Alternatives Analysis
Vineyard Haven

Prepared for:

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1. Introduction

The Town of Tisbury received funding assistance through the Coastal Zone Management (CZM) FY22 Coastal Community Resilience Grant Program to continue work initiated under the Program for FY20 and FY21 to increase public involvement and outreach to refine the conceptual designs. The overall goal was to promote increased community-based resilience and effective future management of flood prone areas in downtown Vineyard Haven by presenting information that can aid project review for the recommended design alternatives. Collaborative efforts between the Town and the residents of Tisbury will strengthen the community's ability to address shared challenges and implement these effective coastal management strategies. It is anticipated that the project will assist both local reviewers and property owners with the identification and technical information necessary to evaluate individual alternatives and implement contemporary pragmatic coastal hazard and flood mitigation strategies. Coastal flooding can result in significant economic losses, including damage to properties, infrastructure, and loss of livelihoods. Continued and reliable use of the Town's roadways and infrastructure as a public resource is dependent on identification of existing and potential coastal vulnerabilities, improvements to existing flood protection/relief mechanisms (e.g. flood barriers and drainage systems), and planning appropriate designs that incorporate flexibility for future adaptation.

Storm generated flood inundation is not a new challenge for Vineyard Haven. Historical flood records detail episodic storm events that have generated storm surge and subsequent damage to residential and commercial infrastructure, roadways, and the natural environment (Figure 1.1). However, 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, threatening to increase the occurrence of these events as well as chronic nuisance flooding from periodic spring tide cycles. Although the southern shoreline of Martha's Vineyard has experienced the Island's highest storm water elevations on record, these events were caused tropical storm systems that generally impact areas in the Northeast on timescales of only a few hours. While relatively protected from tropical storms, the low topographic relief along the waterfront regions of Vineyard Haven and having open water exposure to the northeast makes the area vulnerable to flooding influenced by extratropical storms (or nor'easters), which may last as long as multiple days, creating prolonged exposure to atypical water elevations over and above normal astronomical tide levels. The duration of these storms often result in insufficient opportunity for any significant flood subsidence until the storm has passed. As evidenced by the winter storms of 2018, near-term management approaches are becoming more critical as degradation of existing flood and shore protection structures is accelerating.

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 resilience over the next 30 to 50 years. Coastal hazards can cause serious safety concerns and inhibit emergency response as well as result in significant economic losses, including damage to properties, infrastructure, and loss of livelihoods. Proactive coordinated management strategies can reduce the severity of flood induced impacts by maintaining continuity and functionality of critical roadways to provide safe passage and limit evacuation delays, as well as protect vulnerable low-lying properties. In addition to providing improved resilience critical to downtown Vineyard Haven, successful incorporation of these proactive measures can attract future investments, thus promoting enhanced value for both property owners and the local economy. 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. By recognizing and addressing its coastal vulnerabilities, the Town aims to enhance its resilience and protect its communities, infrastructure, and natural resources from the impacts of coastal flooding. Ongoing monitoring, adaptive planning, and sustainable development practices, as well as inclusive participation and contribution of the collective community, will be crucial to effectively address mitigating the risks associated with Tisbury's coastal vulnerability in the face of a changing climate.

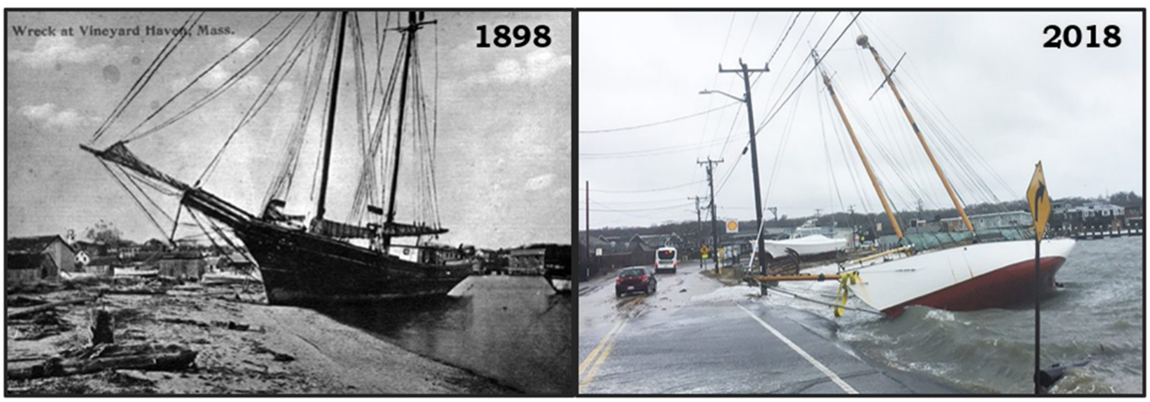

Figure 1.1 Ships washed ashore due to high storm surge flooding in 1898 (left) and 2018 (right) illustrate the long history of coastal flooding in Vineyard Haven.

An initial feasibility assessment of Vineyard Haven was performed to address ongoing flooding concerns, as well as improve existing infrastructure to reduce the impacts of flooding events. The assessment provided an overall review of the flood inundation and shore protection alternatives best-suited to mitigate future flooding and storm damage to the Town. As part of this general evaluation, previous engineering analyses of severe storm conditions, as well as predicted sea level changes, were summarized to describe the forces that govern the vulnerability of this coastline. Acute and chronic coastal flooding of the downtown limits the functionality of public resources and places existing low-lying infrastructure at risk. Additionally, potential flood protection strategies have been presented to meet the site-specific needs of vulnerable locations along the waterfront area. These mitigation strategies were categorized based on the site-specific nature of the problem (wave and storm exposure, flood drainage, chronic tidal flooding, etc.) in combination with the 'allowable' environmental approach to address the problem (i.e. appropriate strategies that can be more readily permitted through the environmental regulatory process).

2. Site Description

Vineyard Haven, located on the northern coast of Martha's Vineyard, is a low-lying coastal town sheltered from daily ocean forces due to the elongated embayment of Vineyard Haven Harbor. Ubiquitous with most low elevation coastal towns, Vineyard Haven faces inherent vulnerabilities due to its proximity to the ocean (Figure 2.1). Yet, these threats are not immediately intuitive because of the sheltered environment of the Harbor and narrow sound separating the island from Cape Cod. However, the associated the coastal hazards threatening Vineyard Haven are amplified by its extremely low elevation resulting from the naturally gradual geomorphic evolution due to the typically tranquil hydrodynamic conditions within the harbor, as well as the anthropogenic development along the shoreline commonly associated with a community built on waterfront industry.

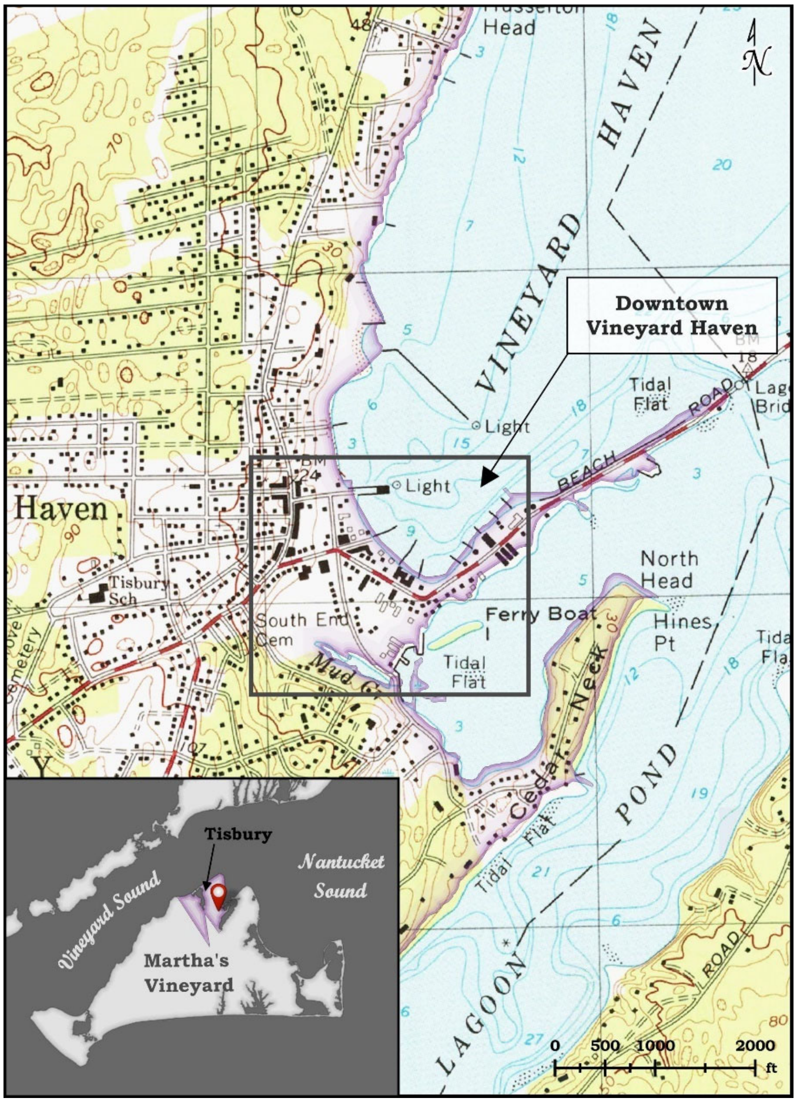

Figure 2.1 Location of Vineyard Haven on the island of Martha's along the southwest shoreline of Vineyard Haven Harbor.

The shorelines along harbor have evolved and have been modified through the years. The low dunes which would have backed the shoreline along the perimeter have been lost. The shoreline is fronting the downtown area along Beach Road is lined with docks extending offshore from the houses and buildings built up against the waterfront (Figure 2.2). The shoreline to the east consists of a barrier beach system that has been heavily armored to stabilize the beach and protect the commercial working waterfront originally built to provide access to the deeper nearshore regions within the harbor. Vertical structures along this stretch of the shoreline have caused a lowering and loss of beach fronting the structures, as well as influencing increased erosion immediately south of the Packer Facility revetment (Figure 2.3). The shoreline to the west is protected by a breakwater extending laterally approximately two-thirds across the harbor (Figure 2.4). The breakwater was constructed north of the Steamship Authority Terminal to reduce wave energy in the inner harbor. The protected shoreline area just south of the breakwater has remained stable since its construction verifying the effectiveness of the structure. Maintenance dredging in the mooring field has been conducted periodically, but it is assumed this material is a result of scour caused by the ferries. Although the wave energy in the inner harbor is significantly attenuated by the breakwater, the lack of a dune system along the shoreline fronting Beach Road increases the risk exposure of the downtown area to floods that may have minimal wave influence.

The upland area adjacent to the harbor shoreline between Beach Road, Lagoon Pond, and Five Corners is extremely low, with many areas lower than the average back beach elevation. The low and flat topography of this area is a result of the land reclamation utilized in the area to promote the expansion of development along the waterfront. The development of the area influenced the density of buildings and increased impervious surface. Due to the abundance of impervious surfaces and lack of natural drainage, flooding that makes its way into these low areas often ponds in the roadway unable to dissipate at the same rate as the receding storm tide. In addition to flooding from the harbor, downtown Vineyard Haven is exposed to being flanked by flood waters, propagating from Lagoon Pond.

Figure 2.2 Aerial Photograph showing the developed shoreline fronting Beach Road (Orientation to the west)

Figure 2.3 Photograph showing the erosion south of the Packer Facility revetment (Orientation is towards the east)

Figure 2.4 Aerial photograph of Vineyard Haven Harbor, with the location of the 1,200-foot breakwater outlined in red.

2.1 Site History

Long before European settlers arrived, the Wampanoag people inhabited Martha's Vineyard, including the area that is now Tisbury. The Wampanoag were skilled fishermen, farmers, and traders, living in harmony with the island's natural resources. Their presence in the region predates the arrival of English settlers by thousands of years, leaving behind a deep cultural and historical imprint. In the 17th century, English colonists established settlements on Martha's Vineyard, including Tisbury. The area was originally named "Nobnocket," derived from the Wampanoag term meaning "a place of shelter." The naturally deep basin of Vineyard Haven Harbor served as a critical port of refuge for passing ships, as well as promoting the Harbor's evolution into a commercial port and forming the foundations of the community.

Tisbury's maritime heritage played a vital role in its growth and prosperity. In the 18th and 19th centuries, the Town became a prominent whaling port, capitalizing on the island's strategic location and the abundance of whales in the nearby waters. Whaling vessels departed from Tisbury, embarking on dangerous and lucrative voyages to hunt whales for their oil and other valuable resources. The whaling industry brought wealth and cultural exchange to

Tisbury, attracting seafarers from various backgrounds, such as shipbuilders, sailmakers, merchants, and crew members. As the whaling industry declined in the mid-19th century, the town embraced other industries such as shipbuilding, fishing, and tourism. Its transformation from a bustling whaling port to a recreational and commercial center epitomizes the changing evolution of the town. The increased activity and population influenced by the working waterfront of the Town contributed to its economic vitality and expansion. Due to rapid economic growth and urban development, land reclamation became necessary to create additional space for infrastructure, commercial industry, and housing. Figures 2.5 and 2.6 depict the early growth of the harbor waterfront and the spreading expansion of development along the low-lying barrier beach.

Figure 2.5 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.

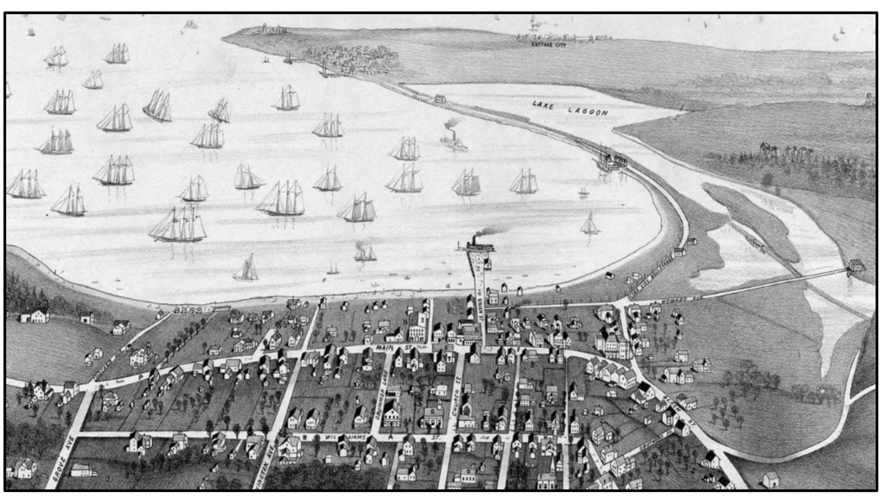

Figure 2.6 Illustration of an oblique view of Vineyard Haven Harbor in 1890 (looking towards the east) showing the roadways constructed from the Vineyard Haven to Eastville along the barrier beach, as well as the pier facility near the eastern extent of the developed harbor waterfront.

As illustrated in Figure 2.5, 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 had been developed along the barrier beach. To improve access to the pier facility and the neighboring communities of Eastville and Oak Bluffs across Lagoon Pond a roadway was constructed along the barrier beach (Figure 2.7). The roadway construction and increased commercial use of the waterfront led to man-made stabilization of the barrier beach system. To provide valuable waterfront access for the construction of wharves, piers, and other structures vital for the Town's maritime and trading activities, land reclamation became common to facilitate the growth of industries such as fishing and shipbuilding, and accommodate the expanding population (Figure 2.7). Although these long-term stabilization efforts have been effective in maintaining the adjacent upland areas, the stabilization of the shoreline inhibits the natural response of the low-lying barrier beach to high energy storm events by disrupting the transport of nearshore sediments and restricting it from migrating landward to adapt to changes in sea level. Figure 2.9 visually indicates the narrow beach system to the east of the port area, where a series of groins were established to mitigate erosion. The disruption in sediment supply for downdrift beaches along the barrier system can be seen in Figure 2.8 and 2.9, where sediment has accreted north of the Lagoon Pond bridge at Eastville Point Beach. Therefore, the sediment available is decreased along the shoreline between the Packer Facility (i.e. the Tisbury Marine Terminal) and the Lagoon Pond inlet resulting in loss of beach fronting the structures and narrowing the barrier system.

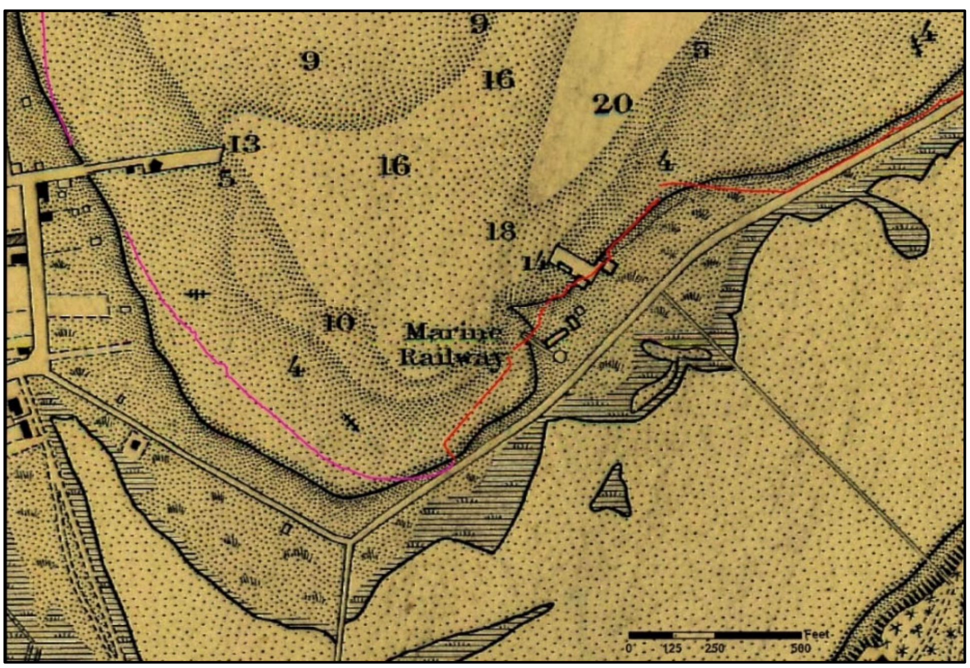

Figure 2.7 Section of the 1890 U.S. Coast Survey navigation chart for Vineyard Haven Harbor illustrating the waterfront development in the vicinity of the Packer Facility, as well as creation of a roadway along the length of the barrier beach system and causeways across the marsh system. The pink and red lines represent the location of the existing shoreline and extent of waterfront development.

