should be prepared and filed with the Massachusetts Historical Commission and MA Board of Underwater Archeological Resources.
- Test pits may also be recommended to observe and characterize the existing roadway subsurface conditions.
- Following approval, DigSafe should be contacted and four borings should be taken to a 25- to 30-ft depth along the roadway and sent to a testing laboratory for grain size analysis.
- The testing results should be used to prepare a recommended design for the sub-base, base, and surface course materials for the raised roadway and potentially to inform inputs to coastal modeling and interpretation of coastal modeling results.

3.8.3.3 Environmental Permitting

The environmental permits that are ultimately required for approval to implement the initial project and subsequent increments will depend on the scale and scope agreed upon in the MOU and refined through the design and permitting process. For this section of the report, it is assumed that the initial project would be similar to the first increment of raising at the high level of intervention described in earlier sections.

In such a scenario, the project would trigger public notice and comment, review, and approval requirements under the following environmental laws and associated policies and regulations:

- MA Wetlands Protection Act (WPA) administered by the Westport Conservation Commission and adjudicated by the MA Department of Environmental Protection (MassDEP);
- MA Environmental Policy Act (MEPA) administered by MassDEP’s MEPA Office;
- MA Endangered Species Act (MESA) administered by MassWildlife’s National Heritage and Endangered Species Program (NHESP) office; and

- If Federal funding is used to assist the project, a federal consistency review from the MA Office of Coastal Zone Management (CZM), though CZM will have review authority under MEPA regardless of whether federal funding is used.

The following design guidelines, identified earlier in this report, should be followed in the development of alternatives to avoid triggering additional environmental regulatory approvals or increasing permitting difficulty:

- No fill should be proposed below the mean high water line or areas with existing salt marsh vegetation.
- Except for the roadway surface, base and subbase, all fill material should be within the range of existing barrier beach sediment characteristics. If pursued as a design strategy, the gabion grid material would be an exception to this guideline.
- The trailer set-asides to be raised on properties abutting the Let should not be expansive to keep the project below the 10 acres of alteration threshold for triggering an Environmental Impact Report under MEPA regulations, avoid impacts to NHESP-regulated habitat, and conserve space for future marsh migration due to sea level rise.

The following activities should be included in the environmental permitting scope:

- *MEPA:* An Environmental Notification Form (ENF) will need to be prepared and submitted to the MEPA Office for interagency review and approval due to the project's location within a FEMA VE Zone and barrier beach. This assumes that the project area of alteration can be limited to less than 10 acres. The second and third increment of raising are almost certain to exceed 10 acres of alteration and trigger the need to develop and submit an Environmental Impact Report. Significant components of the ENF include a detailed project narrative and alternatives analysis identifying the environmental impacts associated with each alternative; supporting the selection of the preferred alternative; and demonstrating that the project avoids, minimizes, and mitigates environmental impacts to the maximum extent feasible. Pre-application consultations with the MEPA Office and agencies such as CZM, NHESP, and, as needed, others should be conducted to inform the alternatives analysis, including the scope of alternatives and evaluation criteria to be considered.
- *WPA:* A Notice of Intent (NOI) will need to be prepared and submitted to the Westport Conservation Commission for review and issuance of an Order of Conditions due to the project's location within multiple wetland resource areas. In addition to the MEPA alternatives analysis, proposed maintenance (including emergency post-storm repairs and recovery) and monitoring conditions should be developed. Pre-application consultations with the Commission and, possibly, NHESP (see below) should be conducted. In addition, active Orders of Conditions in the project area for sediment nourishment, the roadway, and, as needed, other existing structures (accessory structures, septic tanks, wells, utility poles) should be compiled and reviewed to determine what has been approved under precedent permitting.

- *MESA:* The project area is likely to include Priority Habitat of Rare Species and may include Estimated Habitats of Rare Wildlife based on the 14th Edition of the MA National Heritage Atlas. To determine how this may impact the project design or construction, site-specific information on the habitats in the project area must be requested from NHSEP. Pre-application consultations with NHESP should be conducted in coordination with MEPA or WPA consultations. If the subject habitats cannot be avoided through project design, a MESA Project Review Checklist and required project information must be submitted for review and determination of whether the project will result in a "Take" of a state-listed species. If the project is determined to result in a Take, it must either be revised to avoid the Take or a MESA Conservation and Management Permit application would need to be developed and submitted demonstrating that the project will meet the performance standards required for permit issuance.

All permit applications would need to be jointly signed by all participating property owners within the limits of work. Orders of Conditions issued under the WPA would need to be recorded against the deeds of each property. It is critical that commitment to joining in permitting applications in a timely manner is agreed to by parties of the MOU and that subsequent cooperation in design and permitting is carried according to the principles agreed to.

