CZM Coastal Resilience Grant Program

Evaluation of Coastal Processes and Storm Impacts to Support Resilient Planning and Mitigation Strategies for the Vineyard Haven Harbor Shoreline

June, 2021

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Town of Tisbury, MA

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I. Introduction

The Town of Tisbury received funding assistance through the Massachusetts Office of Coastal Zone Management (MCZM) FY21 Coastal Resilience Grant Program to develop conceptual flood protection designs for downtown Vineyard Haven. The overall goal was to perform a more detailed assessment of the recommended options and develop conceptual designs for these flood mitigation strategies. Included in the goal of each design was the development of pragmatic shoreline management strategies that would provide resiliency for the Vineyard Haven Harbor shoreline over the next 30 to 50 years.

Flooding and wave damage from nor'easters is a regular occurrence in downtown Vineyard Haven. The long-term effects of climate change on local sea level will increase the impacts to the low-lying densely populated waterfront town center. With no direct road access to the mainland, residents have learned to be self-reliant, and the Town has planned carefully to respond to severe weather and other emergencies. However, increased impacts from coastal flooding events require improved mitigation efforts to make the Harbor area more resilient. To this end, the Town has been involved with previous planning efforts including the MVP process. While the MVP process provided general planning information relative to future flood risks and mitigation in the long-term, they lacked detailed pragmatic approaches to address ongoing concerns in the Vineyard Haven Harbor area. Specifically, the low-lying areas surrounding the Harbor are well below the existing 100-year (1% Annual Chance) flood level and are even impacted by more frequent storm surges associated with relatively frequent nor'easters.

As sea level has increased over the past 100+ years, the low-lying heavily developed area adjacent to the harbor has gradually become more susceptible to coastal flooding and storm damage. In much of the flood-impacted downtown area, changes to infrastructure to increase overall resiliency are inevitable. While eventual modifications to individual infrastructure will be required in the long-term, some relatively modest adjustments to infrastructure in critical locations downtown could substantially improve coastal resiliency over the next 30 to 50 years. Specifically, improvements that would eliminate flood tide pathways into the lowest-lying areas of downtown, while improving upland drainage, has been shown to substantially mitigate flooding concerns, especially during more frequent minor to moderate nor'easters.

I.1 Project Area

The shoreline evaluated in this study extends from the end of the breakwater at the western side of the Harbor, along the interior of the Harbor, and out to the Eastville jetty (Figure I.1). The overall evaluation focused on identifying "weak points" in existing infrastructure, within the project area, to prevent flooding of downtown along storm tide pathways. The three prioritized regions include (Figure I.2):

A) Harbor Shoreline

B) Beach Road

C) Lagoon Pond Road

From a cost-benefit perspective, understanding the value of potentially flooded properties provides the baseline justification for coastal flood protection in the downtown area. To approximate property values within each downtown region, assessor's parcel information was downloaded from the Town of Tisbury website for the 2020 tax year. The cumulative value of the properties within the respective regions is included in Figure I.2. The total assessed value of downtown properties is $81.8 million. It is anticipated that the real estate property values likely are significantly higher than assessed values under the existing real estate market.

Figure I.1 Map illustrating the Vineyard Haven Harbor area where the site-specific coastal processes analysis was completed.

Figure I.2 Map illustrating the Vineyard Haven Harbor area where the site-specific coastal processes analysis was completed.

I.2 Downtown Elevation Mapping

Light Detection and Ranging (LiDAR) survey data were collected to provide better spatial understanding of topography and bathymetry in and around Tisbury and downtown Vineyard Haven Harbor. LiDAR data provided three dimensional surfaces of topographic, as well as limited nearshore bathymetric, information that could be evaluated within appropriate mapping software. These data were critical for identifying storm tide pathways and adjusting the flood protection designs to properly mitigate for coastal flooding impacts to the greatest extent practicable.

Ideally, multiple LiDAR datasets could be assessed sequentially, to look at bathymetric change over the area of overlapping survey coverage. Due to the lack of multiple LiDAR survey data in the area, the single dataset was used to look at flooding of the downtown, and for integration with model grids. The LiDAR data that were available for Tisbury for this project were collected by the United States Army Corp of Engineers (USACE) during a 2018 flight. The high-resolution bathymetry data within Vineyard Haven Harbor are included as a contour plot in Figure I.3. Finer resolution contouring was provided for elevations between 0.0 and 8.0 feet NAVD88. Qualitative analysis of these LiDAR contour maps allows for the identification of particular regions that are low in elevation and prone to flooding. Some of these areas include the commercial downtown areas at the southern end of the harbor and along Beach Road heading towards Oak Bluffs. This knowledge of low-lying areas was taken into account during the development of potential alternatives.

As part of the overall evaluation, additional pertinent elevation data were collected to compliment the LiDAR data. These elevation data sources include:

- Massachusetts Department of Transportation (MA DOT)
- Vineyard Wind Project
- Applied Coastal Survey (October 22,2020)

The locations of the survey points for the Applied Coastal assessment are shown in Figure I.4, and the additional surveys in Figure I.5. These point data helped to fill in gaps where the 2018 LiDAR had missing data, or were not sufficiently refined to determine the elevation of specific structures or features. The augmented data set provided necessary detail specific to roadway elevations and the shoreline to ensure flood mitigation designs accounted for *in situ* conditions, which is especially critical for Vineyard Haven Harbor, where small differences in topography can have a significant influence upon storm tide pathways.

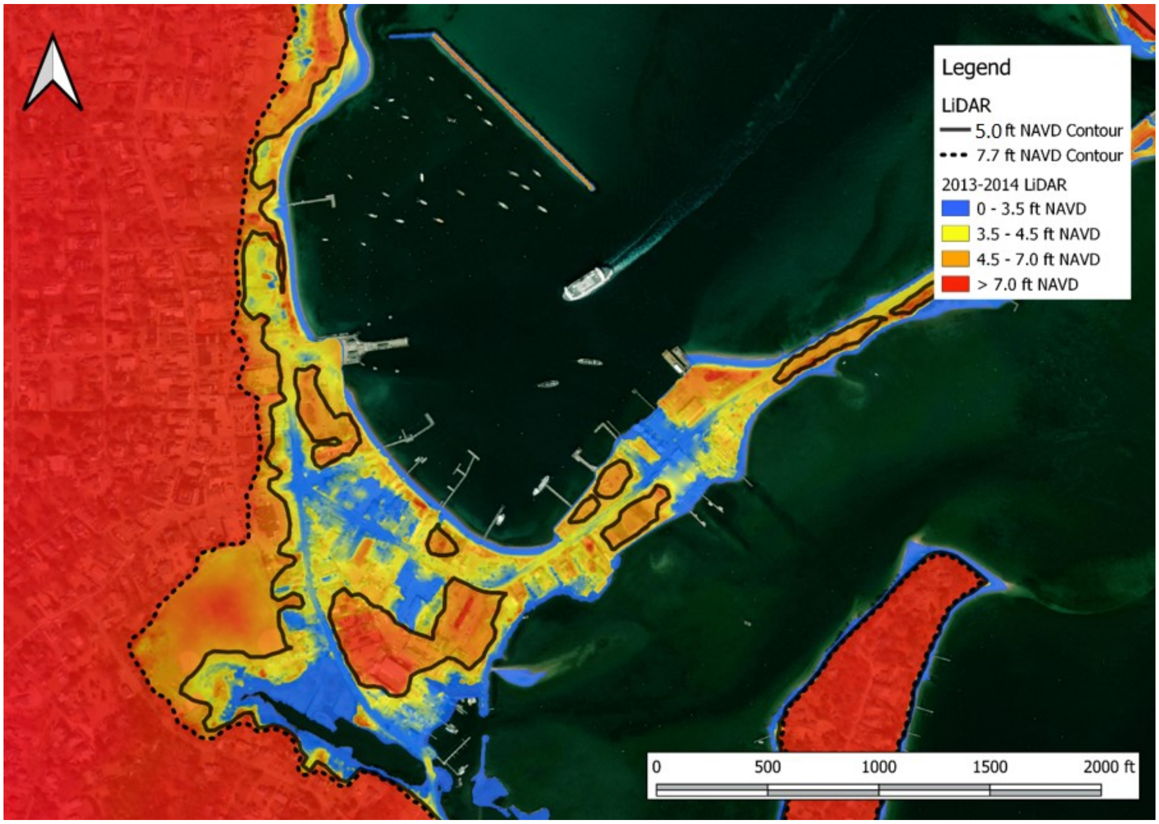


Figure I.3 Color-contour elevation map of Vineyard Haven Harbor shoreline indicating areas below the 100-year flood elevation of 7.7 feet NAVD88 (white line), as well as the severe storm surge levels experienced during nor'easters (5.0 feet NAVD88) in gray.

Figure I.4 Location of points surveyed on October 22nd, 2020 by Applied Coastal.

Figure I.5 Location of all additional survey points collected to compliment the 2018 LiDAR dataset.

I.3 Storm Tide Pathways

Based on the analysis of elevation data from both the LiDAR and surveys, storm tide pathways were identified on aerial maps (Figure I.6). Regionally, the term storm tide pathways is a concept developed by Mark Borelli and Steve Mague (Borrelli et al. 2016), and are defined as the low-lying areas that channelize coastal flood waters during extreme high tide episodes. The identification of these pathways can allow managers and planners to determine what portions of the developed shoreline “enable” coastal flooding during a particular storm event. Mapping and modeling of these storm tide pathways can help coastal communities prepare and plan for inevitable hazards from storms and future sea level rise.

Storm tide pathways were identified in all three regions of the downtown Vineyard Haven as part of this assessment. Along the harbor shoreline, pathways were primarily located at the end of roads or driveways, as well as at beach access points. The simplest method of mitigating these pathways along the harbor shoreline, would be the construction of a dune or other upland feature, to elevate the back of the beach. Another pathway exists to the north of the Steamship Authority terminal (Figure I.7).

Lagoon Pond Road contains the lowest elevation storm tide pathways of all three regions evaluated within downtown Vineyard Haven. Coastal flooding through Lagoon Pond is able to propagate along the northern side of Mud Creek and along the road. The best option to mitigate this pathway would be to connect the higher natural elevations of the glacial moraine to the south and west to the higher developed ground elevations across the street from Veterans Memorial Park.

The Beach Road section includes one pathway across a gravel parking lot located within the Packer Facility. However, it is anticipated that planned projects at this location will elevate the lot to approximately 6.0 feet NAVD. Several pathways exist on the Lagoon Pond side of Beach Road. The section of shoreline furthest to the east is protected by a revetment (Figure I.8). However, the structure is at approximately 3.5-4.0 feet NAVD, and therefore permits flooding during moderate to severe storms. The shoreline to the southwest of that location includes a pathway along some sections of developing marsh with grass behind it (Figure I.9). Several pathways exist along here that connect to Beach Road through gravel parking lots.

The overall pathways were also identified with a 3D terrain map, that included all collected elevation data. A simulation flood of 5.0 feet NAVD was included, to help visualize the extents of the flooding downtown.

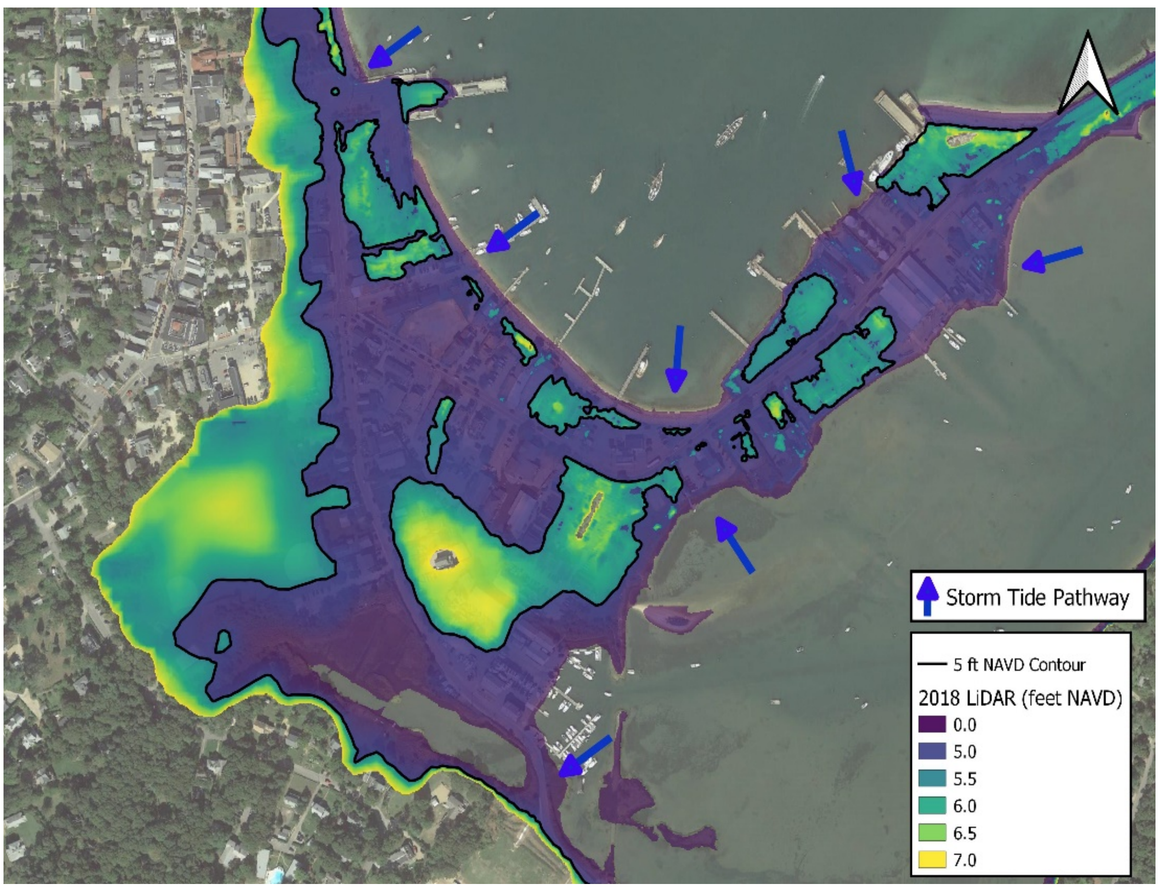


Figure I.6 Identification of storm tide pathways (indicated by blue arrow), as locations downtown at or below 5.0 feet NAVD88 that fringe the harbor or Lagoon Pond, and would allow storm waters to flood downtown areas.