Although the barrier beach has narrowed over time, Figure 2.8 shows that very little bathymetric change has occurred between the mid-1800s and 2022 in many areas of the harbor. 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 2.10 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. A comparison between the early 1900s and 2021 is shown in Figure 2.11 to show the overall scale of the development and expansion of population that has occurred on the barrier beach and filled tidelands near Lagoon Pond Road.

Figure 2.8 Comparison of the 1847 U.S. Coast Survey (top) and 2022 NOAA ENC (bottom) depth charts for Vineyard Haven Harbor (formerly known as Holmes Hole) illustrating the relative bathymetric stability of the inner harbor.

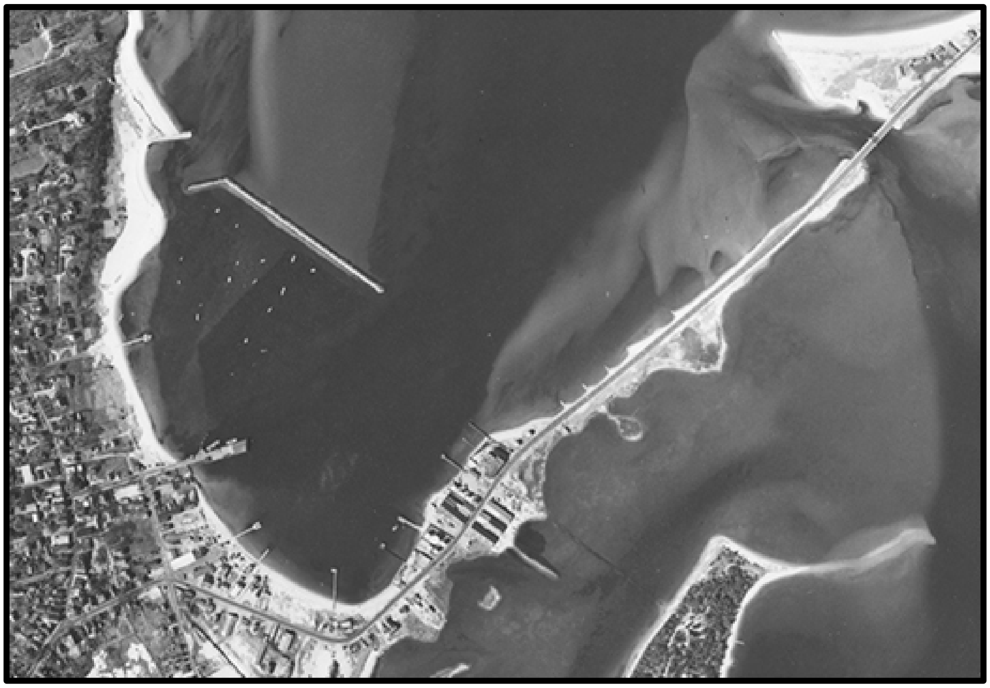

Figure 2.9 Post-World War II aerial photograph from 1948 illustrating the shipbuilding facilities along the barrier beach system, the series of groins to the east of the present-day Packer Facility, and the breakwater protecting the main Harbor basin.

Figure 2.10 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.

Figure 2.11 Development in the low-lying waterfront district of downtown Vineyard Haven is exhibited along the harbor shoreline (upper panel) and Lagoon Pond Road (lower panel) in the early 1900s (right) and 2021 (left). (Orientation is toward the west)

2.2 Existing Conditions

To evaluate the existing conditions of the project area, 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 and in 2021 by USGS. The high-resolution bathymetry data within Vineyard Haven Harbor are included as a contour plot in Figure 2.12. Finer resolution contouring was provided for elevations between 0.0 and 5.0 feet NAVD88 in Figure 2.13. 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, site visits were conducted and additional pertinent elevation data were collected to compliment the LiDAR data. These point data helped to fill in gaps where the 2018 and 2021 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.

Site visits to conduct visual inspection of the Storm Tide Pathways and existing infrastructure influencing the impacts of coastal flooding (Figure 2.14). Failed stormwater drainage outlets were identified along the shoreline fronting Beach Road and are discussed in Section 7.3.

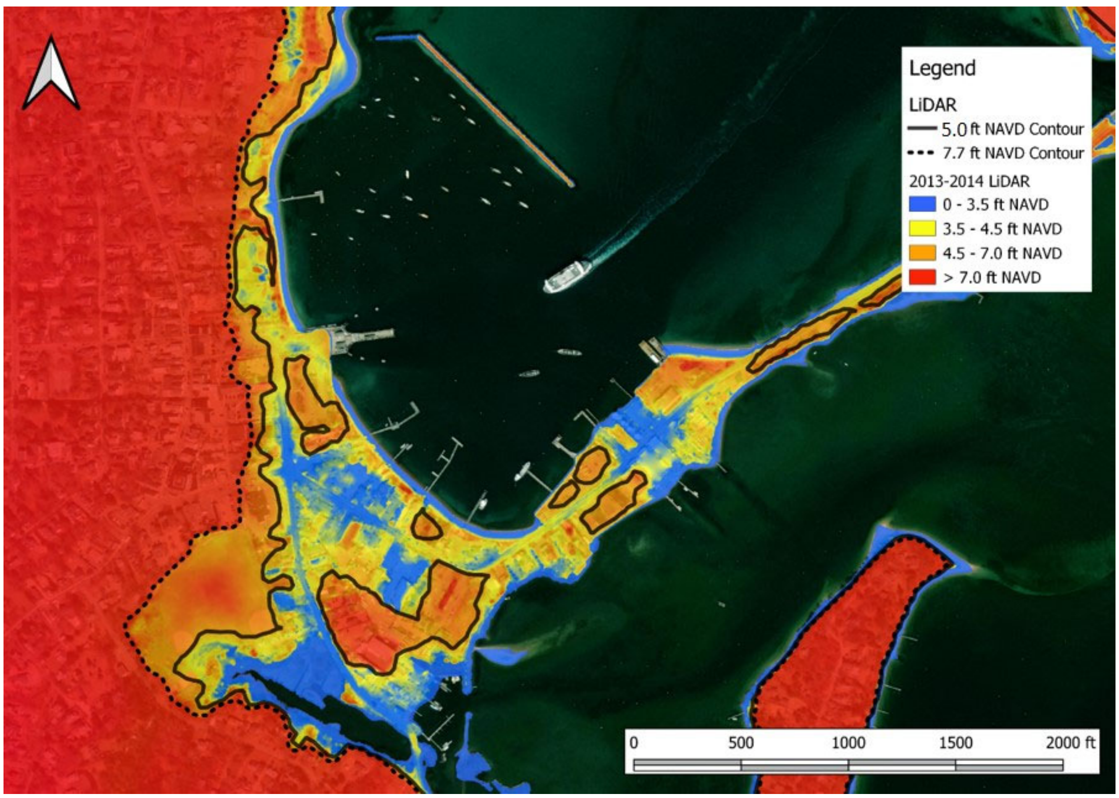

Figure 2.12 Color-contour elevation map of Vineyard Haven Harbor shoreline indicating areas below the 100-year flood elevation of 7.7 feet NAVD88 (white line), as well as the severe storm surge levels experienced during nor'easters (5.0 feet NAVD88) in gray.

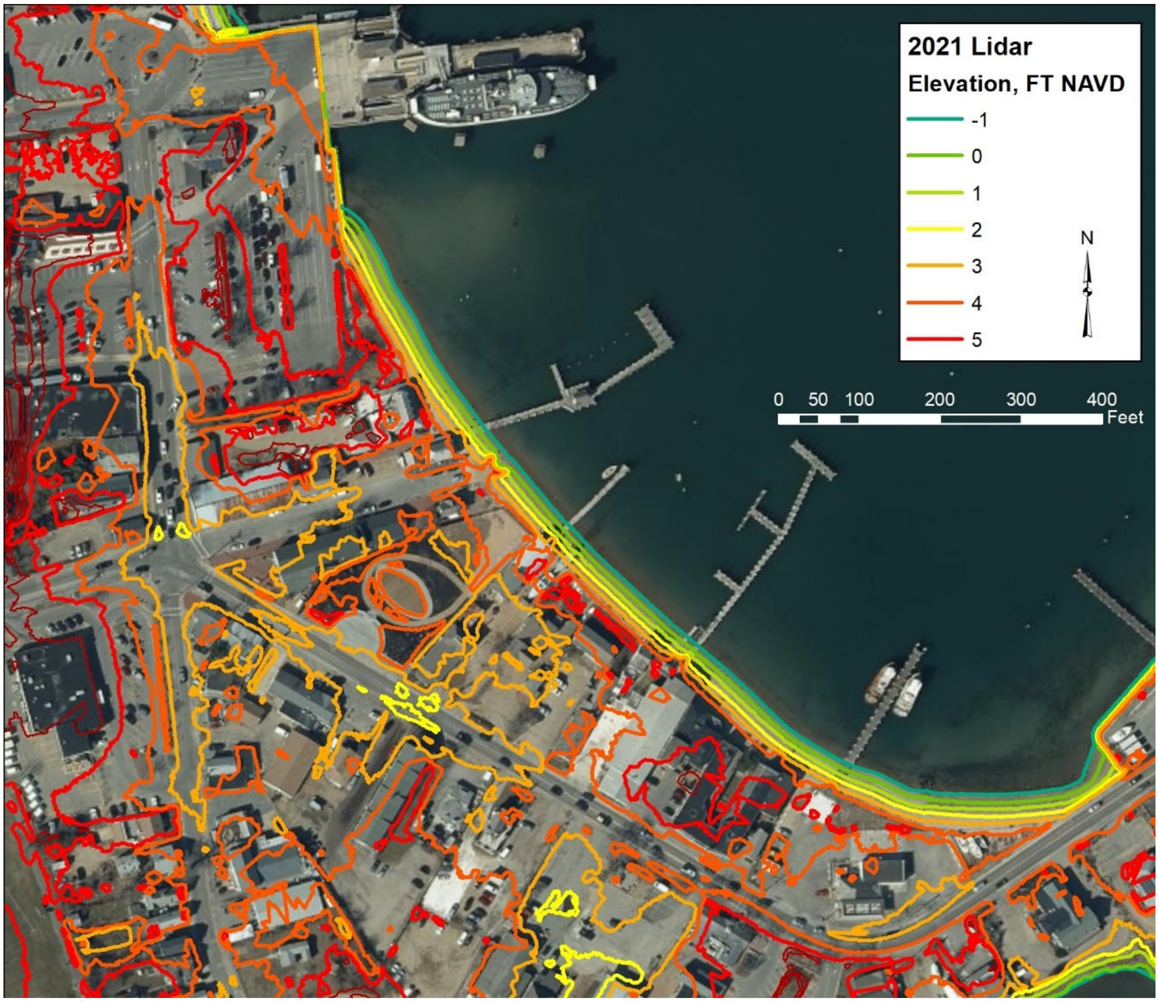

Figure 2.13 Map of downtown Vineyard Haven, overlayed with elevations relative to NAVD88. Color contours indicate change in elevation at 1-foot intervals.

Figure 2.14 Failed stormwater discharge locations near the Gas Station (left) and Beach Street Extension (right)

3. Vulnerable Areas

Based on the analysis of elevation data from both the LiDAR and surveys, the storm tide pathways identified in FY21 report (Figure 3.1) were reinspected during visits to Vineyard Haven to asses any short-term changes in their general condition. As previously discussed, storm tide pathways 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. It is critical to publicly identify and monitor storm tide pathways educate the general public and encourage community involvement in remediating existing vulnerable areas and broadening the search to discover unknown locations that may go unidentified. Additionally, 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. However, the vulnerable areas along the shoreline fronting Beach Road and the Lagoon side near Lagoon Pond were prioritized as these remain to be the critical access points for flood intrusion. 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 implementation of a contiguous barrier or other upland feature, to elevate the back of the beach. 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.

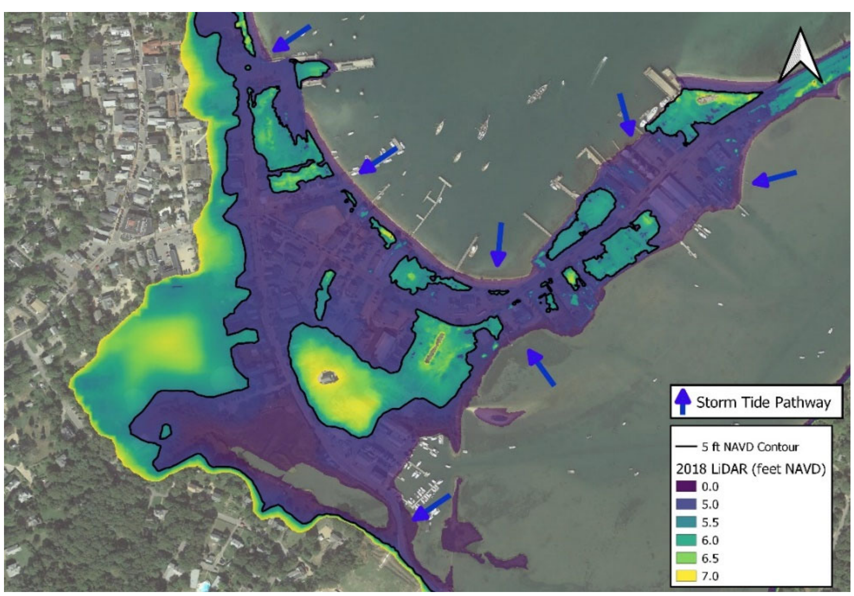

Figure 3.1 Identification of storm tide pathways (indicated by blue arrow), as locations downtown at or below 5.0 feet NAVD88 that fringe the harbor or Lagoon Pond, and would allow storm waters to flood downtown areas.

4. Storms and Water Levels

Typical natural forces governing shoreline stability and sediment transport consist of waves and tides, as well as the currents associated with these forcing mechanisms. Exposure to open ocean waves is limited by the extensive system of shoals in the vicinity of the opening to the Atlantic Ocean, as well as within Nantucket Sound itself. Therefore, waves generated by winds in Nantucket Sound are the primary driving force that influences sediment mobility and littoral transport along the shoreline.

Previously collected tide measurements in Vineyard Haven Harbor were evaluated in the FY20 report and determined to have an average range of approximately 1.74 feet (Table 4.1). The maximum and minimum tides measured during the collection period were 2.8 and -1.1 feet relative to NAVD88, respectively. The relatively small tide range and shelter afforded by the north-northeast orientation of the elongated bay of Vineyard Haven Harbor limit much of the significant impacts along the inner harbor shoreline to primarily nor'easters. Typically, nor'easters are much longer in duration than tropical storms (e.g. hurricanes) and the general wind direction allows storm generated waves and setup to propagate unimpeded into the harbor entrance. While severe tropical storms are infrequent and move through the area much more quickly, there is a well recorded history of extensive damage caused by severe hurricanes (Figure 4.1). The largest tropical storm system to impact Vineyard Haven in the past 50 years was Hurricane Bob; however, prior to that, Martha's Vineyard experienced three (3) major hurricanes over the previous 80 years (in 1938, 1944, and 1954). According to the U.S. Army Corps of Engineers, the August 31, 1954 storm surge from Hurricane Carol is the highest water elevation recorded at nearby Oak Bluffs Harbor at 8.7 feet above mean low water (~6.9 feet NAVD88). While the overall sediment movement is governed by average conditions, the perceived need for shore protection is often related to the influence of severe infrequent storm events.

Table 4.1 Tide datums computed from records collected in Vineyard Haven Harbor May 14 to June 15, 2004. Datum elevations are given relative to NAVD88.

Tide Datum	Offshore (feet NAVD88)
Maximum Tide	2.8
MHHW	1.32
MHW	1.02
MTL	0.22
MLW	0.72
MLLW	-0.92
Minimum Tide	-1.1

Figure 4.1. Aerial photograph of damage, in the general vicinity of what is now the Packer Facility, caused by the hurricane of 1938

Due to the northeast exposure of the harbor, nor'easters create both significant storm surge and storm wave action along the Vineyard Haven Harbor shoreline. In general, nor'easters are relatively frequent occurrences, with elevated water levels that can sometimes persist for several days. The most severe nor'easters may only cause moderate coastal flooding relative to the 100-year storm event; however, these storms produce a combination of both storm surge and energetic wave conditions within the harbor. To quantify the impact of more commonly occurring nor'easters on the Vineyard Haven Harbor shoreline, historic tide data at the long-term Nantucket Harbor gauge was utilized to determine potential extremal regional water levels generated by these extra-tropical storm events, specifically the 50-year storm surge level. Overall, storm surge levels generated by nor'easters are a regional phenomenon and these water levels likely extend across Nantucket Sound. Based on the long-term tide record in Nantucket, this computed 50-year water level above MHW (4.45 feet) was then added to local MHW at Vineyard Haven Harbor (0.46 feet NAVD88) to produce a total 50-year storm surge water level of 4.9 ft NAVD88.