3.8.3.4 Coastal Engineering

Coastal engineering will be needed to design a sediment nourishment template and grading plan within the limits of work that is preferred by parties to the MOU and permittable under existing environmental regulations to which the project approval is subject. Coordination between environmental permitting and coastal engineering tasks will be critical to maximize efficiency.

The following activities should be included:

- At least three alternatives meeting the design guidelines recommended in this report should be refined, based on any guidance in the MOU and pre-permitting consultations. At least one alternative should include an underground gabion for roadway erosion protection unless it has been categorically rejected by regulators in pre-permitting consultations or has been deemed unaffordable. Existing (no build alternative) and proposed grading profiles for each alternative should be developed at an expanded number of cross-shore transects to represent the range of typical existing conditions along the corridor. Proposed profiles should be analyzed in relation to the evaluation criteria established for the project alternatives analysis and inform selection of a preferred alternative. Criteria may include resource area impacts, NHESP priority habitat impacts, quantity of fill, cost, and others potentially identified by regulators or parties to the MOU.
- Hydrodynamic cross-shore modeling of alternatives at each transect should be performed under a selection of storm surge and wave parameters from the distribution of recurrence intervals (e.g., 2-, 5-, 10-, 20-year recurrence) under present and future sea level conditions relevant to the expected service life of the project (considering its incremental

nature). The results should be analyzed to assess the effectiveness of alternatives at mitigating overwash and erosion-based damage and inform the selection of a preferred alternative.

- Long-shore transport of sediment proposed to be added to the corridor should also be evaluated at a high level, as required to inform environmental permitting.
- The coastal processes and engineering alternatives analysis should be documented in a technical memorandum with narrative and figures suitable for integration in environmental permitting applications. The narrative should include a description of each alternative analyzed including the preferred alternative, the methods and results of coastal modeling performed, and the rationale for the selection of the preferred alternative. The preferred alternative may be a hybrid of two or more of the alternatives evaluated. Anticipated means and methods for construction of the preferred alternative should also be included.
- Engineering design drawings, specifications, and estimates of probable construction costs should be developed based on the preferred alternative cross-shore profiles. Design drawings should consist of construction phasing, site preparation, grading, material, and planting plans; profiles; typical sections; and details. The design should cover activities proposed on public and private properties abutting the East Beach Road layout within the limits of work. Coordination with other disciplines may be required to address temporary or permanent alterations to existing accessory structures or other improvements located in areas to be raised, depending on the MOU agreement. Drawings, specifications, and cost estimates should be developed in phases, with refinement and greater levels of detail included in each successive phase, to facilitate the incorporation of input from MOU parties and regulators. The plans should be coordinated with roadway design and be suitable for supporting environmental permit applications.
- Coastal engineering input should also be provided for the development of a monitoring and maintenance plan (including for post-storm emergency repairs and recovery) to support environmental permitting. Elements may include a process for monitoring cross-shore profiles to ensure grades do not exceed permitted limits (e.g., in shorebird nesting habitat), thresholds of erosion under which renourishment is allowed as a maintenance or emergency repair activity, and allowances for the redistribution and regrading of overwash sediment on private lots on the ocean side.

3.8.3.5 Roadway and Utility Design

Transportation and other engineering disciplines will be required to design the elevated roadway within the Town-owned layout and coordinate modifications to utilities and access with abutting properties and intersecting roadways.

The following activities should be included:

- Engineering design drawings, specifications, and cost estimates should be developed for the horizontal and vertical alignment of the roadway within the limits of work. Design drawings should consist of construction phasing, site preparation, erosion control, grading, and material plans; profiles; typical sections; and details. The scope of the roadway design should include the roadway (surface and subsurface), unpaved shoulders and driveways, and intersections with other existing roadways as applicable. The roadway design may also include the buried gabion for erosion protection. Drawings, specifications, and cost estimates should be developed in phases, with refinement and greater levels of detail included in each successive phase, to facilitate the incorporation of input from MOU parties and regulators. The plans should be coordinated with coastal engineering design and be suitable for supporting environmental permit applications.

