ResilientWoodsHole Phase 3 Report

Funded by a CZM Coastal Resilience Grant

June 2022

PREPARED FOR:
ResilientWoodsHole
Woods Hole Oceanographic Institution
Marine Biological Laboratory
NOAA Northeast Fisheries Science Center

PREPARED BY:
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1.0 INTRODUCTION AND PROJECT NEED

With roots in whaling, shipping, and fishing, Woods Hole has been a hub for marine commerce and a significant working waterfront in the Commonwealth for centuries. Since 1871 with the establishment of the U.S. Commission of Fish and Fisheries, Woods Hole has transitioned to its current identity as a center for marine science, management, and education. Currently, three major ocean research organizations – Woods Hole Oceanographic Institution (WHOI), the Marine Biological Laboratory (MBL), and NOAA's Northeast Fisheries Science Center (NOAA) – base their marine operations (as well as other research, operational, and educational functions) out of Woods Hole. As global greenhouse gas emissions have risen since the industrial revolution (on a timescale similar to the existence of the scientific community in Woods Hole), sea level rise and climate change have now become significant drivers of scientific investigation for WHOI, MBL, and NOAA, as well as existential threats to the organizations themselves, and to Woods Hole more generally.

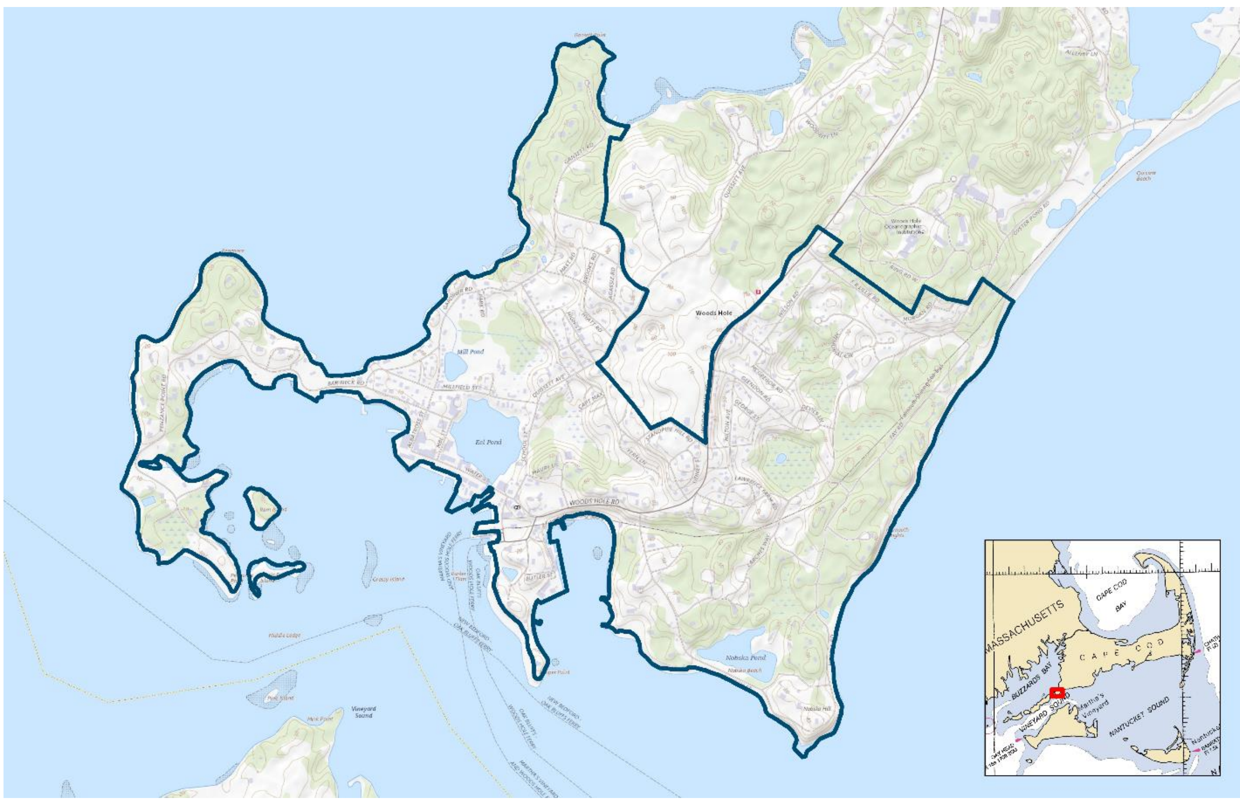


Figure 1. Locus Map for ResilientWoodsHole Study Area.

Resilient Woods Hole Phase 3 builds on prior coastal climate change planning work conducted by the project partners (WHOI, MBL and NOAA) and similar initiatives in the Town of Falmouth. Woods Hole (including the scientific research organizations, business community, residential community, and municipal infrastructure) has experienced the impacts of coastal storms throughout its settled history. With climate change expected to bring increased sea levels and more frequent and more intense coastal storms, Woods Hole will be forced to grapple with these issues sooner than others, especially given the community's close connection to the water. This project used prior vulnerability assessments, a robust public engagement process, and advanced climate projections and tools provided by the Commonwealth to explore a range of adaptation options for Woods Hole (Figure 1).

Resilient Woods Hole Phase 3 was designed to initiate conversations across the community about what types of approaches are desirable in the face of these threats. This project also provided a platform for the science institutions, businesses, residents, and Town officials to start to conceive visions for the future of Woods Hole and the inherent tradeoffs and effective timelines for various approaches. What has emerged is a common understanding that no one actor or group can achieve resiliency alone – the interdependencies in this seaside village necessitate joint stakeholder action.

1.1 PREVIOUS STUDIES

The ResilientWoodsHole initiative began with a climate change vulnerability assessment (CCVA) and adaptation plan (Woods Hole Group, 2020a) focused on the assets owned by WHOI, MBL and NOAA, using the Massachusetts Coast Flood Risk Model (MC-FRM) to assess future impacts from sea level rise and storm surge. ResilientWoodsHole Phase 1 also examined potential coastal habitat change with sea level rise and the potential for future coastal erosion in those areas of Woods Hole without structured shorelines. Funded by a Massachusetts Seaport Economic Council grant, the Phase 1 project explored potential adaptations for individual WHOI/MBL/NOAA assets, as well as building- and parcel-scale strategies to address future tidal flooding and storm surge. Finally, the Phase 1 efforts presented conceptual-level ideas for Village-wide adaptation over the long-term. Some of these Village-wide concepts were later vetted through community review and found to be misaligned with community goals.