Overall, the difference between the computed 50-year flood level associated with nor'easters and the extremal hurricane-induced 100-year storm surge level is an additional 2.8 feet; 4.9 feet NAVD88 for the 50-year event and 7.7 feet NAVD88 for the 100-year event. As shown in Figure 4.2, only a small portion of the low-lying area adjacent to the harbor is in between these two storm surge elevations, indicating that much of the active harbor front area is flooded by more frequent storm events. In this case, even modest efforts to elevate infrastructure will provide substantial benefits for reducing frequent coastal flood damage, where the incorporation of the computed 50-year flood level for mitigation design is a reasonable near-term target to ensure protection of the infrastructure adjacent to the harbor.

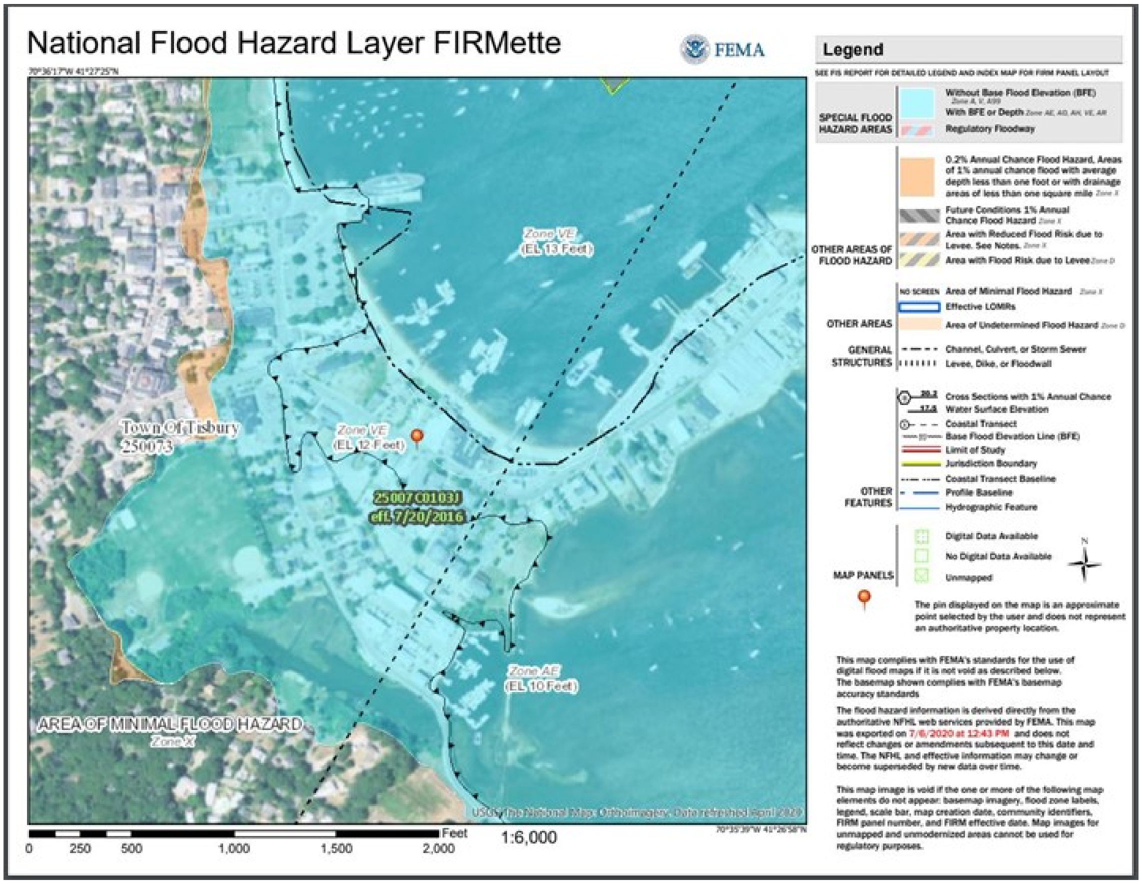

Figure 4.2 FEMA National Flood Hazard map for downtown Tisbury (map source: MassGIS). Flood zones and average flood depths derived from the detailed hydraulic analyses in the FIS are shown within the FIS map.

5. Sea Level Rise

The exposure of the community and infrastructure to flooding in Vineyard Haven has significantly increased over the last few decades. Several factors including coastal urbanization, aging infrastructure, alterations to the natural environment, and sea level rise have all contributed to the increase in flood exposure and are anticipated to continue as mechanisms promoting the acceleration of future flood vulnerability (Sundermann et al., 2014). Among these contributions, the predictions regarding changes in relative sea level exhibit the greatest amount of uncertainty. Indeed, it has been concluded that sea levels are rising, however, the pace and extent to which they may rise over the next 60 to 80 years are the topic of much scientific and political debate. Historical evidence indicates that over the past 90 years the relative sea level in Nantucket Harbor, Massachusetts has been rising generally in a linear fashion, with an average rate of approximately 0.15 inches per year or roughly 1.2 feet per century (Figure 5.1).

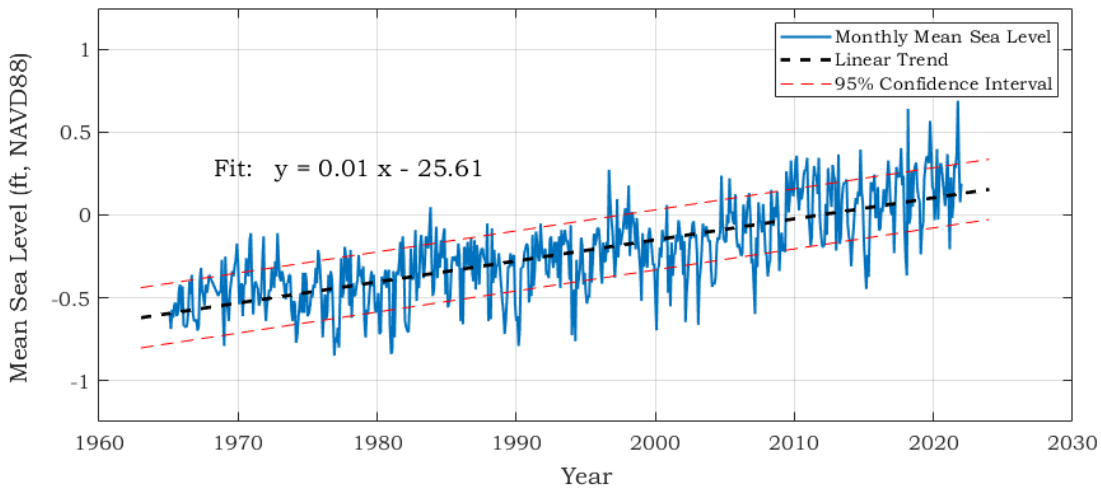

Figure 5.1 Monthly mean water levels recorded in Nantucket between 1965 and 2021 indicate a linear trend in sea level rise over the past ~60 years of approximately 0.01 feet per year (*Source: NOAA).*

While long-term tide records (e.g., Nantucket Harbor) provide valuable insight into historical changes over the past 60 to 100 years, they do not necessarily dictate future response of sea level rise due to changing environmental and anthropogenic conditions. Predictive models have been developed to project the effects of climate change on relative sea level rise in coming decades. New and existing models used to predict sea level rise are continually refined with augmented datasets to reduce output uncertainty; however, there still exists a large range of potential sea level rise scenarios.

Based on the Massachusetts Sea Level Assessment and Projections technical memorandum (DeConto and Kopp, 2017) regarding local mean sea level rise, plots were developed for the Commonwealth of Massachusetts to provide guidance regarding future projections of sea level rise in Nantucket Harbor (Figure 5.2). The range of varying projections are determined based on the probability of exceedance given two future atmospheric greenhouse gas concentration pathways, medium (RCP4.5) and high (RCP8.5; Van Vuuren et al., 2011), and for two methods of accounting for Antarctic ice sheet projections: one based on expert elicitation (Kopp et al., 2014) and one where Antarctic ice sheet projections are driven by a more recent, process-based numerical ice sheet model simulations (DeConto and Pollard, 2016; Kopp, 2017). These localized projections are downscaled from regional and international projections. A brief description of the probabilistic projections is provided in Table 5.1.

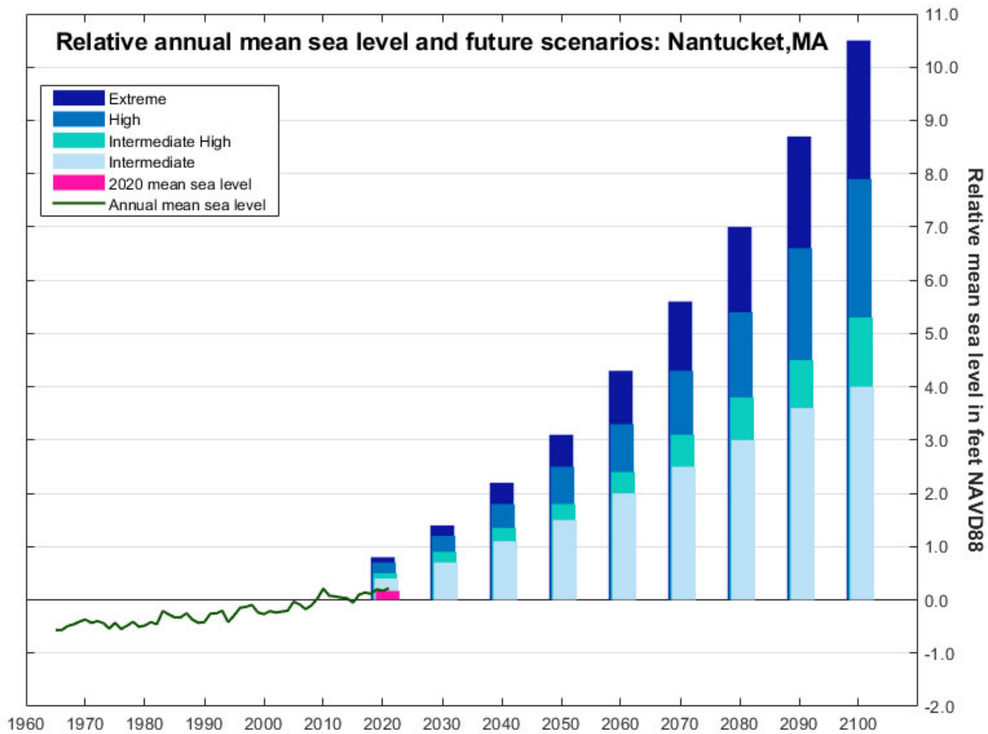

Figure 5.2 Relative mean sea level projections for the Nantucket, MA tide station based on four National Climate Assessment global scenarios with associated probabilistic model outputs from the Northeast Climate Science Center. The probabilistic projections are listed in Table 1. The pink bar denotes the 2020 recorded mean sea level in Nantucket Harbor. The green curve represents the annual mean sea level calculated from the data record presented in Figure 5.1

Table 5.1 Relative mean sea level (feet, NAVD88) projections for Nantucket, MA as presented in DeConto and Kopp, 2017

Scenario	Probabilistic projections	2030	2050	2070	2100
Intermediate	Unlikely to exceed (83% probability) given a high emissions pathway (RCP 8.5)	0.7	1.5	2.4	4.2
Intermediate - High	Extremely unlikely to exceed (95% probability) given a high emission pathway (RCP 8.5)	0.9	1.8	3.0	5.2
High	Extremely unlikely to exceed (99.5% probability) given a high emission pathway (RCP 8.5)	1.2	2.4	4.3	7.9
Extreme (Maximum physically plausible)	Exceptionally unlikely to exceed (99.9% probability) given a high emissions pathway (RCP 8.5)	1.4	3.1	5.5	10.5

The above projections have been incorporated into the Resilient MA analyses tools and serve as the basis for guiding Massachusetts sea level rise policy in the near-term. Tools developed with the DeConto and Kopp (2017) sea level rise projections include the Massachusetts Coastal Flood Risk Model (MC-FRM) and the Resilient Massachusetts Action Team (RMAT) Design Guidance. Therefore, all quantitative analyses depicted by the tools represented in Resilient MA are directly dependent upon the selected sea level rise scenarios. In this case, the state selected the "High" or 99.5% chance of non-occurrence set of sea-level scenarios from Table 1 as the baseline. As indicated below, this sea level rise scenario is shown to substantially over-predict actual water levels in 2020 and more recent NOAA analyses of sea level rise (Sweet, et al., 2022) do not support an acceleration in sea level rise that will cause regional water levels to "catch up" to the "High" scenario depicted in Table 5.1.

Understandably, accurate projections of sea level rise are critical for engineers and coastal managers developing future coastal hazard mitigation and improvement alternatives. Enhanced accuracy in the prediction of future storm driven flood and tidal elevations ensures the consideration of sufficient safety measures, while also maintaining economic feasibility and reducing the potential for adverse environmental impacts. Using the recorded water elevations measured in Nantucket Harbor for 2020, a direct comparison between measured and projected relative sea level can be evaluated to assess the near-term accuracy of the sea level rise projection from Resilient MA (Figure 5.3). The results of this assessment indicate that sea level projections over the first decade, when utilizing the recommended "High" scenario, are overestimated by nearly an order of magnitude relative to the NAVD88 datum.

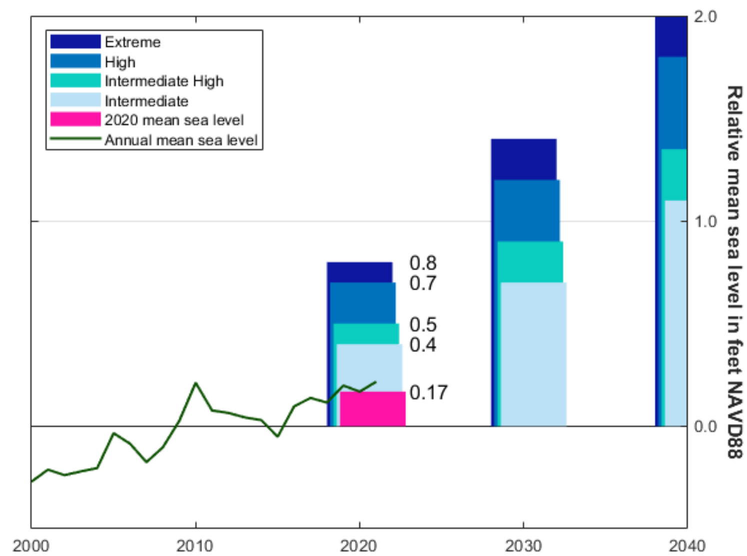

Figure 5.3 Comparison of probabilistic sea level rise projections from Resilient MA (DeConto and Kopp, 2017) and measured annual mean sea level for Nantucket Harbor, Massachusetts.

More recent sea level rise projections from NOAA (Sweet, et al., 2022) suggest significantly lower projected future sea level rise rates for Nantucket (downscaled from the full U.S. analysis), especially between the present and 2050. Figure 5.4 provides the updated NOAA projections, where the 'intermediate' projection represents conditions that are about as likely as not to occur or, in other words, a 50% chance of occurrence. It should be noted that the NOAA utilization of the term 'intermediate' follows standard statistical terminology, where the intermediate result represents the middle curve between the two extremes (high and low) or the 50% chance of occurrence. The Resilient MA documents use a different definition of the 'intermediate' scenario, which likely leads to further confusion when attempting to compare the various sea level rise projections. In the case of Resilient MA, the 'intermediate' sea level rise projection represents a more unlikely scenario, i.e., the 'unlikely to exceed' threshold or a 17% probability of exceedance, rather than the 50% probability of exceedance used by NOAA.

As illustrated in Figure 5.4, the 'intermediate' NOAA sea level rise projection generally matches the 'observed trajectory' projection to 2050, which was based upon extrapolating the observed sea level rise trends between 1970 and 2020. Further, Figure 5.5 demonstrates the applicability of utilizing more moderate sea level rise projections, as the observed sea level rise in Nantucket between 2000 and 2020 (shown in gray) is below all of the projections evaluated by Sweet, et. al. (2022).

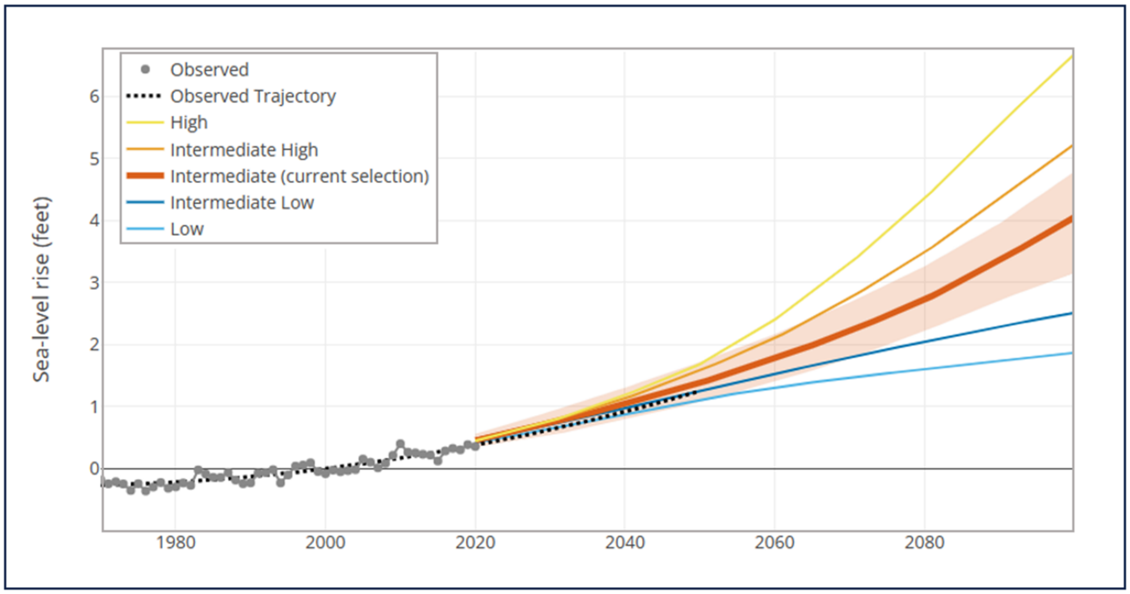

Figure 5.4 Projected sea level rise for Nantucket Harbor, Massachusetts based upon modeling analyses performed by NOAA (Sweet, et. al., 2022). Results for a full range of scenarios can be found at: https://sealevel.nasa.gov/flooding-analysis-tool/projected-flooding?