Figure I.7 October 2020 photograph looking northward along the harbor shoreline, with the storm tide pathway through the sidewalk in the center of the image.

Figure I.8 October 2020 photograph looking northeast along the Lagoon Pond shoreline. Several pathways exist along this section of shoreline, and provide a path for flood waters to reach Beach Road.

Figure I.9 October 2020 photograph looking southwest along the Lagoon Pond shoreline. Several pathways to the east of the Tisbury Market Place allow flooding to reach Beach Road.

Figure I.10 Flood model of downtown simulating a storm of 5.0 feet NAVD. The elevation model highlights the impact of storm tide pathways and the propagation of flood waters downtown.

I.4 Hydrologic Analysis

A recent study was performed by the United States Environmental Protection Agency (EPA) to address frequent flooding in the downtown area of Vineyard Haven (Paradigm Environmental et al. 2020). The report conclusions confirmed that flooding issues are exacerbated by generally poor transmission of stormwater runoff related to and resulting from impervious cover. The staff for this project included a team with members from EPA Region 1, the University of New Hampshire Stormwater Center, and Paradigm Environmental.

The collaborative study brought together regulators, technical experts, and community leaders to identify opportunities for innovative stormwater management techniques. While it did include in-depth analyses of storm volume and total nitrogen (TN) load reduction opportunities, it did not take into account the details of the existing stormwater routing network. A major issue in the existing stormwater drainage network is the sedimentation and clogging of one of the major harbor outfalls (i.e., Outfall #2; Figure I.11). The outfall that crosses the beach at Beach Road Extension tends to fill with sand during storm conditions, preventing the outfall from being effective (Figure I.12).

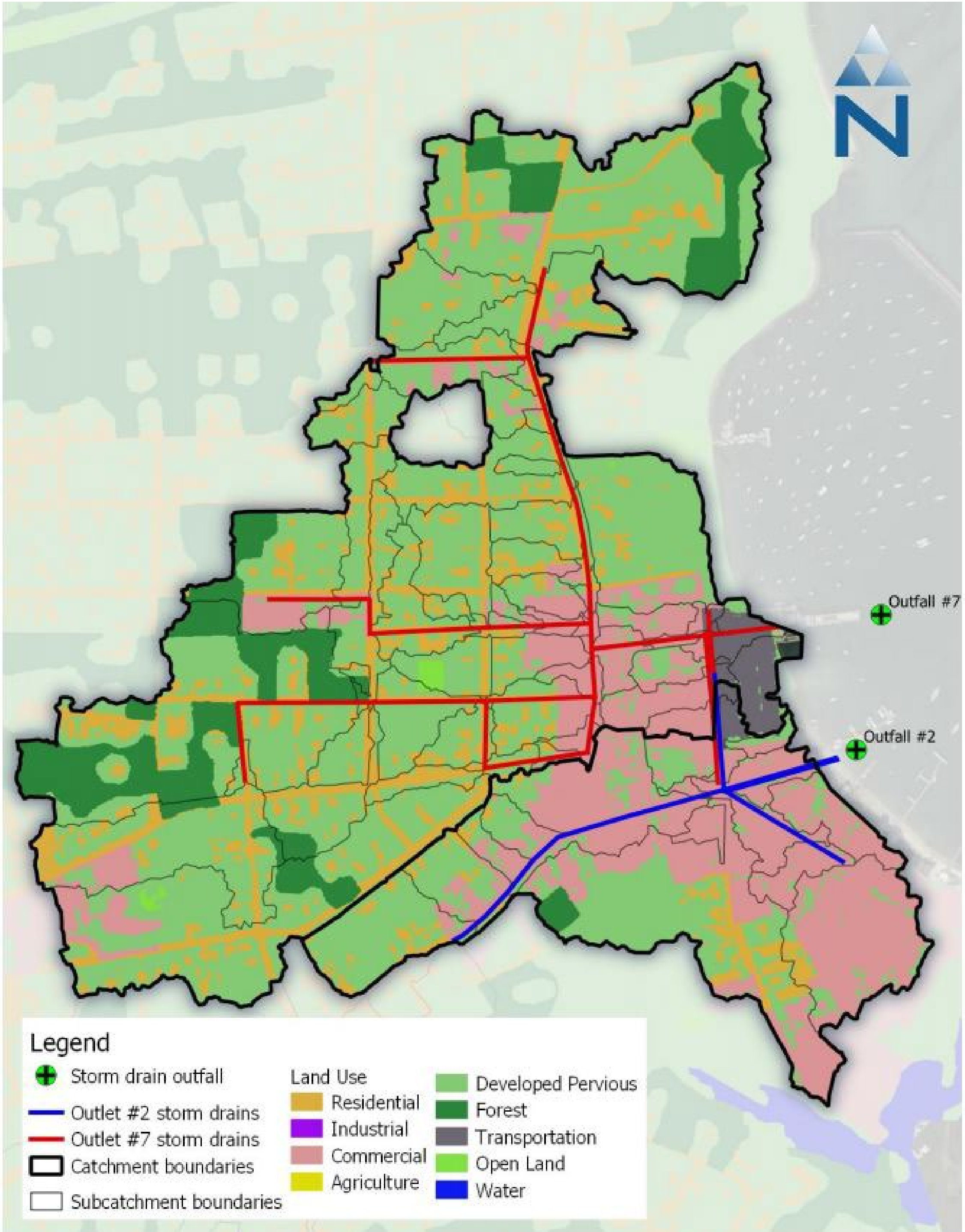


Figure I.11 Sub-catchment delineation and major land use in the drainage areas to outfall #2 and #7 (Paradigm Environmental et al. 2020).

Figure I.12 Drainage pipes at the Outfall #2 location (Figure I.11).

As both storm surge and rainfall within the harbor watershed generate flooding in downtown areas, it is critical to determine the relationship between the two phenomena. To assess the watershed influence, the EPA report used a 20-year (1998 to 2018) hourly precipitation timeseries and daily air temperature data collected at the NCDC Global Hourly Surface Data gauge located at Martha's Vineyard Airport (USAF-ID 725066). They developed an exceedance probability curve (Figure I.13), which indicates a storm with a 100% annual exceedance probability to generate 1.5 inches of daily rainfall. A 2-3% exceedance probability (30–50-year storm) is approximately 4.2 inches of daily rainfall.

A comparison was made to storm surge data during this time frame, with water level data from the nearby Nantucket tide gauge. During this time period, there were no significant storm surge events (i.e., water surface > 4.5 feet) that coincided with a rainfall greater than a 1.5 inch or 1-year (100% exceedance probability) rainfall event (Figure I.14). The average daily rainfall was averaged for each month over the 20-year period and shown in Figure I.15. Only days that had measured rainfall greater than 0.01 inches were included in the average. Also, the total number of days in which a moderate to significant rainfall event occurred, with rainfall that exceeded 0.5 inches is included in Figure I.16. Both figures indicate that the significant rain events for Tisbury, occur during the summer and fall months (June through October). Severe nor'easter storms typically do not occur during these months, and the relatively short duration of the storms generally do not setup a significant storm surge in the harbor. The March 2018 Winter Storm Riley storm was a unique event that included some significant rainfall. However, the rain occurred prior to the peak of the storm surge (Figure I.17), indicating that had the outfalls been operating effectively, the stormwater would have drained prior to the surge induced flooding.

Anecdotally, flooding of the downtown area from rainfall occurs frequently for a broad range of events, for both moderate and severe rainfall. However, improvements to the drainage system, accompanied by proper maintenance of stormwater outfalls, will eliminate most of the stormwater flooding, when there is no corresponding significant storm surge. The extent of flooding at five corners flooding is shown in Figure I.18.

Significant rainfall events in which there is no surge, can be mitigated for with a pump located in the five corners area. Other options include diverting of some of the stormwater towards Mud Creek along Lagoon Pond Road. Routing of this stormwater drainage network could be accomplished during Lagoon Pond Road flood mitigation improvements. The value of making these stormwater modifications is recognized, and will be accounted for as the other designs outlined in this report are pursued.

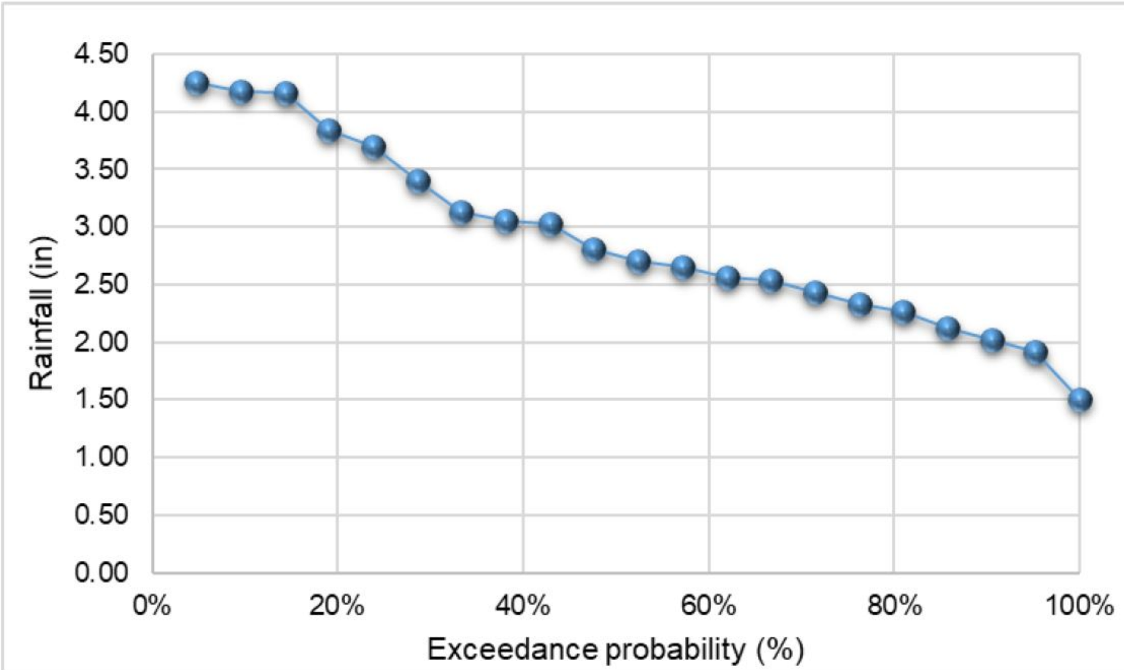


Figure I.13 Exceedance probability for annual maximum daily rainfall amounts for 21-year period (1998-2018) for Tisbury, MA (Paradigm Environmental et al. 2020).

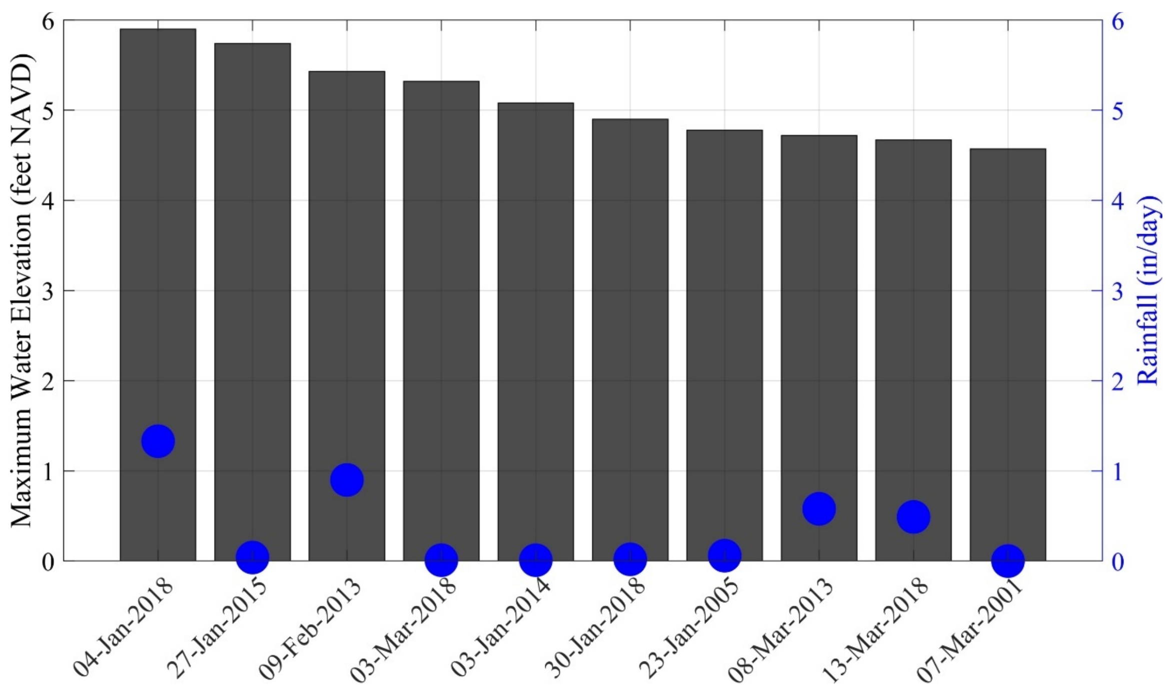


Figure I.14 Maximum water elevation during the ten largest rain events between January 1, 1998 and December 31, 2018.