- A Stormwater Report and Checklist should be prepared, as required under WPA regulations, for the roadway drainage system. It is assumed that the existing country drainage design would be maintained, though best management practices beyond those current in place may be required based on findings of the Stormwater Report.
- Roadway engineering input should also be provided for the development of a monitoring and maintenance plan (including for post-storm emergency repairs and recovery) to support environmental permitting. Elements may include allowances for the collection of sediment overwash deposited on the roadway and redistribution of sediments onto private lots on the ocean side following storms.
- Modifications to utility poles within the Town-owned road layout and private properties may be required, in coordination with the utility company pole owners. This will depend on the findings of the overhead line analysis described previously. To minimize cost and service disruption, existing poles should be left in place and buried to a greater embedment depth as part of the filling activities to the extent allowable. If modifications are required based on the findings, alternatives should be analyzed including removing and resetting existing poles in place or in new locations, replacing and embedding poles to a greater depth, or replacing existing wooden poles with poles made of more wind damage resistant materials. The fate of utility poles should be indicated in design drawings, and specifications for proposed improvements should be provided.
- If applicable, based on the scope of the MOU, modifications to private septic systems and wells may be required because of proposed filling. Engineering plans and specifications should be developed for these modifications insofar as they are included in the project scope defined in the MOU. Coordination with the Westport Board of Health should be conducted to determine permitting implications. No further details are available at the time of this report to refine what the associated scope of activities may include.

3.8.4 Funding

Financial constraints are the next most critical constraint to implementation. The height to which the corridor can be raised will depend on the willingness and ability of the Town, property owners, and other financial contributors to pay the associated incremental costs. Conceptual order-of-magnitude cost estimates indicate that implementation of the incremental corridor raising strategy as described herein would require substantial near-term and recurring expenditures, totaling about $4.5 to $6 million over the next 30 years ($1 million more if a roadway erosion protection strategy is included). The Town and other beneficiaries will need to collectively commit to a given level of investment and cooperate to determine an equitable way of sharing these costs and in seeking outside funding. Implementation of this strategy could be supported by a variety of external public funding sources.

Potential State funding sources include:

- Annual Chapter 90 Program apportionments,
- 2021 Transportation Bond Bill funding – climate change adaptation and resilience projects are specifically identified as eligible for funding.
- Municipal Vulnerability Preparedness (MVP) Action Grant program, and
- CZM Coastal Resilience Grant program.

MVP and CZM grants are reimbursement-based and require a 25% minimum match. Town and private funds or in-kind support can be used to meet the match requirement. Costs incurred prior to the effective date of any grant contract between the State and Town are not eligible for reimbursement or counting towards the match. Of the two programs, MVP has historically had higher maximum allowable grant sizes than CZM ($2 million versus $1 million, respectively). Benefit cost analysis is not required for State grant programs, unlike many federal hazard mitigation grant programs listed below.

The Massachusetts Department of Conservation and Recreation (DCR) has a stake in the reliability of East Beach Road, as one of its two emergency routes from the Horseneck Beach State Reservation and its sole utility corridor. Potential partnership between DCR and the Town should be explored. DCR and the Town could cooperate on or coordinate the elevation of the low-lying intersection of John Reed Road and East Beach Road. DCR may be willing to act as the State sponsor for a federal grant (e.g., FEMA Building Resilient Infrastructure and Communities – BRIC) grant to support the project work.

Other potential federal funding sources include:

- Public Assistance funds to reimburse the Town for a portion of the costs if East Beach Road is damaged during a federally-declared disaster.
- Hazard mitigation funding in associated disaster appropriations legislation to implement additional increments of raising.
- Federal funding could also be accessed through the region's Transportation Improvements Program, though this is a limited funding source for the Town and may be needed for other transportation priorities.
- Future infrastructure resilience grant programs. The Biden-Harris Administration has made improving the climate resilience of infrastructure a priority, already resulting in climate resilience being added to eligible project types for existing competitive grant programs such as the US DOT's Infrastructure for Rebuilding America program.

3.8 Plan for Redundancy and Sustainability in the Utility System

Both historical experience and modeling analyses show that the electrical and telecommunications utilities routed through the East Beach Corridor is presently vulnerable to damage and failure in extreme coastal flooding events. In 2050-2070, flood-related failures are projected to be 5 times more likely to occur than at present, without considering the impact of wind and debris. The impacts of East Beach utility pole failure are far reaching, affecting residents, businesses, the State Reservation, and the Route 88 drawbridge.

The Town of Westport should work with Eversource and Verizon, or whomever the future utility companies may be, to study the feasibility of constructing a redundant utility connection under the Westport River. A redundant connection would provide greater reliability of grid-based electricity and telecommunications in the near or medium-term. It would also, if necessary over the long-term, enable managed retreat and relocation from East Beach without stranding other less vulnerable land uses on the barrier beach. While the Town would not lead the construction of utility infrastructure, it can advocate for the study and provide support through the regulatory and legal process should a project proceed to implementation. Siting and design of infrastructure on both sides of the Westport River should take long-term climate projections into account to ensure the redundant connection is more resilient than the East Beach infrastructure.

Alternatives to adding redundancy would be to strengthen the resilience of poles located on East Beach and possibly elsewhere, including the following strategies:

- Replacing wooden poles with stronger composite material poles,
- Increasing the embedment depth of poles,
- Adding concrete foundations around embedded sections of poles, and
- Relocating poles to the Let side of East Beach Road.