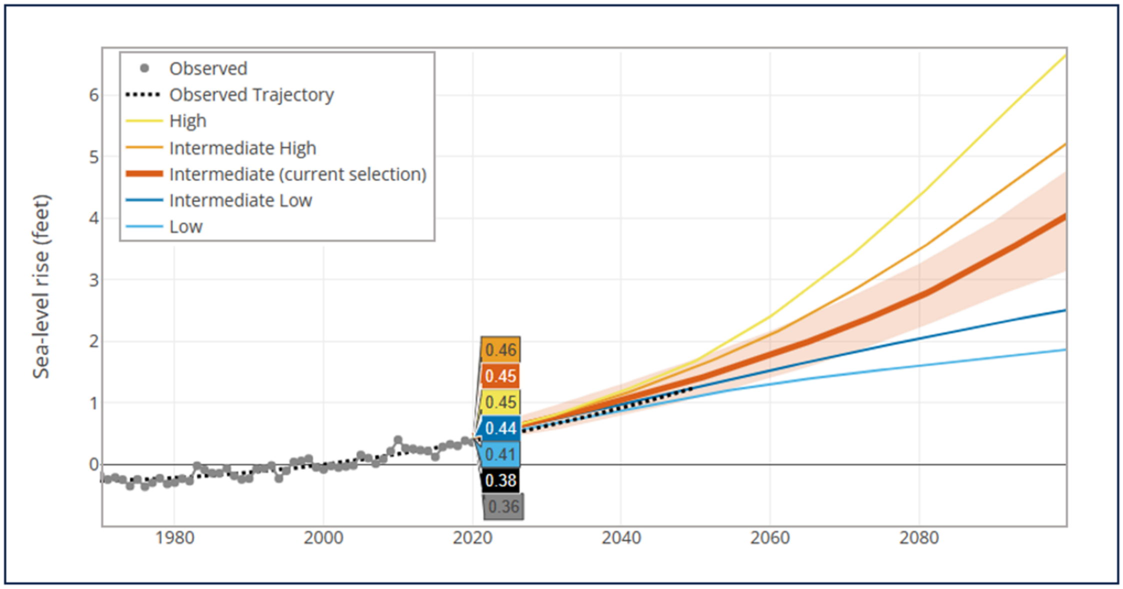

Figure 5.5. Projected sea level rise for Nantucket Harbor, Massachusetts based upon modeling analyses performed by NOAA (Sweet, et. al., 2022). The colored numbers represent the modeling results for the various scenarios for 2020, as well as the observed mean sea level. Results for a full range of scenarios can be found at: https://sealevel.nasa.gov/flooding-analysis-tool/projected-flooding?

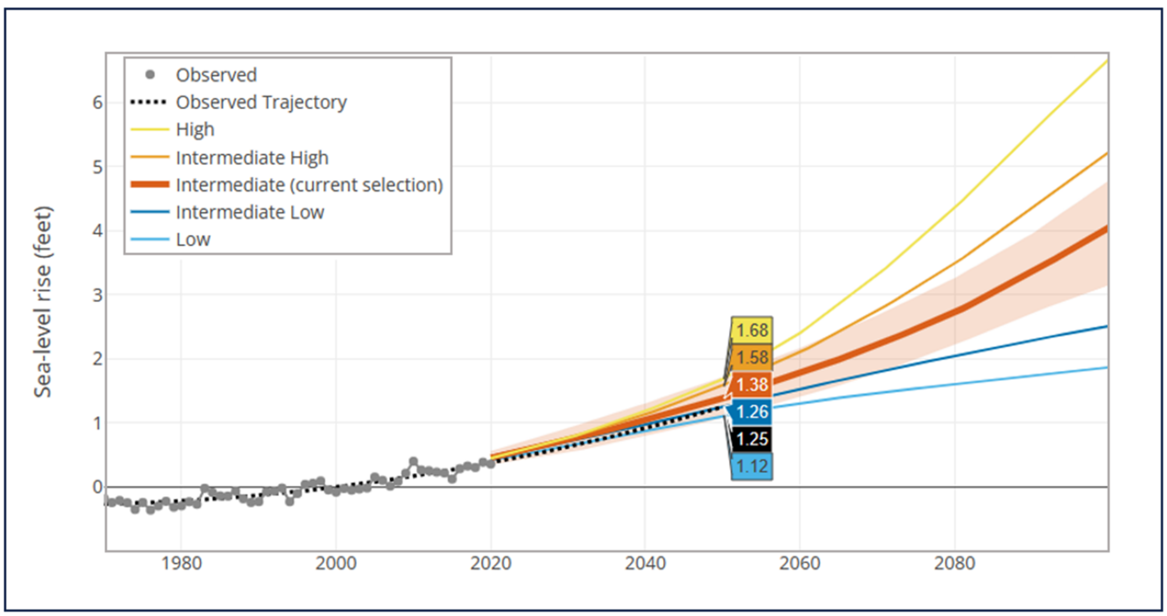

Figure 5.6 Projected sea level rise for Nantucket Harbor, Massachusetts based upon modeling analyses performed by NOAA (Sweet, et. al., 2022). The colored numbers represent the modeling results for the various scenarios for 2050. Results for a full range of scenarios can be found at: https://sealevel.nasa.gov/flooding-analysis-tool/projected-flooding?

Based on this updated information, a reasonable expectation for near-term (through 2050) sea level rise in the Natucket region, inclusive of the project area, is within the range of sea level rise projections illustrated in Figure 5.6 In this case, the 2050 mean sea level can be expected to be approximately 1.4 feet above the 2000 level or approximately 1.0±0.4 feet NAVD88. This value is substantially lower than the projections provided in the Resilient MA documentation (Table 1). Specifically, the updated NOAA evaluation indicates that expected sea level rise in Nantucket by 2050 is ~40% of the value recommended for planning by Resilient MA.

For planning of future infrastructure, incorporating a safety factor to accommodate potential future sea level rise is warranted; therefore, the Resilient MA 'High' sea level rise projections are useful to ensure that future development is safe from the impacts of sea level rise. However, when developing flood mitigation strategies for existing infrastructure, designing for future sea level conditions that are 'extremely unlikely to occur' can be both cost-prohibitive and unnecessary. Figure 5.7 provides both the 2022 NOAA projections and the projections that have been utilized for project planning by SCS engineers over the past decade that was based on IPCC modeling with the addition of ice sheet contribution from Rignot et al., 2011. Good agreement between these two sets of projections indicates that this pragmatic approach continues to provide a valid science-based methodology for evaluating future sea level rise for near term planning.

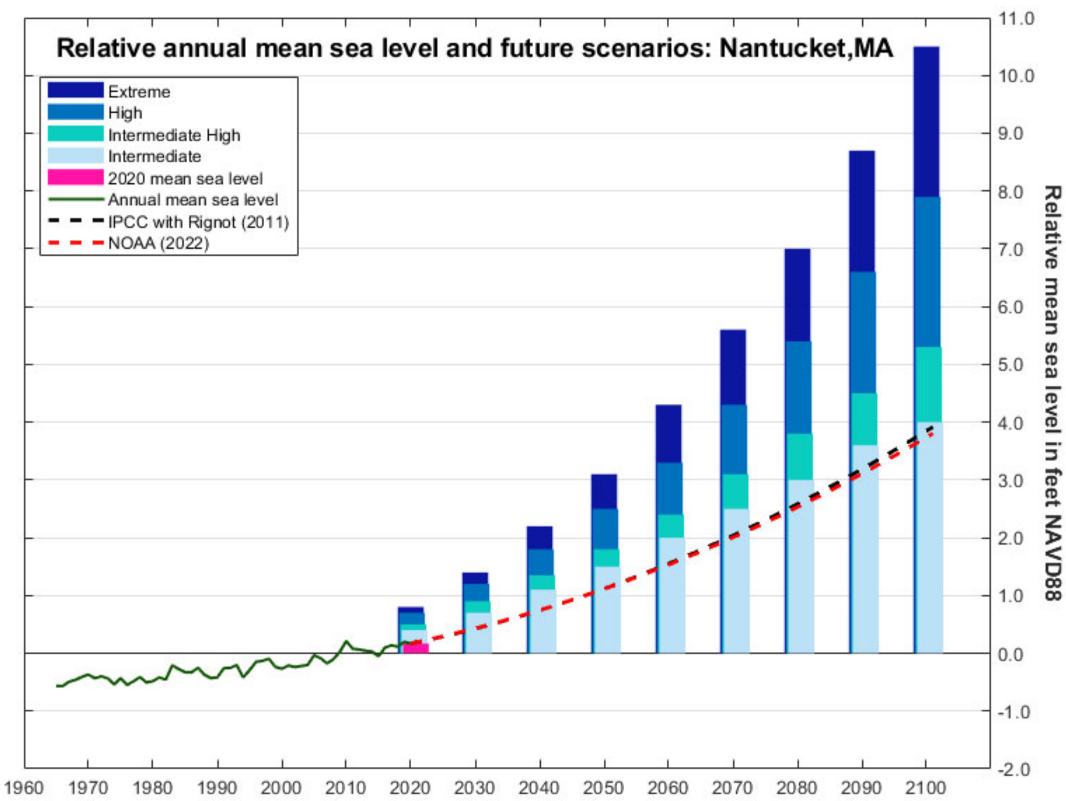

Figure 5.7 Sea level rise projections with the latest NOAA projections (adjusted to account for current mean sea level; dashed red line) and a curve representing flood projections from the IPCC augmented by sheet ice contributions determined by Rignot et al. (2011; dashed black line). The bar plot represents the sea level rise projections presented in Resilient MA.

As discussed above and provided in the FY21 report, extreme approaches to account for long-term seal level rise predictions that involve a high level of uncertainty are not practicable for near term remediation. The scale and financial viability of the projects would inhibit the Town's ability to pragmatically mitigate an already occurring hazard and prove challenging to keep pace with actively working towards a lasting protection measure while also repairing continually impacted infrastructure. 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 MassDOT, 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 MassDOT 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.

7. Alternatives

Based on the understanding of general site conditions, as well as the forces governing future flooding concerns, a feasibility assessment was previously performed to evaluate potential strategies to mitigate flood risk and storm damage to the waterfront area of downtown Vineyard Haven. In addition, the low-lying nature of area indicates that future SLR will likely exacerbate flood and storm damage in the future. As described above, potential mitigation strategies were based on the site-specific nature of the problem (wave and storm exposure, flood drainage, chronic tidal flooding, etc.) in combination with the 'allowable' environmental approach to address the problem (i.e. appropriate strategies that can be more readily permitted through the environmental regulatory process).

Initial evaluation of potential alternatives in the FY20 and FY21 reports included a broad range of options tailored to meet the specific needs of the existing vulnerable areas, while maintaining the overall focus on reducing stillwater flooding impacts primarily caused by the effects of storm surge. Numerous site-specific engineering alternatives exist to potentially reduce the risk of flood inundation of existing low elevation areas, as well as improve stability of the shoreline fronting Beach Road. Considering the frequency of flooding events and the potential severity that large scale flooding could cause, maintaining the status quo and not implementing pragmatic mitigation strategies was determined to not be a viable option. Furthermore, the initial list of potential alternatives included in the FY20 report was refined and the preferred alternatives were further evaluated at a conceptual level in the FY21 report and presented to the Town. Feedback from the community was incorporated into modifications of the alternatives to develop increased detail to determine specifications regarding approximate sizes, locations, and extent sufficient to perform a more extensive engineering analysis focused on the practicality and feasibility of the refined design alternatives. Detailed representations of the alternatives were created to provide the Town and abutting property owners the technical information needed to incorporate valuable feedback and cohesive support to increase the effectiveness of the flood protection and determine the most appropriate management strategy to advance to the permitting level. It is important to note that all alternatives may be necessary to establish future flood prevention required for downtown, however even short(er) term solutions will afford the Town extra time critical for future management planning. In this report, review and public feedback regarding the following proposed conceptual designs are provided in the subsequent sections.

- *Harbor Shoreline Dune Barrier*
- *Elevating Low-lying Roads*
- *Improving Drainage*
- *Managed retreat and rehabilitation of the natural environment*
- *Combinations of the above options*

7.1 Harbor Shoreline Dune Barrier

Over the past few decades, implementation of 'soft' engineering approaches for coastal protection have become common, especially along shorelines that experience relatively low energy wave conditions. these measures are often combined with appropriate vegetation for additional stabilization. Constructing a dune as an uninterrupted barrier is a proven 'soft' engineering technique for coastal flood protection, shoreline stabilization, and maintaining natural morphologic processes. Generally, engineered dune barriers are most appropriate in areas where an existing coastal beach is present and wide enough to accommodate the appropriate scale of dune protection needed. Based on these considerations, the shoreline area fronting Beach Road, spanning from the Steamship Authority parking lot to the Packer Facility revetment (Figure 7.1), was determined to provide a suitable location such that increasing the back beach elevation and restoring the beach as a natural defense mechanism could enhance flood protection for the Town. This stretch of shoreline presents several critical storm tide pathways into downtown, the lowest being only 3.7 feet. In many locations the maximum beach elevation between beachfront buildings is as a low as 3.3 feet, severely exposing these structures to the impacts of storm generated waves and surge.

The low energy environment of Vineyard Haven in combination with the relatively small tidal range has prevented significant erosional retreat of the shorelines. Although, due to the sediment-starved nature of the harbor there is no hope of natural evolution of the beaches and dunes to adapt to sea level rise. Therefore, the influence of engineered alternatives to restore the natural function while balancing the waterfront uses of the shoreline and downtown area can be amplified since relatively small volumes of dune enhancement will likely have a significant effect on successfully mitigating flood inundation. Typical engineered dune design guidance provided by the Federal Emergency Management Agency (FEMA) suggests a crest elevation above the local 100-year still water elevation. Extreme measures to protect the downtown from flood levels associated with low exceedance probability flood elevations (i.e. 7.7 feet NAVD88 for the 100-year event determined by FEMA) is not justified from a practical, ecological, or financial standpoint due to the spatial limits constrained by the narrow beach width (Figure 7.2). However, restoring the natural functions of the beach and dunes to buffer against the more frequent storm flooding influenced by nor'easters will still provide increased protection of existing infrastructure and maintain the 'working waterfront', while also bolstering the natural resources and enhancing the ability of the natural littoral system to respond to climate change and sea level rise. A more modest dune design with a crest elevation of 6.0 feet NAVD88 was determined in the FY21 report to be sufficient in height to provide meaningful protection from flood levels (5.0 feet NAVD88) corresponding with the most severe nor'easters experienced in the Vineyard Haven Harbor. Figure 7.3 shows the extent of proposed dune footprint as well as the cross-shore profile at various locations along the shoreline. The proposed dune is approximately 1300 feet long and extends roughly 50 feet from where the 1V:3H back-slope ties into the existing grade, offshore to the toe of the 1V:4H fore-slope at the existing -2-foot contour. The dune will require 7000-8500 CY of compatible material and have a minimum crest width of 15 feet to ensure ample stability and reduce the frequency of future maintenance. Additional dune crest width was in included in the vicinity of the Marine Railway to accommodate proper slope and transition needed to maintain functionality of the railway tracks (Figure 7.4).

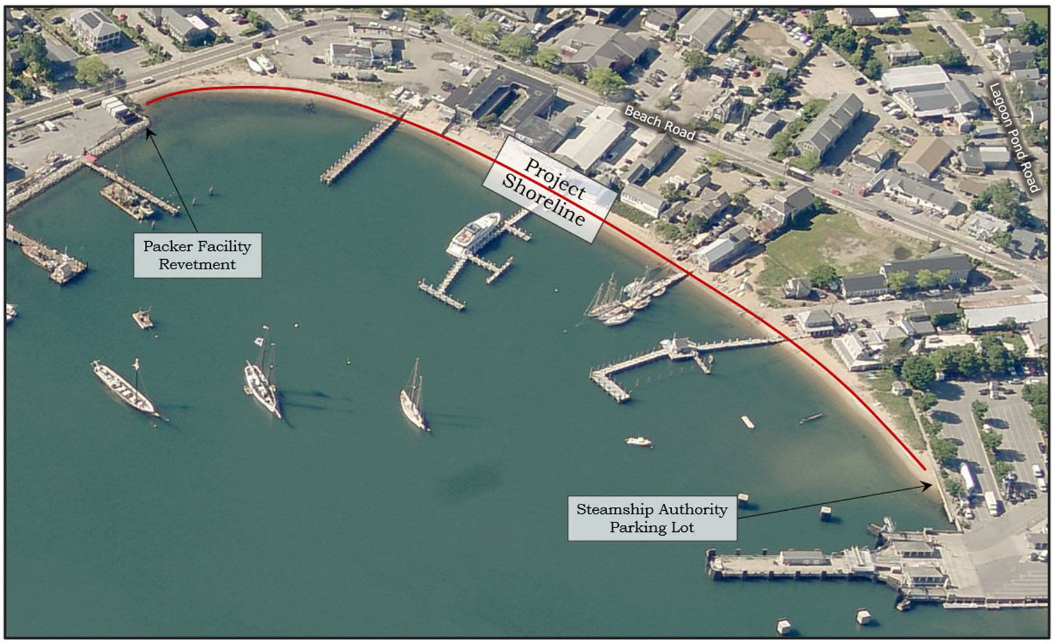

Figure 7.1 June, 2017, aerial photo (view oriented to the southwest; photo obtained from MassDOT) showing the extents of the project shoreline for the proposed dune barrier.

