Hyannis Harbor Municipal Vulnerability Preparedness Resilience Plan

Hyannis Harbor Flood Vulnerability Assessment and Conceptual Coastal Flood Resilience Recommendations

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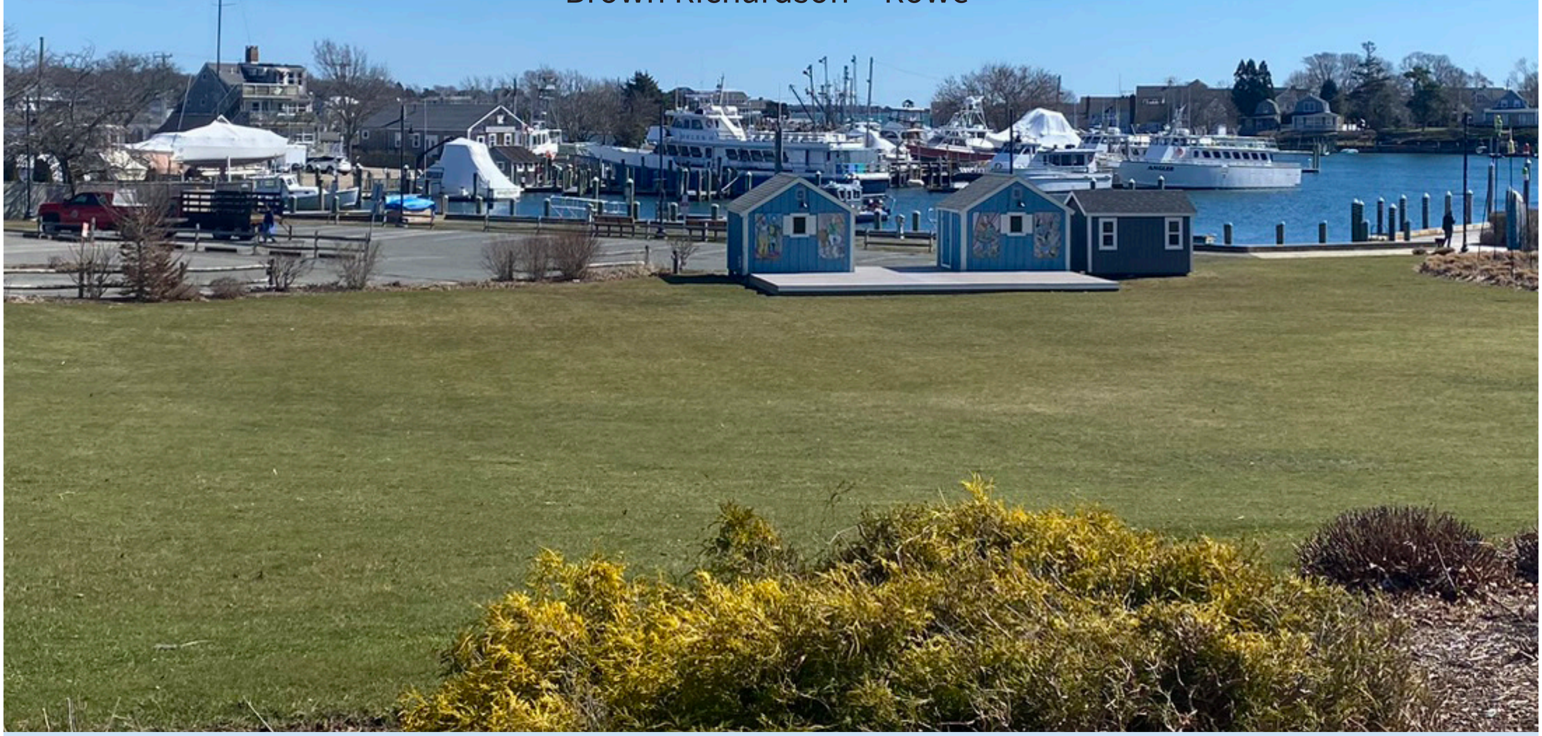

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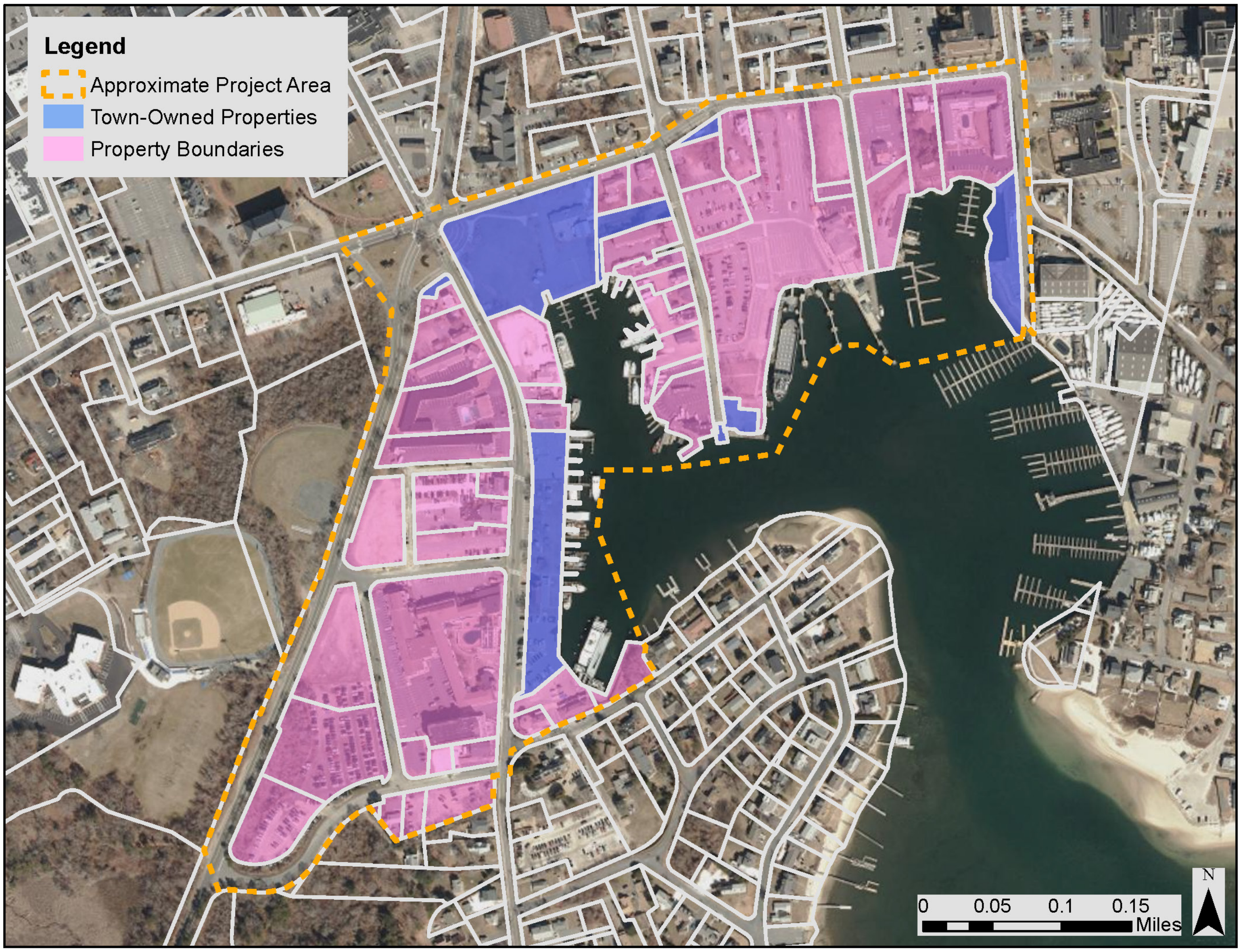
1.1 Project Overview and Background

For the Town of Barnstable (the "Town") to realize its vision for the Hyannis Harbor (the "Harbor") area, the community needs to focus on promoting the various desired harbor and waterfront uses, commercial and recreation activities, and development patterns for both the land and water, influenced by a clear understanding of current and future flood risk within the district. The Hyannis Harbor Municipal Vulnerability Preparedness ("MVP") Resilience Plan has been tasked with identifying flood risk vulnerabilities and other constraints, exploring opportunities, and providing recommendations for land use improvements, climate resiliency, economic development strategies, and public space enhancements for the approximately 57-acre inner Hyannis Harbor area (the "Project Site") to help shape this vision. Across its 54 parcels and the adjacent watersheet, the Project Site contains a variety of uses, including both public and private marinas, commercial fishing operations, ferry terminals, public parks, hotels, restaurants, surface parking lots, and other businesses. These elements need to have symbiotic relationships for the Project Site to be as successful as possible in the eyes of the public, residents, property owners, businesses, tourists, and Town officials. The recommendations in this memorandum explore actions and regulations for the built environment and ideas for a cohesive strategy for activating the Harbor area, while also ensuring the Harbor and associated development areas are more resilient to the threats of climate change. Please note the strategies and initiatives highlighted in this memorandum represent a menu of options which can be used in their totality for the most effective approach to make future changes, or as piecemeal endeavors to be implemented over time.

Hyannis Harbor (the "Harbor") is a deepwater harbor located in Hyannis, the largest village in the Town of Barnstable, Massachusetts. Hyannis hosts Cape Cod's largest airport, and functions as a major hub for tourism, business, commercial fishing, and travel to and from Nantucket and Martha's Vineyard. The Project Site contains property owned by the Town of Barnstable and private property with commercial and residential uses (Figure 1). The Hy-Line Cruises and Steamship Authority terminals provide critical year-round passenger and car service to Nantucket, as well as auxiliary service to Martha's Vineyard during the summer. Due to the low-lying geography and its proximity to the waterfront, the area surrounding the Harbor is susceptible to both sea level rise and storm surge flooding. Incorporating information about flood vulnerability into the ongoing Hyannis Harbor Master Plan is critical to ensuring the Harbor remains functional and vibrant in future conditions. This technical memorandum outlines the approach used to determine building and asset vulnerability within the Hyannis Harbor Project Site and provides insight into future flooding scenarios to inform decisions regarding flood risk adaptation at the building and district scales and long-term planning.