Acknowledging the need for holistic adaptation and resilience planning in Woods Hole, where there are many interdependencies among the marine science institutions, the business and residential community and municipal government, Phases 2 and 3 initiated a community-wide evaluation and planning process.

Resilient Woods Hole Phase 2 (Woods Hole Group, 2022) extended the coastal vulnerability assessment to lifeline infrastructure (including Town of Falmouth sewer and the U.S. Coast Guard Woods Hole facility), commercial buildings, residential buildings and both Town and privately owned roadways. This study also used the MC-FRM to project future tidal inundation and storm surge water levels. Phase 2 additionally assessed initial flood pathways for moderate-level near term storm inundation to identify potential areas and solutions for immediate and effective flood protection. Finally, the Phase 2 project refined building- and parcel-scale adaptation strategies conceived in Phase 1, and developed additional adaptation strategies for WHOI/MBL/NOAA individual assets, buildings and parcels.

ResilientWoodsHole Phase 3 utilizes the Phase 1 and Phase 2 analyses and data to inform adaptation. Additionally, ResilientWoodsHole Phase 3 is related to and draws from similar work conducted by the Town of Falmouth. The Town of Falmouth conducted a detailed town-wide climate change flood vulnerability assessment (Woods Hole Group, 2020b) to better understand the risk to individual municipal assets from flooding today and in the future given climate change and sea-level rise impacts. In addition to specifically evaluating municipal infrastructure in Woods Hole (including both sewer lift stations and the Woods Hole drawbridge), the Town-wide study presented a screening assessment of roadways and parcels. Following the Town-wide vulnerability assessment, the Town of Falmouth developed dynamic adaptation pathways for the Surf Drive Area (Woods Hole Group, 2020c). The Surf Drive project, which explored a range of adaptation actions for important assets in the Surf Drive Area and evaluated their effectiveness and potential phasing over time, was the model for this ResilientWoodsHole Phase 3.

Finally, in 2021, the Falmouth Coastal Resiliency Action Committee (CRAC) submitted to the Town Select Board a final report (Falmouth CRAC, 2021) outlining its progress on coastal resiliency and recommendations for future work. Among other initiatives, the CRAC recommended that each coastal neighborhood conduct a more detailed coastal vulnerability assessment. Woods Hole was designated as one of these priority neighborhoods, and the ResilientWoodsHole Phase 2 and Phase 3 work directly fulfill this recommendation from the Town's committee.

1.2 STUDY GOALS

The goals of this study were to develop dynamic adaptation pathways for the Woods Hole Community (inclusive of the scientific research organizations, business community, residential community and municipal infrastructure) based on the expanded community-wide vulnerability assessment and the evaluation of the potential effectiveness and phasing of a range of adaptation actions aligned with community goals and vision.

1.3 STUDY METHODS

Every community is different and resiliency plans that do not resonate with the local community or do not meet its goals will not be implemented. Due to the magnitude of some of the changes that may need to be considered as climate change evolves, it was essential to engage the public (including local residents, Village business owners and visitors) as well as Town and WHOI/MBL/NOAA staff to hear directly their goals and vision for a resilient Village. Project goals were developed and refined through this process. Outreach related to this project consisted of:

- Phase 2 Symposium (in-person, November 18, 2021)
- Steering committee meetings (10/19/21, 12/9/21, 4/13/22, 4/27/22)
- Community Workshop #1 with public comment tools (virtual, February 9, 2022)
- Twelve (12) interviews with fifteen (15) local stakeholders
- Online public survey
- Paper maps from Community Workshop #1 available for review/comment at Woods Hole Public Library (March 2022)
- Project website (https://resilientwoodshole.org/)
- Meeting with the Woods Hole Business Association (April 12, 2022)
- Community Workshop #2 (in-person, May 19, 2022)
- Booth at the Woods Hole May Day Festival (May 29, 2022)

- Project StoryMap (https://arcg.is/0efeLG)
- Exhibit of project materials for additional feedback (pending location)

With the various coastal hazards facing Woods Hole, and diverse vulnerable assets ranging from scientific research facilities to roads and municipal facilities to private homes and businesses to natural resources, decisionmakers face tough choices about how and when to act, what assets to prioritize, and how to balance the varying needs of the community. The complexity of these decisions is further compounded by changing environmental conditions and the uncertainties related to climate change and sea level rise.

This study evaluates risk based on a high sea level rise scenario. This approach aligns with state standards and is recommended by the Massachusetts Office of Coastal Zone Management (CZM) for assessing sea-level rise. A high sea level rise scenario is also being used by the Resilient MA Action Team (RMAT) and its Climate Resilience Design Standards and Guidelines. These projections are also built into the Massachusetts Coast Flood Risk Model (MC-FRM), informing both the Town of Falmouth and Woods Hole coastal vulnerability assessments (Woods Hole Group, 2020a/b).

To achieve the Community's goals, a multi-phased, flexible management approach is required to improve the coastal resiliency of Woods Hole. To develop this plan, a dynamic adaptation pathways approach is applied, which involves the following key steps:

1. Identification of risks and vulnerability (problem formulation)
2. Establish adaptation priorities (key features and community goals)
3. Development of potential actions and timeframes
    a. Proposed a range of adaptation alternatives
    b. Assess their efficacy over time given evolving climate conditions
4. Develop implementation pathways
    a. Diagram effectiveness of alternatives over time
    b. Evaluate benefits, impacts and potential costs
5. Develop phasing and implementation plan (select preferred pathways)

Each of these steps is described in more detail in the following sections.

2.0 IDENTIFICATION OF RISKS AND VULNERABILITIES

Woods Hole is at risk from coastal hazards, including storm surge flooding and sea level rise. Detailed assessments of flood risk for Woods Hole scientific institutions and Town of Falmouth municipal assets were initially completed as part of the Woods Hole Climate Change Vulnerability Assessment and Adaptation Plan and Falmouth's Climate Change Vulnerability Assessment and Adaptation Study (Woods Hole Group 2020a, 2020b). The current project – focused on the mixed-use Woods Hole area – builds on the 2020 vulnerability assessments by extending the vulnerability assessment to consider coastal risks to residential structures, businesses (including retail, food service and hospitality), non-profits, lifelines, and roadways within Woods Hole.

For this study, sea level rise projections served as a basis for understanding how future tidal inundation may impact Woods Hole. The sea level rise projections used for Woods Hole were developed by the Commonwealth of Massachusetts (DeConto & Kopp, 2017) for climate change planning and developed using long-term tidal datum (19-year tidal epoch) information from the Woods Hole tide gauge.