A complementary means of increasing electrical redundancy, while reducing greenhouse gas emissions, would be to promote renewable energy generation and storage on the barrier beach system. The high solar exposure of rooftops, high wind energy resource, coupled with the potential to develop solar or wind on large parking lots at the State Reservation raise the potential for local generation at a sufficient scale to serve the limited local energy demands. Siting and flood- and wind-resistant design should be informed by future climate projections to ensure that those resources are able to function as redundant energy supply should utility infrastructure on East Beach Road be damaged. The Town has already adopted zoning to promote rooftop solar and provide the conditions for approval of small or large scale solar or wind. The Town Energy Committee should explore and provide recommendations to the Board of Selectmen on additional actions the Town can take to incentivize rooftop solar and partner with DCR on renewable generation on the barrier island.

Ideas from Westport Residents:

- *"Plan for alternate route of electricity/utilities across/under Westport river"*
- *"Relocate power to Rt 88"*

3.9 Develop and Implement a Climate Action Plan

The Town of Westport should continue to implement policies, programs, and projects to reduce greenhouse gas emissions, generate renewable energy, and conserve and restore coastal and terrestrial natural resources that remove and store carbon dioxide from the atmosphere. The Town should develop a Climate Action Plan to assess its baseline greenhouse gas footprint, develop targets for footprint reduction, and identify priority initiatives to implement. The plan can also identify priorities for adapting to climate change, incorporating or building on the MVP Community Resilience Building Workshop Summary of Findings. While Westport's actions alone will not prevent the impacts of climate change on East Beach, they can contribute to the success of State, national, and global efforts. If these collective efforts are successful, it will be more likely that sea level rise follows the Intermediate projection.

Ideas from Westport Residents:

- *"Get off fossil fuels very quickly"*

3.10 Monitor and Plan for Long-Term Managed Retreat and Relocation

At present, with knowledge of East Beach's historical vulnerability, the Town continues to invest in the maintenance of East Beach Road, the utility companies in their poles and lines, and people continue to reside along its shores each summer. Private properties in the Corridor continue to be bought and sold, with over half of the properties transacted in the last 5 years being passed into family trusts or between relatives for nominal prices of $0 to $100 and the others for market values averaging about $130,000 for seasonal trailer lots. One of the few lots with a permanent single-family structure sold for $750,000 in 2019. Regardless of sale prices, East Beach properties provide a source of annual tax revenue for the Town, on the order of $100,000 in 2020, and their residents and visitors contribute to local economic activity. Due to existing By-laws and regulations that restrict any substantial form of development on East Beach, the threat of intensifying land uses and population density in this vulnerable area is minimal. In short, the East Beach Corridor, as it exists today, has worth and value despite the clear risks posed by coastal hazards, and retreating en masse in the near-term does not appear to be a reasonable strategy.

That said, if the long-term erosion and tidal inundation risks identified in this report come to fruition, and are not mitigated, East Beach Road and many properties that abut it will eventually not be suitable for their existing uses. In the intermediate time, the cumulative impacts of nuisance and extreme events may cause the Town, utilities, or some private property owners to limit or cease further investment or use in the Corridor – this is called unmanaged retreat. The demand for or value of property may decline for these or other reasons. It is also possible that in the future public necessity will require that some private property be acquired or taken by eminent domain, for example to provide space needed to mitigate flood damage to East Beach Road or expand public beach access or preserve natural resources. These are all hypothetical but reasonably foreseeable future scenarios. Monitoring for changes in conditions and planning for a transition in land use over the long-term is a reasonable strategy. Doing so can limit the negative consequences of unmanaged retreat and create positive opportunities for the Town and the community.

There are several important elements of planning for retreat that the Town and community can take through sustained engagement:

- Build a common understanding of past, present, and future risks as the driving reason for why retreat may become necessary.

- Build a positive vision for what retreat could look like. This should be self-determined by the East Beach community. To inspire creative thinking, imagine that developable property is identified, close to East Beach, where property owners can relocate when they are ready. They are safe from the cost, danger, and stress of constant coastal flooding. They remain part of the Westport and East Beach community. They retain the ability to have an affordable coastal summer destination. They are made financially whole and retain real estate for their own financial gain or to pass on to their relatives. They can obtain seasonal trailer permits through simpler administrative processes, with longer renewal periods. They can build permanent homes, sheds, decks, and fences and make other landscaping improvements with less regulatory complexity and community oversight. They have free access to a naturally restored East Beach that is open to the public (or even a privately held portion of the beach) for recreation and enjoyment, that commemorates the history of the community that once resided there, and that supports healthy habitats for plants and animals that are under threat from climate change.