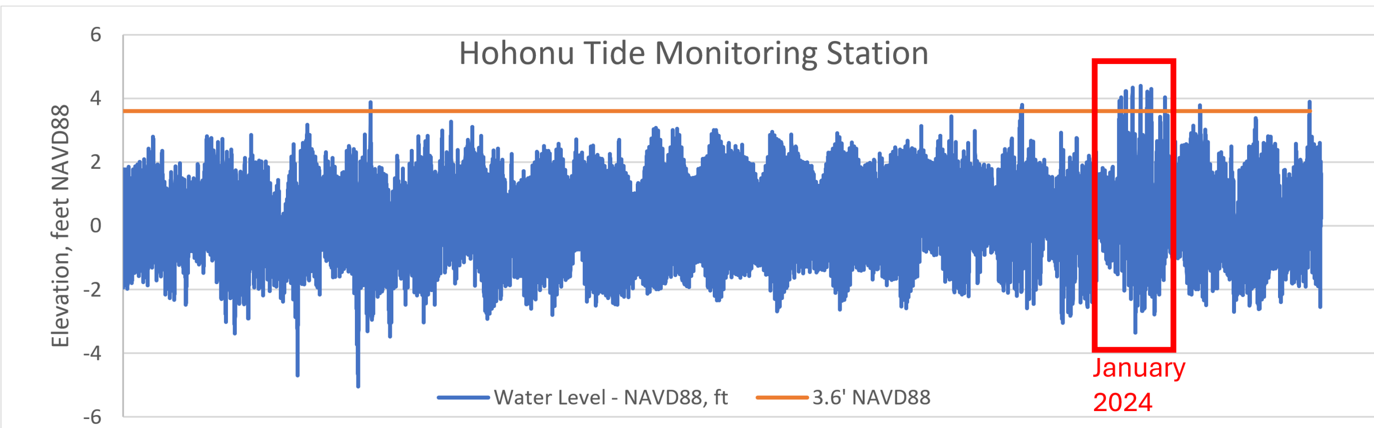
Figure 1: Hyannis Harbor Project Site and Property Inventory Map (Barnstable, MA)



1.2 Recent Coastal Flood Events

In October of 2022, Hohonu installed a tide monitoring station in Hyannis Harbor. Hohonu is a startup company creating a network of real-time tidal and overland flood monitoring stations. Data from the Hyannis Harbor Hohonu tidal station is publicly available on their website.[1] Figure 2 shows water levels in Hyannis Harbor from November 2, 2022 to May 10, 2024. The horizontal line represents the lowest parts of the bulkhead edge, or the elevation at which minor fringe flooding over the bulkhead at Bismore Park starts to occur. For reference, the gravel parking lot at the end of Pleasant Street is approximately one foot lower than the edge of the bulkhead at Bismore Park, and would also have flooding impacting its use at the water level indicated by the horizontal line. Between November 2022 and May 2024, at least thirteen flood events occurred that overtopped the Bismore Park bulkhead. At least eleven of those flood events occurred between May 2023 and May 2024, with several in the repeated storms of January 2024 (red box). This cluster of flood events raised awareness of the challenges even minor flooding can pose.

Figure 2: Hohonu Tidal Monitoring Station Data from November 2022 to May 2024 compared to current Bismore Park bulkhead critical elevation. January 2024 is indicated with the red box.



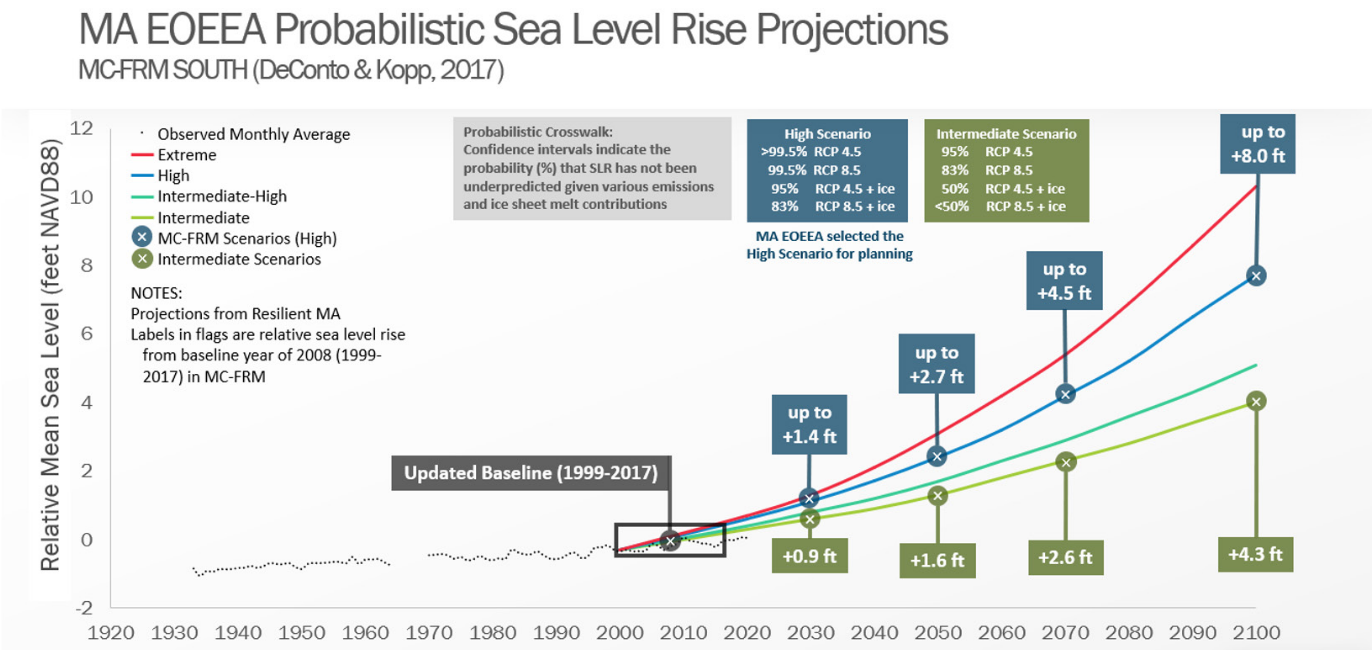
1.3 Sea Level Rise Projections and Nuisance Flooding Exposure

"Nuisance flooding" refers to coastal flood conditions related to high tides rather than storm events and is sometimes called "sunny day" flooding. To determine the impact of future water levels, Mean High Water ("MHW") shorelines have been developed for the Massachusetts coastline for 2030, 2050, and 2070 conditions. Mean High Water refers to the average of all high tides over a tidal epoch. The future MHW shorelines are based on projections of future mean sea level elevation for use in climate change planning that are locally downscaled from global climate models (DeConto & Kopp, 2017). These scenarios include different levels of greenhouse gas emissions and different contributions from global ice sheet melt.[2] The state uses the High scenario for climate change planning, which for nearby Woods Hole corresponds to 1.4 feet of sea level rise from a 2008 baseline as soon as 2030, 2.7 feet as soon as 2050, and up to 4.5 feet as soon as 2070 (Figure 3). Use of the High scenario is deliberately conservative and ensures future sea levels are not being underpredicted in large infrastructure and planning projects. This sea level rise projection is used to calculate local tidal datums for the 2030, 2050, and 2070 time horizons and is also incorporated into the Massachusetts Coast Flood Risk Model ("MC-FRM").

1 https://dashboard.hohonu.io/map-page/hohonu-111/HyannisHarbor,MA

2 https://doi.org/10.1038/nature17145

Figure 3: Massachusetts Executive Office of Energy and Environmental Affairs (MA EOEEA) Probabilistic Sea Level Rise Projections (Tide Gauge Station Woods Hole, MA)



Based on MC-FRM projected tidal benchmarks, MHW in Hyannis Harbor could reach 3.1 ft NAVD88 as soon as 2030, 4.4 ft NAVD88 as soon as 2050, and 6.3 ft NAVD88 as soon as 2070 (Table 1). For comparison, the published MHW datum at the nearest National Oceanic and Atmospheric Administration ("NOAA") tide gauge station in Hyannisport is 1.35 ft NAVD88. This datum was converted from Mean Lower Low Water ("MLLW") to NAVD88 using NGS Benchmark Sheet AA7166. It is important to note that this datum comes from the 1983 – 2001 tidal epoch, and does not account for sea level rise since 1992.

Table 1: MC-FRM Projected Tidal Benchmarks for Hyannis Harbor, MA

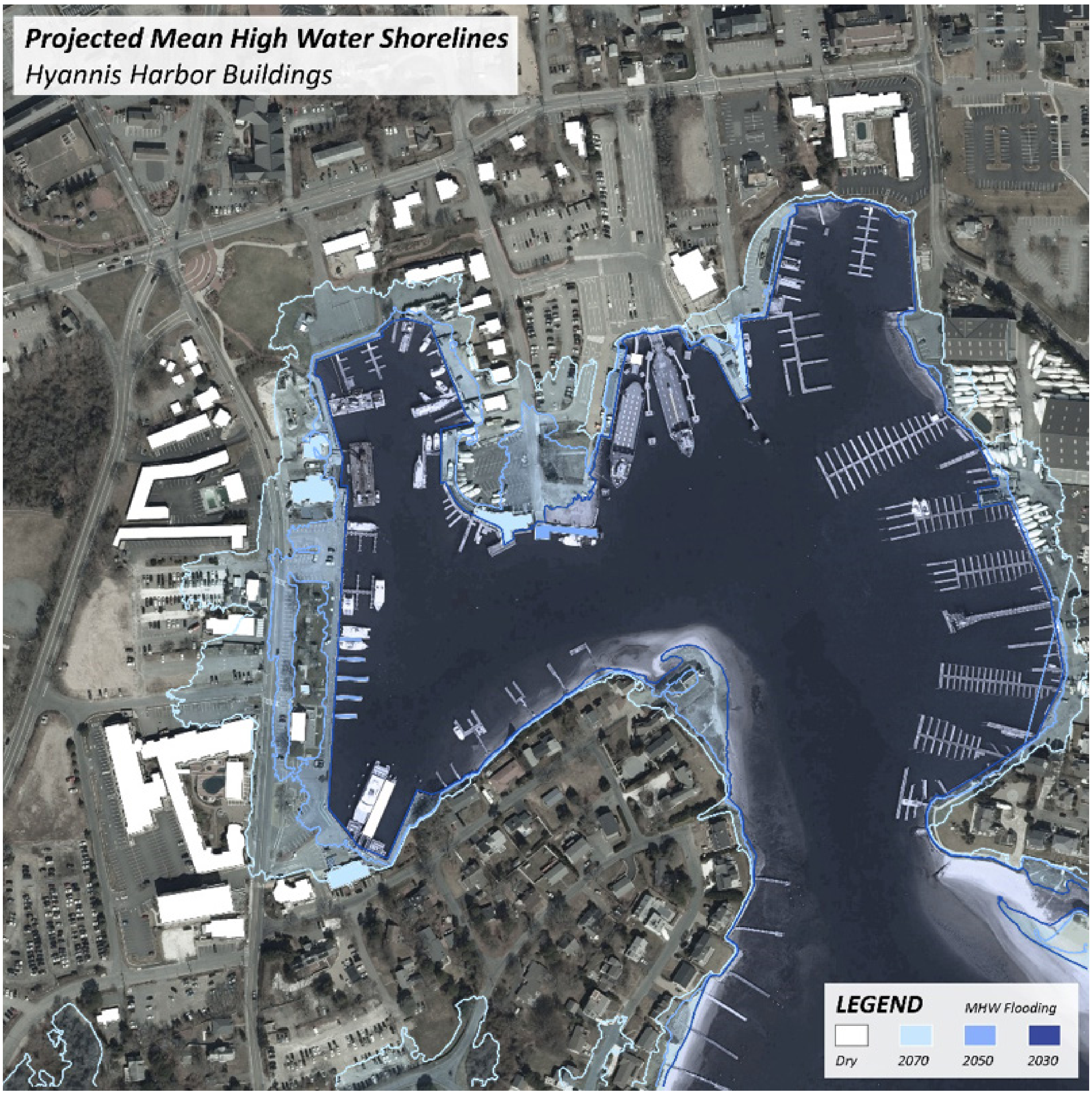
	Projected Tidal Benchmarks (elevation in ft. NAVD88)		
	Hyannis Harbor		
	MC-FRM Tidal Benchmarks		
	2030	**2050**	**2070**
MHHW	3.4	4.7	6.5
MHW	3.1	4.4	6.3
MLW	1.4	2.7	4.5
MLLW	-0.3	1	2.7

In 2023, the Massachusetts Office of Energy and Environmental Affairs and ResilientMA contracted Woods Hole Group to develop statewide future Mean High Water Shorelines. The shorelines are Geographic Information System ("GIS") representations of the projected future MHW extents for each local area (Figure 7), and were developed by extracting corresponding elevation contours from the most current terrain elevation measurements available from the MassGIS LiDAR Terrain Data. LiDAR, which stands for Light Detection and Ranging, is a remote sensing technology that uses laser light to create highly accurate and detailed maps of the contours of Earth's surface.