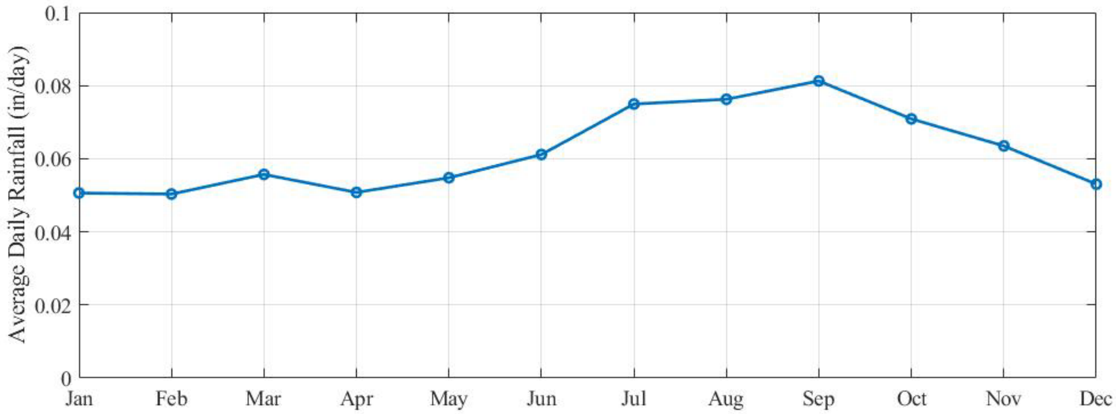


Figure I.15 Average daily rainfall for each month of the 20-year period. Only days in which measured rainfall was greater than 0.01 inches were included in the average.

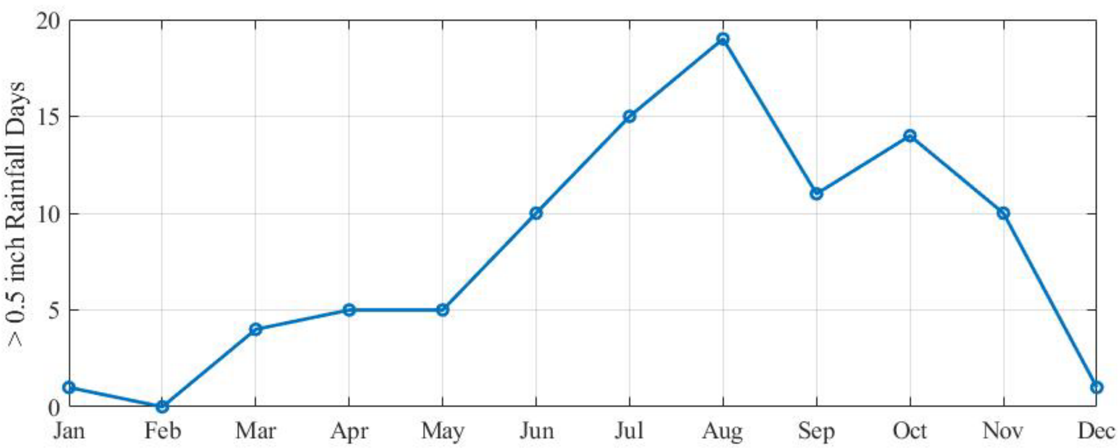


Figure I.16 Number of days in which rainfall greater than 0.5 inches were recorded at Martha's Vineyard Airport between 1998 and 2018.

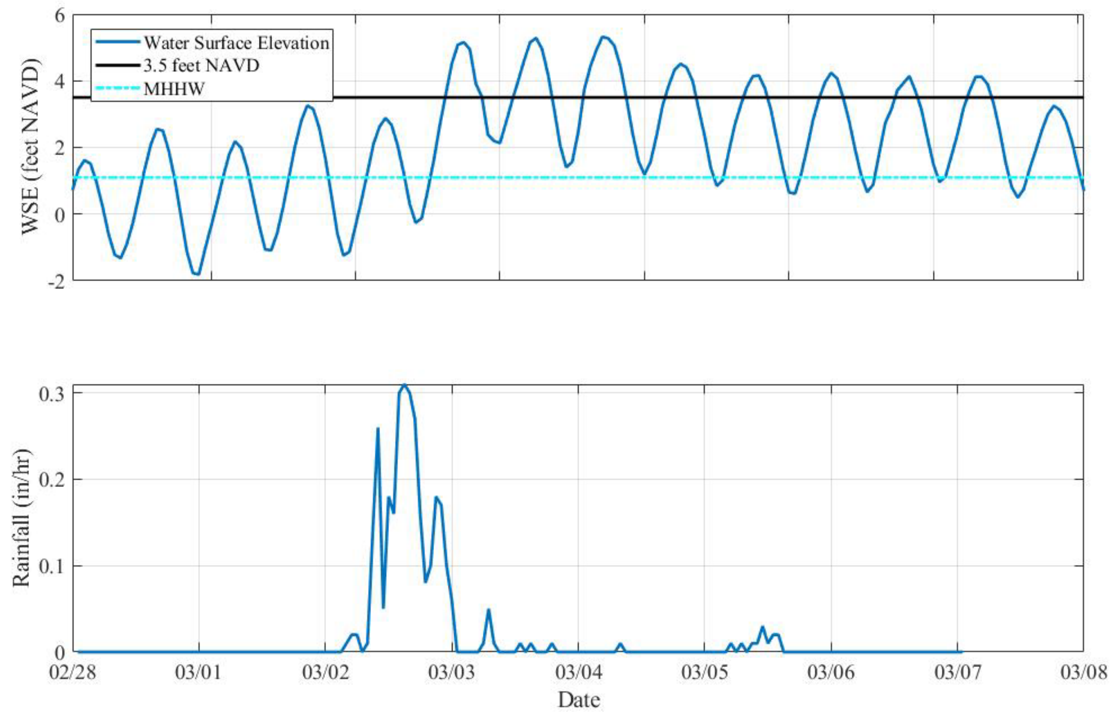


Figure I.17 Plot of eight days of water surface elevation (top) and the corresponding rainfall (bottom). The location of the 3.5-foot NAVD flood elevation contour provided in Figure I.18) is included for reference, in addition to mean higher high water (MHHW).

Figure I.18 Location of coastal storm surge and stormwater flooding during a 3.5-foot NAVD flood elevation. Stormwater primarily will flood around the five corners intersection of downtown.

I.5 Site History and Review of Mitigation Options

To properly evaluate conceptual designs for each region, historical literature and imagery were reviewed. Vineyard Haven Harbor historically established itself as a commercial Harbor along the route between the major ports of New York City and Boston. Prior to the establishment of the Cape Cod Canal, ships traveling between the two major ports sailed through Vineyard and Nantucket Sounds, and around Cape Cod. Vineyard Haven Harbor served as a critical port of refuge, especially since the shoals, as well as the tidal currents and storm wave activity, made the Cape and Islands area frequently treacherous to navigate. For example, between 1865 and 1915, some two thousand ships were wrecked, and more than seven hundred lives lost, between Gay Head at the gateway to Vineyard Sound and Provincetown on the tip of the Cape (Dunlop, 2010).

The naturally deep thoroughfare down the major length of the protected Harbor (Figure I.19), running northeast to southwest, provided the basis for a commercial port in Vineyard Haven Harbor, where in the late 1800s there were lofts to repair sails; a shipbuilding company to repair hulls and rigging; and a marine hospital. Vineyard Haven (called Holmes Hole until 1871) was home to the Holmes Hole Marine Railway starting in the 1840s that constructed numerous schooners along the barrier beach system separating the Harbor from Lagoon Pond (see 1890 chart in Figure I.20). Subsequent to the marine railway development, thousands of feet of Harbor shoreline were commandeered as a construction site for barges and high-speed rearmament/personnel boats for World War II. This shoreline remains in commercial use as the Tisbury Marine Terminal.

Figure I.19 Section of the 1847 U.S. Coast Survey navigation chart for Holmes Hole (Vineyard Haven Harbor) illustrating the natural deep channel along the length of the Harbor, as well as early pier development in the vicinity of the Packer Facility.

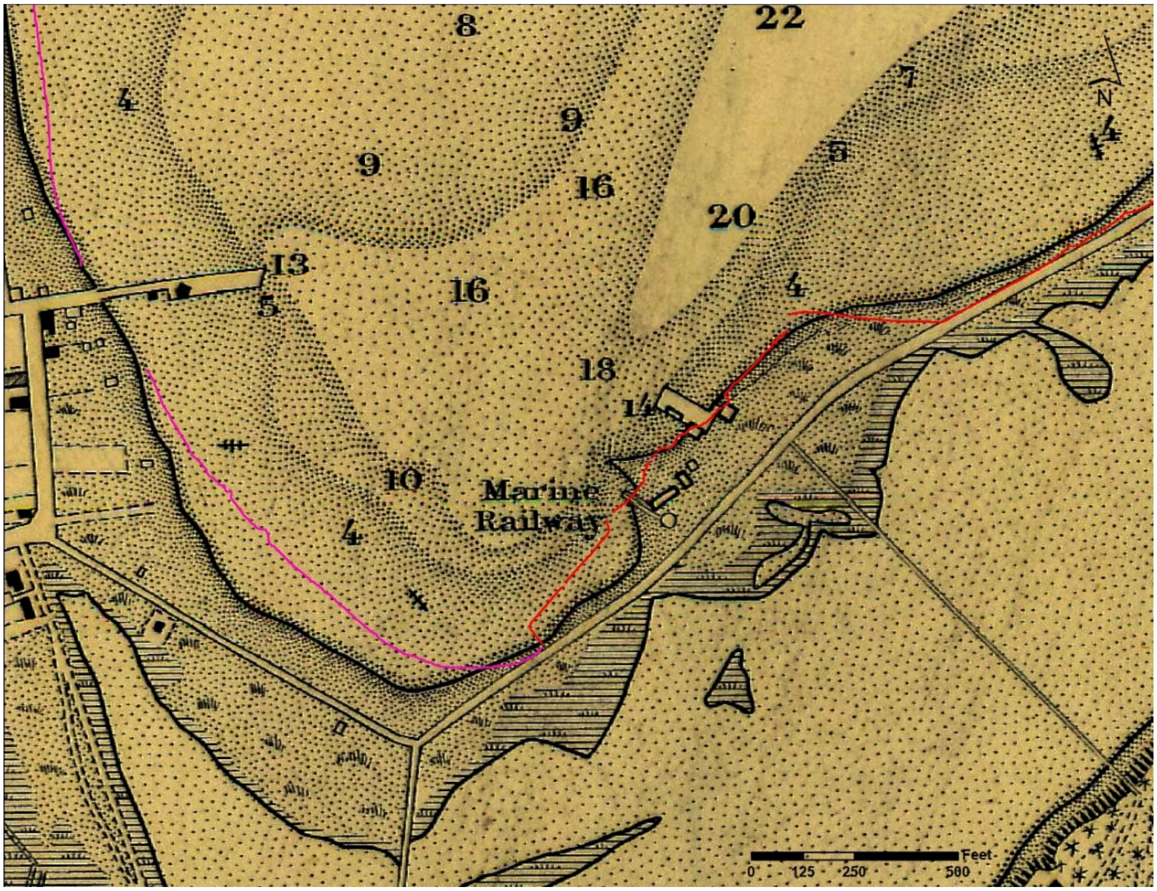


Figure I.20 Section of the 1890 U.S. Coast Survey navigation chart for Vineyard Haven Harbor illustrating the marine railway development in the vicinity of the Packer Facility, as well as creation of a roadway along the length of the barrier beach system and causeways across the marsh system.