As detailed in the Falmouth CCVA (Woods Hole Group, 2020b), Woods Hole Village CCVAs (Woods Hole Group, 2020a), and ResilientWoodsHole Phase II report (Woods Hole Group 2022) MC-FRM uses sea level rise projections developed by the Commonwealth of Massachusetts (DeConto & Kopp, 2017) for climate change planning. These projections for future mean sea level elevation (in NAVD88) are based on a range of potential greenhouse gas emissions scenarios and potential contributions from ice sheet melt (from current scientific consensus), using a probabilistic approach. Each projection is associated with a range of confidence intervals depending on greenhouse gas emissions and ice sheet contributions. The intent of these projections is not to state that mean sea level will be "at elevation X by year 20YY" but rather to indicate very high degrees of confidence that conditions will "not be worse than elevation X by year 20YY." This important distinction highlights the unique purpose of these projections (planning for an uncertain future), and underscores the importance of applying them in a flexible framework given the expanding uncertainty with far future planning horizons. The Massachusetts probabilistic sea level rise projections for Woods Hole are presented in Figure 2

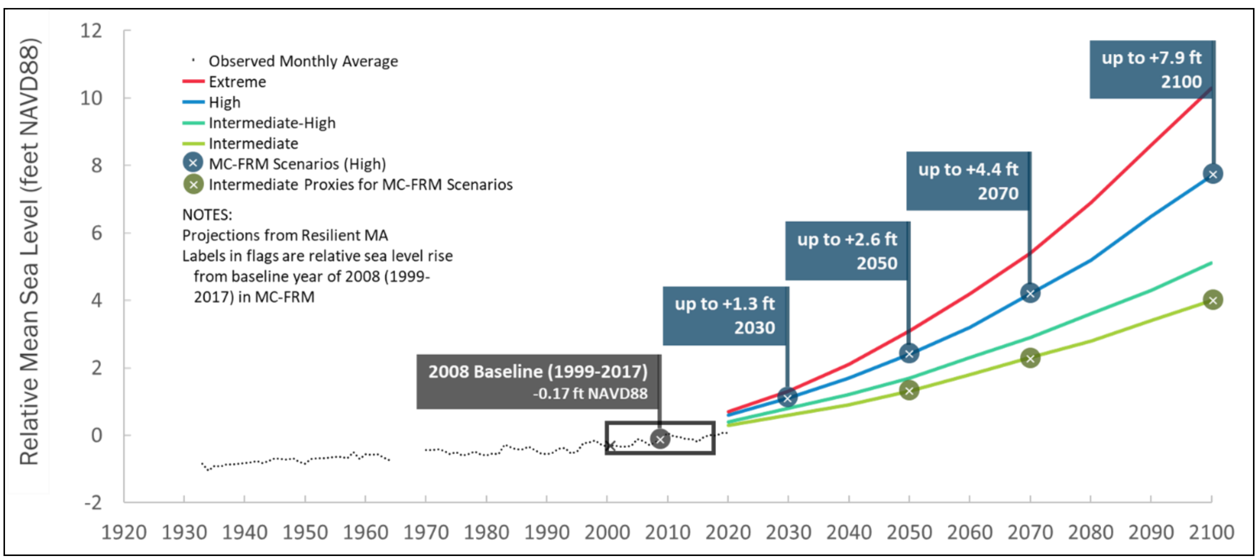


Figure 2. Probabilistic Sea Level Rise Projections for Woods Hole (DeConto & Kopp, 2017)

2.1 DAILY TIDAL FLOODING

High tides occur twice each day (one higher than the other due to diurnal inequality) and can pose a risk to low lying communities. As sea-level rises, so too will the elevation of the high tides becoming more of a nuisance to low lying areas and roadways. Inundated roads cannot provide reliable transportation corridors or emergency access; buildings surrounded by water at high tide cannot be readily accessed (and may additionally suffer long-term water damage). It is therefore crucial to evaluate areas that may experience this type of inundation in the future and develop a plan for how to adapt.

This evaluation begins with identifying the future tidal benchmark elevations for Mean High Water (MHW) for various planning horizons consistent with the sea level rise projections described above. Based on local MC-FRM modeling, projected sea level rise, and shoreline configuration, mean high water elevations at Woods Hole could be:

Buzzards Bay Shoreline-

- as high as 3.3 ft NAVD88 as soon as 2030
- as high as 4.6 ft NAVD88 as soon as 2050
- as high as 6.4 ft NAVD88 as soon as 2070

Woods Hole/Vineyard Sound Shoreline-

- as high as 2.1 ft NAVD88 as soon as 2030
- as high as 3.4 ft NAVD88 as soon as 2050
- as high as 5.2 ft NAVD88 as soon as 2070

Comparing these elevations with the existing topography (Figure 3) reveals which areas within Woods Hole may be impacted by future daily tidal flooding between 2030 and 2070, or beyond. Daily tidal flooding is not projected to impact roadways or structures in Woods Hole until the 2050 planning horizon, when daily flooding could impact the northern portion of Gansett Road, Gardiner Road and Mill Pond. As soon as 2070, daily tidal flooding could significantly impact the roads and structures along Millfield Street and the Spencer Baird corridor, as well as some low-lying areas of Penzance Point.