1.4 Tidal Flood Exposure

The future MHW shorelines for Hyannis Harbor were also used to identify land areas that could be affected by daily tidal flooding in the 2030, 2050, and 2070 time horizons. Building critical elevations were also compared to the tidal benchmark elevation for each time horizon to identify buildings and other infrastructure that are vulnerable to nuisance flooding (Figure 8). According to the future MHW shorelines for the Project Site, most of Hyannis Harbor should remain unaffected by daily tidal flooding in the near-term (2030) time horizon. As soon as 2050, areas of Bismore Park and Ocean Street may be affected by tidal flooding. Water is also projected to overtop the current elevations of fixed docks at Bismore Park and Pleasant Street, and the bulkhead at the Hy-Line Cruises ferry terminal as soon as 2050. As soon as 2070, most of the area east of Ocean Street and areas at the end of Pleasant Street are projected to flood twice daily (on average). Several buildings are also affected in this time horizon, including the Hy-Line Cruises ticket building and three restaurants.

Figure 4: Buildings affected by MHW projections for Hyannis Harbor, Massachusetts



1.5 MC-FRM Background

Data from the MC-FRM were used to assess the vulnerability of facilities (buildings and other assets) in the Hyannis Harbor Project Site to storm surge flooding in the 2030, 2050, and 2070 time horizons. The MC-FRM is a probabilistic hydrodynamic model that is used as the state standard for coastal climate change planning in Massachusetts.[3] The MC-FRM considers a variety of factors such as sea level rise projections, historical and projected future hurricanes and nor'easters, elevation data, and land cover data to provide an accurate representation of potential flood impacts along the state's coast. With coastal communities facing significant risks from rising sea levels and increasingly intense storms due to climate change, the MC-FRM is an essential tool for decision makers in identifying areas that are most vulnerable to flooding. The outputs of the model include 2030, 2050, and 2070 storm surge flooding projections for a range of annual exceedance probabilities ("AEPs"). The Annual Exceedance Probability of a point refers to that point's probability of flooding in a given year. This vulnerability assessment evaluated future flood risk to buildings on a site-specific basis.

1.6 Vulnerability Assessment Process

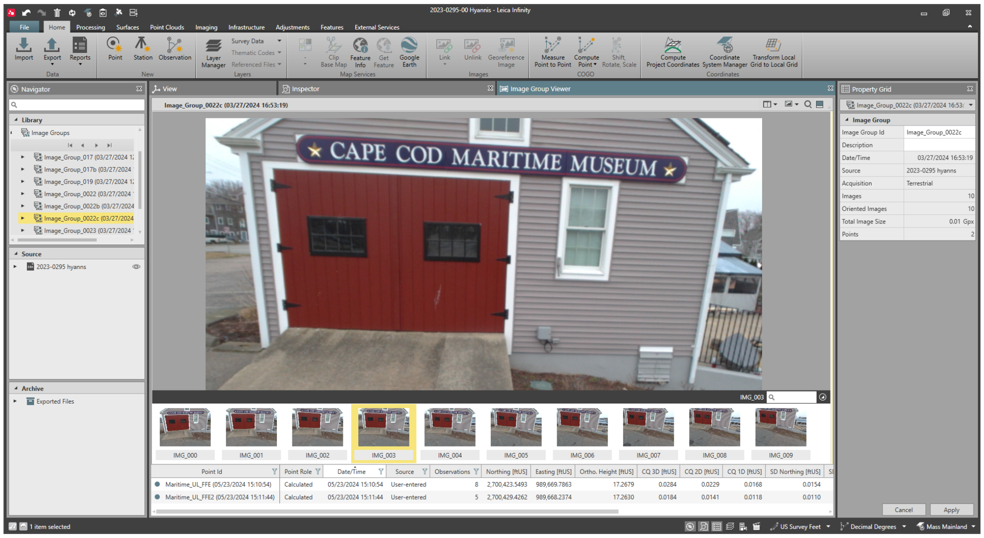
The MC-FRM results for Hyannis Harbor include a range of flood probabilities and associated water surface elevations, which can be used to assess the vulnerability of buildings and other assets. These flood probabilities are expressed as AEPs. A 1% AEP water level has a 1 in 100 chance of occurring in any given year, while a 50% AEP water level has a 1 in 2 chance of occurring in a given year. Areas within the 1% AEP flood extent and lower in elevation than the corresponding water surface elevation have a 1% or higher AEP.

The flood risk associated with storm events of lower AEPs is higher, since these tend to be more intense storms that impact wider areas. Conversely, more moderate storm events cause flooding only in areas with higher AEPs. Within the Project Site in Hyannis Harbor in 2030, the maximum 20% AEP water level is 7.0 ft NAVD88, while the highest 0.1% AEP water level is almost 6 feet higher at 12.8 ft NAVD88. The model also considers a range of time horizons – near-term (2030), mid-term (2050), and long term (2070). As time progresses and sea levels rise, more intense storms with higher associated water levels will become more frequent. The maximum 0.1% AEP water surface elevation in 2030 is 12.8 ft, and by 2070 water levels associated with a 0.1% AEP increase to 20.6 ft.

To assess risk of flooding to facilities (buildings and other assets), water surface elevations corresponding with different AEPs obtained from the MC-FRM are compared to the critical elevations of built infrastructure (the elevation at which flood water would enter a building or damage an asset). Woods Hole Group conducted a critical elevation survey for all facilities within the Project Site on March 27, 2024. Facilities were visited and the elevations of finished first floors, important exterior infrastructure (e.g. generators), basement windows, or other possible flood entry points were surveyed using a Leica Real-Time Kinematic Global Positioning System ("RTK-GPS") and in-field measurements. An RTK-GPS is a type of GPS instrument that uses a network of reference stations to collect highly accurate elevation position measurements. This particular RTK is also outfitted with a camera capable of "scanning" buildings so exact elevations of points of interest can be identified later from an elevation point cloud using the Leica Infinity software (Figure 4). This feature was utilized to facilitate harbor-wide data collection and supplemented with a number of standard surveyed elevation points.

3 https://eea-nescaum-dataservices-assets-prd.s3.amazonaws.com/cms/GUIDELINES/MC-FRM_FAQ_04-06-22.pdf

Figure 4: Critical Elevation Survey Methods – Leica Infinity Scan Analysis (Left) and In-Field RTK Surveying (Right)

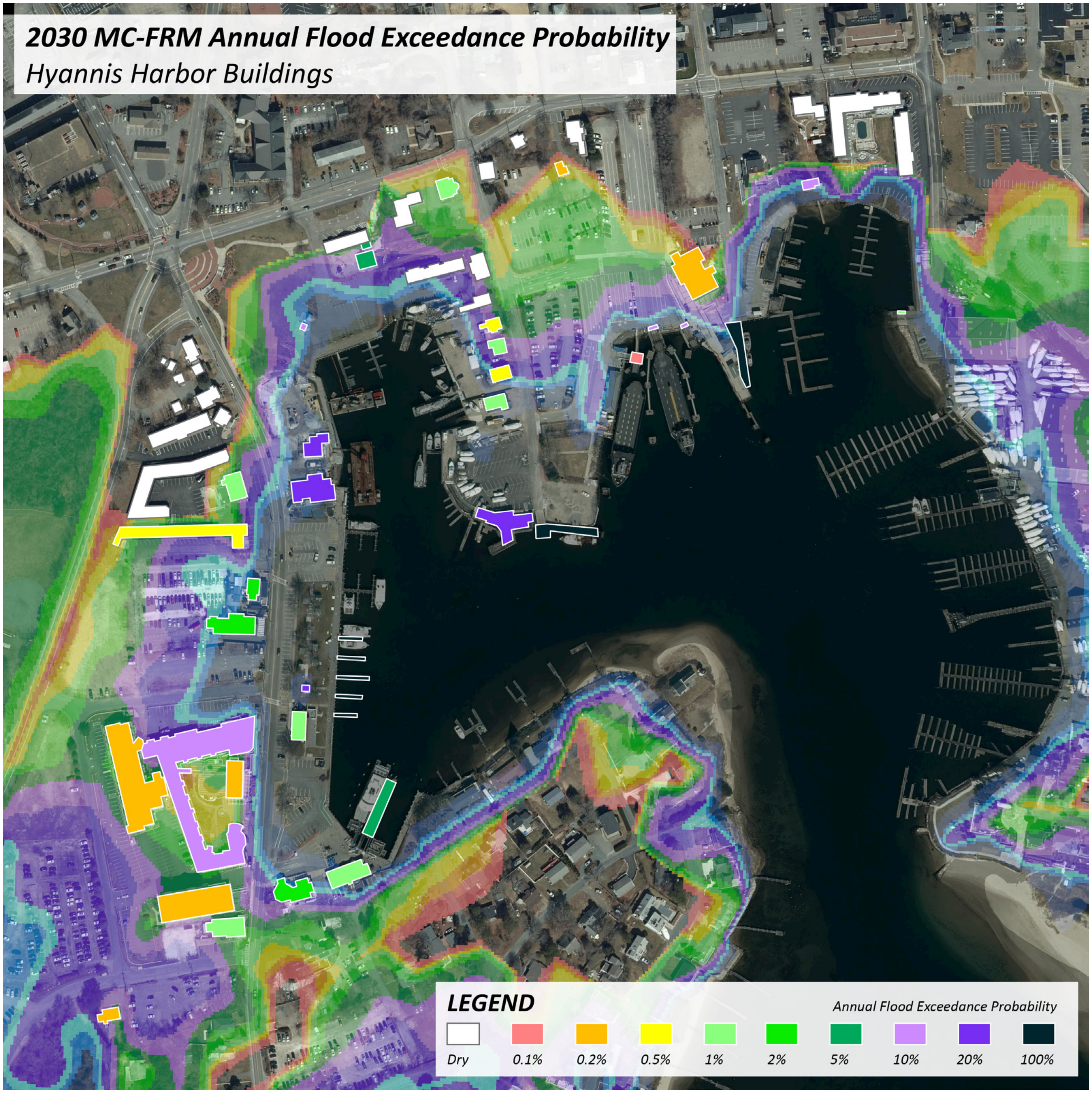


The data gathered during the scanning survey was compiled into a GIS database including building names, addresses, owners, and first floor elevations ("FFE") (Appendix A). For Town-owned assets, the distance between vulnerable equipment such as electrical panels/switches, generators, and air conditioning units, and the ground or floor was noted in the field and compiled into an excel spreadsheet of critical elevations (Table 2). These critical elevations were then compared to the projected water surface elevations from the MC-FRM across different time horizons (2030, 2050, and 2070) and for different flood probability levels (AEPs ranging from 0.1% to 100% annually). Facilities were then assigned an AEP based on the highest probability water level that would exceed its critical elevation in a given projected year. This means that different buildings in the Hyannis Harbor Project Site have different flood probabilities in different time horizons. For instance, the Harbormaster building in Bismore Park has a first floor elevation of 9.23 ft NAVD88. This elevation is exceeded by the water level associated with a 1% AEP in 2030, a 20% AEP in 2050, or a 20% AEP in 2070.