The series of oblique views of the Harbor from 1856, 1880, and 1890 are shown in Figure I.21, Figure I.22, Figure I.23, respectively. These sketches illustrate the gradual development of the port facilities along the low-lying section of the barrier beach system. As illustrated in Figure I.21, it is clear that after construction of the pier facility that was developed to reach the naturally deep water in Vineyard Haven Harbor, access to the pier was along the inter-tidal beach and no formal road was developed along the barrier beach. Subsequent time periods indicate that the development of causeways across Lagoon Pond and roadway construction led to man-made stabilization of the barrier beach system. These long-term stabilization efforts prevented the low-lying barrier beach from naturally migrating landward as a result of gradual sea-level rise over the past 100+ years or to periodic storm events.

As depicted in Figure I.19 and Figure I.24, very little bathymetric change occurred between the mid-1800s and 1948 along the area immediately north of the barrier beach system, as the shallow shoal system adjacent to the shoreline continued to persist. As shown in Figure I.19, the initial pier construction from the barrier beach system was located at the closest proximity to the naturally deep Harbor channel. Overall, it appears that prior to WWII, the water depths adjacent to the barrier beach were generally natural. However, development in the WWII time-period formalized the vertical structures along the Harbor-facing portion of the port that was part of the historical marine railway.

Figure I.21 Artist's rendering of Holmes Hole (Vineyard Haven Harbor) in 1856, where the pier facility along the barrier beach separating the Harbor from Lagoon Pond is depicted in the foreground. Note, no roadway existed along the barrier beach at this time and goods were transferred to town along the sandy beach.

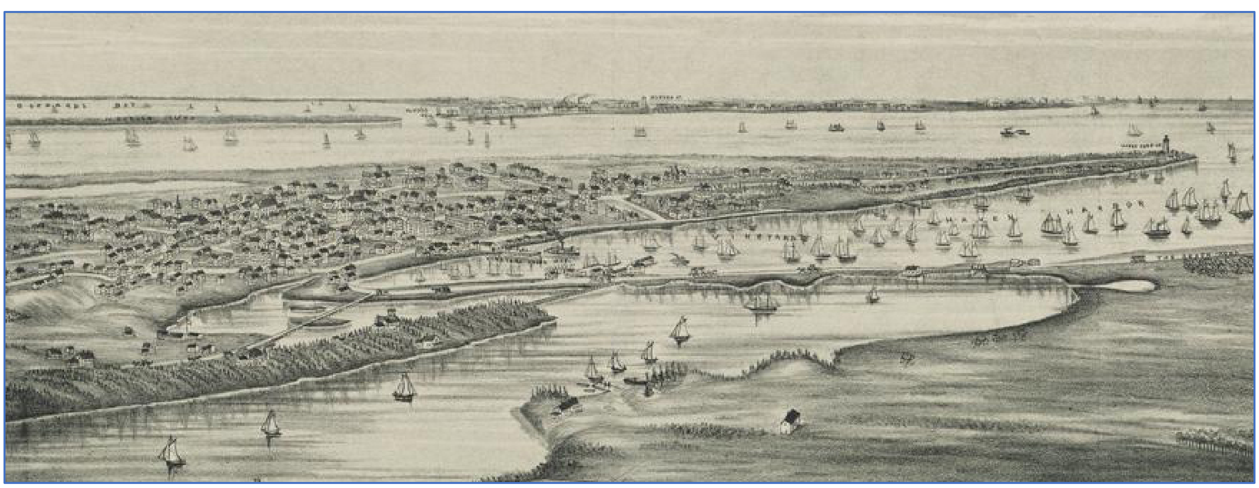


Figure I.22 Birdseye view of Vineyard Haven Harbor in 1880 (from the south) illustrating the causeways constructed from the mainland to the barrier beach, as well as the roadway along the beach.

Figure I.25 provides photographic evidence of the historical low-lying nature of the barrier beach in 1900 relative to the port facilities constructed along the barrier beach. In addition, Figure I.24 visually indicates the narrow beach system to the east of the port area, where a series of groins were established to mitigate erosion. Over the subsequent decades, State Road and adjacent upland development has been stabilized to ensure access between Vineyard Haven and Eastville. These stabilization efforts have worked to prevent landward migration of the barrier beach system; however, they also have prevented natural erosion processes from occurring. Therefore, the sediment supply along the beach system has decreased over time and sediment availability along the shoreline between the Packer Facility (i.e. the Tisbury Marine Terminal) and the State Road bridge to Eastville is minimal.

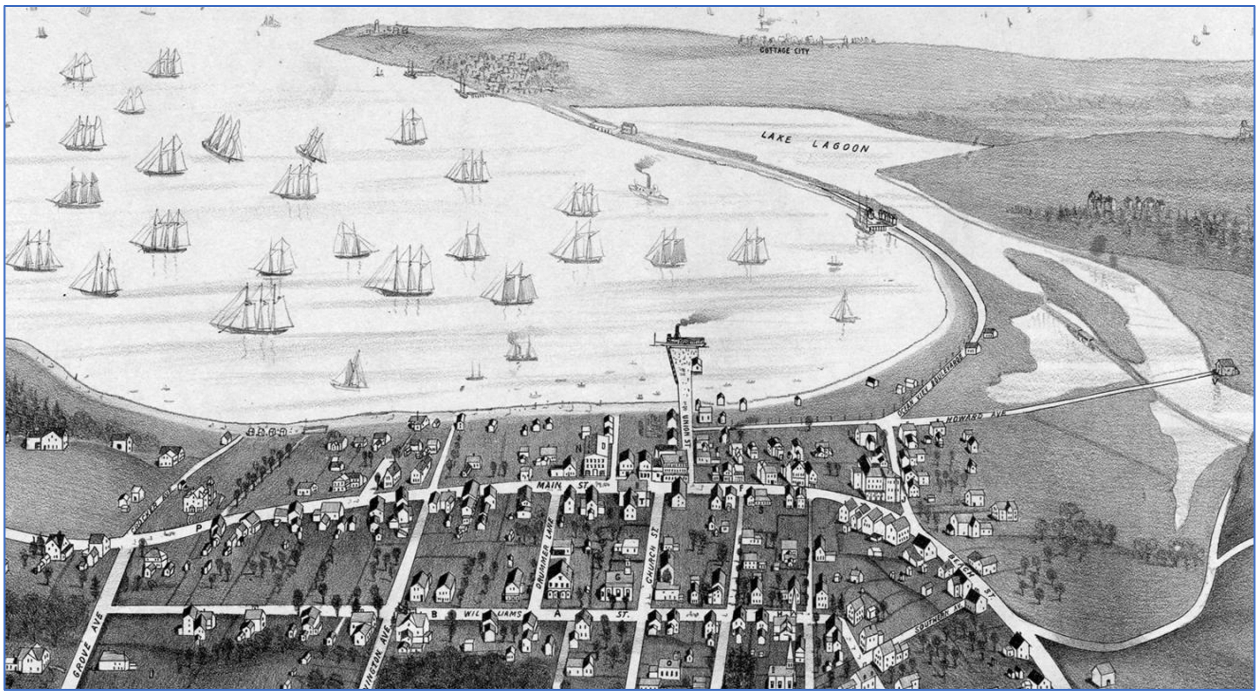


Figure I.23 Birdseye view of Vineyard Haven Harbor in 1890 (from the west) illustrating the causeways constructed from the mainland to the barrier beach, as well as the roadway and pier facility along the beach.

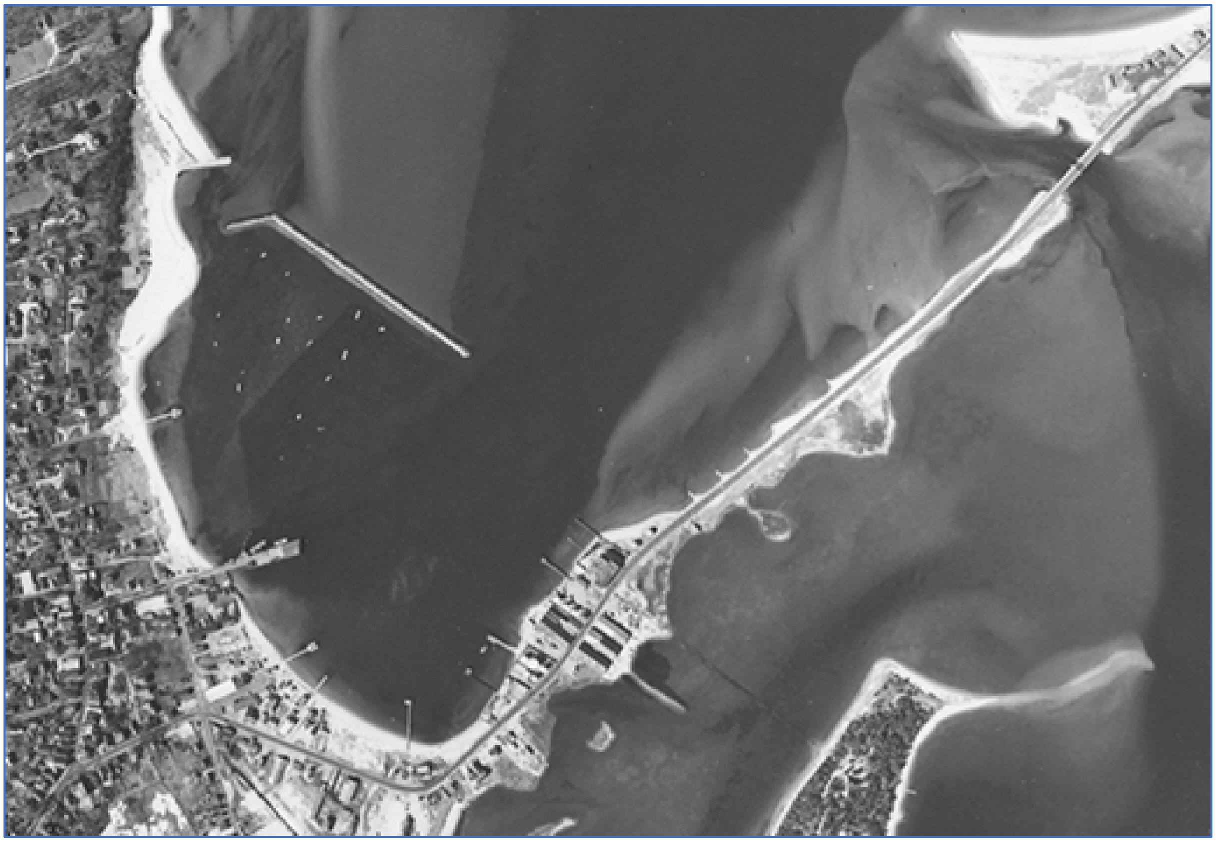


Figure I.24 Post-World War II aerial photograph from 1948 illustrating the shipbuilding facilities along the barrier beach system, the series of groins to the east of the present-day Packer Facility, and the breakwater protecting the main Harbor basin. Based on the photograph, it appears that the water immediately adjacent to the upland had not been dredged.

Figure I.25 Photograph from 1900 showing the Steamship Pier in the foreground. The low-lying barrier beach system and pier facility along the barrier beach can be seen in the upper part of the photograph.

To compliment the review of historical imagery, more recent reports were reviewed that include resiliency planning options to account for sea level rise and flooding downtown, including the MVP process (Horsley Witten Group 2018). A poll completed during the MVP process found that the attendees considered the top four climate hazards to be (Figure I.26): 1) hurricanes or nor'easters, 2) coastal flooding, 3) sea level rise and 4) intense rain and flooding. The overall prioritization of critical hazards, reflects what many small coastal communities are most concerned with.

While the MVP process provided general planning information relative to future flood risks and mitigation in the long-term, the report lacked detailed pragmatic approaches to address ongoing concerns in the Vineyard Haven Harbor area. Specifically, the low-lying areas surrounding the Harbor are well below the existing 100-year (1% Annual Chance) flood level and are even impacted by more frequent storm surges associated with relatively frequent nor'easters.

In addition to the MVP report, an EPA resiliency assessment was reviewed. This report was included in the stormwater assessment completed for the town (EPA 2020), which was discussed in Section 1.4. The report detailed both near term (1-10 and 10-30 years) and long-term (30-50 years) options for the town moving forward. The evaluation of all possible strategies is important for the Town, however, many of these ideas are not practicable in the near term, as the scale and financial viability of the projects would prove challenging for the Town of Tisbury. Current sea level rise data do not warrant many of the extreme measures proposed in the report over the next 1-10 years.

For example, the construction of a Beach Road Causeway was recommended in the near term 1-10 years. As a State Road, maintained by MA DOT, the near-term viability of creating a causeway along Beach Road is not feasible in the recommended time frame. It would even be challenging to accommodate in the next 10-30 years, based on the existing MA DOT plans for Beach Road. Also included in this near-term recommendation is the hardening of the shoreline with a revetment. Although this design would mitigate for wave action in the harbor, it would not prevent flooding of the downtown, and therefore would not provide the necessary protection. Realistic strategies that were proposed include potential zoning amendments, elevating buildings on pilings, and continuing to monitor sea level rise.