Figure 7.2 Seaweed washed up from a recent fall storm forms a wrack line against beachfront buildings showing the extent of modest storm runup and the exposure of existing structures due to close proximity to the water.

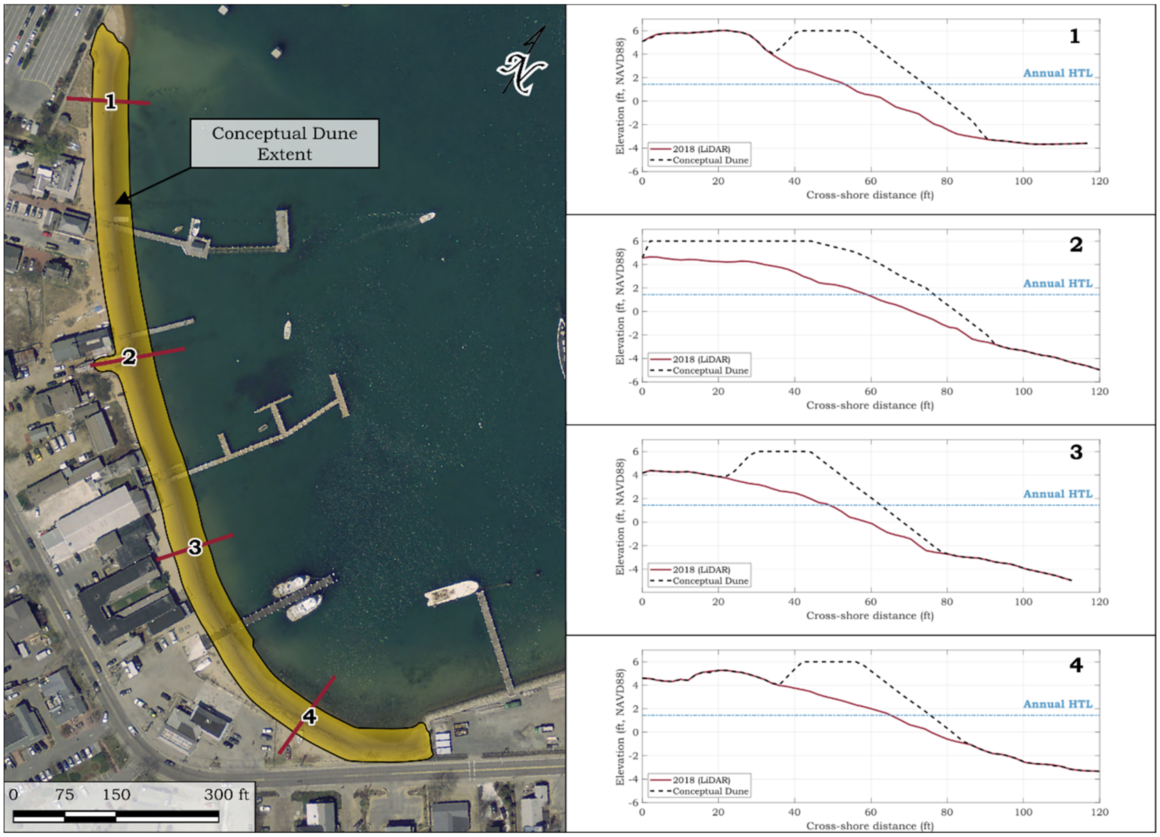

Figure 7.3. Proposed dune design spanning the shoreline between the Steamship Authority parking lot and the Packer Facility revetment. Representative transects are included to illustrate cross-shore profiles at varies locations along the shoreline.

A continuation of periodic nourishments and dune maintenance following large storms may be required as nourishment material will be mobile during energetic wave conditions. However, as previously described, the relatively quiescent conditions of the inner harbor and stability of the downtown shoreline indicate that these events will be infrequent. If appropriate material is utilized for implementation of the engineered dune, a lasting project can be developed to protect the beach area while reducing wave energy and flood vulnerability. Consideration of future modifications could then be applied to facilitate the management and planning of further dune development to address climate related changes as future projections become more refined.

It is likely that the application of a dune along this shoreline will require paths or specific walkway locations to maintain access to the water. Likewise existing docks may need to be elevated near the shoreline to avoid interference with the working waterfront (Figure 7.4). Certainly, these modifications can be easily incorporated the design of the dune due the low crest elevation represented by the example dune shown in Figure 7.5. Additionally, this alternative does not address the storm tide pathways that are susceptible to flooding from Lagoon Pond, nor does it remediate the current drainage issues in town. However, the low cost and minimal project duration of this alternative relative to the other options provides the Town with the opportunity to utilize additional measures in conjunction with this one.

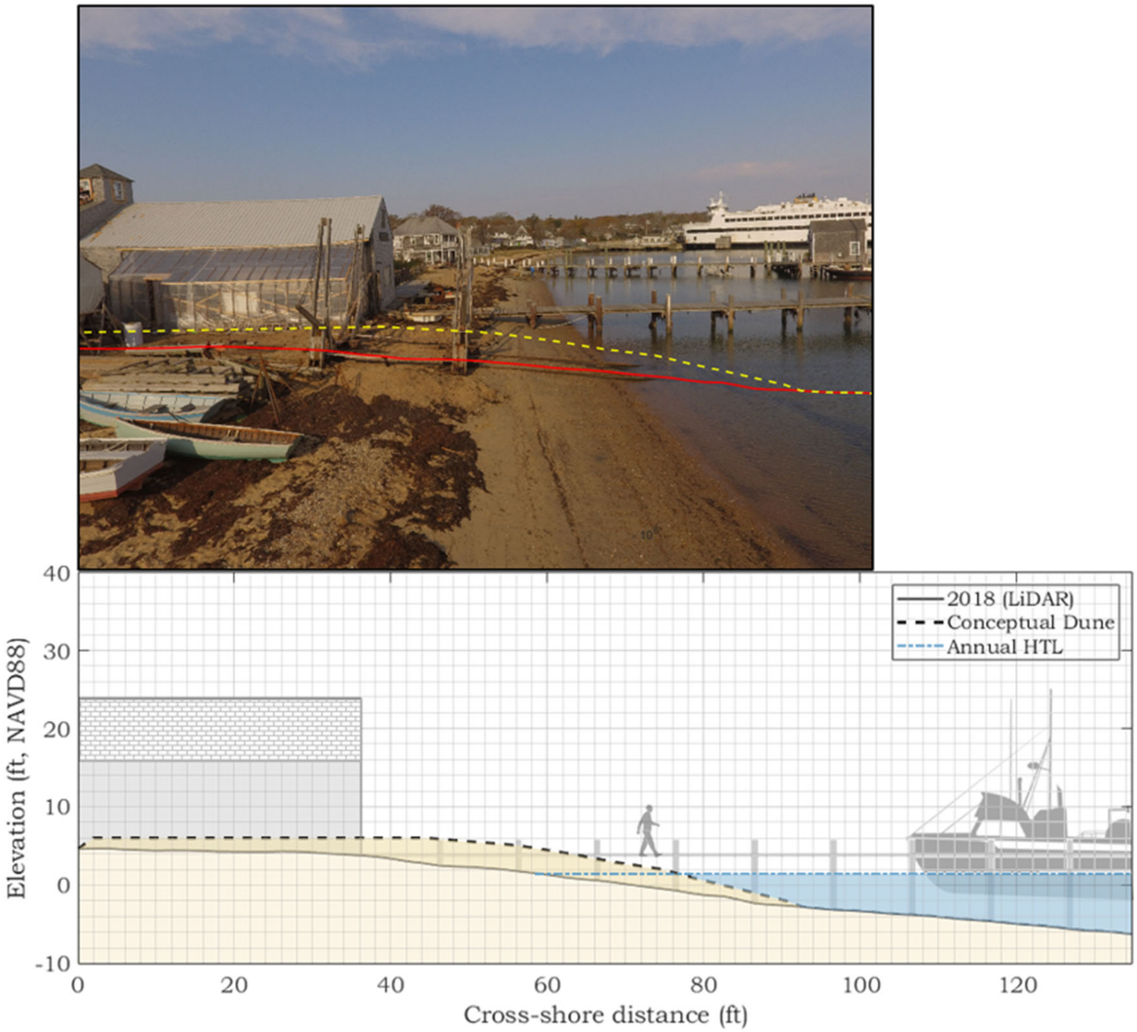

Figure 7.4. Oblique drone imagery imposed with a cross-section of the proposed dune barrier design (top; orientation is to the northwest) and a profile view (bottom) provided to show approximate scale of the dune at the Marine Railway (referenced as transect 2 in Figure XX).

Figure 7.5 Example of a low-elevation dune constructed for storm and flood protection in Cotuit, MA.

While coastal dunes engineered to serve as natural barriers to protect against storm surges and erosion as well as provide valuable ecological functions, the effectiveness and sustainability of this alternative is dependent on providing a continuous crest elevation threshold along the entire span of the low-lying beach. In doing so, flood waters cannot flank the ends or discontinuities of the barrier and inundate the low areas inland of the beach. Maintaining a holistic buffer that fosters an interconnectivity between the natural and anthropogenic coastal environment requires inclusive participation from the Town and all abutting waterfront property owners. Additionally, the inclusion of all abutting waterfront property owners ensures the conservation of this interface by promoting long-term ecological sustainability and a shared economic investment. While the necessity of inclusive participation and contribution from the Town and waterfront property owners is evident from ecological, economic, and social perspectives, challenges including financial constraints, conflicting interests, and coordination difficulties are likely to arise. To address these challenges and facilitate open dialogue, Sustainable Coastal Solutions incorporated considerable public outreach, meetings, site visits, and individual communication with all parties involved. By participating in, contributing to, and providing feedback for the design of the dune barrier, it was hoped that the Town and property owners along the waterfront could develop a collective decision-making that would address any individual concerns while preserving the common goal of increasing community flood protection and ensuring that vulnerable areas of the shared coastal community are not disproportionately compromised. Implementing a fair and transparent decision-making process, providing technical support, and educating the community about the benefits of coastal flood protection is critical to encourage collaboration and ensure the success of the dune barrier design.

Ultimately, universal support from the community for the proposed dune design could not be resolved and the associated concessions with this alternative were not agreeable to all parties involved. As mentioned above, the success of utilizing a dune for coastal flood protection is dependent on the dune being a single uninterrupted feature spanning the entire length of the area vulnerable to flood inundation. Otherwise, any gaps in the design would adversely redirect flood waters and render this alternative ineffective. Although Massachusetts does have legal frameworks in place to regulate coastal development and protect coastal areas which often include provisions that require participation or may involve land takings to allow for constructing and maintaining coastal protective measures, the preferred outcome was refining this alternative to develop a mutually beneficial design and encourage collective participation to effectively address coastal flooding vulnerabilities associated with this section of the harbor shoreline.

7.2 Elevating Low-lying Roads

Unlike temporary flood barriers that need to be installed and removed for each flood event, an elevated coastal road serves as a permanent and continuous flood protection measure. It offers reliable protection against regular tidal inundation and storm surges. This elevation helps to redirect or prevent the flow of water into vulnerable coastal communities, protecting infrastructure and properties. Compared to other flood protection measures, such as dikes or seawalls, an elevated coastal road can minimize disruption to the natural landscape. By following the natural contour of the coastline, it avoids the need for extensive alterations to the shoreline and preserves the aesthetic and ecological values of the area.

Apart from flood protection, an elevated coastal road also sustains reliable accessibility and connectivity for coastal communities. It ensures uninterrupted transportation routes during flood events, allowing residents to evacuate or emergency services to reach affected areas more easily, as well as serving multiple other functions to enhance its value. For example, it can incorporate pedestrian walkways, cycling paths, or green spaces, providing recreational opportunities for the community and attracting tourism. While the initial construction of an elevated coastal road can be a significant investment, it offers long-term cost-effectiveness. Regular maintenance costs are typically lower than the expenses associated with rebuilding or repairing properties damaged by recurrent floods. Moreover, the road infrastructure can generate economic benefits through improved transportation, trade, and tourism.

Generally, an elevated coastal road is designed to account for projected sea-level rise. By constructing it at a sufficient height above current sea levels and incorporating adaptive design principles, it provides a buffer against future increases in sea levels, ensuring continued flood protection for years to come. However, due to the spatial constraints of downtown Vineyard Haven, the conceptual design included in this project is aimed achieving the design threshold elevation of 5 feet NAVD88 along Beach Road, Lagoon Pond Road, and Water Street (Figure 7.6). Utilizing the road and sidewalk dimensions provided in the design plans for Beach Road from MassDot, and maximum side-slopes of 1V:3H it is clear that the width of footprint needed for the fill to transition into the existing grade of a road elevated to 5 feet NAVD88, will still be constrained in some areas as shown in Figures 7.7 and 7.8. However, it is anticipated that the target elevation will provide protection from nuisance flooding and mitigate the impacts of large-scale episodic events for the next 30-50 years while providing the Town with additional time to appropriately plan for future flood and coastal hazard management. The effectiveness of elevating the primary arteries along the waterfront in Vineyard Haven is shown Figure 7.9. While access and transportation will be maintained with this alternative, existing drainage systems will still need to be maintained to minimize the adverse effects of redirected runoff. Furthermore, Figure 7.9 shows that this alternative does not address the protection needed for waterfront properties along Beach Road.

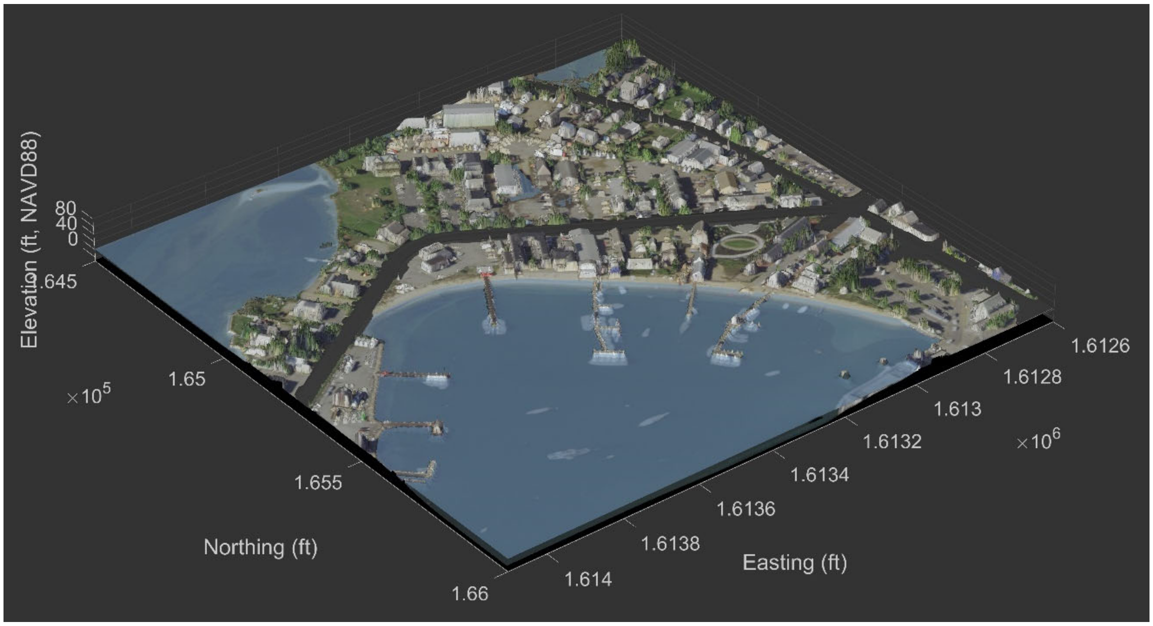

Figure 7.6 Rendering of Beach Road, Lagoon Pond Road, 5 Corners, and Water Street were elevated to the design flood elevation of 5 feet NAVD88.