For this analysis, the FFE (and critical elevation) of each building within the Project Site was assumed to be at the level of the lowest visible entrance, except where information on existing building-level floodproofing was available. Figures 5-7 show the results of the vulnerability assessment in the Project Site for 2030/2050/2070 MC-FRM water levels. The buildings are colored according to the highest AEP (lowest water level) that would exceed the building's critical elevation. The flooding map presented underneath the building footprints is the publicly available MC-FRM data for the same range of AEPs, indicating approximate on-the-ground extents of flooding by AEP. To be assigned an AEP, the building must be within the flood extent of a given AEP and have a designated critical elevation lower than the associated water surface elevation.

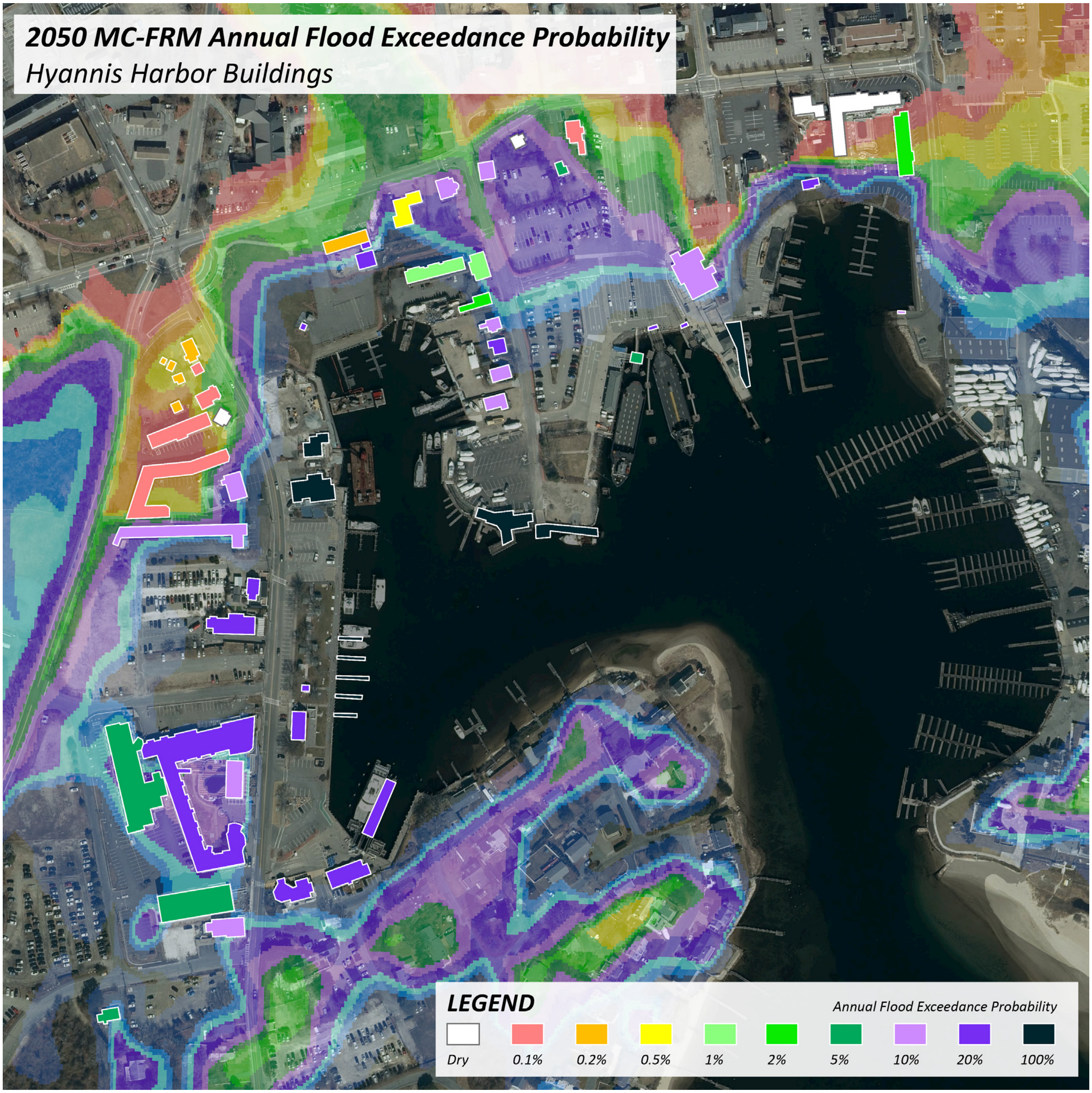
1.7 Vulnerability Assessment Results

Figure 5: 2030 MC-FRM Projected Flood Impact Probability for the Hyannis Harbor Project Site – Critical Elevation as Finished Floor Elevation



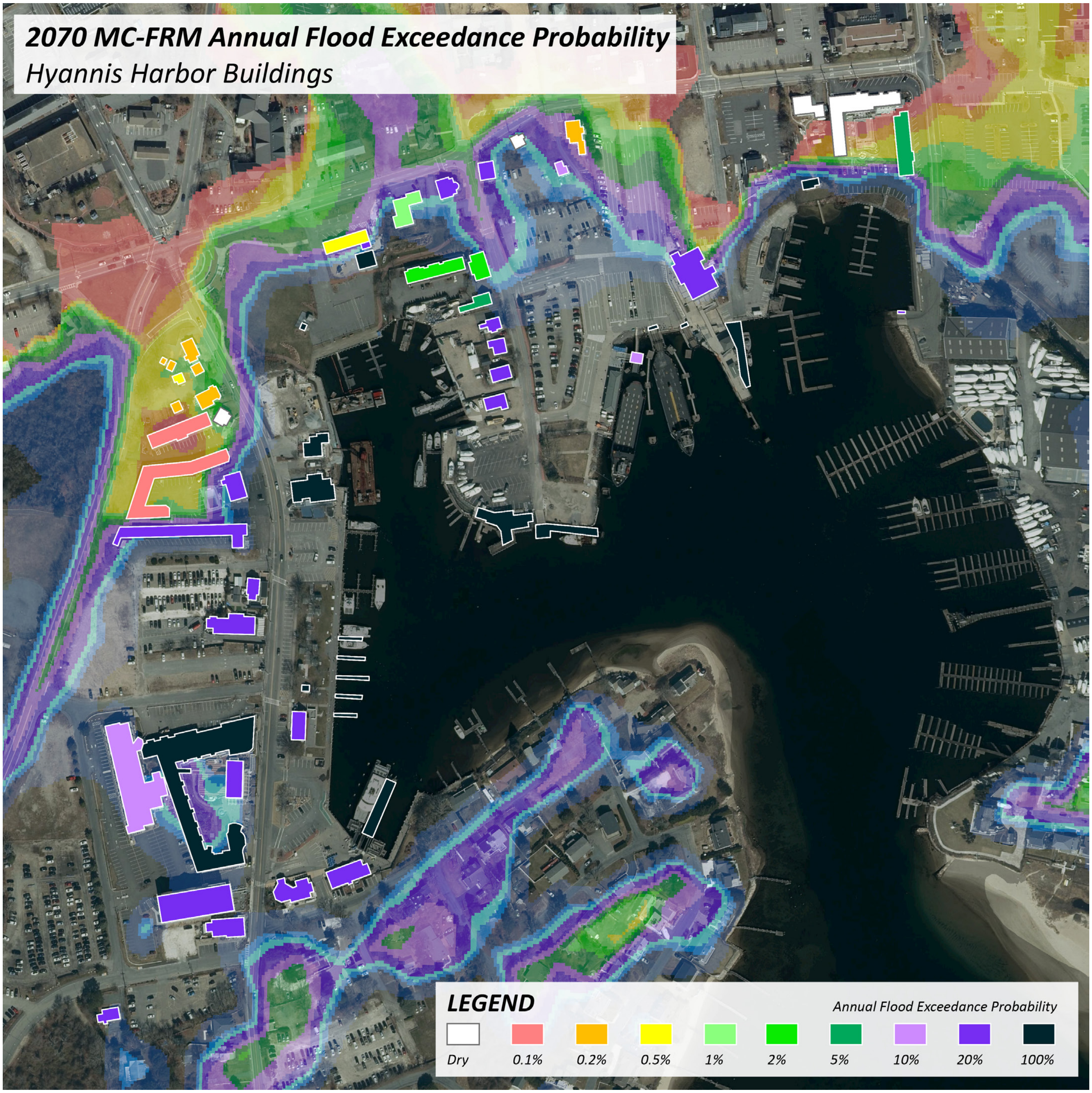
According to the 2030 MC-FRM data, only a few buildings are highly vulnerable to storm surge flooding. The restaurants at 134 Ocean Street and 190 Pleasant Street (Spanky's Clam Shack and Baxter's Boathouse) have a 20% AEP. The Harbormaster's Office, Hy-Line Cruises ticket office, and several other buildings have a 1% AEP. The Hy-Line Cruises ticket office critical elevation is higher than the FFE, reflecting deployable barriers currently used at the doorways. The Cape Cod Maritime Museum's lower level has an AEP of 5%, and the upper level remains dry. All wooden docks included in the survey have a 100% AEP in 2030, but the fixed concrete docks at the ferry have a much lower probability of flooding (Figure 5). Detailed vulnerability of selected Town and Steamship Authority assets, including electrical equipment that could experience flood damage, is available in Table 2.

Figure 6: 2050 MC-FRM Projected Flood Impact Probability for the Hyannis Harbor Project Site – Critical Elevation as Finished Floor Elevation



In 2050, most buildings fronting the harbor have AEPs between 10% and 100%, indicating they have greater than a 1 in 10 chance of flooding in a year. The Harbormaster building and the Maritime Museum lower level have AEPs of 20%, and the Harbormaster building's upper level has an AEP of 0.2%. Buildings along South Street and near the Six Points intersection mainly have AEPs of less than 1%. (Figure 6).

Figure 7: 2070 MC-FRM Projected Flood Impact Probability for the Hyannis Harbor Project Site – Critical Elevation as Finished Floor Elevation



In 2070, more buildings, including the facilities of both ferry companies and several residences along Pleasant Street, have an AEP of 20%. The Harbormaster building and the Cape Cod Maritime Museum's lower level have an AEP of 20%, the Maritime Museum's upper level has an AEP of 0.5%. Notably, the buildings at 119 Ocean Street, 91 South Street, 25 South Street, and 1 South Street remain dry in all MC-FRM time horizons (Figure 7).