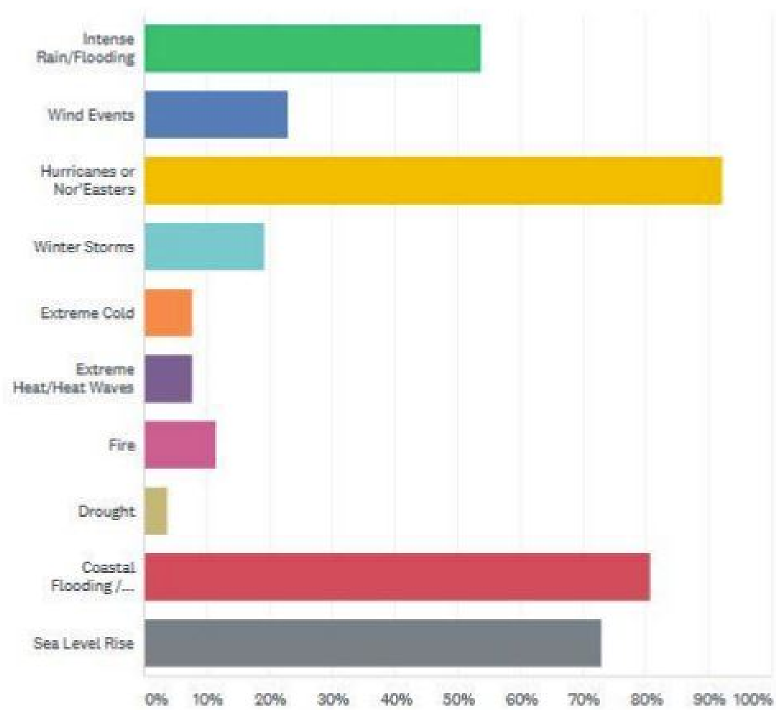
Despite the lack of near-term viability for the projects, the options and strategies provided in the EPA resiliency report, should be re-visited as threshold sea level rise criteria are met during the monitoring process. Under the existing circumstances and sea level conditions, the predecessor of the FY21 report, the FY20 report, presented several practicable alternatives for Vineyard Haven. The report determined 5.0 feet NAVD to be the target elevation to mitigate for flood tide pathways over the next 30 to 50 years. While each conceptual design was established individually, it is important to recognize the fact that all designs are critical to establishing the flood prevention required for the downtown area. In this report, the following sections contain descriptions of the conceptual design and planning for each region:

- Section A: Harbor Shoreline Dune
- Section B: Beach Road modifications
- Section C: Lagoon Pond Road, Veterans Memorial Park Parking Lot Modifications, and Grass Berm

The conceptual designs of this study sought to provide pragmatic solutions to sea level rise and flooding over the next 30-50 years.

Select what you think are the Top 4 climate change hazards facing Tisbury.

Answered: 26 Skipped: 0



ANSWER CHOICES	RESPONSES	
Intense Rain/Flooding	53.85%	14
Wind Events	23.08%	6
Hurricanes or Nor'Easters	92.31%	24
Winter Storms	19.23%	5
Extreme Cold	7.69%	2
Extreme Heat/Heat Waves	7.69%	2
Fire	11.54%	3
Drought	[illegible]	1

Figure I.26 MVP report online survey results (Horsley Witten Group 2018).

	Stategy	Near-Term (1-10 years)*	Mid-range (10-30 years)*	Long-term (30-50 years)*
PROTECT	***Vineyard Harbor Pedestrian Boardwalk and Revetment***	Observe local sea level rise (slr) rates	Construct boardwalk feature and with access ramps	Build adjacent buildings with second store loading
	Extending Eastville Beach Breakwater	Constuct Eastville Beach Break water extension	Provide pedestrian access	
ACCOMODATE	***Elevate water-dependent business***	construct buildings on pilings	relocate water-dependent business from the lagoon side of Beach Road to the harbor side	re-establish tidal marsh on lagoon side of Beach Road
	Beach Road Causeway	Construct Beach Road Causeway Construct service road between existing Beach Road and Lagoon Pond Road for temporary access to business	Raise adjacent land on the harbor side of Beach Road to meet grade of the causeway	Raise adjacent land on the lagoon side of Beach Road to meet grade of causeway
	Culverts under Beach Road	Envoronmental Impact study of impacts to Lagoon Pond and hydrologic engineering studies	Construct x number of culverts along beach road	
RETREAT	***Phasing out nonwater dependent***	Map low flood lands Zoning amendments	Begin to develop conservation easements and land purchase strategies with landbank Phase out existing non-water-dependent business and facilities	Restablish former tidal marsh

Figure I.27 Strategies proposed in the EPA Coastal Resiliency Report (EPA 2020).

A) HARBOR SHORELINE DUNE

The harbor shoreline presents several critical storm tide pathways below the target 5.0-foot NAVD elevation. These pathways, if left as-is, will allow coastal flood waters to propagate into downtown Vineyard Haven during moderate and severe nor'easters. It was determined that the best design option to mitigate for these pathways along the harbor shoreline would be to include a dune along the eastern shoreline between the Steamship Authority Parking Lot and the Packer Facility revetment. The FY20 report includes a discussion of the reasoning behind choosing a dune over a beach nourishment. Under existing conditions, the maximum beach elevation fronting several of the buildings along the shoreline is as low as 3.3 feet NAVD88, with the lowest storm tide pathway into downtown at 3.7 feet NAVD. This low elevation severely exposes many of these structures to wave impact during a storm event, and it is critical for the resiliency of the downtown that additional protection is provided.

A dune is a "soft" engineering or green infrastructure feature, that can serve to protect upland infrastructure from erosion and flooding. It should be noted that the proposed dune is an engineered feature that would be constructed with appropriate materials to withstand the storm wave environment within Vineyard Haven Harbor. Coastal dunes, when appropriately designed, can provide an integral part of a well-planned coastal defense system. Coastal dunes provide an upland barrier that can protect infrastructure landward of the dune system from both storm wave and coastal flooding impacts, understanding that the "soft" dune feature will require periodic maintenance to ensure sustainable flood protection.

In general, larger volume high dunes provide more lasting protection; however, the appropriate scale of dune shore protection is dictated by the local storm surge elevation, as well as the storm wave climate. Due to the natural and man-made shore protection features of Vineyard Haven Harbor, the storm wave climate is relatively modest. Further, the project purpose is to address more frequent coastal flooding events caused by nor'easters; therefore, the dune elevation necessary to mitigate storm surge flooding also is modest. While the existing shoreline has variable levels of shore protection from beach and dune features, the major storm tide pathways are primarily at beach access points at the end of each road. Figure A.1 shows the variability in elevations along the shoreline, with the beach crossing near the Steamship Authority Parking Lot, at approximately 3.8 feet NAVD in elevation.

Figure A.1 Example of the variability in shoreline elevation, looking southeast from the western end of the harbor shoreline towards the Black Dog Tavern.

Figure A.2 Example of the variability in shoreline elevation, looking southeast from the western end of the harbor shoreline towards the Black Dog Tavern.

Existing best design practices for engineered dunes follows the Federal Emergency Management Agency (FEMA) guidance associated with mitigating for 100-year return period storm conditions. Based on an analysis of dune erosion during hurricanes, FEMA identified a crest elevation above the 100-year still water elevation as the critical parameter for protection against a 100-year storm event. Based upon the most recent Flood Insurance Rate Maps (FIRM) developed by FEMA, Tisbury experiences a 100-year flood elevation of 7.7 feet, which would require approximately 4-4.5 feet of additional elevation to the existing back beach area. A dune of this elevation along the Harbor shoreline would be problematic to implement due to impacts to the nearshore environment, as well as impacting the functioning of the ‘working waterfront’.

Alternatively, a more modest dune to mitigate the influence of frequent nor’easters can be designed with a dune at an elevation of approximately 5.0 to 6.0 feet NAVD. As described above, this elevation corresponds to the target elevation for shore protection associated with the most severe nor’easters experienced in Vineyard Haven Harbor. Steps could then be provided to facilitate the progression of dune modifications looking forward to meet further climate related changes.

Massachusetts Department of Transportation (Mass DOT) designed and permitted a beach nourishment at the eastern end of the shoreline, in between the Shell station and the revetment that fronts the Packer Facility. Although most of the harbor is sheltered from open Nantucket Sound storm wave energy, the eastern end of the shoreline is heavily eroded (Figure A.3 and Figure A.4) primarily due to impacts from the adjacent armored shoreline (i.e., "end effects" associated with the structure). Long-term shoreline change analysis in the FY20 report concluded that erosion is prominent at this end of the shoreline (Figure A.5). In addition, the report provided wave modeling results within the harbor during a storm (Figure A.6) and found that this section will require additional protection as compared to the remaining sections of shoreline. Therefore, it is anticipated that the MA DOT nourishment project will include coarse material (i.e., gravel or cobble) to mitigate the "hot spot" erosion at this location. It is important to recognize that the purpose of this project, is first and foremost to provide protection for upland infrastructure (e.g., Beach Road). The crest of the nourishment is designed to an elevation of 4.5 feet NAVD (Figure A.7 and Figure A.8), which does not meet the 30-to-50-year target flood protection elevation of 5.0 feet NAVD. Therefore, supplemental material will be required to raise the profile, although the necessary volume will be inconsequential relative to the dune construction requirements for the remainder of the shoreline.

Figure A.3 Image looking to the east along the harbor shoreline from the section of beach fronting the Shell Station (November 7th, 2019).

Figure A.4 Image looking to the west from the eastern end of the harbor shoreline along Beach Road, on March 3rd, 2018. The high storm surge flooded Beach Road, resulting in difficulties with navigation.

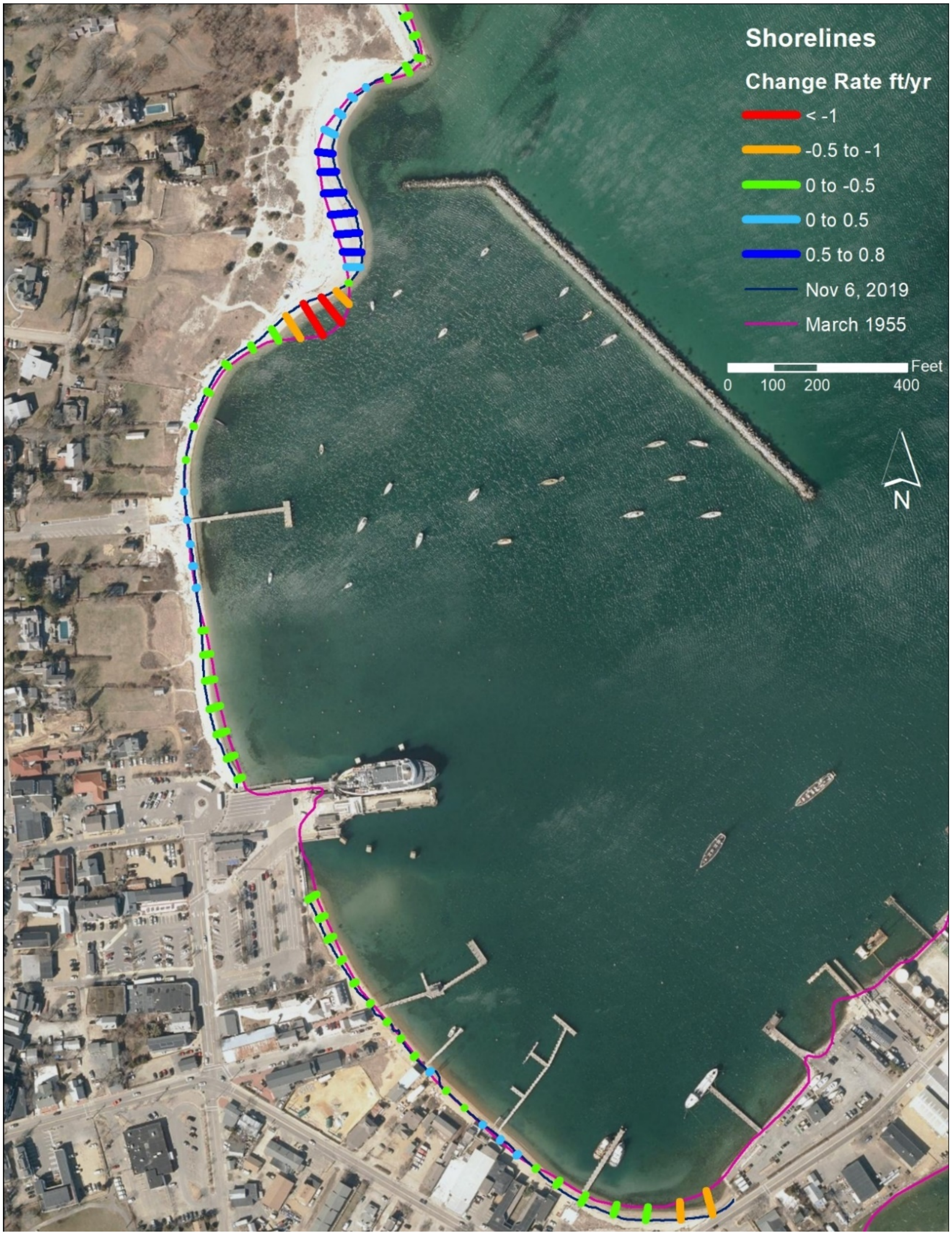


Figure A.5 Results of shoreline change analysis using the March 1955 and November 2019 RTK-GPS shorelines. Color bars indicate a range of shoreline change computed along Vineyard Haven shoreline. Negative rates indicate erosion, and are represented by the colors yellow, orange, and red. Areas of accreting shoreline are indicated by green and light and dark blue.