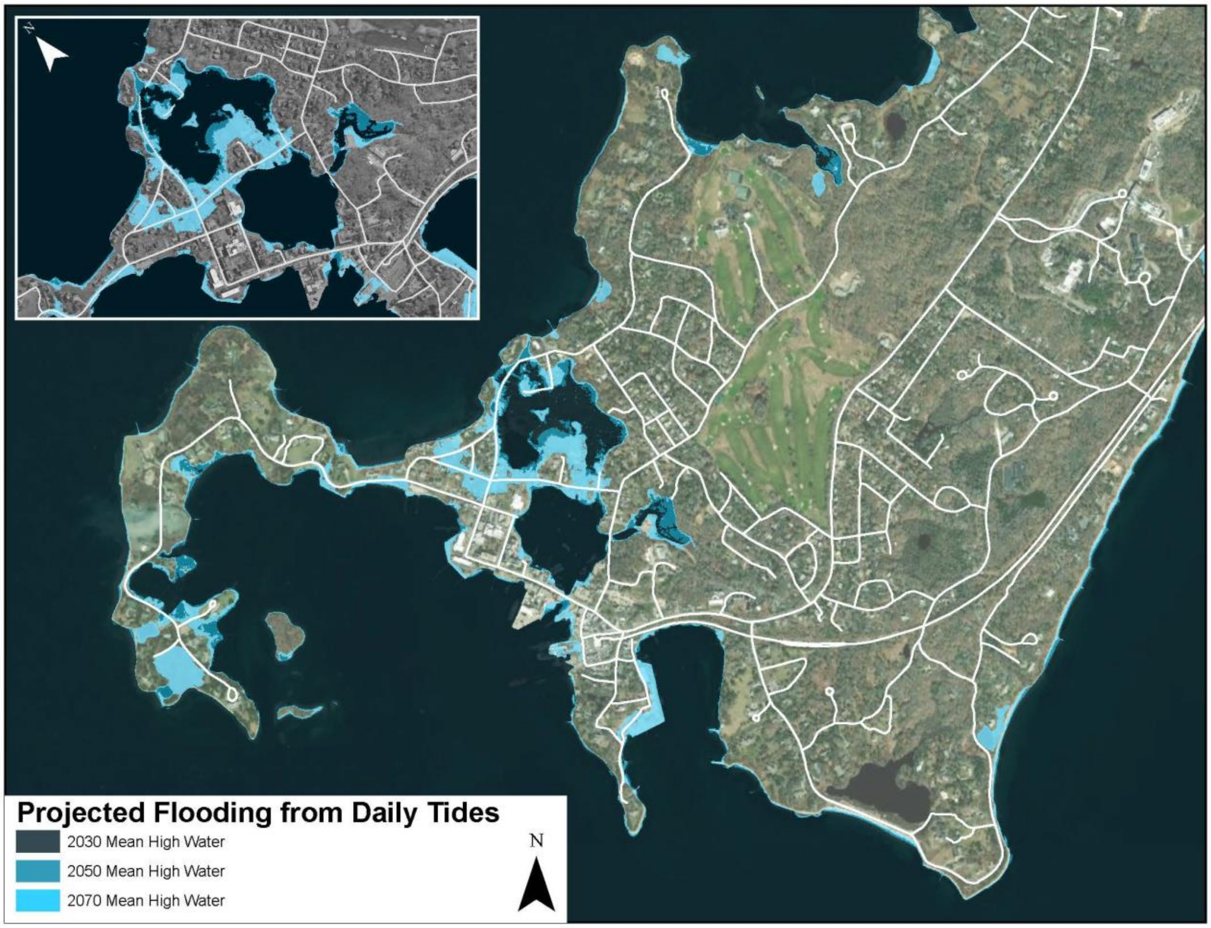


Figure 3. Projected 2030, 2050 and 2070 Mean High Water inundation in Woods Hole.

2.2 STORM SURGE INUNDATION

Previous studies assessing storm surge vulnerability to Woods Hole were performed using the Massachusetts Coastal Flood Risk Model (MC-FRM) and associated water surface elevation data. Specific details of the highly resolved hydrodynamic MC-FRM model can be found in the previously completed Woods Hole Village CCVA (Woods Hole Group, 2020b) and Resilient Woods Hole Phase 2 Report (Woods Hole Group 2022).

Projected Water Surface Elevation (WSE) is the projected elevation for a specific future annual coastal flood exceedance probability (ACFEP), considering storm surge, tides, and wave setup. Therefore, these values represent the still water surface elevation without inclusion of the added elevation due to waves propagating at this stillwater surface elevation. Asset-specific vulnerability assessments were performed by comparing the projected water surface elevation (WSE) to the critical elevation (CE) for the asset. Since both elevations were reported in NAVD88, they could be readily compared to determine whether an asset could be flooded under different circumstances. The CE for an asset can also be subtracted from the WSE to determine the depth of flooding above the critical elevation.

In this assessment, each projected water surface elevation (WSE) is associated with a certain probability level (chance of flooding during a calendar year). Projected WSEs for specific ACFEPs are presented as 0.1%-100% flood probabilities in the vulnerability assessment table or "probability of flood exposure" in the vulnerability assessment maps. An ACFEP of 1% indicates there is a 1% chance of occurrence any given year, often referred to as a 100-year event.

The following methodologies were used to assess several asset groups:

Lifeline Infrastructure

The vulnerability of lifeline infrastructure storm surge inundation was evaluated by comparing MC-FRM projected water surface elevations to asset critical elevations to determine the probability of flooding. Lifeline infrastructure included: the Woods Hole Drawbridge; Town-owned sewer pump stations; U.S. Coast Guard Station Woods Hole buildings; and the Steamship Authority's proposed buildings and ramps. Critical elevations for the U.S. Coast Guard Station Woods Hole were derived by adding field-measured heights to bare earth elevations extracted from the latest LiDAR data. Critical elevations for the proposed Steamship Authority renovated facilities (buildings and ramps) were derived from reviewing the Woods Hole Ferry Terminal Reconstruction design drawings (dated June 11, 2021).

Probabilities of flooding were determined by comparing these critical elevations to the projected MC-FRM Coastal Flood Exceedance Probability (CFEP) distributions extracted from MC-FRM model output at the grid points (nodes) used in the Woods Hole Village CCVA (Woods Hole Group, 2020b).

Residential and Business Structures

Woods Hole Group evaluated the vulnerability of buildings in Woods Hole to storm surge inundation by extracting the maximum probability of flooding within each building footprint (July 2021 MassGIS Building Structures 2-D) in the study area from MC-FRM probability maps. This building level analysis was supplemented by the Woods Hole Village CCVA (Woods Hole Group, 2020b) results for WHOI/MBL/NOAA buildings (including the CWATER project replacing the existing Iselin facility), the Falmouth CCVA (Woods Hole Group, 2020a) for Town-owned buildings, and the lifelines assessment (Section 2.1) for Steamship Authority and Coast Guard buildings using the critical elevation and CFEP distribution water surface elevation comparison.

Roadways

Woods Hole Group evaluated the vulnerability of roadways in the study area to storm surge inundation by comparing MC-FRM projected water surface elevations to roadway critical elevations to determine the probability of flooding. Roadway critical elevations were determined by extracting bare earth elevation from the recent LiDAR dataset (2016 USGS CoNED

Topobathymetric Model) on a 20-foot interval along road segment centerlines. The road segments used for this assessment were derived from the same source as the Falmouth CCVA (Woods Hole Group, 2020a).

The results shown in Figures 4-6 provide discrete risk estimates at various time horizons to assist with both near- and long-term planning. While coastal storms are episodic in nature, more frequent and intense coastal storms present a significant threat to roadways (e.g., undercutting, flooding) and infrastructure that support essential functions of Woods Hole.