- Identify a set of objective and mutually agreed upon metrics to monitor and thresholds for transitioning from planning to implementation. Examples could be average annual MHHW as measured at the Woods Hole tide gage, public expenditures on East Beach Road storm damage repairs, or average fair market value of real estate.

- Plan for voluntary acquisition of East Beach parcels for open space, recreation, and, if needed, more resilient infrastructure. Future Town Master Plans, Open Space and Recreation Plans, Hazard Mitigation Plans, and Transportation Improvements Plans should all consider whether acquisition of East Beach properties is a priority. The Town has experience using several funding mechanisms to acquire property for public uses, including Town Budget, Community Preservation Act, Westport Land Conservation Trust, State and federal grants, and partnerships with conservation organizations. MA Executive Order 181 provides direction to state agencies that "the highest priority for disaster assistance funds shall go towards relocating willing sellers from storm damaged barrier beach areas." Some East Beach property owners may be willing to grant the Town first right of refusal on future sales offers or create other agreements by which their property would pass to the Town through their estate based on mutually agreeable terms.

Ideas from Westport Residents:

- "Convert East beach to all town public beach or short term camping sites. Use CPA money to buy land from owners."
- "Encourage relocation away from areas that will be made uninhabitable by rising sea levels"
- "Buy back the land in that area, restore it to its pre-colonial natural form as best as possible and then let nature run its course"
- "Removing the trailers that are directly on the beach and make it a natural area… owners can be compensated"
- "Get rid of the RVs and homes and electrical poles & wires"
- "Start preparing the trailers to lose their property to sea rise"
- "Prepare East Beach residents for the abandonment of their property"
- "Prevent further development by changing the zoning laws"
- "Ensuring public beach access"

4.0 IMPLEMENTATION PLAN

The recommended adaptation strategies in the Section 3, are summarized below as an implementation plan, with an overall timeline and specific initiatives. The Town should annually track and report on its progress towards implementing the plan and, as needed, make adjustments. For example, additional actions may need to be added to the implementation plan in the future based on the findings of the recommended coastal processes study and long-term alternatives analysis.

For each recommendation identified in Section 3, the following information is provided below:

- **Champions** are identified as being the most appropriate Town bodies or departments to lead implementation.

- **Supporters and Stakeholders** are identified as other Town bodies or departments; State, federal, or regional agencies; resident associations; or private and non-profit entities; with capabilities to support or an interest in the process or outcomes of implementation. These supporters and stakeholders should be engaged in the implementation process.

- **Resources Needed** are identified as staff or volunteer labor; capital, operations, and maintenance costs, including equipment; technical assistance or contracted services; and eligibility for grant funding, where relevant. Estimated costs are order of magnitude and sometimes provided as a range.

- **Start Year** is identified by which time it is recommended that the Town initiate implementation, sometimes provided as a range.

- **Duration** is identified as the approximate amount of time it is estimated to take, in years, to complete implementation. Sometimes duration is provided as a range or broken down by phases.

- **Priority Level** is identified as High, Medium, or Low based on the plurality rating of the East Beach Vulnerability Study Steering Committee members. All the actions are important, but the Steering Committee acknowledges that the Town's capacity to implement all concurrent recommendations may be limited, and, therefore, prioritization may be needed.

- **Summary of Actions** is identified, breaking down the more detailed rationale and analysis narrative in Section 3 into specific next steps for the Town and its partners to take.

IMPLEMENTATION TIMELINE

*Color of the first row indicates Priority Level (High = Green, Yellow = Medium, Orange = Low)

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050	2070	2100
Establish and Sustain a Coastal or Climate Resilience Committee	Initiate	Sustain committee activity												
Raise Awareness of Permittable and Not Permittable Property Protection Strategies on the Barrier Beach	Initiate	Disseminate												
Develop an Emergency Access/Egress Contingency Plan	Initiate	Plan maintenance and exercises												
Establish a Dune and Beach Monitoring Program	Initiate		Ongoing monitoring											
Model Coastal Processes to Evaluate the Impact of the Causeway and In-Water Adaptation Strategies	Initiate		Complete (earliest)	Complete latest)	Plan to implement selected long-term strategies									
Elevate East Beach Road and Coastal Dunes on Abutting Properties	Initiate					Complete (earliest)	Complete latest)	Monitor for when to initiate next increment						
Plan for Redundancy and Sustainability in the Utility System	Initiate					Complete (earliest)					Complete latest)			
Develop and Implement a Climate Action Plan	Initiate	Complete (earliest)	Complete latest)	Implement recommendations, update plan every 5 years										
Monitor and Plan for Long-Term Managed Retreat and Relocation										Initiate	Ongoing monitoring, planning, action			