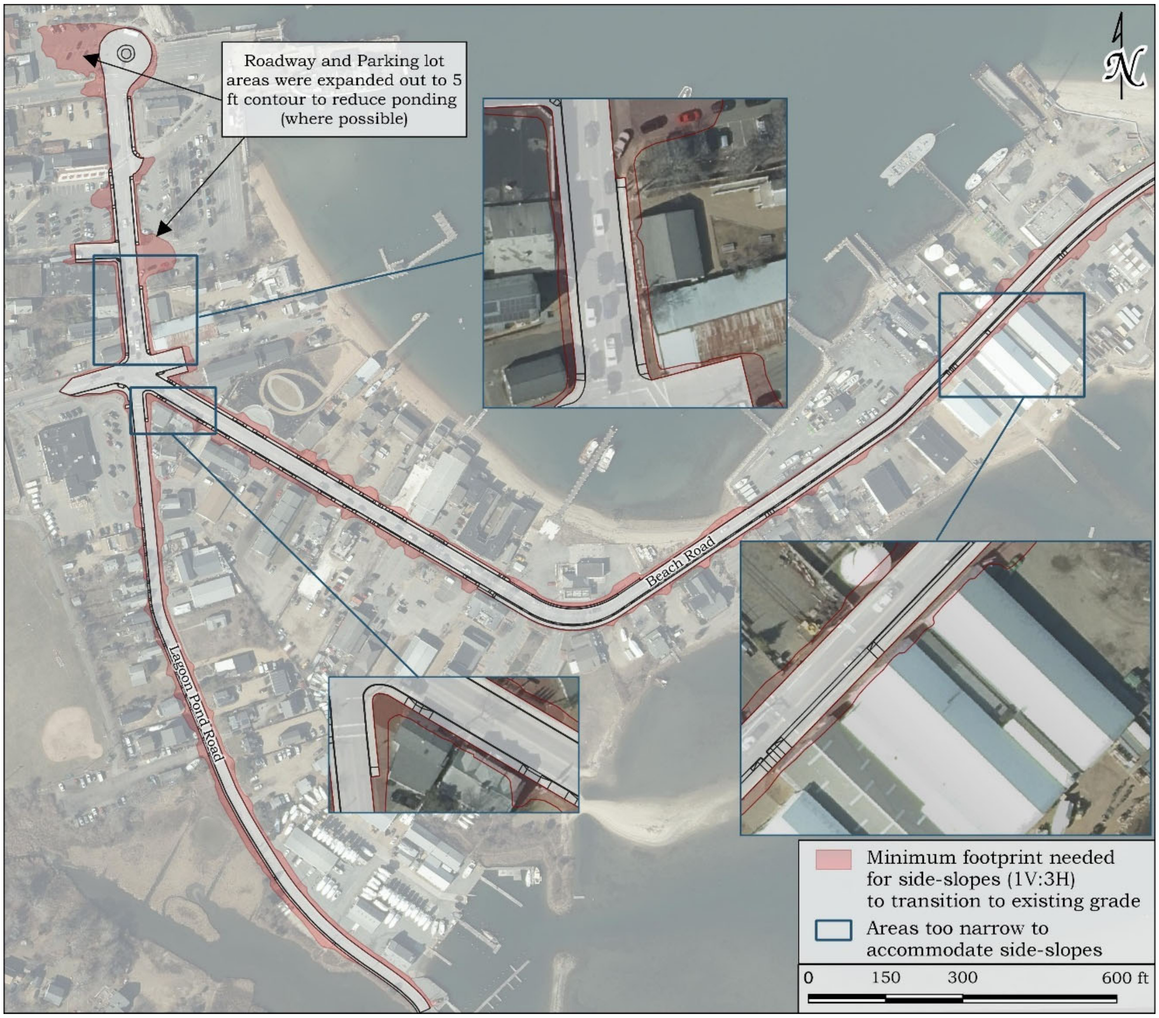

Figure 7.7 Low-lying roads in the downtown Vineyard Haven waterfront area elevated to 5 feet NAVD88 to meet the recommended design flood elevation threshold. The road layout including width, sidewalks, and curbing were designed to be consistent with the May 2021 MassDOT plans for the Beach Road Improvement Project. The red shaded regions represent the approximate footprint needed for elevated road segments to tie into the existing grade with a maximum slope of 1V:3H. The subset regions show areas where there is insufficient cross-street width between buildings to accommodate a maximum slope of 1V:3H. *To reduce roadway and parking lot ponding from runoff, the design footprint was extended out to the existing 5-foot contour where possible.*

Figure 7.8 Shows the potential encroachment of the proposed road improvements into tax parcels (outlined in yellow) obtained from MassGIS, as well as areas where the footprint of the design will likely be restricted by existing buildings (outlined in black).

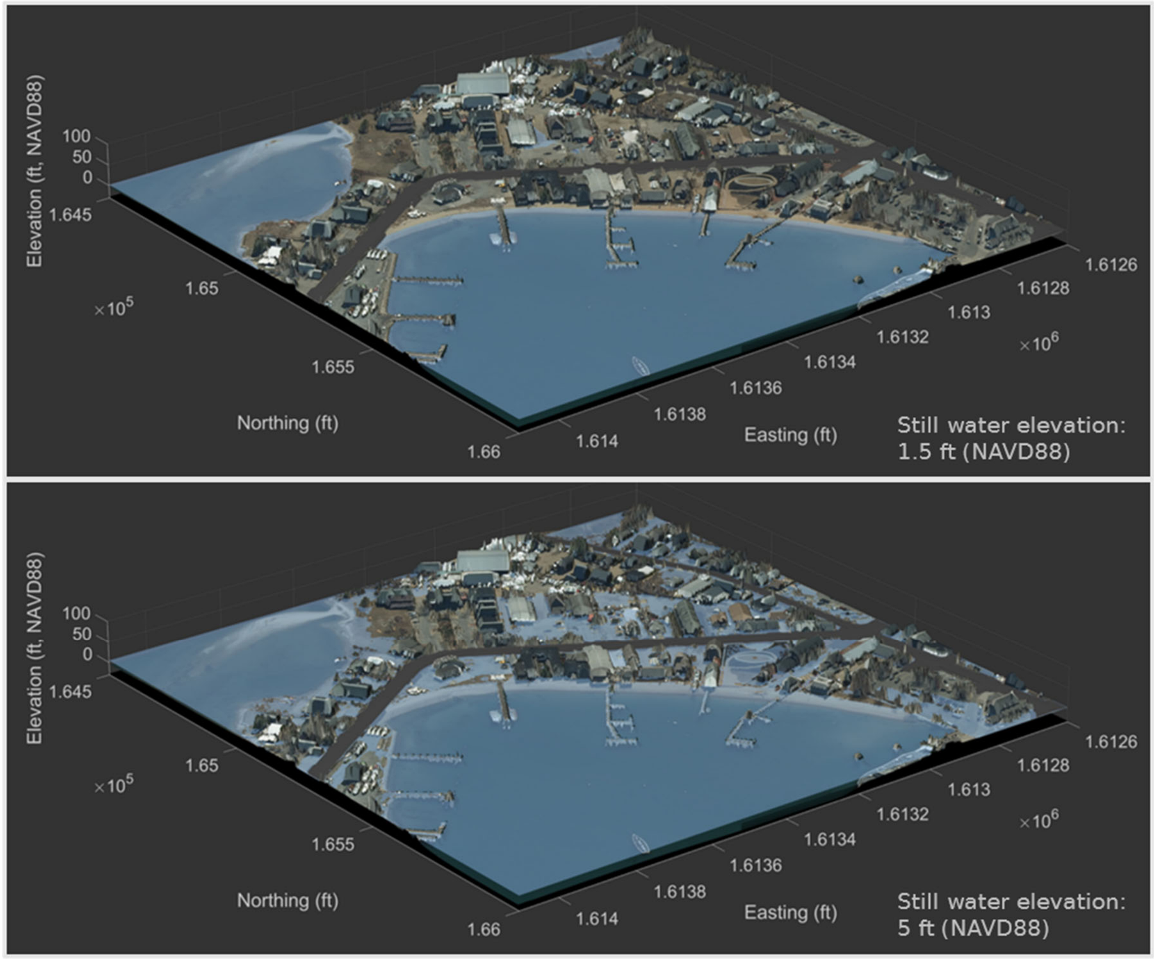

Figure 7.9 Comparison of improved road conditions during average annual high tide conditions (top) and design flood conditions of 5 feet NAVD88 (bottom).

While the financial constraints of elevating downtown roads may limit the total length of roadway segments able to be raised, without additional flood protection measures implemented it will be necessary to, at minimum, increase the elevation of the Five Corners Intersection and Beach Road. Elevations of the roadway measured by the 2021 LiDAR survey show that currently Five Corners and an area of Beach Road approximately 400 feet southeast of the intersection are the some of the lowest roadway points in downtown Vineyard Haven (Figure 7.10). Additionally, improving the elevation of Five Corners and Beach Road is necessary to maintain vital emergency access to the Hospital. Elevating Water Street will not be effective as a flood protection barrier or provide adequate transportation access without first increasing the elevation of Lagoon Pond Road and Beach. Also, while raising of Lagoon Pond Road would prevent flooding of a significant portion of this part of town, there are two culverts along the road that act as a storm tide pathway and facilitate flooding despite the raising of Lagoon Pond Road. It's important to note that the effectiveness of an elevated coastal road as a flood barrier depends on careful planning, engineering expertise, and consideration of local conditions. Environmental impact assessments, community engagement, and coordination with relevant authorities are crucial for ensuring the success of such infrastructure projects. Within this framework, the scale of this alternative would require further evaluation and extensive coordination with MassDOT, regulatory agencies, and the residents of Tisbury to refine the alternative and formulate more detailed design specifications before approximate cost and volumes could be considered.

Without full support of a flood protection barrier along the shoreline, raising the elevation of the low-lying roads in downtown Vineyard Haven is paramount to preserve emergency access and critical evacuation routes during storms, as well as daily connectivity to minimize community disruption during smaller scale flooding events. Beach Road runs adjacent to the harbor shoreline from the Five Corners intersection and across the Lagoon Pond bridge providing the most efficient route from Vineyard Haven to the hospital. Compared other available alternatives, elevating Beach Road, Lagoon Pond Road, and Water Street will involve a much longer timeline to be completed and will require the utilization of temporary flood protection measures to mitigate coastal flooding in the near-term. Additionally, this alternative will likely be cost prohibitive and logistically challenging to complete as a single project. Completing the project in phases by elevating each road one at a time will ensure that egress and available access is maintained. It is important to note that eventually the low segments of these roads will need to be addressed to maintain functionality of Beach Road, Water Street, Lagoon Pond Road and the Five Corners intersection as primary transportation arteries.

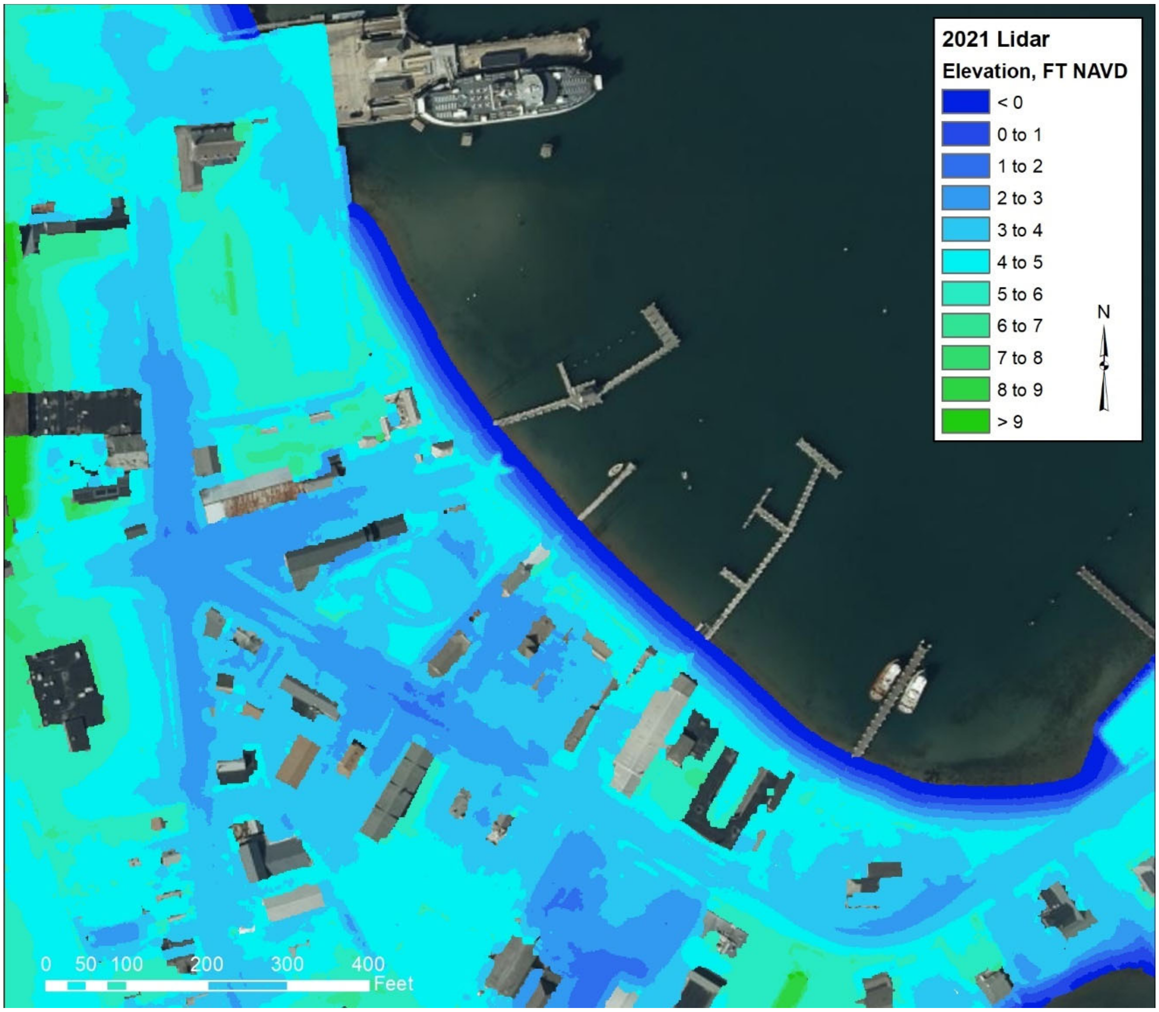

Figure 7.10 Existing road elevations collected from the 2021 USGS LiDAR survey show that all roadway elevations along Beach Road, Lagoon Pond Road, and Water Street are below 5 feet NAVD88.

7.3 Drainage Improvements

The filling of intertidal or wetland areas in Vineyard Haven can be traced back to the 19th century when the area experienced rapid economic growth and urban development. As the town expanded, land reclamation became necessary to create additional space for infrastructure, industries, and housing. Filling these areas allowed for the construction of roads, houses, wharves, and other structures vital to the town's maritime and commercial activities. While the creation of additional land provided valuable waterfront access for shipping and trade, facilitated the growth of industries such as fishing and shipbuilding, and accommodated the expanding population, it also resulted in the loss or degradation of important coastal habitats, such as salt marshes and intertidal zones. These ecosystems provide critical functions, including habitat for diverse flora and fauna, flood mitigation, water filtration, and drainage. Specifically, the filling of Bass Creek has altered the natural drainage of the area encompassed by Lagoon Pond Road, Beach Road, and the Five Corners intersection. Bass Creek was the primary hydraulic connection between Holmes Hole Harbor

(Vineyard Haven Harbor) and the Lagoon (Figure 7.11), it provided enough width and depth to allow large vessels into the inner harbor (now Lagoon Pond), until the Gale of 1815 broke through the causeway where the Lagoon Pond bridge is now located. After years of slowly shoaling in from reduced hydraulic efficiency, hampered by the new inlet formed by the breach, the Town decided to block off Bass Creek completely. In 1838, a boat under the name 'Zeno' was loaded with sand and stone was sunk in the vicinity of what is now the Five Corners (Figure 7.12), allowing for the construction of Beach Road to connect the Town with the barrier beach spanning the southeastern side of the harbor. The former Bass Creek area including the tidal wetlands to the west were gradually filled over the next 100 years, providing the area to develop between Lagoon Pond Road and Beach Road and Veterans Memorial Park, respectively. Consequently, these areas no longer provide the natural drainage or function of damping coastal flooding, resulting in many areas that susceptible to ponding and retaining water long after a flooding event has occurred. Specifically, Five Corners has a long history of recorded flooding events influenced by both rain events and coastal storms (Figure 7.13).

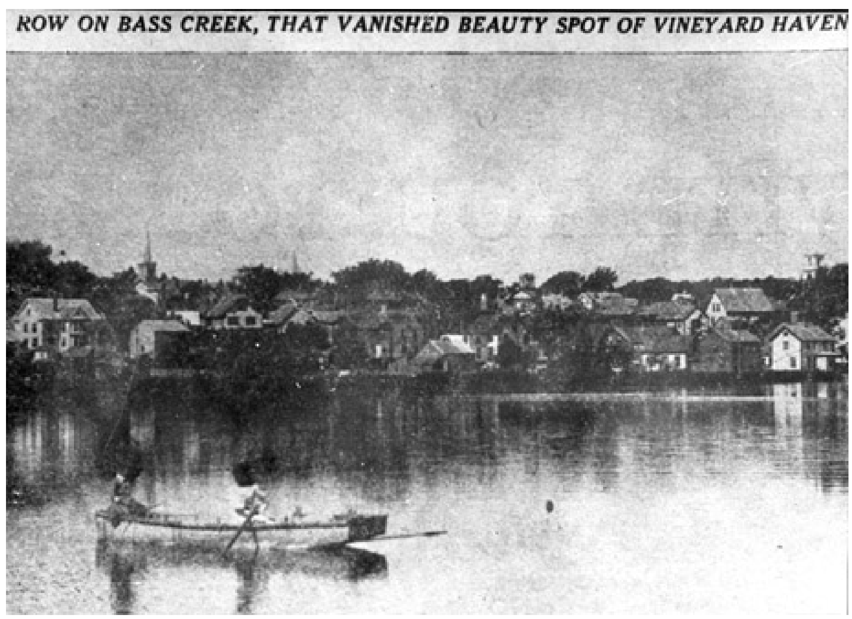

Figure 7.11 Two people rowing in Bass Creek behind the barrier beach after the inlet was closed off to the harbor.