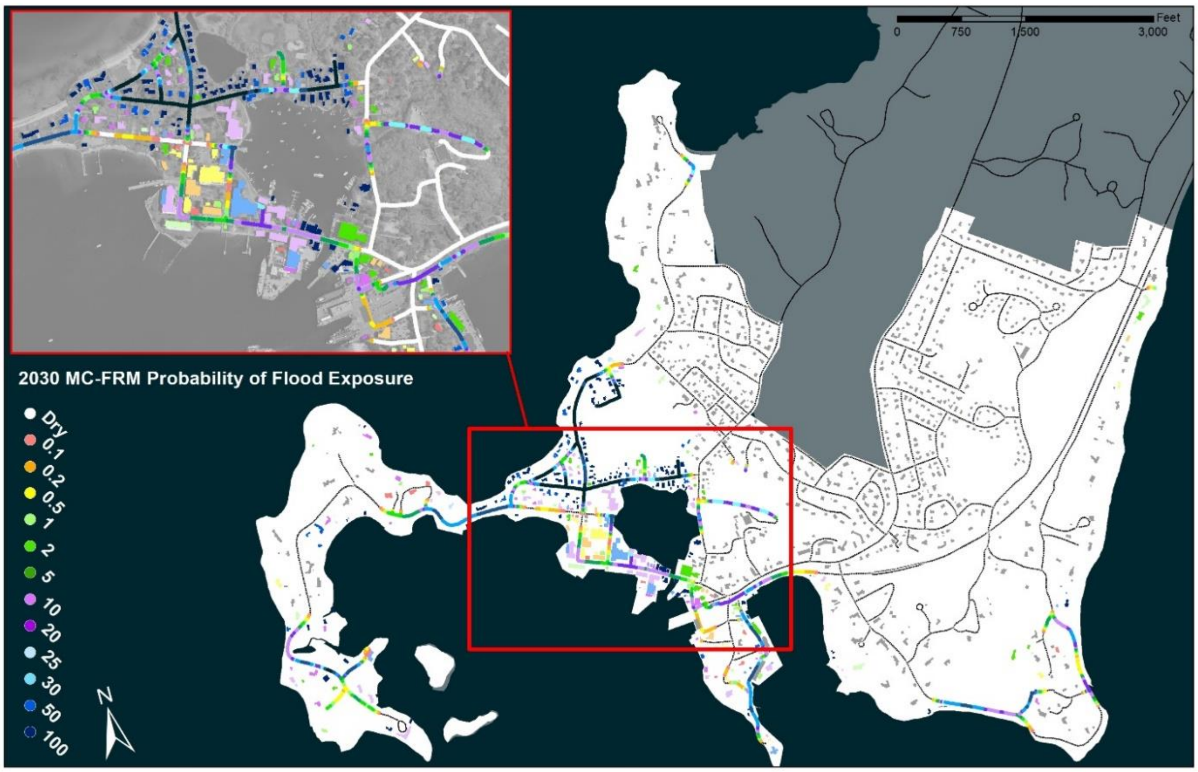


Figure 4. MC-FRM probability of inundation results for structures and roadways in 2030.

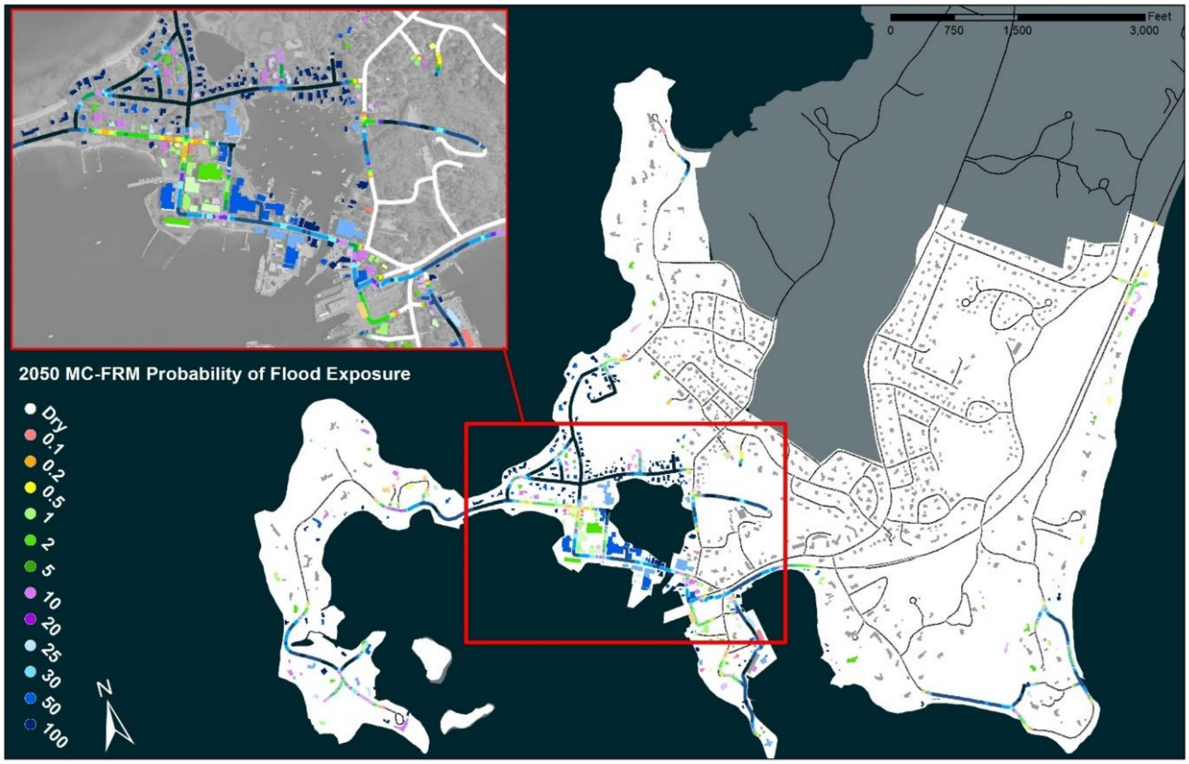


Figure 5. MC-FRM probability of inundation results for structures and roadways in 2050.