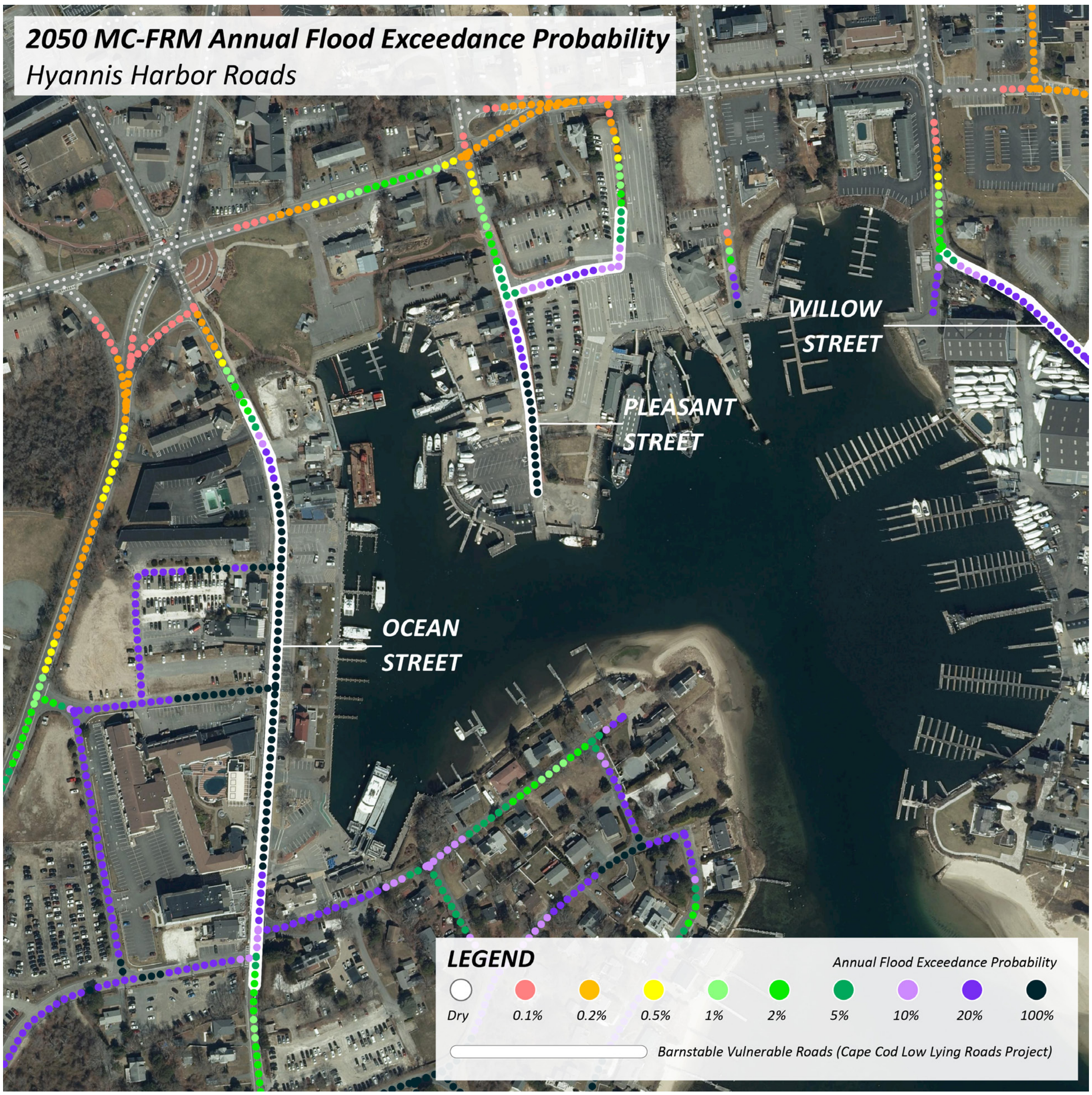
Table 2: Town- and Steamship Authority- Owned Buildings and Assets in the Project Site

Property	Item	Elevation, ft NAVD88	2030 AEP	2050 AEP	2070 AEP
Cape Cod Maritime Museum	Lower Level FFE	7.68	5	20	20
	Upper Level FFE	17.26	0	0.2	0.5
	Solar Production Meter	12.83	0	2	5
	PV System Combiner Panel	12.68	0	2	5
	PV System Shutoff	12.83	0	2	5
	Alarm Panel	13.03	0	2	5
	Electrical Panels (2)	11.58	0.1	5	10
	Low Air Alarm	12.88	0	2	5
	Fire Bell	12.63	0	2	5
	Sprinkler Pump	8.88	2	20	20
	Outdoor Power Outlet	9.18	1	20	20
	Outdoor Power Box	10.85	0.2	10	20
	Windows (3)	10.43	0.5	10	20
Harbormaster's Office	Office FFE	9.23	1	20	20
	Outdoor Outlets (4)	10.58	0.5	10	20
	Windows (15)	12.38	0	2	10
	Doors (4)	9.23	1	20	20
	Water Heater	9.73	1	10	20
	Electrical Panel	9.58	1	10	20
	Industrial Faucet	11.98	0.1	5	10
	AC Units (2)	4.94	20	100	100
	Electric Meter	7.14	10	20	100
Aselton Park	Electrical Box	6.08	20	100	100
	Electrical Meters	15.62	0	0.5	1
Bismore Park	Shore Power (6)	6.05	20	100	100
	South Pumpout Tank	3.67	100	100	100
	South Pumpout Electrical	5.58	20	100	100
	North Pumpout Tank	4.01	100	100	100
	North Pumpout Electrical	5.00	20	100	100
	Electrical Box	4.41	100	100	100
Hyannis Harbor Park	NW Electrical Meters	4.83	20	100	100
	NE Electrical Panels	5.7	20	100	100
	Shore Power	5.11	20	100	100
	Pumpout	4.61	100	100	100
	Little Shed	2.11	100	100	100
Steamship Authority	Pumpout Station	6.78	10	20	100
	West Ramp Controls	9.09	1	20	20
	East Ramp Controls	8.19	5	20	20
	South Oil Storage Hut	9.39	1	20	20
	North Oil Storage Hut	9.07	2	20	20

1.8 Hyannis Harbor Roadway Vulnerability

In 2021, the flood vulnerability of all roads in the Town of Barnstable was assessed as part of the Cape Cod Low Lying Roads project.[4] The assessment process was similar to the building vulnerability process described above, except that points on the road centerline were evaluated rather than buildings. A criticality score for each road point was also calculated, taking into account use volume, proximity to businesses and critical facilities, and location near socially vulnerable populations to estimate overall significance to the community. The criticality score for each road point was multiplied by the road's AEP to yield a risk score. Barnstable's roads were then ranked by risk score, and the highest scoring roads were listed as Top Vulnerable Roads. Figure 9 shows the 2050 AEP of road points in Hyannis Harbor. Ocean Street, Pleasant Street, and Willow Street were identified as Top Vulnerable Roads near Hyannis Harbor. From the Town-wide list of Top Vulnerable Roads, two Priority Roads were chosen for the development of conceptual adaptation alternatives, one of which was Ocean Street.

Figure 9: Roadway flood vulnerability in the 2050 time horizon and top vulnerable roads near Hyannis Harbor.



4 https://www.capecodcommission.org/our-work/low-lying-roads-barnstable/

2.0 HYANNIS HARBOR RESILIENCE RECOMMENDATIONS

Understanding the existing vulnerability in Hyannis Harbor allows for the development of recommendations to improve the resilience of the area. Preventing most or all flooding in the Hyannis Harbor waterfront is not feasible given the uses of the waterfront and presence of flanking pathways. It is also not necessary to prevent all inundation of assets such as docks and parking lots that can experience periodic flooding with little damage. In general, the resilience strategies outlined here aim to preserve daily use at the water's edge while intervening at the building or asset level to minimize flood damage from storms. Interventions that aim to preserve daily use in the future have the additional benefit of preventing flooding in common present-day high water events. Where the design lifetime of an intervention ends after the target time horizon (i.e. a bulkhead has a 50-year design lifetime and a target elevation based on 2050 conditions) it is important to integrate flexibility and adaptability into designs.

2.1 Recommendations from Prior Work

Prior work from the Cape Cod Low Lying Roads project and the ongoing project to improve the bulkhead at Bismore Park is generally compatible with Harbor-level recommendations presented below.

During the Cape Cod Low Lying Roads project, Ocean Street was selected by the Town of Barnstable for the development of conceptual adaptation alternatives. Figure 10 provides a summary of those alternatives and the MC-FRM annual exceedance probabilities of each. In general, rerouting via Old Colony Road is possible while flooding blocks Ocean Street. However, parts of Ocean Street are within the projected 2050 Mean High Water shoreline, meaning that intervention is needed to preserve sunny-day use of Ocean Street in the long term.

Figure 10: Summary of the alternatives for Ocean Street developed in the Low Lying Roads Project.

OCEAN STREET, BARNSTABLE

Summary of alternatives

	Description	Critical Elevation	Annual Exceedance Probability 2030	2050	2070	Vulnerable to Tidal Flooding	Impacts to Resource Area(s)	Impacts to Private Property	Estimated Cost*
EXISTING	A segment of 20 foot wide road adjacent to Hyannis Harbor.	4.2 feet	100%	100%	100%	2050	N/A	N/A	N/A
ALTERNATIVE 1: GRAY	944 linear feet of town-owned road is elevated to 7.5 feet with 4:1 traditionally vegetated side slopes. The road slopes to parking lots and side streets, and the current perpendicular parking on the east side of the road becomes parallel parking.	7.5 feet	5%	20%	100%	N/A	N/A	Yes	$626,000
ALTERNATIVE 2: HYBRID	A system of parapet walls, berms, and sliding gates protect the road to 8.3 feet. Some negotiation with private property owners is necessary.	8.3 feet	2%	20%	100%	2050	N/A	Yes	$1,870,000
ALTERNATIVE 3: BULKHEAD EXTENSION	Land at the existing bulkhead is raised to maintain the waterfront's usability during the highest tides in 2050. The bulkhead edge's cap is raised to protect against the 10% storm in 2030. A glass panel seawall can also be added to protect against the 2% storm in 2030, but flanking flood pathways would need to be addressed. Deployable barriers are needed at nine locations.	7.7 feet	5%	20%	100%	2070 (unless adjusted over time)	Possible	Yes	TBD
		9.7 feet	1%	20%	20%				

*2023 installed material cost +40% escalation (through 2029) and 15% contingency. Excludes design, permitting, mobilization, stormwater and wastewater infrastructure, and site controls. Costs based on experienced contractor opinion and MassDOT costing data.

The three alternatives presented in Figure 10 were developed with a focus on Ocean Street and do not take into account the vulnerability of other assets in the area. However, they align with recommendations from the current project that suggest raising Ocean Street, implementing deployable barriers, and raising the bulkhead at Bismore Park.