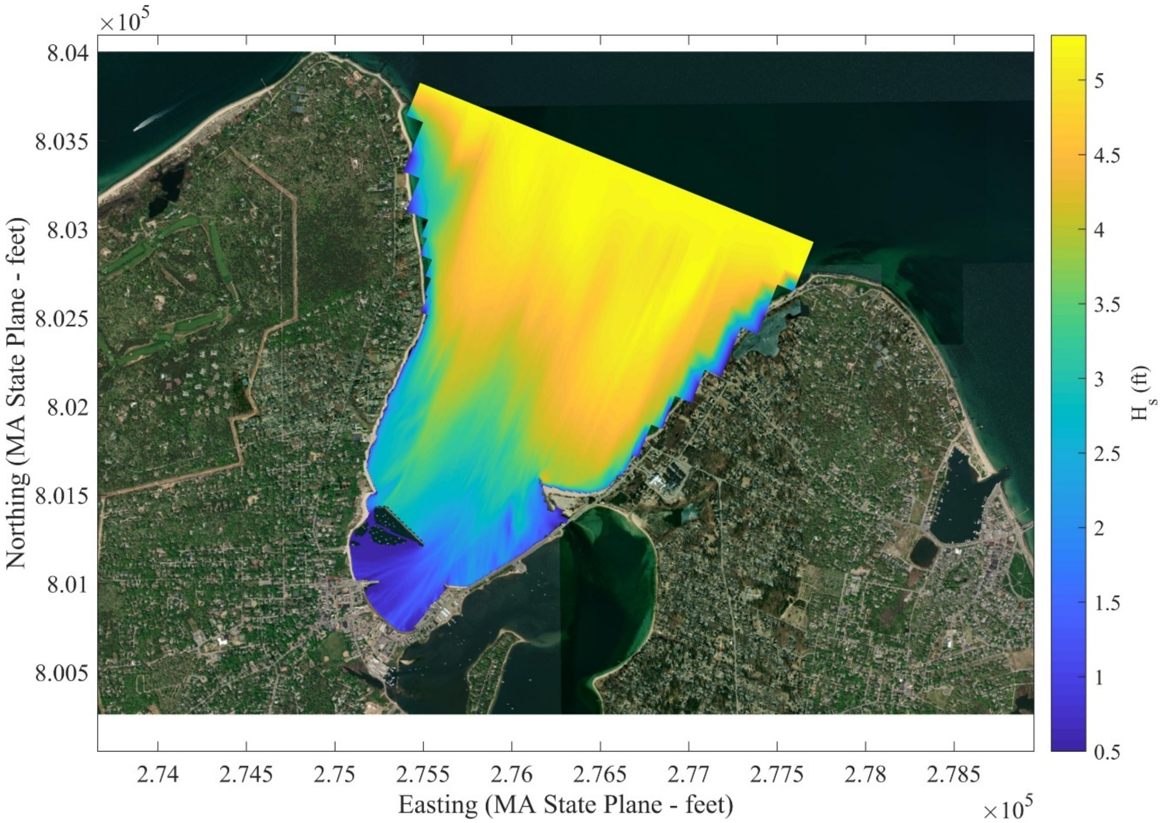


Figure A.6 Map of significant wave height in feet within the harbor. Wave heights prescribed at the seaward limit of the harbor in Vineyard Sound were on average 5.3 feet, based on outputs from the large-scale regional grid.

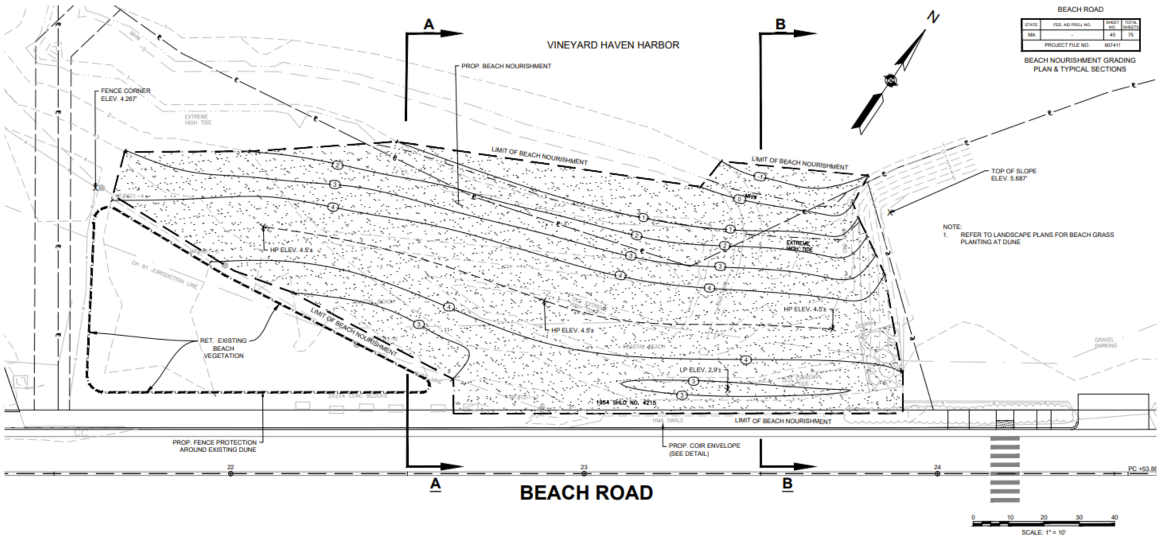


Figure A.7 Footprint of Massachusetts DOT Beach Road Project nourishment. The location of transects A-A and B-B (Figure A.8) are identified in the map.

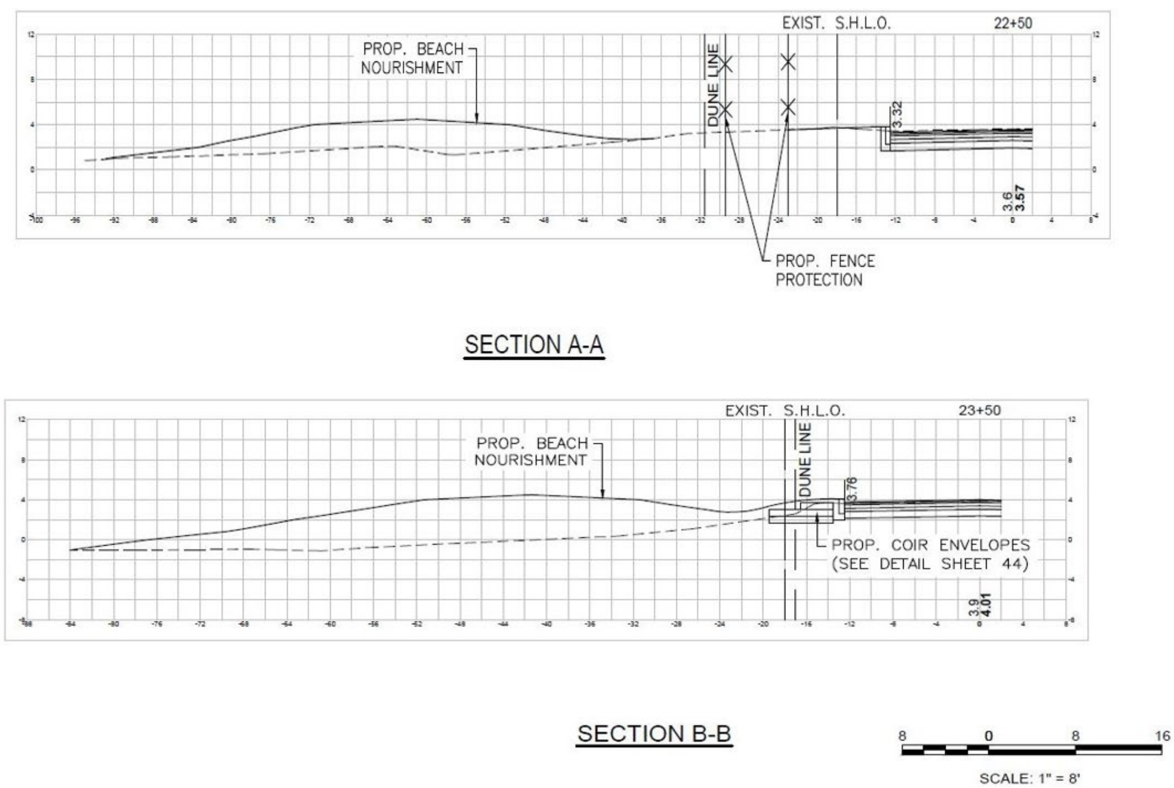


Figure A.8 Cross sectional view of the profile elevations along transects A-A and B-B.

The primary purpose of this dune design, would be to elevate the existing shoreline to meet the target elevation of 5.0 feet NAVD. The length of the dune would extend along the 1,280-foot stretch of shoreline between the Steamship Authority and the Packer Facility (Figure A.9). The dune footprint was worked into the existing contours from 2018 LiDAR, supplemented by the Applied Coastal survey. Due to the extreme variability in existing grade and shoreline features, the design dune volume will vary significantly along the shoreline. Therefore, both permitting and design drawings will require numerous cross-sections to provide necessary detail for evaluating potential environmental impacts and planning construction.

These detailed sections will accommodate public feedback throughout the process, to ensure full support. A pamphlet was developed specifically for the harbor shoreline project, to provide nearby property owners information about the design (see Appendix A). Some initial public feedback was incorporated from several meetings held over the year, including a small group meeting on May 26th, 2021 (see Appendix B for meeting minutes). Extensive public engagement will be incorporated, for all design regions, as the project moves forward.

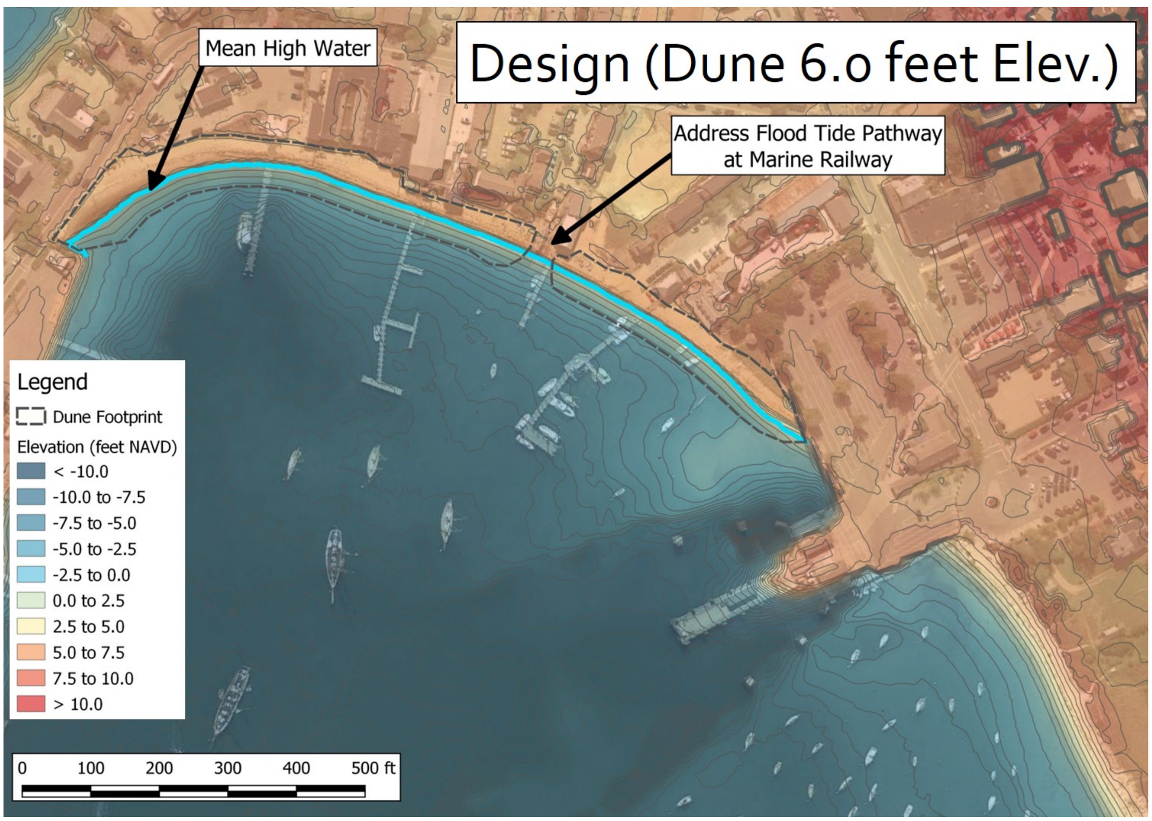


Figure A.9 Design contours based on digital elevation model. The dune footprint is included as a dashed line along with the existing mean high water (MHW) position for reference. The width of the dune fluctuates along the 1,280-foot stretch of shoreline between the Steamship Authority and the Packer Facility.

Figure A.10 Example of a low-elevation dune constructed for storm and flood protection in Cotuit, MA.