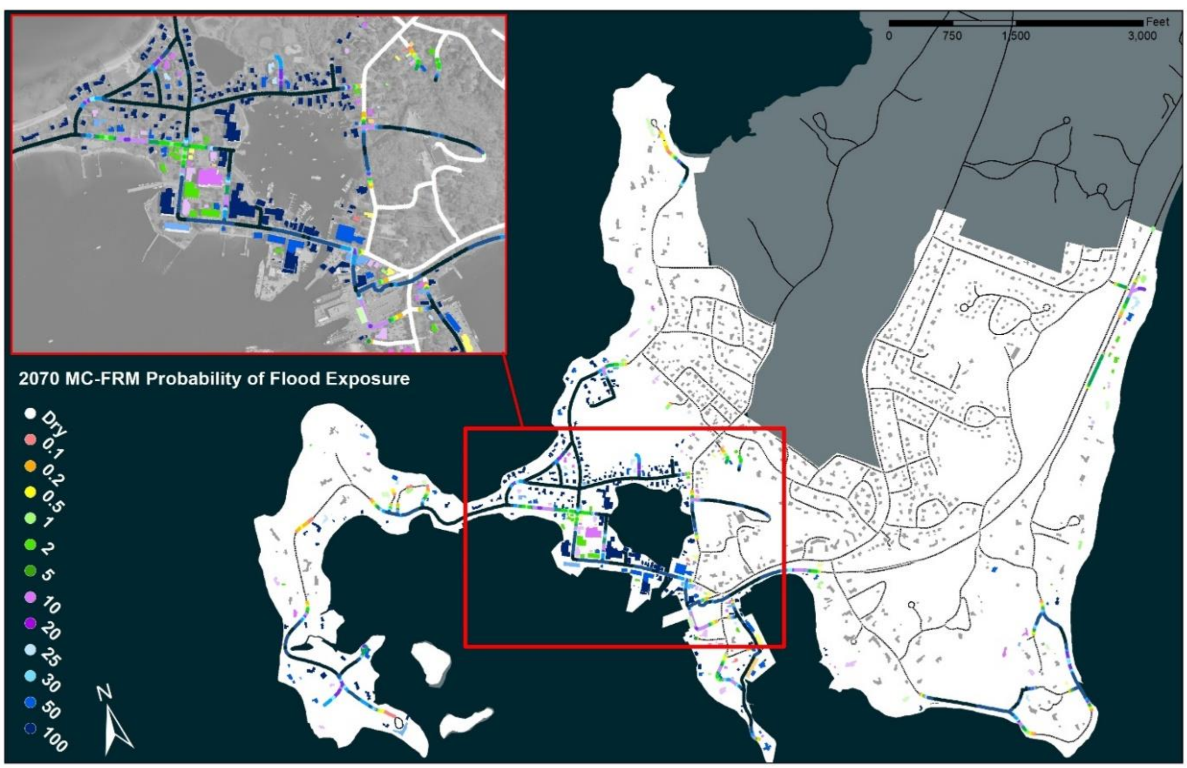


Figure 6. MC-FRM probability of inundation results for structures and roadways in 2070.

In general, risks to storm surge increase over time throughout Woods Hole. Areas with the most at-risk structures and roadways are surrounding Millfield St, Spencer Baird, and Gardiner Road.

The complete results of the extended vulnerability assessment for the Woods Hole study area are presented in Tables 1 and 2. The 1% and 10% chance storm events are often used as indicators for storm surge flooding vulnerability. The 1% chance storm event (or 100-year flood event) is used in FEMA mapping and familiar to the public. In 2030, it is projected that 238 residential buildings, 15 business structures, and 10 lifeline structures/infrastructure could be flooded by the 1% chance storm event. This exposure increases to 257 residential buildings, 17 business structures, and 11 lifeline structures/infrastructure under 2050 climate conditions, and 281 residential buildings, 18 business structures, and 12 lifeline structures/infrastructure under 2070 climate conditions. Of the scientific institutions (WHOI, MBL, NOAA), 31 structures could flood in 2030 and 44 structures could flood as soon as 2050 or 2070.

The 10% chance event (or 10-year flood event) is often used to assess building and roadway vulnerability since the cumulative risk of this event occurring over the typical lifespan of a building mortgage or roadway is nearly 100%. As soon as 2030, 203 residential buildings, 12 business structures, and 7 lifeline structures/infrastructure could be vulnerable to a 10% chance storm surge. This could increase to 219 residential buildings, 15 business structures, and 10 lifeline structures/infrastructure under 2050 climate conditions, and 250 residential buildings, 17 business structures, and 11 lifeline structures/infrastructure under 2070 climate conditions. Of the scientific institutions (WHOI, MBL, NOAA), 23 structures could flood in 2030 and 29 structures as soon as 2050, and 37 structures as soon as 2070.

Table 1. Extended vulnerability assessment results for structures in Woods Hole.

	2030					2050					2070				
	WHOI-MBL-NOAA	Lifelines	Business	Residential	Non-Profit	WHOI-MBL-NOAA	Lifelines	Business	Residential	Non-Profit	WHOI-MBL-NOAA	Lifelines	Business	Residential	Non-Profit
0%	110	3	6	616	12	107	1	6	604	12	104	0	5	590	12
0.1%	43	11	18	263	7	46	13	18	275	7	49	14	19	289	7
0.2%	41	11	17	253	7	44	12	18	270	7	48	14	19	286	7
0.5%	36	10	15	251	7	44	11	18	265	7	46	13	19	285	7
1%	31	10	15	238	7	44	11	17	257	7	44	12	18	281	7
2%	28	10	15	225	7	37	11	17	256	7	44	11	18	273	7
5%	25	8	14	217	6	32	10	15	243	7	44	11	17	265	7
10%	23	7	12	203	5	29	10	15	219	7	37	11	17	250	7
20%	10	6	12	178	4	24	9	14	206	5	32	10	15	232	7
25%	8	4	9	151	4	24	8	12	180	4	30	10	15	210	6
30%	8	4	9	143	4	24	7	11	170	4	30	10	15	200	5
50%	1	3	7	132	4	15	6	11	158	4	26	10	13	190	5
100%	1	0	6	94	4	1	3	8	122	4	19	6	12	153	4

Table 2. Extended vulnerability assessment results roadways in Woods Hole.

Road Miles Exposed to Projected Flooding

	2030	2050	2070
0.1%	4.8	5.4	5.8
0.2%	4.6	5.2	5.7
0.5%	4.3	5.1	5.5
1%	4.0	4.9	5.4
2%	3.7	4.6	5.2
5%	3.3	4.2	5.0
10%	2.9	3.8	4.6
20%	2.3	3.4	4.2
25%	1.9	3.2	4.0
30%	1.7	3.0	3.8
50%	1.1	2.4	3.5
100%	0.7	1.1	2.3

The results of the roadway vulnerability assessment are presented in Table 2. As soon as 2030, it is projected that 4.0 miles of roads in Woods Hole could flood from the 1% chance storm event. This exposure could increase to 4.9 miles of roadways under 2050 climate conditions and 5.4 miles as soon as 2070. Considering the 10% storm event, 2.9 miles of roadway could flood under 2030 climate conditions. As soon as 2050 3.8 miles of roadway could flood and as soon as 2070, 4.6 miles of roadways could flood.