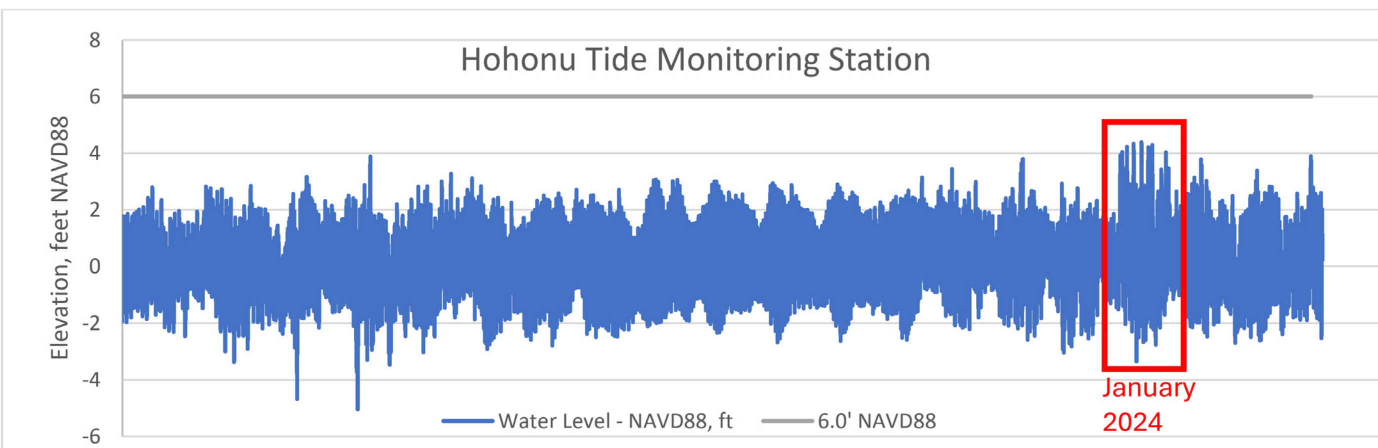
The existing bulkhead at Bismore Park was constructed in the 1960s, and Barnstable DPW is aiming to reconstruct it in 2025. Foth Engineering has developed design alternatives that recommend reconstructing the bulkhead with a cap at 6.75' NAVD88 and with a land elevation of 6.75' NAVD88. These elevations meet the recommendations presented in this project. Just as the project at Ocean Street focused on only one component of the Harbor, this bulkhead reconstruction project focuses exclusively on the Town-owned bulkhead, and will not prevent flood water from entering the Ocean Street corridor over the Hy-Line Cruises bulkhead without further coordination with private owners.

2.2 District Wide Resilience Recommendations

While the Town can make physical interventions on public property, policies and standards are necessary to increase the resilience of privately-owned parcels and assets throughout the Harbor district. We recommend adopting a new Coastal Flood Overlay Zoning District for Hyannis Harbor that includes new standards for bulkhead and building elevations.

In order to preserve daily use at the water's edge through the 2050 time horizon, we recommend requiring minimum elevation of 6.0' NAVD88 for replaced and significantly repaired bulkheads and fixed docks throughout the Harbor. This elevation exceeds the projected 2050 MHHW level of 4.7' NAVD88 and is designed to provide use in the highest sunny day tides of 2050 while preserving use in present-day low water conditions. This elevation also increases resilience to common present-day storm conditions, as shown in Figure 11. According to the tide gauge data, none of the thirteen flood events that significantly overtopped the Bismore Park bulkhead between November 2022 and May 2024 would have overtopped a 6.0' NAVD88 bulkhead. All road raisings in the Harbor district should also be required to meet or exceed this elevation. The planned bulkhead reconstruction at Bismore Park reaches elevation 6.75' NAVD88 and exceeds this standard. Foth's plans also specify replacing fixed timber docks with floating docks, which is another valid strategy to preserve water access in a variety of conditions. We recommend the Town implement projects similar to the current project at Bismore Park in order to ensure all other Town-owned water access meets 6.0' NAVD88.

Figure 11: Hohonu Tidal Monitoring Station Data from November 2022 to May 2024 compared to the recommended Harbor Bulkhead Elevation. January 2024 is indicated with the red box.

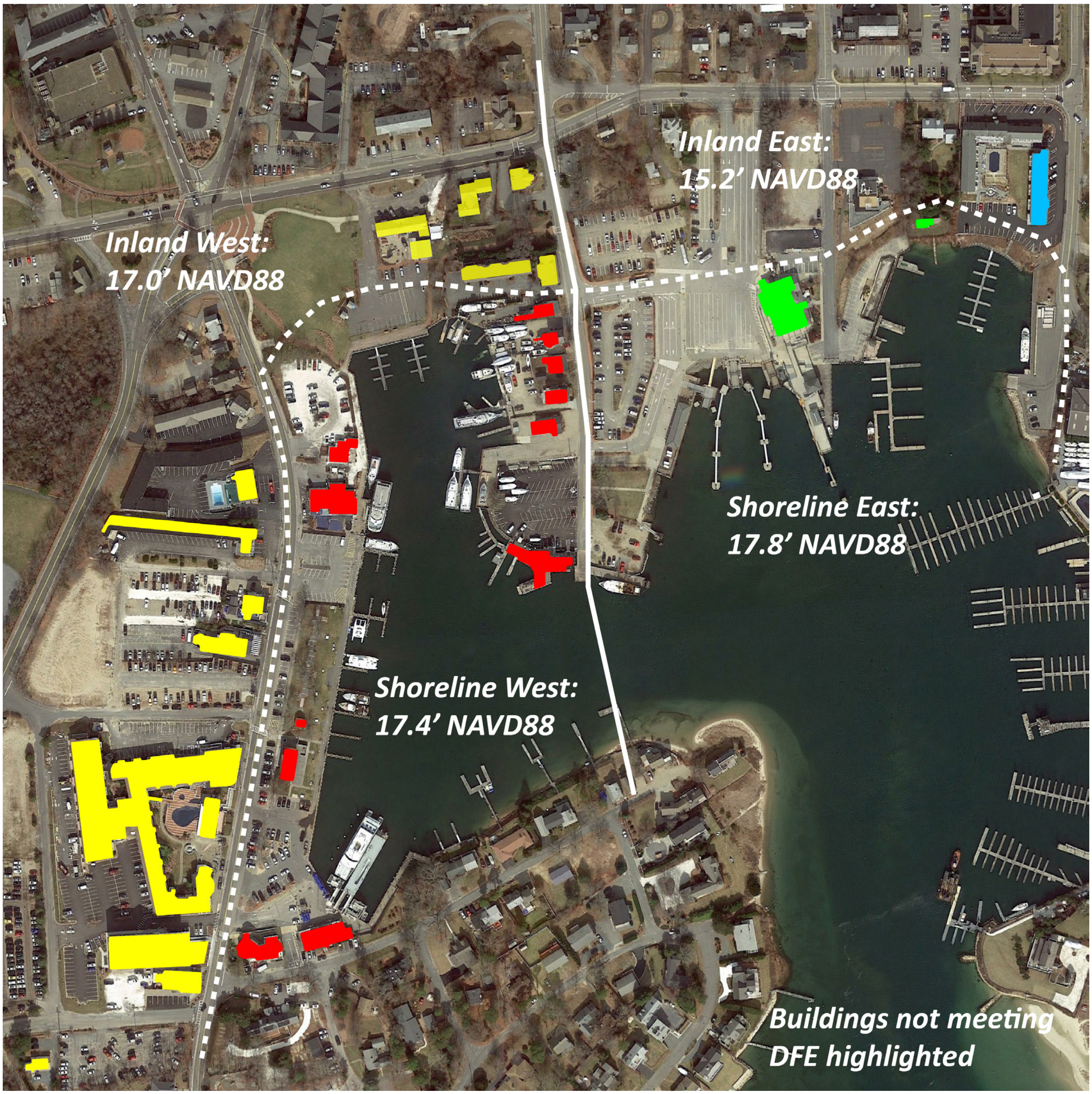


In addition to the standard waterfront elevation, we recommend implementing a Coastal Flood Overlay Zoning District that includes new building Design Flood Elevations ("DFEs") for various parts of the Harbor. Currently, the Harbor District includes primarily Federal Emergency Management Agency ("FEMA") Zone AE, with a Base Flood Elevation ("BFE") of 11.0' NAVD88 southwest of Aselton Park and a BFE of 12.0' NAVD88 east of Aselton Park. These elevations were developed for insurance rating purposes and represent an approximate present-day 1% AEP water level derived from historical data. In order to maintain resilience in future conditions, new DFEs were derived from MC-FRM 2050 1% AEP water level and wave height data (specifically, significant wave crest elevations). Future sea level rise and wave dynamics (setup and runup) are already accounted for in these elevations, and therefore additional freeboard is not necessary. Similar future-focused DFEs could be developed for other areas of Barnstable to create a consistent standard of resilience throughout the Town. Figure 12 and Table 3 show the specific elevations and buildings that would need modifications to meet the proposed DFE, based on information from the screening level vulnerability assessment performed for this project. Buildings within the Harbor district that are not highlighted are assumed to already meet the DFE for their zone (based on this preliminary analysis).

Table 3: Town- and Steamship Authority- Owned Buildings and Assets in the Project Site

Climate Horizon, AEP	West Inner Harbor		East Inner Harbor	
	Inland Areas (feet, NAVD88)	Shoreline (feet, NAVD88)	Inland Areas (feet, NAVD88)	Shoreline (feet, NAVD88)
2050, 1%	17.0	17.4	15.2	17.8

Figure 12: Recommended DFEs for Hyannis Harbor.



These DFEs would apply to new construction, significant renovation, and floodproofing projects. Although local regulations are required not to conflict with the state building code, language similar to 4.2.6.2 in Swampscott's Zoning Bylaw ("Any new construction or substantial improvement to be undertaken within Zones AE and VE shall be in accordance with the Massachusetts State Building Code (780 CMR), and shall take into consideration the long-term effects of sea level rise and storm surge in determining additional freeboard height above the minimum freeboard required by the Massachusetts State Building Code (780 CMR)") can be used to implement flexible freeboard requirements. The recommended DFEs outlined above could provide a guideline for how to meet this requirement in the Hyannis Harbor Coastal Flood Overlay Zoning District. For residential buildings without water-dependent uses, elevation is the primary strategy to meet the DFE. For commercial or water-dependent uses, wet or dry floodproofing to a certain level can maintain everyday ground-level uses while minimizing damage from flooding. More information on strategies that could be used to meet these DFEs is available in the Cape Cod Commission's Flood Area Design Guidelines.

Changes to certain uses in the Harbor district may also be appropriate. Currently, there are long-term parking lots on Steamship Authority property and adjacent to Old Colony Road that are highly vulnerable to flooding. As flood vulnerability increases, cars that remain in these lots for days or weeks will be more likely to experience damage from flooding. If alternate parking locations are found, flood risk to cars would decrease, and the parking lots could be converted to open space, green stormwater infrastructure, or other appropriate uses as determined by the Town.

2.3 Municipal Resilience Recommendations

Buildings and waterfront structures owned by the Town should be floodproofed or elevated to meet the suggested DFEs described above. In particular, the Harbormaster's Office should be retrofitted or relocated to improve access during storm conditions. One possibility for achieving this goal is to move some or all of the Harbormaster's operations to the upper level of the Cape Cod Maritime Museum, which meets the recommended DFE. The single exposed wall of the lower level of the Maritime Museum could be dry floodproofed.

Town-owned stretches of bulkhead should also be modified to meet the recommended Harbor Bulkhead Elevation of 6.0' NAVD88. As previously stated, the existing project at Bismore Park is a first step towards implementing this recommendation. Bulkheads at Aselton Park and at the end of Pleasant Street also need to be raised. The Steamship Authority bulkhead already exceeds 6.0' NAVD88, but collaborating with the Hy-Line Cruises ferry company to elevate their bulkhead should be a high priority due to the public impacts of both flooding through that bulkhead and interruptions in ferry operations.