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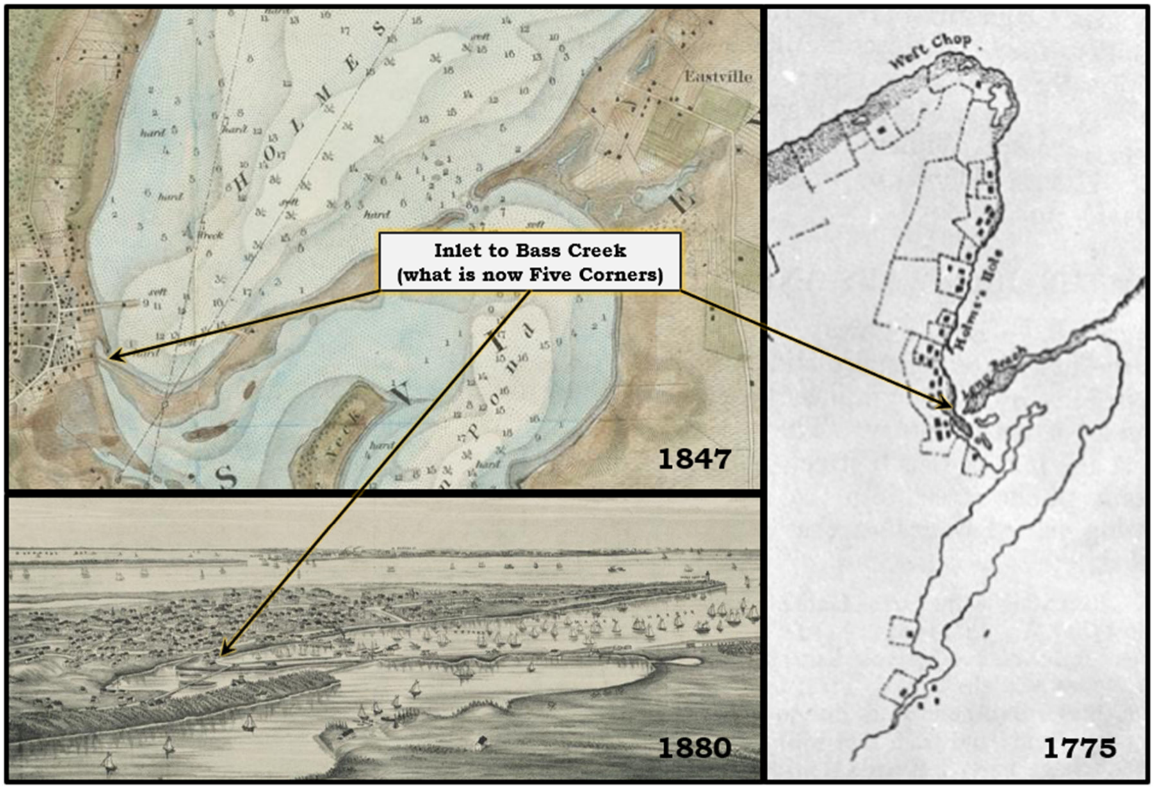

Figure 7.12 Location of the former Bass Creek inlet (the approximate location of Five Corners) before the area was filled and downtown was expanded.

Figure 7.13 Historical flooding at the Five Corners intersection in downtown Vineyard Haven in (clockwise from top left) 1954, 1991, 2018, and 2022 illustrates the consistency of the flooding problem that has been an ongoing issue for over 100 years.

Flooding in downtown Vineyard Haven is made worse by the inability of the existing drainage infrastructure to effectively drain impeding water caused by rain and coastal storms resulting in flooding of low-lying areas of downtown roads, specifically the Five Corners intersection. To remediate the impacts of standing floodwater improvements and/or replacement of the existing drainage system is needed. 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 7.14). 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 7.14). Results from the FY21 report determined that the rain during the March 2018 storm occurred prior to the peak of the storm surge, indicating that had the outfalls been operating effectively, the stormwater would have drained prior to the surge induced flooding. 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 7.15.

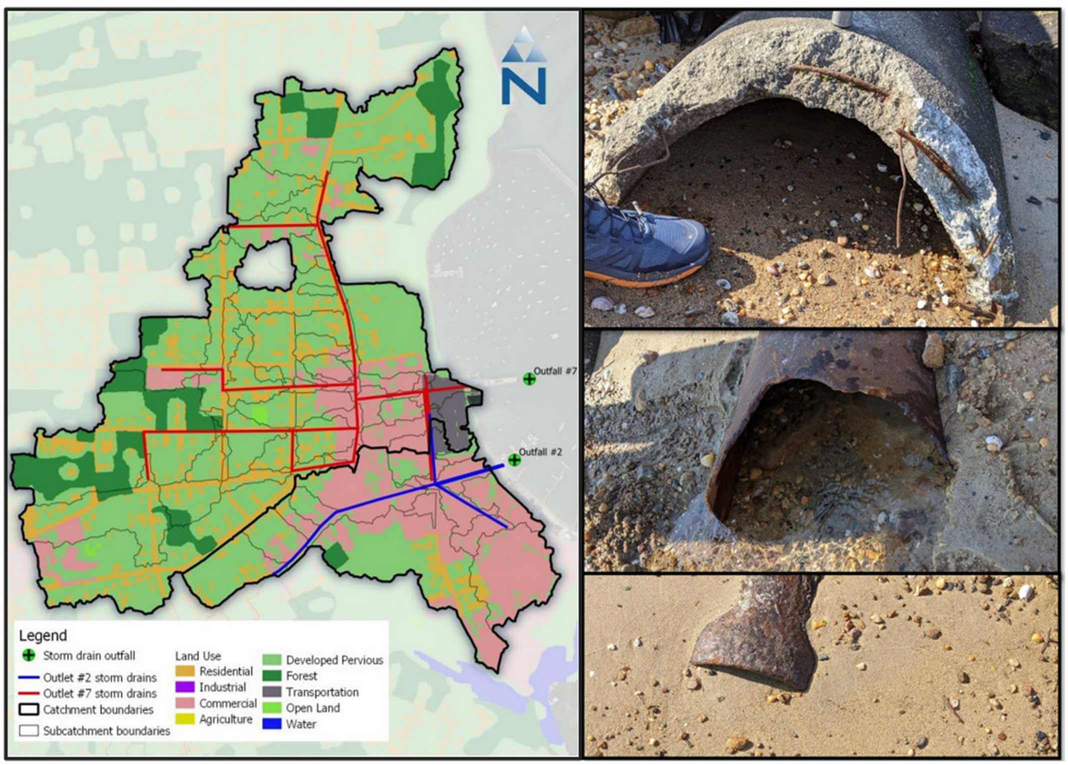

Figure 7.14. A map (left) showing the sub-catchment delineation and major land use in the drainage areas to outfall #2 and #7 (Paradigm Environmental et al. 2020), and photos (right) of the drainage pipes at the Outfall #2 location.

Figure 7.15 Location of coastal storm surge and stormwater flooding during a 3.5-foot NAVD88 flood elevation. Stormwater primarily will flood around the five corners intersection of downtown.

A potential alternative to improve stormwater drainage in vicinity of Five Corners, that has been discussed at meetings held with the town, is utilizing the location of the former Bass Creek drainage trench (Figure 7.16) to install adequate stormwater pipes and direct the ponding flood water away from the intersection. To properly assess the viability of this alternative, a comprehensive hydrologic and environmental analysis would be necessary to ensure that a design could be implemented to provide adequate stormwater conveyance without adversely affecting fragile wetland ecosystems. If viable, this alternative may allow for efficient drainage to complement existing stormwater infrastructure with minimal impacts to existing properties (Figure 7.17). Historical plans from 1929 and 1936 (see Appendix A for reference) show that the back edge of the properties plotted on the fill area were delineated by the location of the Bass Creek drainage system. Although adequate drainage does not protect inland areas from coastal flooding, it does reduce the duration of flooding and decreases the overall exposure to flood inundation of an area. Beyond providing relief to areas commonly inundated with standing water, improving the existing stormwater infrastructure will also protect inland areas from coastal flooding. In order to mitigate potential flooding from these discharge locations, it is recommended that modifications be made to restrict flow to one direction during storm events.

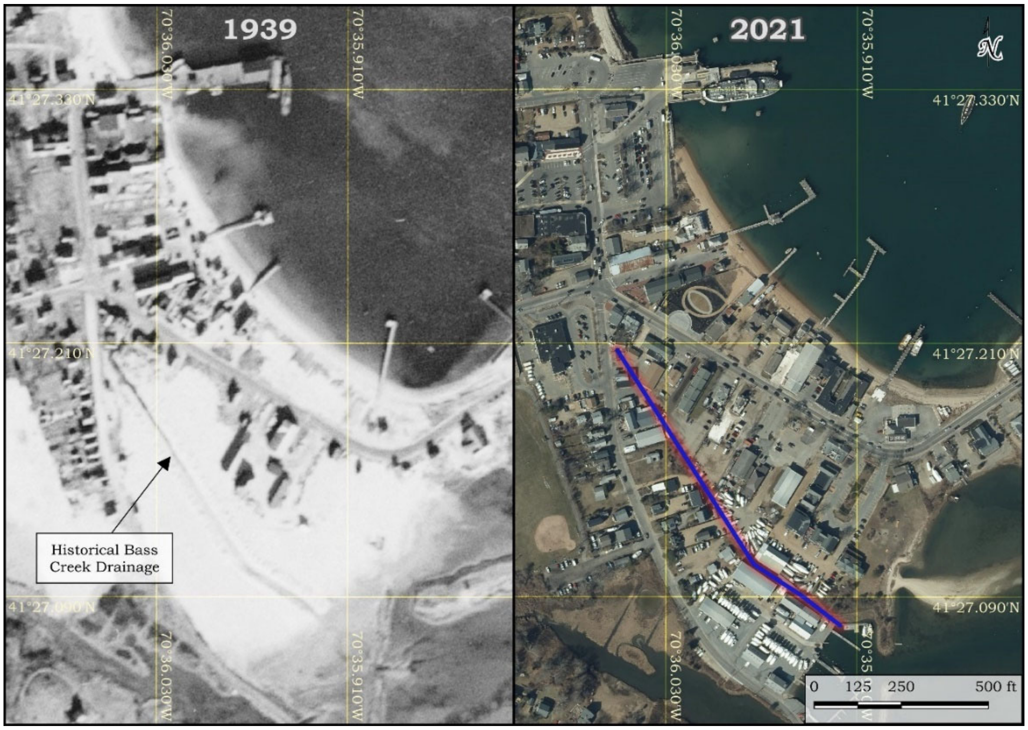

Figure 7.16 Aerial imagery from 1939 (left) and 2021 (right) illustrating the expansion of downtown development on filled tidelands and the location of former Bass Creek drainage system.

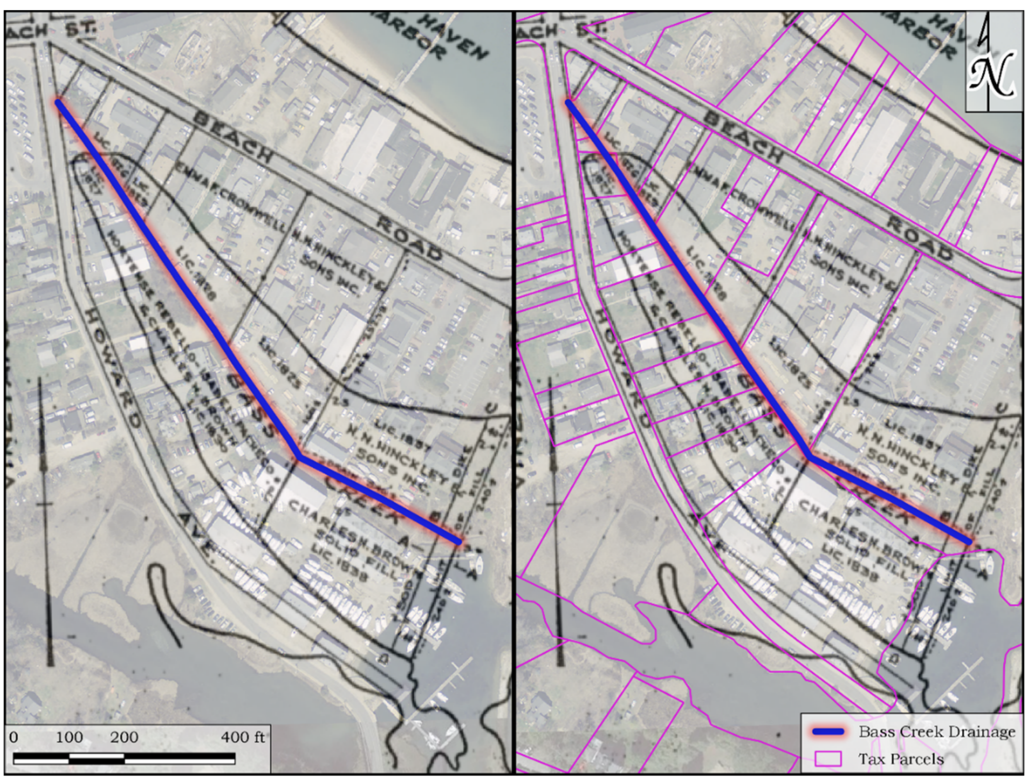

Figure 7.17 Bass Creek fill and drainage plans from 1936 overlaid on 2019 aerial image of downtown Vineyard Haven. The figure on the right also maps the 2023 tax parcel outlines for reference.

8 Summary

Generally, flood mitigation and protection in coastal communities is a complex problem to manage and successful remediation often requires multifaceted strategies that address minimizing flood intrusion while also increasing the effectiveness of flood prone areas to dissipate standing flood water. These complexities are amplified in Vineyard Haven due to the extremely low elevation of the working waterfront and the adjacent upland encompassed by Beach Road, Lagoon Pond Road, and the Five Corners intersection, as well as the compromised condition of existing drainage infrastructure. Based on the above considerations, a stand-alone alternative to provide comprehensive flood protection in the near term does not exist. While coastal flood intrusion can be sufficiently mitigated by implementing an adequately engineered barrier or utilizing temporary flood protection measures while critical infrastructure is elevated above the minimum design flood threshold, the impacts of rain induced flooding will remain significant and will likely continue to worsen without proper collection and conveyance of stormwater or remediation of the existing drainage systems near the waterfront. Likewise, implementation of stormwater BMPs as a stand-alone mitigation strategy will aid in relieving the impacts of flooding, but due to the area's close proximity to the coast and existing storm tide pathways, these measures will quickly become overwhelmed during significant coastal storms and consequently will require frequent maintenance. Within this framework, it is recommended, as a priority, to address the urgency of restoring the functional integrity of the existing drainage infrastructure while continuing working towards a pragmatic protection measure that receives collective support from the community.