2.3 FLOOD PATHWAYS ASSESSMENT

To develop a comprehensive phased management approach for this area, a detailed analysis of potential flood pathways for future climate conditions was completed. Flood pathways indicate low-lying entry points and conduits for coastal storm surge within the developed and natural landscape. Within the boundaries of the MC-FRM Present Day 1% flood extent, Woods Hole Group used high resolution elevation data to investigate these potential first entry points for flooding to identify strategic points of intervention for low-level storms.

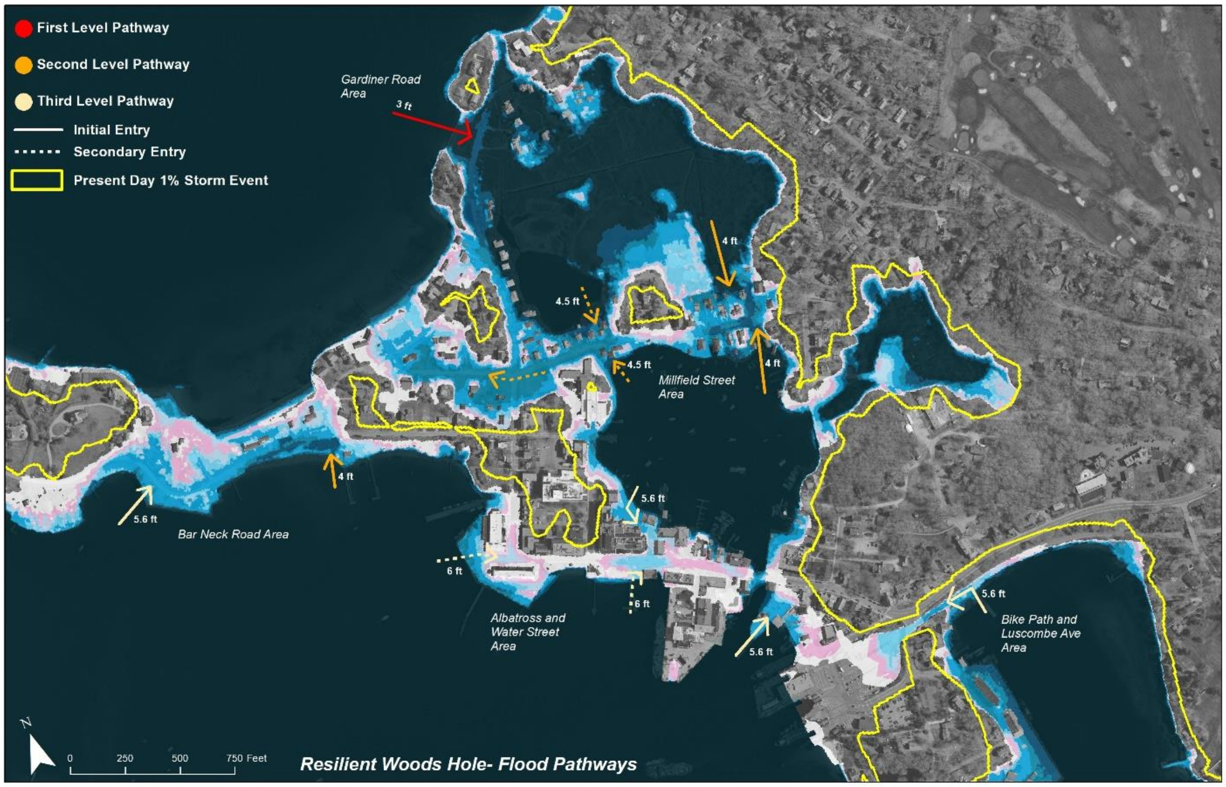


Figure 7. Flood pathway analysis for the Woods Hole study area.

The flood pathways analysis (Figure 7) indicates multiple points of entry for flooding in the low-lying village core. Initial incursion at ~3.0 ft NAVD88 occurs over Gardiner Road into Mill Pond and the Woods Hole Park area wetlands, affecting homes along Gardiner Road. Secondary incursion of flooding occurs along Millfield Road, both from the north via the Woods Hole Park wetlands and Mill Pond, as well as from the south via Eel Pond. At ~4.0 ft NAVD88, flooding encroaches on the eastern portion of Millfield Road. At ~4.5 ft NAVD88, flooding overtops Mill Pond from the north and Eel Pond from the south near the Bell Tower and Swope, affecting western portions of Millfield Road and flowing west along Spencer Baird Road. Similar flood levels can also inundate Bar Neck Road, restricting access to Penzance Point. Tertiary incursion of flooding at ~5.6 and ~6.0 ft NAVD88 affect the commercial and institutional corridor. At these levels, storm surge can flow under Crane Street via the Bike Path affecting the Steamship Authority lot, up around Dyers Dock, throughout the parking lot behind Lillie Laboratory, and eventually along Water Street from Lillie and the NOAA campus.

2.4 SUMMARY OF RISKS AND VULNERABILITIES

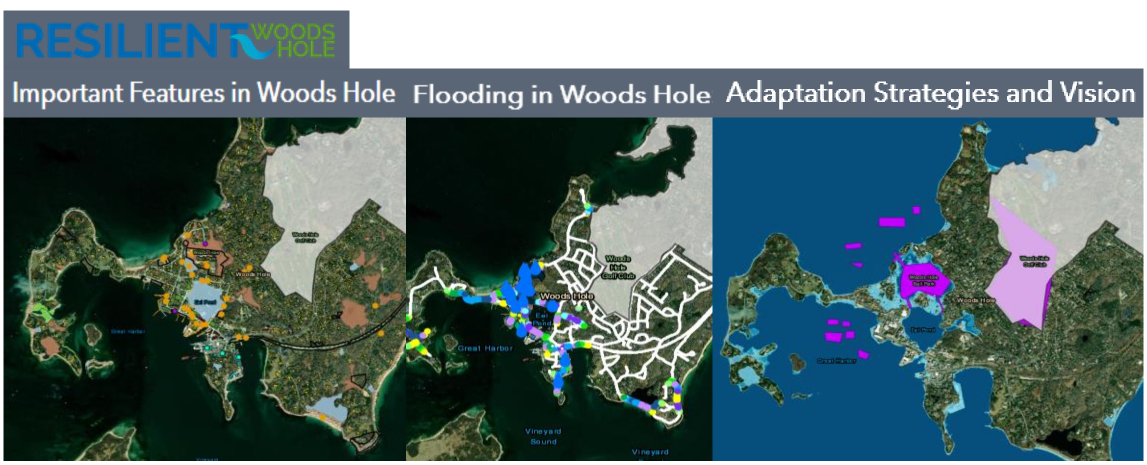
Collectively, these results show Woods Hole and the surrounding roadways, municipal assets, and residential neighborhoods to be extremely vulnerable to inundation during storms under future climate conditions, as well as to inundation during high tides in the future due to sea level rise. As such, ResilientWoodsHole is starting a strategic planning and extensive community engagement process to develop a robust adaptation strategy program to improve coastal resiliency in Woods Hole.