ESTABLISH AND SUSTAIN A COASTAL OR CLIMATE RESILIENCE COMMITTEE

Champions:	Planning Board, Board of Selectmen
Supporters and Stakeholders:	Conservation Commission, Highway Department, Building Department, Beach Committee, East Beach Association, MA DCR
Resources Needed:	Town staff and volunteer hours
Start Year:	2021
Duration:	<1 year to initiate, ongoing thereafter
Priority Level:	High
Summary of Actions:	• Create a local committee dedicated to thinking about coastal climate change and providing recommendations to the Town on how to manage risks from coastal flooding, erosion, sea level rise, and potentially other priority climate change risks, including impacts from changes in temperature and rainfall. East Beach residents should be included in the committee membership. • Responsibilities could include monitoring sea level rise and other coastal or climate changes, recommending priorities for implementation, pursuing grant and Town funding, providing oversight on future projects, identifying opportunities to integrate climate resilience in other planning processes or capital improvements, and engaging with stakeholders in an ongoing dialogue.

RAISE AWARENESS OF PERMITTABLE AND NON-PERMITTABLE PROPERTY PROTECTION STRATEGIES ON THE BARRIER BEACH

Champions:	Conservation Commission
Supporters and Stakeholders:	Building Department, Beach Committee, Planning Board, MA CZM, MA DEP
Resources Needed:	Town staff and volunteer hours
Start Year:	2021
Duration:	< 1 year to create, ongoing thereafter for dissemination
Priority Level:	Medium
Summary of Actions:	• Create informational material (e.g., fact sheet, Frequently Asked Questions page, presentation slides) summarizing the major federal, state, and local regulations affecting coastal engineering structure permitability on the barrier beach, including the limited conditions under which such structures may be permitted. • Make this informational material available on an appropriate page of the Town's website and in print at Town Hall, and proactively distribute and disseminated to residents either through mailings or relevant future public meetings.

Develop an Emergency Access/Egress Contingency Plan

Champions:	Fire Department (Emergency Management)
Supporters and Stakeholders:	EMS, Police Department, Harbormaster, Highway Department, MA DCR, MassDOT, MA CZM, MA EEA, MEMA, US Coast Guard, DHS/FEMA, other mutual aid and volunteer partners
Resources Needed:	• Town staff and volunteer hours • $25,000 - $50,000 for technical assistance, if needed • Eligible for state grant funding at 25% cash/in-kind match
Start Year:	2021
Duration:	< 1 year to complete plan, ongoing thereafter for plan exercises/maintenance
Priority Level:	High
Summary of Actions:	• Work with partners to develop a post-flood emergency access and egress contingency plan for the barrier beach. The plan should identify the actions and resources needed to address scenarios in which the barrier beach does not have roadway access to the mainland during the immediate post-flood period. This is the period when search and rescue, emergency medical, and firefighting services are critical for lifesaving. • Conduct a tabletop exercise to test and improve the plan.

Establish a Dune and Beach Monitoring Program

Champions:	Beach Committee, Coastal/Climate Resilience Committee
Supporters and Stakeholders:	Highway Department, DCR, Conservation Commission, East Beach Association

Resources Needed:	• Profile monitoring
	  o Approximately $35,000 in year 1 and $5,000 per year thereafter if conducted with Town and volunteer labor
	  o Approximately $20,000 per year if conducted by contractors
	• Grain size sampling
	  o Approximately $2,000 in year 1 and periodically in years thereafter
	• Water level monitoring
	  o Approximately $6,800 - $8,800 in year 1 and $3,800 – 5,800 per year thereafter depending on the Town's O&M capacity

Start Year:	2021-2022
Duration:	Ongoing
Priority Level:	High
Summary of Actions:	• Establish, in partnership with the DCR, a network of long-term cross-shore transects regularly spaced along East Beach and Horseneck Beach for periodic monitoring of elevation/bathymetry as well as grain size. Survey controls should be established for each transect. • Conduct surveys twice a year, at a minimum, to capture seasonal variability in beach/dune profile and composition. • Install one or more water level sensors to track sea level rise locally, as well as tidal and storm response differences between the Let and the open coast.