B) BEACH ROAD

Critical Beach Road storm tide pathways that were considered for this study are located primarily along the eastern end of Beach Road, between the Shell gas station and the Lagoon Pond bridge. With several sections of Beach Road with existing elevations below 3.5 feet NAVD, it is critical that existing pathways are mitigated. The primary objective for mitigating these pathways, would be to elevate critical sections of Beach Road to the target design elevation of 5.0 feet NAVD. However, due to the designated ownership of the road and challenges to perform any modifications in the short-term, other near term design alternatives will be pursued as the project moves forward. Beach Road is a state roadway, controlled by Massachusetts Department of Transportation (MA DOT); therefore, making flood mitigation modifications to the road depend on agency coordination. Unfortunately, MA DO has final design plans prepared, as well as a construction contracts in place, for roadway improvements for Beach Road and discussions with the agency have indicated that design modifications to improve coastal resiliency are not realistic at this stage of the process.

Several attempts were made to work with MA DOT to include elevated road sections to meet the target design elevation. Project Team members met with members of both MA DOT and the Town to present several minor modifications to the plans that would enable the target roadway elevation to be met. However, due to the late stage in the project, accommodations were not possible to have the target roadway elevation met as part of the existing project. It will be important to prioritize elevated road considerations with future Beach Road work, and further discussions with MA DOT will be pursued moving forward.

The high elevation point in the Beach Road MA DOT project is approximately 4.5 feet NAVD, and is located adjacent to the Tisbury Market Place. This is the primary storm tide pathway into the downtown Vineyard Haven area from the Beach Road area. While this elevation is still below the target elevation of 5.0 feet NAVD, it is less critical than mitigation of Lagoon Pond Road and the Harbor shoreline storm tide pathways, which are closer to 3.5 feet NAVD. As discussed in the Storm Tide Pathways text in Section I.

Figure B.1 Location of critical Beach Road section and the prioritized locations for elevating to 5.0 feet NAVD.

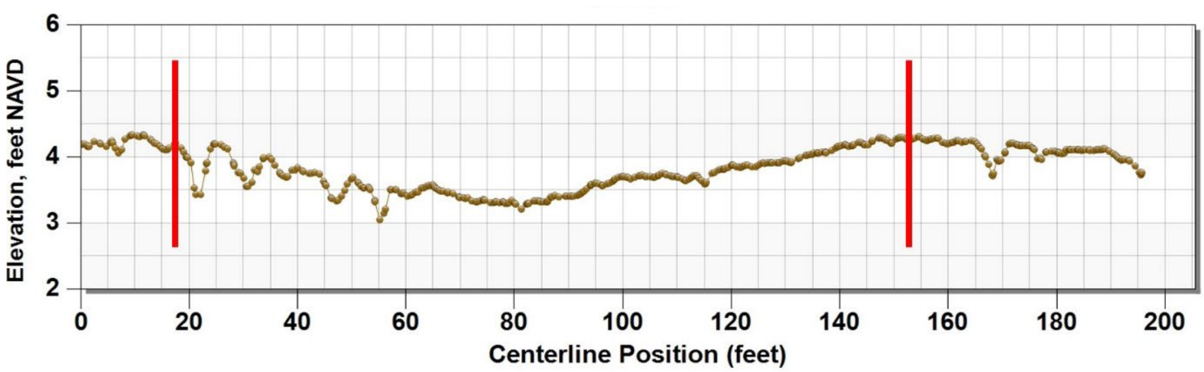


Figure B.2 Cross-section of Beach Road centerline elevations from a 2018 LiDAR dataset along the critical section identified in Figure 1. Also identified are the prioritized locations for reaching a road elevation of 5.0 feet NAVD.

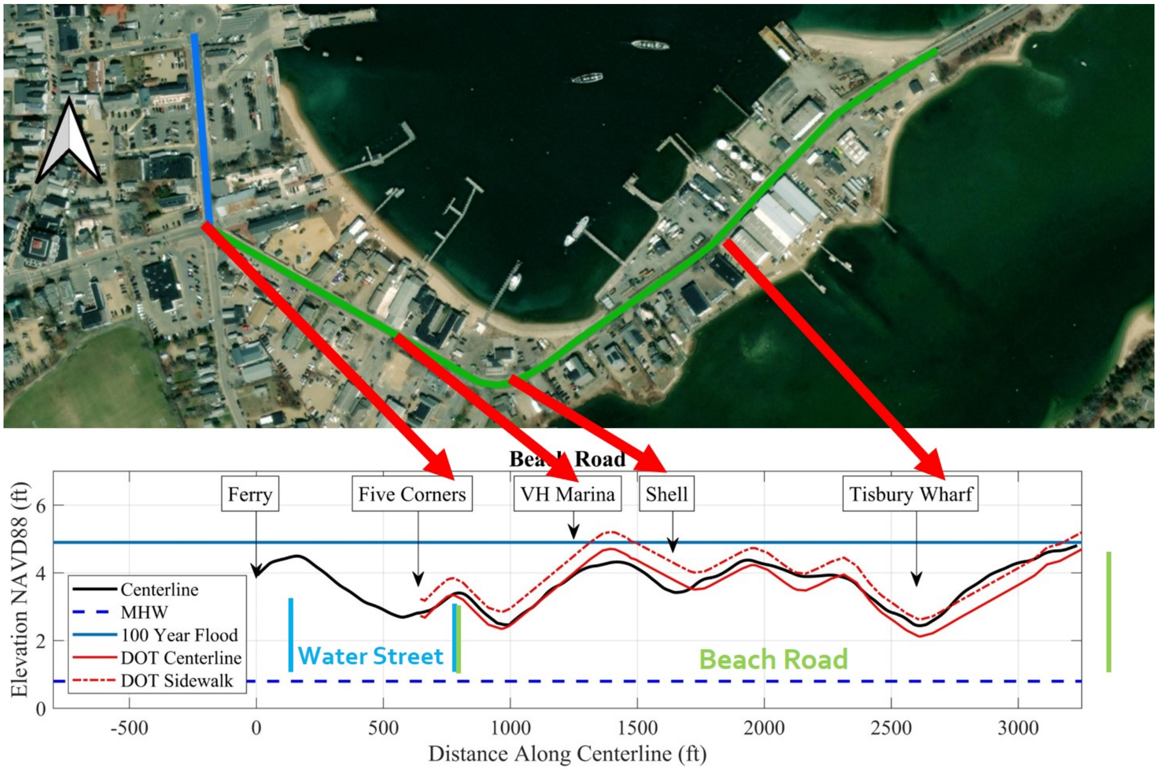


Figure B.3 Elevation profile of Lagoon Pond Road and Water Street. The red arrows identify important landmarks along the road.

C) LAGOON POND ROAD

The Lagoon Pond Road region of downtown is the most vulnerable section of Town to coastal flooding, as it includes the lowest storm tide pathways into the downtown region. The primary pathway for floodwaters in this area is Mud Creek. In the FY20 report, several culvert options were considered to try to prevent flow from entering the creek and propagating into the downtown area from Lagoon Pond. It was determined that while modifications to the culvert would provide some preventative flood measures, pathways exist along the road itself near the marina, and therefore modifications to the culvert would not prevent flooding.

Following the October 2020 survey, an alternative approach to elevating land along Veterans Memorial Park became the preferred alternative over the culvert modification options, as elevating infrastructure would provide a method that could be readily modified as sea levels continue to rise. These structural modification options include the elevating of Lagoon Pond Road, the park parking lot, and the section of park at the southern end. The conceptual design would link the increased elevations within the park and along Lagoon Pond Road to the higher elevations to the west of downtown, as well as the high elevations to the east across the Lagoon Pond Road from Veterans Memorial Park. The relative locations of the designs are included in Figure C.1.

The conceptual design includes the elevating of Lagoon Pond Road, beginning at the eastern end of the Prime Marina Shipyard at 100 Lagoon Pond Road (Figure C.2). The road can be modified further south, however, it only needs to reach the target design elevation of 5.0 feet in one location to meet the goals of the project. Due to the water dependent activities of the marina, it is recommended that buildings are elevated, rather than modifications be made to the shoreline itself. The southernmost building at the shipyard was elevated recently to bring the building above the FEMA 100-year flood level.

Figure C.1 Aerial map with location of proposed designs.

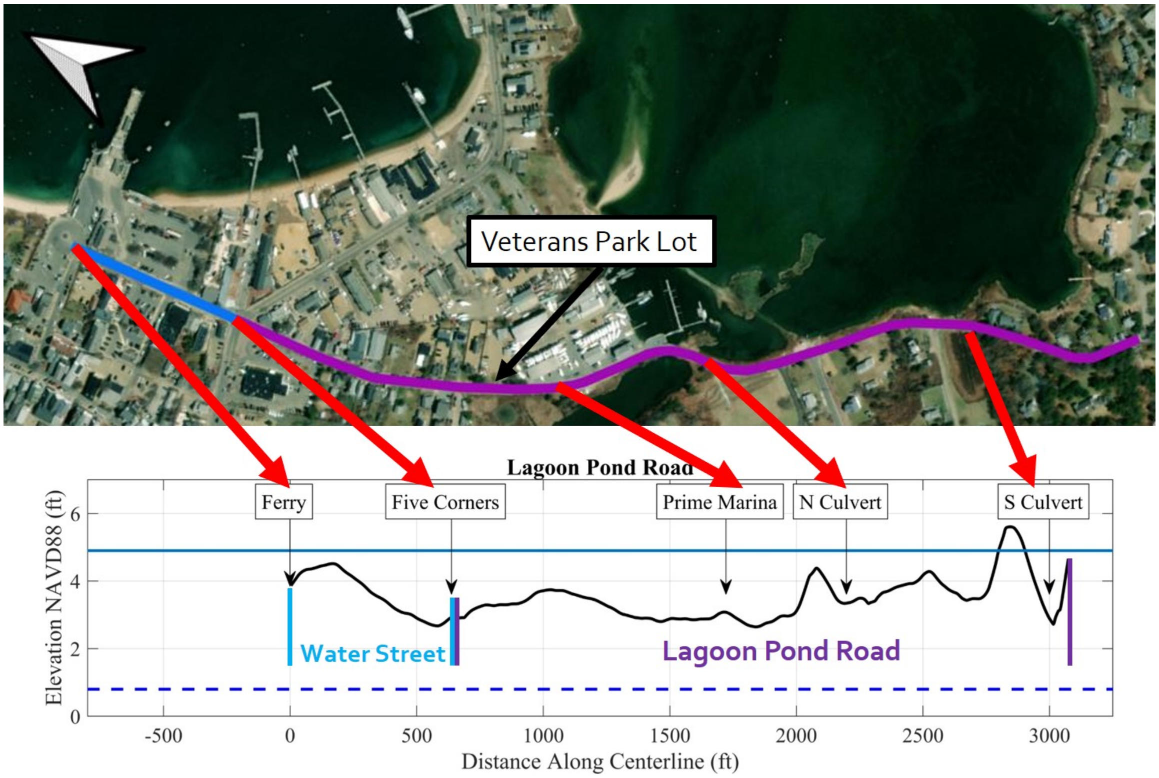


Figure C.2 Elevation profile of Lagoon Pond Road and Water Street. The red arrows identify important landmarks along the road.

The road modifications should, at minimum, be made to the Veterans Memorial Parking Lot, to achieve the target elevation. The critical section of road is included in Veterans Memorial Parking Lot, to achieve the target elevation. The critical section of road is included in Figure C.4, looking southeast. An important consideration to be made is the modifications that will be made to abutting property owner driveways. However, with most of the homes along this section of Lagoon Pond Road have first floor elevations that are already above the road elevation, and driveway elevations should transition into the road well. The road modifications will tie into an elevated Veterans Memorial Parking Lot (Figure C.5). It is recommended that both the road and parking lot meet the 5.0 feet NAVD target, with the consideration of further elevating in the final design. Preliminary Lagoon Pond Road and parking lot grading are included in Figure C.6.

From the parking lot, a section of the park will be raised to approximately 7 to 8 feet NAVD, with a variable width of 20 to 25 feet. The change in topography to the existing contours are included in Figure C.7. This grass berm design would connect to the elevated parking lot and road to the higher elevations west of downtown. The design can feature seating areas for spectators to view events at the park and sporting fields. With only 3 to 4 feet of elevation modifications, any changes will be minimal.

Figure C.3 Prime Marina structure at 100 Lagoon Pond Road. Some properties have begun to elevate service building in the waterfront (EPA 2020).

Figure C.4 October 2020 photograph looking southeast along the proposed section of Lagoon Pond Road to be elevated.

Figure C.5 October 2020 photograph looking southeast along the proposed section of Lagoon Pond Road to be elevated.