At the landscape scale, the main opportunities for reducing flood impacts lie on the western half of the site. A series of elevated land, walls, and deployable barriers could be implemented through the area east of Ocean Street in a variety of alignments. Bismore Park offers space to achieve elevation through a berm or make space for green stormwater infrastructure. One possible design is outlined in detail in the Low Lying Roads hybrid alternative for Ocean Street. Elevation could also be achieved at the bulkhead, as outlined in the gray Low Lying Roads alternative for Ocean Street. If the target elevation is higher than 8.0' NAVD88, management of the flanking pathway across and under Nantucket Street would be necessary. Raising or deploying barriers at Nantucket Street and installing a surge gate on the culvert under Nantucket Street are two possible ways to achieve these goals.

2.4 Project Focus Area Physical Interventions

Previous memos have split the site into focus areas in order to recommend specific interventions. Following that structure, the physical resilience interventions that may be appropriate in each focus area are outlined below.

Aselton Park and Gateway Marina:

This area is a possible destination for the Harbormaster's Office. The Town-owned bulkhead here can be raised using a concrete cap, reconstructed at a higher elevation, or replaced with decking at a higher elevation. The Town-owned buildings here can be protected with deployable barriers on the harborwalk or building-level floodproofing. There is an opportunity to tie together high elevations between Aselton Park and the Pleasant Street pedestrian crossing along the waterfront or through the existing parking lot to gain flood protection. Numerous alignments and layouts exist for achieving resilience benefits.

West of Ocean Street:

Raising Ocean Street would resolve both coastal and pluvial flooding issues for the road. Flanking pathways to Ocean Street and the waterfront pass through this area, and are overtopped at approximately 8.0' NAVD88. Minor flooding on Nantucket Street and in low-lying parking lots can be mitigated with a surge gate for the culvert under Nantucket Street and a modest raising of Nantucket Street. Relocating parking and restoring wetland in the lowest-lying parking lots is a long-term strategy.

Waterfront Properties Along Ocean Street:

Deployable barriers could mitigate storm surge into Ocean Street during smaller storms. Flanking pathways through Nantucket Street and the hotels affect Ocean Street at water surface elevations of approximately 8.0' NAVD88, so it does not make sense to achieve an elevation higher than this with deployable barriers. Raising Ocean Street would resolve both coastal and pluvial flooding issues for the road. The Town-owned bulkhead here can be raised using a concrete cap, reconstructed at a higher elevation, or replaced with decking at a higher elevation. Precipitation-based flooding is a concern if interventions in Bismore Park and at the bulkhead edge are implemented without raising Ocean Street. Cooperation from Hy-Line Cruises is essential to mitigate flanking pathways after raising the Town-owned bulkhead.

Pleasant Street Corridor:

Assuming the goal is to move the commercial fishing offloading area to Pleasant Street, a redevelopment of that dock area and raising of the end of Pleasant Street is recommended. Meeting the recommended bulkhead elevation with any new dock facility is essential.

School Street and Lewis Bay Road:

Town-owned boat ramp and parking lot appear to meet the recommended bulkhead elevation, but should be monitored to anticipate when intervention will be needed to maintain usability.

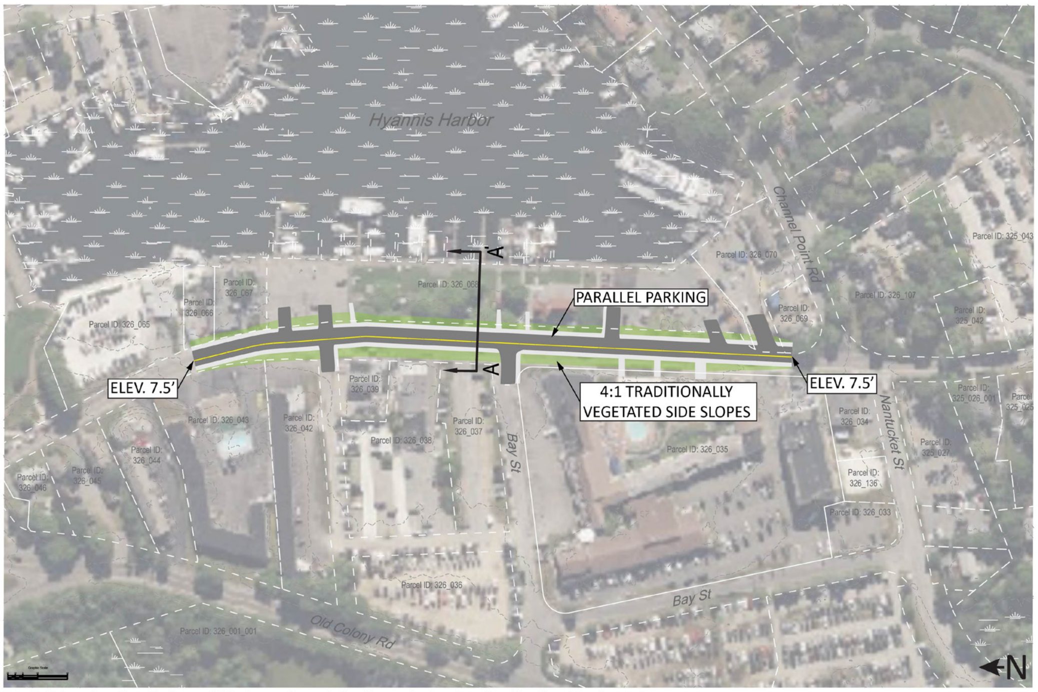
APPENDIX A: BUILDING VULNERABILITY DATABASE

Building Name	Address	Critical Elevation	CE Notes	MHW Vulnerability	2030 AEP	2050 AEP	2070 AEP
	121 South Street	15.46	FFE	N/A	0	0.5	1
Hyannis Harbor Hotel	213 Ocean Street	7.09	FFE	N/A	10	20	100
	220 Ocean Street	9.13	Top of deployable barriers	2070	1	20	20
HI Hyannis Hostel 1	111 Ocean Street	17.7	FFE	N/A	0	0.2	0.5
Anchor In Lower	1 South Street	13.27	FFE	N/A	0	2	5
	145 Pleasant Street	9.36	FFE	N/A	1	20	20
Anchor In	1 South Street	21.54	FFE	N/A	0	0	0
	101 Ocean Street	17.75	FFE	N/A	0	0.2	0.2
	175 Ocean Street	8.16	FFE	N/A	2	20	20
Harborview Hotel	213 Ocean Street	10.77	FFE	N/A	0.2	10	20
	133 Pleasant Street	12.64	FFE	N/A	0	2	5
	137 Pleasant Street	10.12	FFE	N/A	0.5	10	20
	120 Ocean Street	5.99	FFE	2070	20	100	100
	131 Ocean Street	9.66	FFE	N/A	1	10	20
	180 Ocean Street	6.24	FFE	2070	20	20	100
	101 Ocean Street	18.05	FFE	N/A	0	0.2	0.2
SSA Ticket Office	71 South Street	10.85	FFE	N/A	0.2	10	20
Pump Station	91 South Street	21.51	FFE (upper level)	N/A	0	0	0
	102 Pleasant Street	9.85	FFE	N/A	0	10	20
	145 Pleasant Street	10.37	FFE	N/A	0.5	10	20
Maritime Museum - Lower Level	135 South Street	7.68	FFE	N/A	5	20	20
	105 Pleasant Street	9.74	FFE	N/A	1	10	20
	131 Ocean Street	20.29	FFE	N/A	0	0.1	0.1
	25 South Street	33.2	FFE	N/A	0	0	0
	149 Ocean Street	10.84	FFE	N/A	0.5	10	20
	101 Ocean Street	17.83	FFE	N/A	0	0.2	0.2
	235 Ocean Street	9.82	FFE	N/A	1	10	20
	157 Pleasant Street	9.74	FFE	N/A	1	10	20

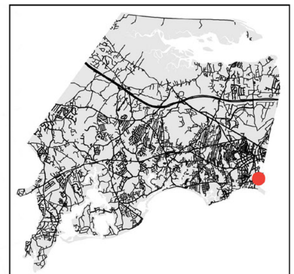
Building Name	Address	Critical Elevation	CE Notes	MHW Vulnerability	2030 AEP	2050 AEP	2070 AEP
	230 Ocean Street	8.79	FFE	N/A	2	20	20
HI Hyannis Hostel 2	111 Ocean Street	17.8	FFE	N/A	0	0.2	0.2
	125 Pleasant Street	14.78	FFE	N/A	0	1	2
	119 Ocean Street	22.69	FFE	N/A	0	0	0
Spanky's Restaurant	134 Ocean Street	5.67	FFE	2070	20	100	100
Hy-Line Marketing Office	27 Nantucket Street	11.18	FFE	N/A	0.2	5	20
Aselton Park Sheds	135 South Street	7.01	FFE	N/A	10	20	100
Guest House	25 South Street	7.5	FFE	N/A	10	20	100
HI Hyannis Hostel 3	111 Ocean Street	18.3	FFE	N/A	0	0.1	0.2
	125 Pleasant Street	14.78	FFE	N/A	0	1	2
	119 Ocean Street	23	FFE	N/A	0	0.1	0.1
Harbormaster's Office	180 Ocean Street	9.23	FFE	N/A	1	20	20
	77 South Street	18.79	FFE	N/A	0	0.1	0.2
	488 South Street	8.77	FFE	N/A	2	20	20
	77 South Street	11.69	FFE	N/A	0.2	5	10
HI Hyannis Hostel 4	111 Ocean Street	18.3	FFE	N/A	0	0.1	0.2
Baxter's Boathouse	177 Pleasant Street	5.37	FFE	2070	20	100	100
Boat Shop	135 South Street	7.68	FFE	N/A	5	20	100
	213 Ocean Street	11.17	FFE	N/A	0.2	5	20
School Street Dock	0 School Street	4.65	Dock	2070	100	100	100
Town Dock		4.21	Dock	2050	100	100	100
Hy Line Dock		7.6	Dock	N/A	5	20	100
Bismore Park Dock 1	180 Ocean Street	4.1	Dock	2050	100	100	100
Bismore Park Dock 2	180 Ocean Street	4.1	Dock	2050	100	100	100
Bismore Park Dock 3	180 Ocean Street	4.1	Dock	2050	100	100	100
Bismore Park Dock 4	180 Ocean Street	4.1	Dock	2050	100	100	100
Bismore Park Dock 5	180 Ocean Street	4.1	Dock	2050	100	100	100
Town Boat Ramp		9.79	Dock	N/A	1	10	20
SSA Car Loading 1	71 South Street	6.96	Ground	N/A	10	20	100
SSA Car Loading 2	71 South Street	6.96	Ground	N/A	10	20	100
Hyannis Harbor Hotel	213 Ocean Street	11.34	FFE	N/A	0.2	5	10

Building Name	Address	Critical Elevation	CE Notes	MHW Vulnerability	2030 AEP	2050 AEP	2070 AEP
Maritime Museum - Upper Level	135 South Street	17.16	FFE	N/A	0	0.2	0.5
SSA Fixed Passenger Dock	71 South Street	11.77	Dock	N/A	0.1	5	10