MODEL COASTAL PROCESSES TO EVALUATE THE IMPACT OF THE CAUSEWAY AND IN-WATER ADAPTATION STRATEGIES

Champions:	Planning Board, Coastal/Climate Resilience Committee
Supporters and Stakeholders:	Board of Selectmen, Conservation Commission, Beach Committee, Shellfish Wharfinger Department, Board of Health, MA DCR, MA CZM, MA EEA, East Beach Association
Resources Needed:	• Town staff and volunteer hours • Approximately $200,000
Start Year:	2021-2022
Duration:	1-2 years to complete study
Priority Level:	High
Summary of Actions:	• Carry out a coastal processes study, including site-specific data collection, hydrodynamic modeling, wave transformation modeling, sediment transport modeling, and associated analysis and interpretation, to develop a detailed technical understanding of how water and sediment move through the barrier beach and estuarine system and the impact of the Gooseberry Island causeway on that movement. • Use the data, models, and understanding gained to evaluate the feasibility, sustainability, and effectiveness of a range of conceptual project alternatives, including causeway removal or modification, beach nourishment, offshore wave attenuation (including nature-based), and permanent breach or opening of the Let, for mitigating overwash and erosion on the barrier beach system and enhancing habitat and mitigating flooding and storm damage in the Westport River estuary. • Based on the findings of the evaluations, select the projects that merit implementation and develop a plan to guide next steps, including design, permitting, and funding of construction.

ELEVATE EAST BEACH ROAD AND COASTAL DUNES ON ABUTTING PROPERTIES

Champions:	Board of Selectmen, Highway Department
Supporters and Stakeholders:	Town Counsel, Conservation Commission, Planning Board, Beach Committee, SRPEDD, MA DCR, MA CZM, MA EEA, MA NHESP, MassDOT, East Beach Association
Resources Needed:	• Town staff and volunteer hours • Approximately \$0.4 - \$1.8 million for first increment • Approximately \$1.8 - \$2.0 million for second increment • Approximately \$2.1 - \$2.3 million for third increment • Eligible for grant funding in each phase from various state and federal programs with different match requirements (see report)
Start Year:	2021-2022

Duration:	• Minimum of 5 years per increment of raising
	  ○ < 1 year to complete MOU
	  ○ < 1 year to complete data gathering
	  ○ 1 year to complete design and pre-permitting consultations
	  ○ 1-2 years to complete permitting and final design (plus up to 2 years if litigation or appeals)
	  ○ 1 year to complete construction

Priority Level:	High
Summary of Actions:	• Develop the governance mechanisms, designs, permits, and funding needed to elevate East Beach Road and coastal dunes on abutting properties, incrementally, over time, as sections of the roadway need to be repaired or reconstructed. • Establish a Memorandum of Understanding (MOU) between the Town, all willing private property owner participants, and any other willing partners (e.g., DCR) that will govern the process of cooperation through all phases of future elevation projects including design, permitting, legal agreements, construction, and monitoring and maintenance. • Carry out activities needed to inform design and permitting, including survey, wetlands and habitat mapping, and geotechnical investigations. • Carry out coastal engineering, roadway, and utility design alongside environmental pre-permitting consultations with regulators. • Complete environmental permitting and approvals processes and finalize design. • Construct the approved improvements.

Plan for Redundancy and Sustainability in the Utility System

Champions:	Board of Selectmen, Town Administrator
Supporters and Stakeholders:	Town Counsel, Building Department, Planning Board, Cable Advisory Board, Eversource, Verizon, Charter, MA DCR, MA DOER
Resources Needed:	• Town staff and volunteer hours • Assumed that capital costs would be funded through rates
Start Year:	2021-2022
Duration:	< 1 year to initiate, 5-10 years to plan and complete
Priority Level:	High
Summary of Actions:	• Work with Eversource, Verizon, and Charter to study the feasibility of constructing a redundant utility connection under the Westport River and other alternatives to enhance the resilience of existing utility pole infrastructure (e.g. replacing wooden poles with stronger composite material poles, increasing the embedment depth of poles, adding foundations, and relocating poles to the Let side of East Beach Road). • The Town's role would be to advocate for the study, provide support through the regulatory and legal process should a project proceed to implementation, and ensure that siting and design of infrastructure on both sides of the Westport River take long-term climate projections into account. • Take additional actions to promote renewable energy generation and storage on the barrier beach system, including incentivizing rooftop solar and partnering with DCR on renewable generation. Siting and flood- and wind-resistant design should be informed by future climate projections.

Develop and Implement a Climate Action Plan

Champions:	Board of Selectmen
Supporters and Stakeholders:	Planning Board, Conservation Commission, Building Department, Energy Committee, MA EEA, MA DOER
Resources Needed:	• Town staff and volunteer hours • \$50,000 - \$100,000 for Climate Action Plan technical assistance • Project costs TBD • Eligible for grant funding or low/no interest financing, depending on the scope
Start Year:	2021-2022
Duration:	1 year to complete plan, ongoing thereafter for policies/programs/projects, update plan every 5 years
Priority Level:	Low
Summary of Actions:	• Develop a Climate Action Plan to assess the Town's baseline greenhouse gas footprint, develop targets for footprint reduction, and identify priority initiatives to implement. • Implement policies, programs, and projects to reduce greenhouse gas emissions, generate renewable energy, and conserve and restore coastal and terrestrial natural resources that remove and store carbon dioxide from the atmosphere.