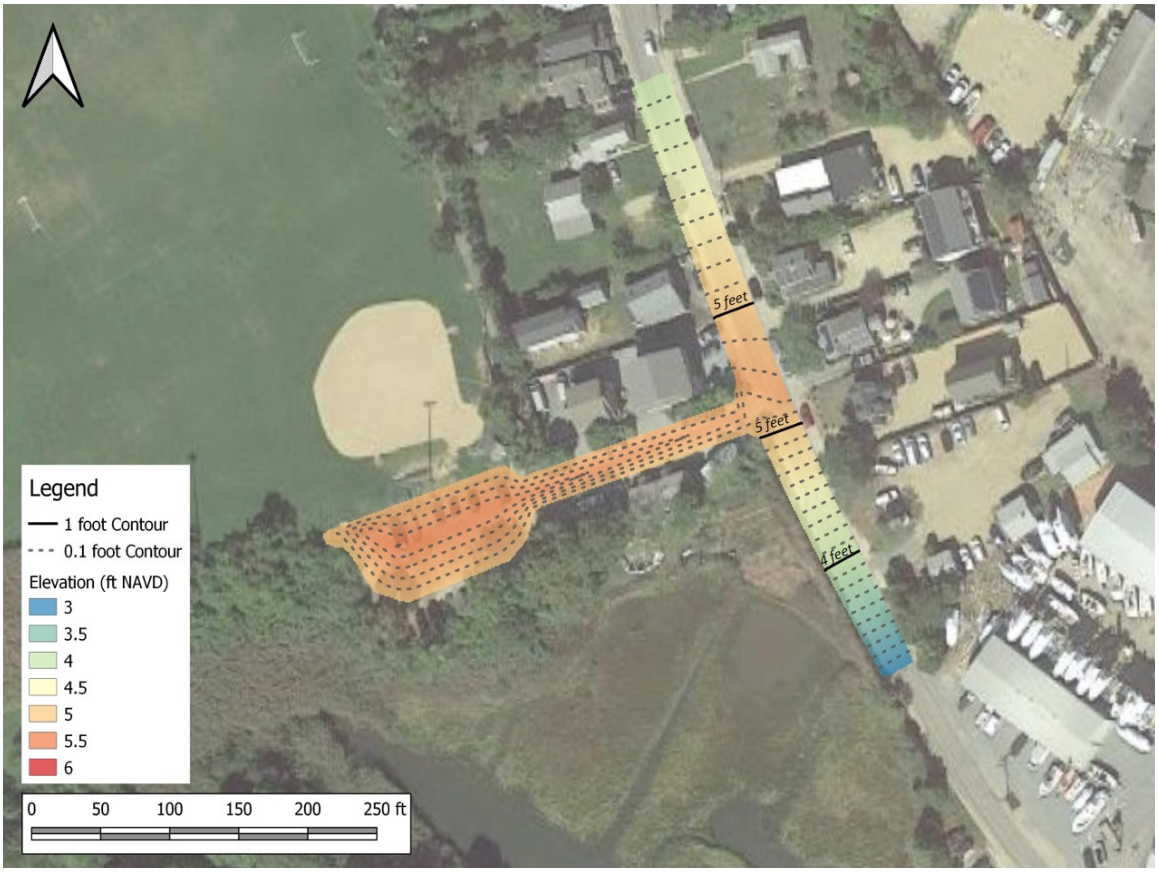


Figure C.6 Color contour elevations of the Lagoon Pond Road design.

Figure C.7 Color contour elevations of the berm design for Veterans Memorial Park.

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Borrelli, Mark, Steve T. Mague, Theresa L. Smith, and Bryan Legare. 2016. "A New Method for Mapping Inundation Pathways to Increase Coastal Resiliency, Provincetown Massachusetts." https://doi.org/10.13140/RG.2.2.35863.47523.

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APPENDICES

Appendix A: Homeowner Resiliency Project Pamphlet

(see next page)

DOWNTOWN VINEYARD HAVEN RESILIENCY AND FLOOD MITIGATION DESIGNS

The low-lying portions of downtown Vineyard Haven are susceptible to flooding from coastal storms and associated damage under present day conditions and will become increasingly susceptible in the future, as sea-level continues to rise. The current mean high-water level (average high tide) is around 1-foot NAVD. Higher estimates of sea level rise bring that level closer to 3.0 feet NAVD. With a significant portion of downtown at or below 3 feet NAVD and a majority of the area below 5 feet NAVD, it is critical to develop long term solutions to address flooding, sea level rise will result in frequent nuisance flooding during spring tides every month.

The Town of Tisbury with Project Team members Massachusetts Coastal Zone Management and Applied Coastal Research and Engineering developed a number of alternatives to provide resiliency and flood mitigation to downtown Tisbury. Prior to developing alternatives, an evaluation of potential risk over the next 30-to-50-year timeframe (2050 to 2070) was performed by the Project Team. This assessment was science-based, where both historic data and the accurate projections of future conditions were incorporated to ensure the most appropriate information for future risk-based decision making. State-of-science tools, including physical processes numerical models and Geographic Information System (GIS) applications were used to effectively characterize site-specific coastal hazards, as well as to provide assessment of potential future flooding mitigation options.

Based on the analysis of historical water level data at a tide gauge in Nantucket Harbor, an elevation of 5 feet NAVD was selected as the initial design elevation to mitigate for flooding. This selected elevation compliments the National Weather Service (NWS) designation of 5.0 feet NAVD as the flood stage for a moderate flood event. Analysis of past storm records indicates that design to this elevation would protect against strong northeast storm events.

Using this design elevation, in addition to the analysis of existing topography, several designs were developed and analyzed to try to prevent and minimize storm flooding along particular pathways indicated in Figure 1. These designs are relatively low impact, manageable projects for the Town to undertake to provide flood protection. The predominant proposed designs are as follows:

- Harbor Shoreline Dune – Restore and recreate the dune system along the Vineyard Haven shoreline
- Lagoon Pond Road - Elevate the roadway elevation adjacent to Mud Creek
- Grass Berm (Veterans Memorial Park) – To prevent flooding from Lagoon Pond and Mud Creek
- Beach Road Modifications* - Elevate the roadway elevation in the vicinity of Tisbury Market Place and the Packer Facility

To best visualize how these alternatives would look downtown, several maps were developed to see both the location of the designs (Figure 2), and the flood mitigation impacts. It is important to note that smaller modifications can contribute to flood protection efforts, and that these modifications can be increased moving forward.

In order to protect downtown infrastructure to a specific elevation, it is important that all flood pathways below the target elevation (5.0 feet NAVD) are mitigated. The importance of including all designs is shown in the comparison of an example 4.5 ft NAVD flood elevation for the existing conditions (Figure 3) and a scenario in which all designs are included (Figure 4).

Moving forward, the Project Team will be working on incorporating feedback and contributions from the public in the further development of these resiliency designs.

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*Beach Road is a state road, controlled by Massachusetts Department of Transportation (Mass DOT) and therefore making flood mitigation modifications to the road depend on working with the agency. If modifications are unable to be constructed, other alternatives can be pursued to mitigate for flooding along the Lagoon Pond Shoreline.

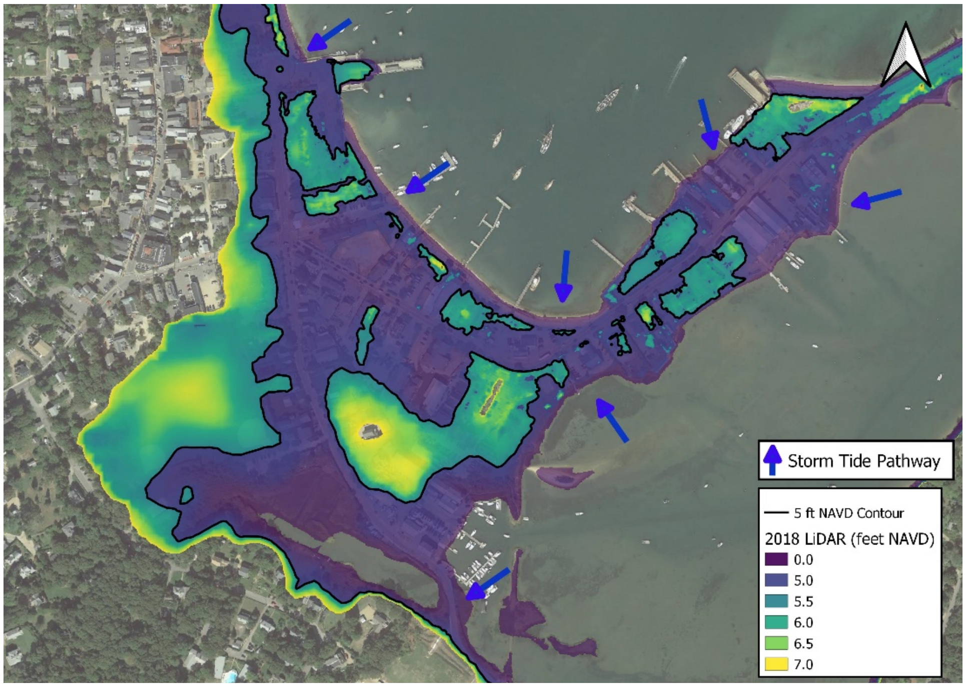

Figure 1 Location of primary storm tide pathways for the 5.0-foot NAVD design elevation. The 5.0-foot NAVD contour is outlined in black, with the primary storm tide pathways identified with a blue arrow.

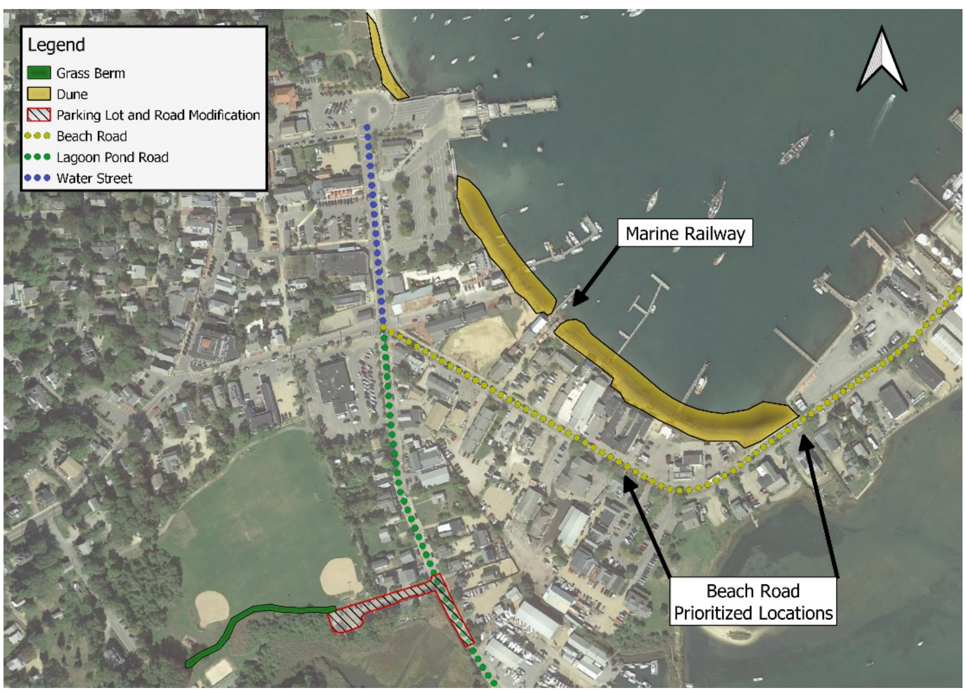

Figure 2 Locations of alternative designs proposed for downtown Vineyard Haven. As Beach Road is a state road, modifications ultimately depend on working with Massachusetts DOT. It is also important to note that alternative design options are under consideration at the location of the marine railway to maintain flood mitigation, but not impede on the operation of the structure.

Figure 3 Flooding extents downtown during a 4.5-foot NAVD storm water level if no resiliency measures are incorporated in to Vineyard Haven.

Figure 4 Flooding extents downtown during a 4.5 foot NAVD storm water level if all resiliency designs are accounted for.

Appendix B: Public Outreach Meeting Notes

(see next page)

Tisbury Direct Abutters Meeting

CZM Coastal Resilience Grant Program, FY21

Applied Coastal / Town of Tisbury / Massachusetts Office of Coastal Zone Management

May 26, 2021, Zoom

Minutes of Meeting

Team Attendees: R. Haney (CZM), S. McKenna (CZM), J. Ramsey (ACRE), M. Doelp (ACRE), T. Ruthven (ACRE), J. Crocker (Tisbury), C. Doble (Tisbry), Ben ?? (Tisbury),

Public Questions and Comments

1. Steve Moran
    a. Once the water is inside the 'dike' what happens?
    b. How does the dune fit around the piers out into the water?
    c. Periods of sustained rain causes flooding during northeast wind events. What is proposed to address the storm water?
    d.
2. Peter Givertzman
    a. How far does the dune between Owen Park and the Ferry extend?
    b. How do interested parties stay in touch on developments associated with the project?
    c.
3. Phil Wallis
    a. What is the sea level rise over the last 50-years?
    b. Rainwater is the major culprit for causing flooding.
    c. Questions about specific properties relative to flooding. Gannon and Benjamin
    d. Who will be responsible for paying for the proposed solutions?
    e. Describe the berm in the park?
    f. The Marine Railway needs to be incorporated, what are the cost sharing options for required improvments?
    g. Will there be a website for the project?
4. Debbie Packer
    a. When beaches are nourished with public funds, they become public. If owners allow nourishment will there be a permanent easement?
    b. Filled storm drains are large component of the flooding occurring due to a lack of ongoing maintenance. Is anything being done?
    c. The pictures of boats on shore are misleading and dramatizing the situation, a majority of those boat washed up due to faulty moorings.
    d. Additional concerns on easements, or right of ways, and long-term management of public features on private property.

Minutes Issued:
Prepared by: T. Ruthven