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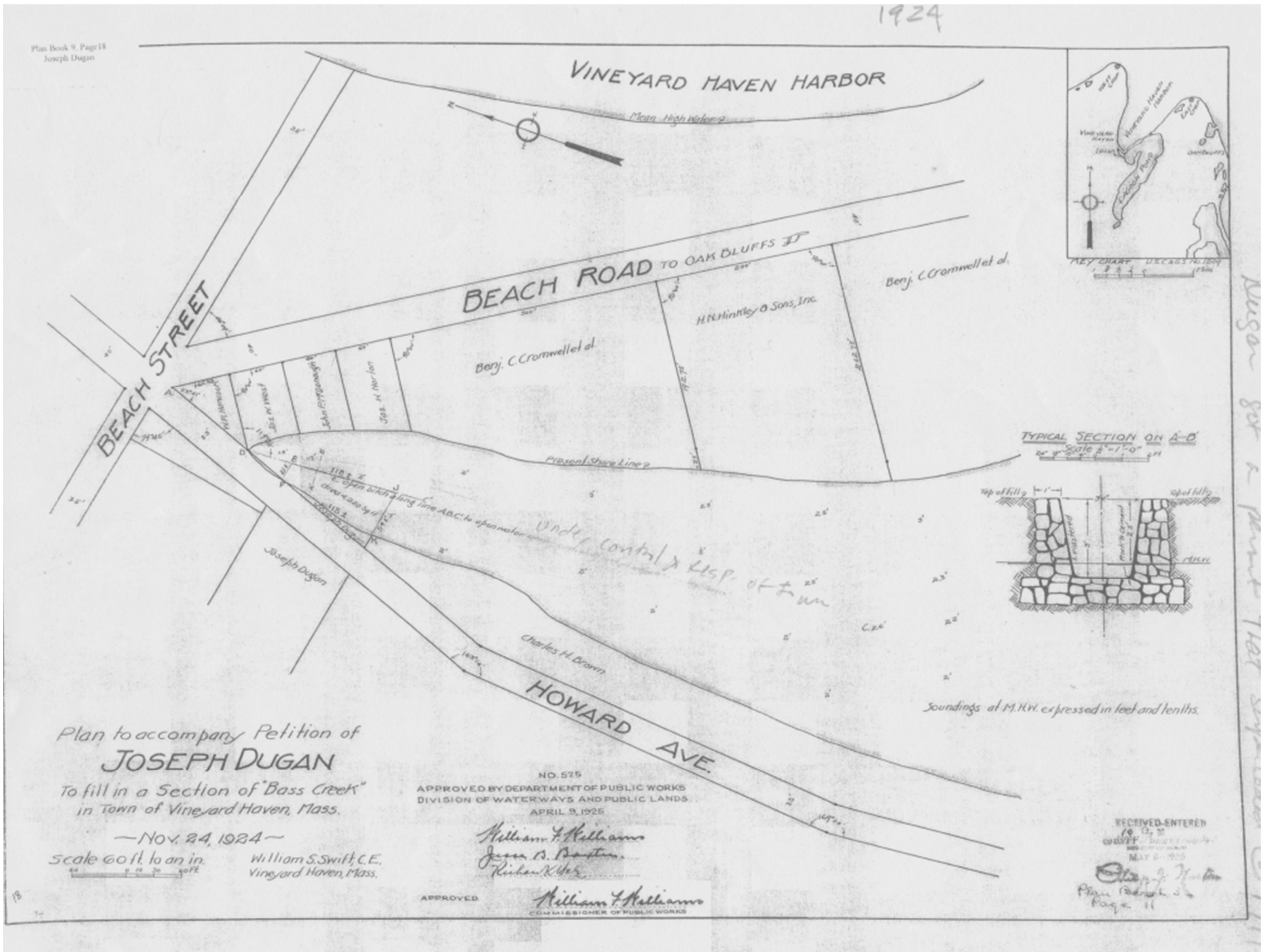
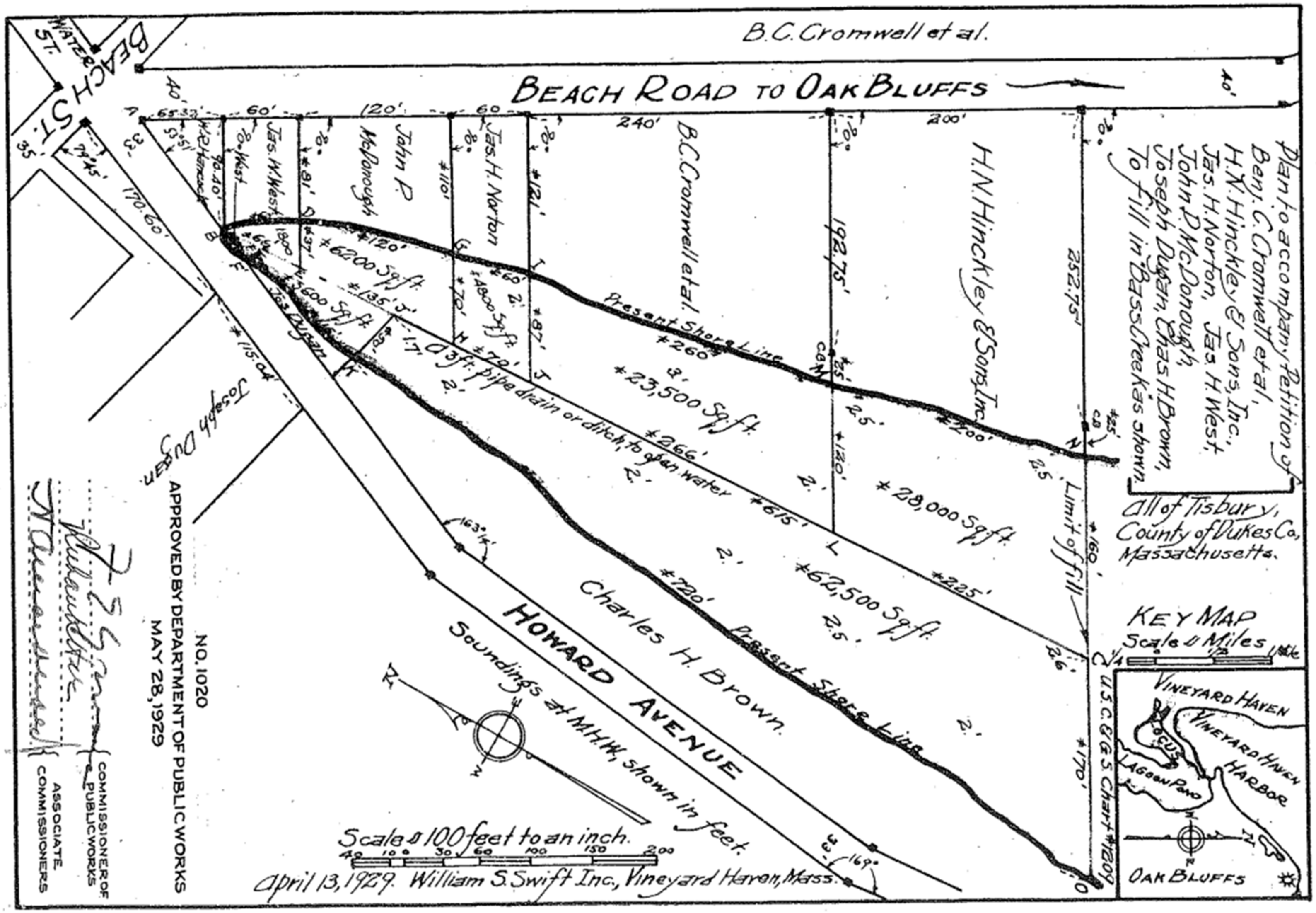
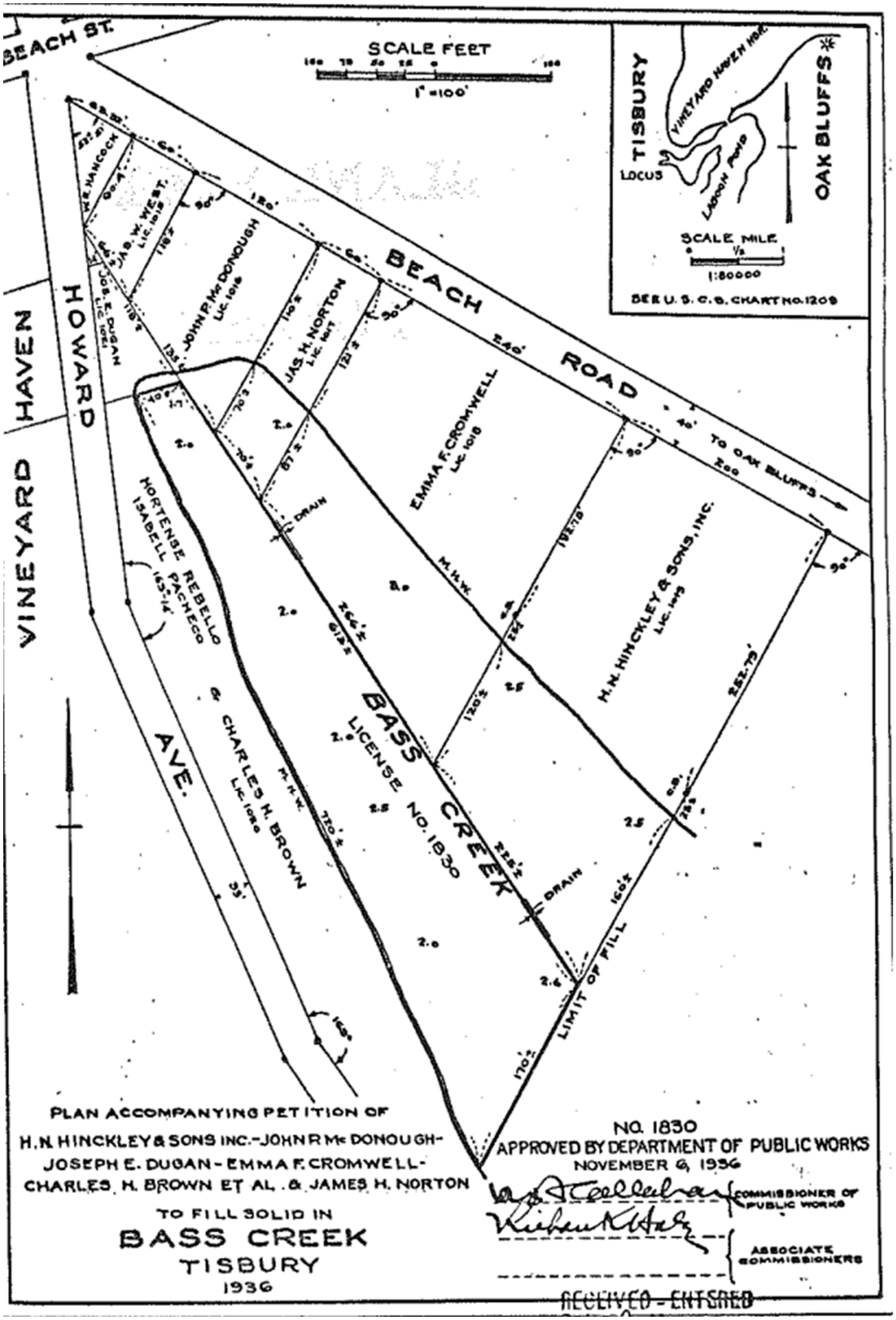
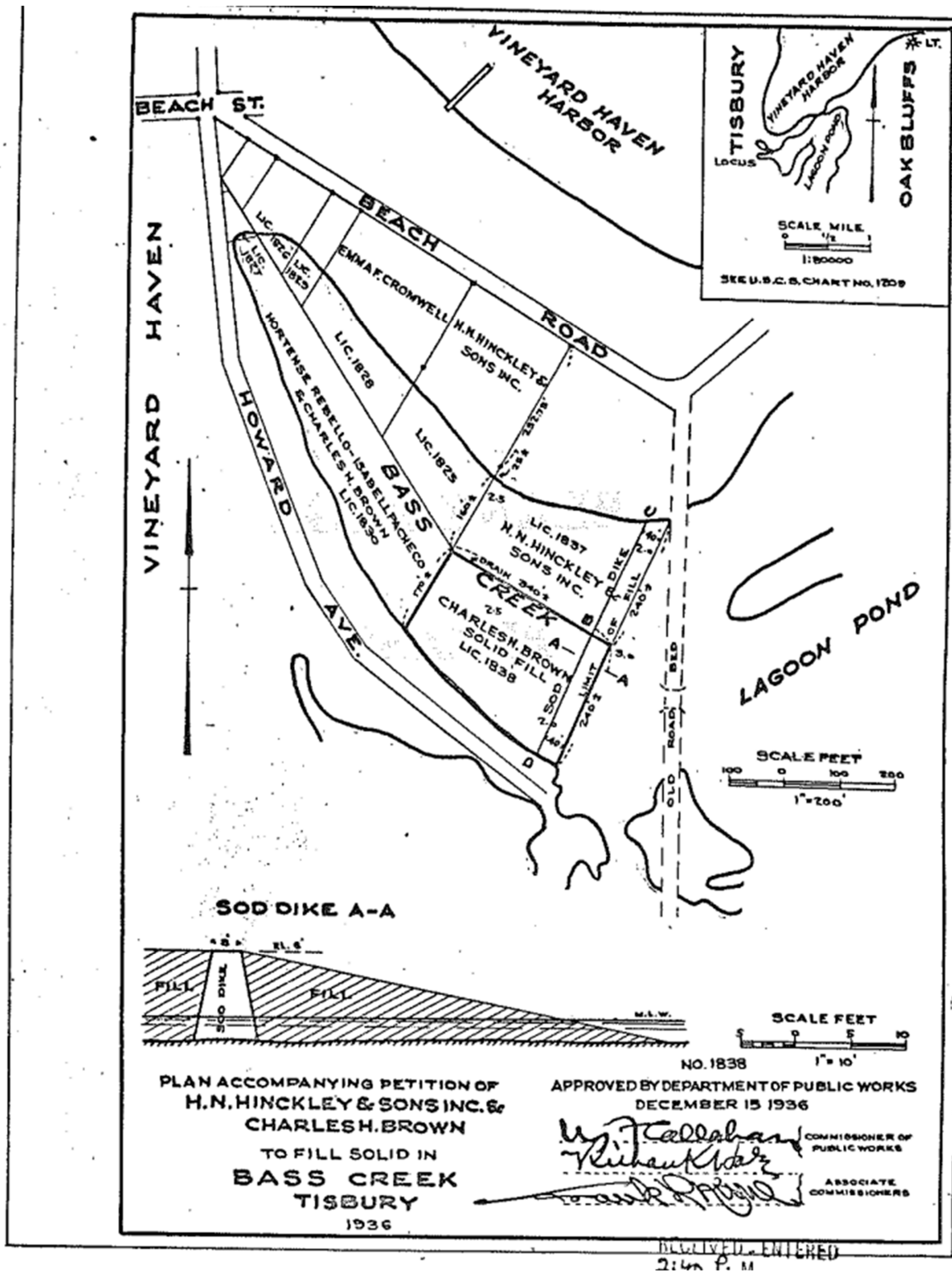
Appendix A – Historical Bass Creek Fill and Drainage Plans


1924
Plan Book 9, Page 18
Joseph Dugan
VINEYARD HAVEN HARBOR
Mean High Water
BEACH ROAD TO OAK BLUFFS
BEACH STREET
Benj. C Cromwell et al.
H.N. Hinckley & Sons, Inc.
Present Shore Line
Joseph Dugan
Charles H. Brown
HOWARD AVE.
TYPICAL SECTION ON A-B
Top of fill
Soundings at M.H.W. expressed in feet and tenths.
Plan to accompany Petition of
JOSEPH DUGAN
To fill in a Section of "Bass Creek"
in Town of Vineyard Haven, Mass.
—Nov. 24, 1924—
Scale 60 ft. to an in.
William S. Swift, C.E.
Vineyard Haven, Mass.
NO. 575
APPROVED BY DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATERWAYS AND PUBLIC LANDS
APRIL 9, 1925
APPROVED
COMMISSIONER OF PUBLIC WORKS
RECEIVED-ENTERED
KEY CHART


B.C. Cromwell et al.
BEACH ROAD TO OAK BLUFFS
BEACH ST.
WATER ST.
Jas. H. West
John P. McDonough
Jas. H. Norton
B.C. Cromwell et al.
H.N. Hinckley & Sons, Inc.
Joseph Dugan
Charles H. Brown
HOWARD AVENUE
Present Shore Line
3ft. pipe drain or ditch to open water
±6200 Sq.ft.
±4800 Sq.ft.
±23,500 Sq.ft.
±28,000 Sq.ft.
±62,500 Sq.ft.
Limit of fill
Plan to accompany Petition of Benj. C. Cromwell et al, H.N. Hinckley & Sons, Inc., Jas. H. Norton, Jas. H. West, John P. McDonough, Joseph Dugan, Chas. H. Brown, To Fill in Bass Creek as shown.
All of Tisbury, County of Dukes Co., Massachusetts.
KEY MAP
Scale in Miles
VINEYARD HAVEN
VINEYARD HAVEN HARBOR
LAGOON POND
OAK BLUFFS
U.S.C.&G.S. Chart #1209
Soundings at M.H.W. shown in feet.
Scale 100 feet to an inch.
April 13, 1929. William S. Swift Inc., Vineyard Haven, Mass.
NO. 1020
APPROVED BY DEPARTMENT OF PUBLIC WORKS
MAY 28, 1929
COMMISSIONER OF PUBLIC WORKS
ASSOCIATE COMMISSIONERS


BEACH ST.
SCALE FEET
1" = 100'
TISBURY
VINEYARD HAVEN HBR.
LOCUS
LAGOON POND
OAK BLUFFS
SCALE MILE
1:80000
SEE U.S.C.G. CHART NO. 1209
BEACH ROAD
TO OAK BLUFFS
VINEYARD HAVEN
HOWARD AVE.
JAS. W. WEST
JOHN P. McDONOUGH LIC. 1016
JAS. H. NORTON LIC. 1017
EMMA F. CROMWELL LIC. 1018
H. N. HINCKLEY & SONS, INC. LIC. 1019
HORTENSE REBELLO ISABELL PACHECO
& CHARLES H. BROWN LIC. 1020
BASS CREEK
LICENSE NO. 1830
M.H.W.
DRAIN
LIMIT OF FILL
PLAN ACCOMPANYING PETITION OF
H. N. HINCKLEY & SONS INC. - JOHN P. McDONOUGH -
JOSEPH E. DUGAN - EMMA F. CROMWELL -
CHARLES H. BROWN ET AL. & JAMES H. NORTON
TO FILL SOLID IN
BASS CREEK
TISBURY
1936
NO. 1830
APPROVED BY DEPARTMENT OF PUBLIC WORKS
NOVEMBER 6, 1936
COMMISSIONER OF PUBLIC WORKS
ASSOCIATE COMMISSIONERS


VINEYARD HAVEN HARBOR
BEACH ST.
BEACH ROAD
VINEYARD HAVEN
HOWARD AVE.
BASS CREEK
LAGOON POND
OLD ROAD BED
TISBURY
VINEYARD HAVEN HARBOR
LAGOON POND
LOCUS
OAK BLUFFS
SCALE MILE
1:80000
SEE U.S.C.&G. CHART NO. 1209
LIC. 1827
LIC. 1826
LIC. 1829
EMMA F. CROMWELL
H.N. HINCKLEY & SONS INC.
LIC. 1828
LIC. 1825
HORTENSE REBELLO-ISABELLA PACHECO & CHARLES H. BROWN LIC. 1830
LIC. 1837 H.N. HINCKLEY SONS INC.
DIKE OF FILL
CHARLES H. BROWN SOLID FILL LIC. 1838
SOD LIMIT
SCALE FEET
1"=200'
SOD DIKE A-A
FILL
SOD DIKE
M.L.W.
SCALE FEET
1"=10'
NO. 1838
PLAN ACCOMPANYING PETITION OF
H.N. HINCKLEY & SONS INC. &
CHARLES H. BROWN
TO FILL SOLID IN
BASS CREEK
TISBURY
1936
APPROVED BY DEPARTMENT OF PUBLIC WORKS
DECEMBER 15 1936
COMMISSIONER OF PUBLIC WORKS
ASSOCIATE COMMISSIONERS