MONITOR AND PLAN FOR LONG-TERM MANAGED RETREAT AND RELOCATION

Champions:	Planning Board, Coastal/Climate Resilience Committee
Supporters and Stakeholders:	Board of Selectmen, Town Counsel, Conservation Commission, Highway Department, Assessors Department, Beach Committee, Board of Health, East Beach Association
Resources Needed:	Town staff and volunteer hours
Start Year:	2030-2040
Duration:	Ongoing
Priority Level:	Medium
Summary of Actions:	• Establish or identify mechanisms for sustained engagement between the Town and East Beach residents to monitor for changes in conditions and plan for a transition in land use over the long-term. This could be through the Coastal or Climate Resilience Committee. • Build a common understanding of past, present, and future risks as the driving reason for why retreat may become necessary. • Build a positive vision for what retreat could look like. This should be self-determined by the East Beach community. • Identify a set of objective and mutually agreed upon metrics to monitor and thresholds for transitioning from planning to implementation. Examples could be average annual MHHW as measured at the Woods Hole tide gage, public expenditures on East Beach Road storm damage repairs, or average fair market value of real estate. • Plan for voluntary acquisition of East Beach parcels for open space, recreation, and, if needed, more resilient infrastructure. Future Town Master Plans, Open Space and Recreation Plans, Hazard Mitigation Plans, and Transportation Improvements Plans should all consider whether acquisition of East Beach properties is a priority.

REFERENCES

American Socity of Civil Engineers, 2017, Minimum Design Loads and Associated Criteria for Buildings and Other Structures. Reston, Virginia.

Aubrey Consulting, Incorporated, July, 1997, Historical Evolution of The Shoreline: Rhode Island Sound and Buzzards Bay from Acoaxet to The Entrance of Allen's Pond.

Benoit, J.R., 1989. Massachusetts shoreline change project

Collin, J.G. (2016), Timber Pile Design and Construction Manual, Timber Piling Council Southern Pressure Treater's Association.

Danielson, Jeffrey, Tyler, Dean, U.S. Geological Survey, 2017, Topobathymetric Model for the New England Region States of New York, Connecticut, Rhode Island, and Massachusetts, 1887 to 2016

DeConto, R.M. and R.E. Kopp, 2017, Massachusetts Sea Level Assessment and Projections. Technical Memorandum.

DeConto, R. and D. Pollard, 2016, Contribution of Antarctica to past and future sea-level rise. Nature. 531: 591–597. https://doi.org/10.1038/nature17145.

Deltares, 2018, XBeach Technical Reference: XBeachX Release, Model Description and Reference Guide to Functionalities.

Himmelstoss, E.A., Farris, A.S., Weber, K.M., and Henderson, R.E., 2019, Massachusetts shoreline change project, 2018 update–A GIS compilation of shoreline change rates calculated using Digital Shoreline Analysis System version 5.0, with supplementary intersects and baselines for Massachusetts (ver. 2.0, August 2019): U.S. Geological Survey data release, https://doi.org/10.5066/P9RRBEYK.

Irschik, K, 2007, Impact loading of slender pile structures induced by depth limited breaking waves. PhD-Thesis, TU Braunschweig (in German).

National Climate Change Adaptation Research Facility (NCCARF), 2019, Coastal Adapt Program Infographics. Australian Department of the Environment and Energy. [https://coastadapt.com.au].

Nielsen, P., 1985, Explicit Solutions to Practical Wave Problems, in Proc. 19th International Conference on Coastal Engineering, Houston, TX, ASCE, pp. 968-982.

Sumer, B.M. and Fredsoe, J., 2002, The Mechanics of Scour in the Marine Environment, Advanced Series on Ocean Engineering – Volume 17, World Scientific Publishing, Singapore.

Thieler, E.R., O'Connell, J.F. and Schupp, C.A., 2001, The Massachusetts Shoreline Change Project: 1800s to 1994. US Geological Survey Administrative Report, 39.

Thieler, E.R., Smith, T.L., Knisel, J.M. and Sampson, D.W., 2013, Massachusetts shoreline change mapping and analysis project, 2013 update (No. 2012-1189). US Geological Survey.

US Army Corps of Engineer, 2003, Coastal Engineering Manual. Washington, D.C.

USGS, 2013, Massachusetts Shoreline Change Mapping and Analysis Project, 2013 Update.

van Rijn, L.C., 2007, Unified View of Sediment Transport by Currents and Waves: part I and II. Journal of Hydraulic Engineering, pages 649–689.

Woodruff, J.D., Venti, N., Mabee, S., DiTroia, A., Beach, D., 2020, Massachusetts Beach Grain Size and Slope Data