APPENDIX B: CAPE COD LOW LYING ROADS ALTERNATIVES FOR OCEAN STREET



Note: Project overlap with wetland areas, rights of way and property lines is approximate and needs confirmation with a site survey

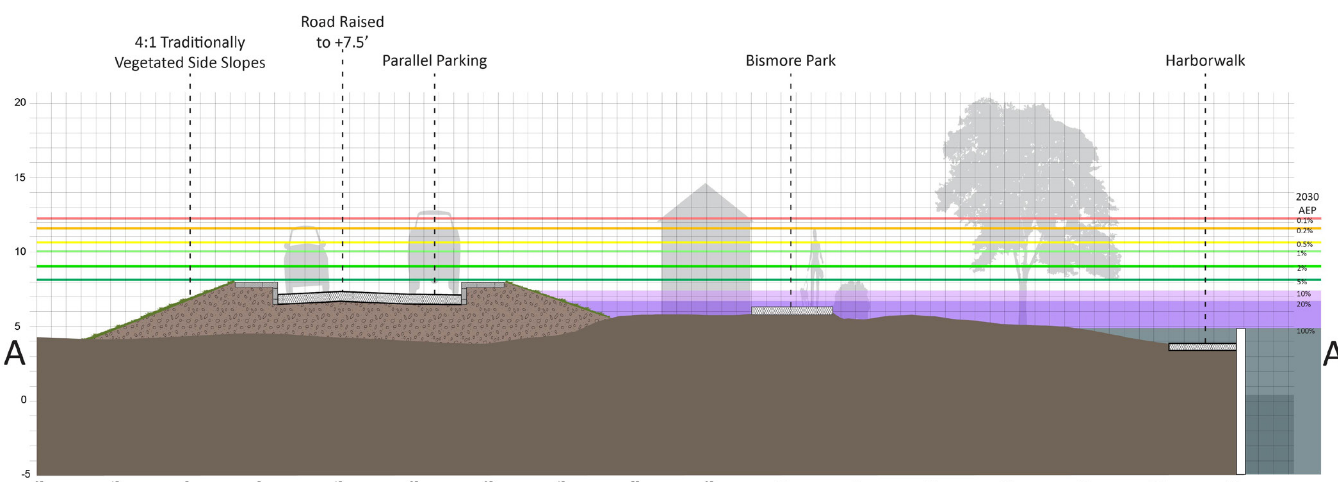


Ocean Street
BARNSTABLE

ALTERNATIVE 1: GRAY

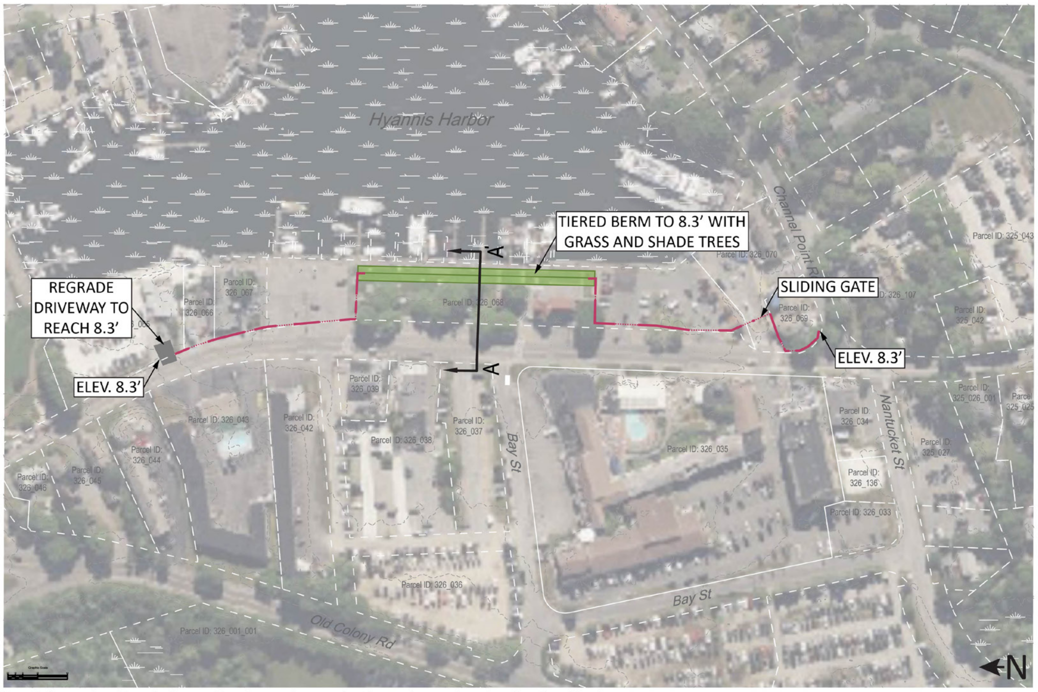
944 linear feet of town-owned road is elevated to 7.5 feet with 4:1 traditionally vegetated side slopes. The road slopes to parking lots and side streets, and the current perpendicular parking on the east side of the road becomes parallel parking.

WOODS HOLE GROUP



ALTERNATIVE 1: GRAY
Ocean Street, Barnstable

WOODS HOLE GROUP



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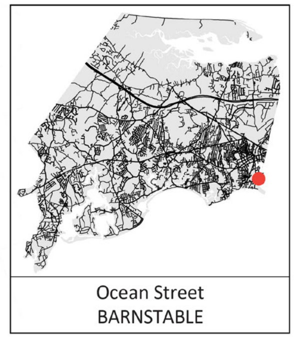
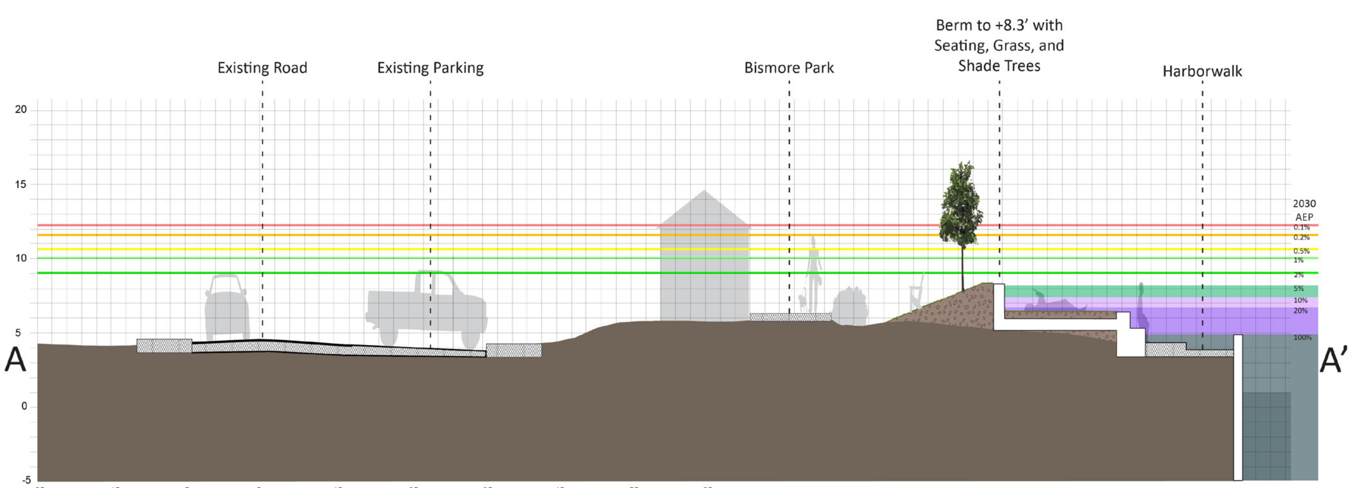


ALTERNATIVE 2: HYBRID

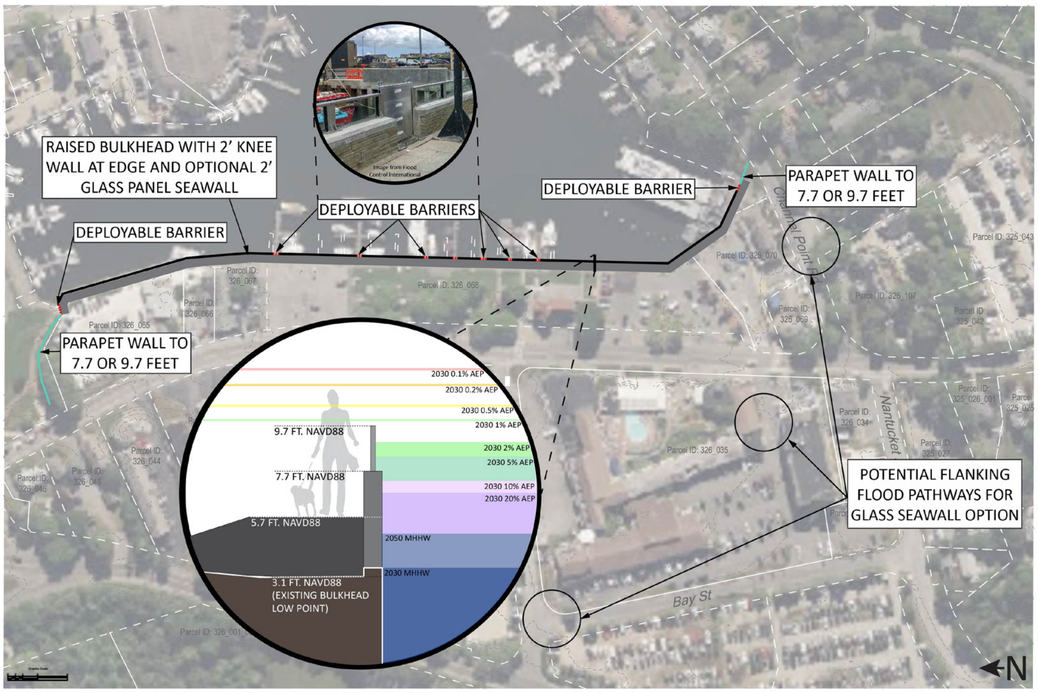
A system of parapet walls, berms, and sliding gates protect the road to 8.3 feet. Some negotiation with private property owners is necessary.

WOODS HOLE GROUP

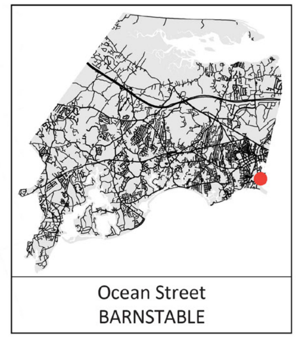


ALTERNATIVE 2: HYBRID
Ocean Street, Barnstable

WOODS HOLE GROUP



Note: Project overlap with wetland areas, rights of way and property lines is approximate and needs confirmation with a site survey



ALTERNATIVE 3: BULKHEAD EXTENSION

Land at the existing bulkhead, which has a lowest point of 3.1ft, is raised to 5.7ft to maintain the waterfront's usability during the approximated highest tides in 2050. The bulkhead edge's cap is constructed an additional 2.0ft tall to reach elevation 7.7ft and protect against the 10% storm in 2030. A glass panel seawall 2.0ft high can also be added to protect against the 2% storm in 2030, but flanking flood pathways would need to be addressed in order to achieve the full 9.7ft of protection. Deployable barriers or gates are needed at nine locations.

WOODS HOLE GROUP

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