3.0 PUBLIC ENGAGEMENT PROCESS AND ESTABLISHING ADAPTATION PRIORITIES

Stakeholder engagement is a critical component of every climate change adaptation and planning project to help communities embrace eventual implementation of recommended actions. Over the course of Phase 3, there were many opportunities for public outreach and engagement aimed to gather input, feedback, and questions from residents, business owners, and community stakeholders. The information received during these engagement opportunities were then used to inform development of short- and long-term goals for operations in Woods Hole.

3.1 COMMUNITY WORKSHOP #1

The Phase 3 Community Vision Workshop was scheduled for February 9th, 2022, as a virtual event due to COVID-19 concerns. The intention of the workshop was to present results of the community vulnerability assessment and ask how community stakeholders would like to see Woods Hole adapt to sea-level rise and coastal storms. Additionally, attendees were introduced to a series of interactive mapping tools showing results of the community vulnerability assessment. These interactive mappers included public comment tools for stakeholders to provide details of their own experiences of flooding in Woods Hole, and to offer their own ideas for adaptation strategies. The interactive mappers were made available on ResilientWoodsHole's website: [Interactive Data Viewers]



3.2 STAKEHOLDER INTERVIEWS

A total of twelve (12) stakeholder interviews were conducted between November 2021 and January 2022, with members of the Woods Hole community. The stakeholders interviewed included representatives from the Woods Hole Oceanographic Institution (WHOI), Marine Biological Laboratory, Town of Falmouth, Coast Guard, and various residents as summarized in Table 3 below. The goal of the interviews was to generate information about individual experiences with coastal flooding, determine essential functions of Woods Hole, identify key assets, determine potential measures of improvement, and identify adaptation strategies finding stakeholder resistance.

Table 3. List of interviewed community stakeholders.

Name	Affiliation	Interview Date
Judy Laster	Neighborhood liaison	November 10, 2021
CDR Paul Mangini	U.S. Coast Guard Woods Hole	November 15, 2021
Amy Lowell and Tom Bott	Town of Falmouth (Wastewater and Planning)	November 17, 2021
Pam Harvey	Neighborhood liaison	November 17, 2021
Rick Murray	Woods Hole Oceanographic Institute	November 17, 2021
Nipam Patel and Paul Speer	Marine Biological Laboratory	November 18, 2021
Peter Jeffrey	Neighborhood liaison	November 19, 2021
Jennifer Lincoln	Town of Falmouth (Conservation)	November 22, 2021
Peter de Menocal	Woods Hole Oceanographic Institute	November 23, 2021
Dave Derosiers	Woods Hole Oceanographic Institute	November 23, 2021
Catherine Bumpus	Woods Hole Community Association	December 15, 2021
Jon Hare and Nicole Cabana	NOAA Northeast Fisheries Science Center	January 11, 2022

All interviews were prefaced with results of the extended vulnerability assessment and were conducted with same basis of questions to initiate discussion. Key takeaways from the stakeholder interviews are summarized below:

- residents, institutions, businesses, and Town rely on one another for support, and need to adapt together rather than in silos
- near-term preference for solutions that enhance ability to ride out storms and rebound, rather than building walls or retreating
- long-term recognition that some non-water dependent functions can relocate, but a relocation strategy is not universally feasible
- long-term recognition that other assets that are water-dependent or limited alternatives may need to explore protective measures
- strong preference to maintain the existing character of the Village (active and walkable scale with amenities like the market, post office, and bank; more amenities are desirable) and maintain "third places" that facilitate innovation/collaboration and community. It is important to note that it's a campus within a village rather than vice versa
- identity of Woods Hole Village is tied to close-knit community, working waterfront, science and access to the ocean, business/tourism, and open space
- desire to reduce traffic and congestion, which could enhance character and accessibility as well as open space
- desire to increase access to and engagement with outdoors, waterfront, and institutions (community and scientific)
- desire to enhance awareness of and preparedness for coastal flooding among homeowners and businesses

3.3 PUBLIC SURVEY

A short public survey was posted ResilientWoodsHole's website, distributed through the ResilientWoodsHole Listserv, and provided to community representatives for distribution. The survey asked about locations where flooding is known to occur in Woods Hole, the important features of Woods Hole, and potential adaptation strategies. Overall, there were 41 responses to the survey, primarily from seasonal and year-round residents of Woods Hole. Fourteen (14) respondents either owned businesses or were employed at local businesses or other Woods Hole entities (Figure 8).

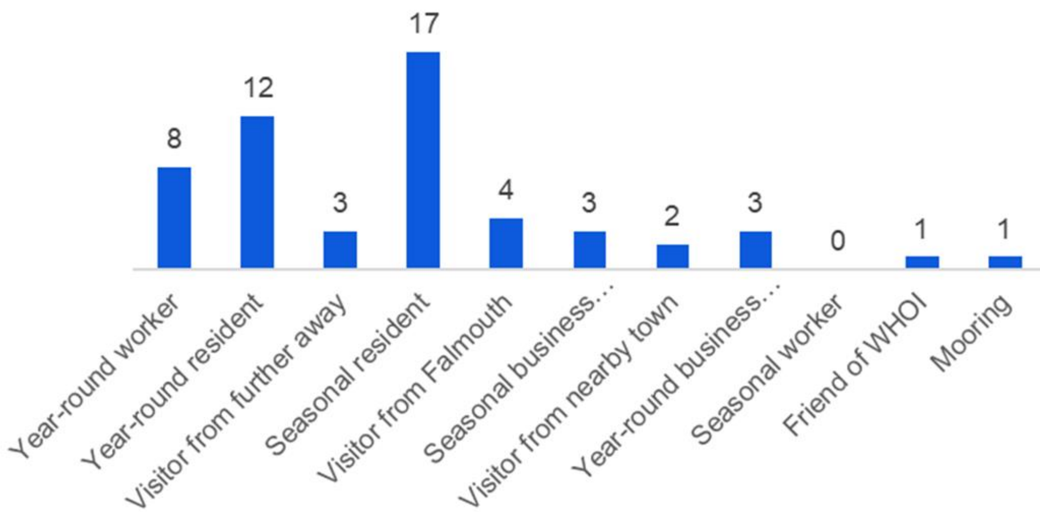


Figure 8. Profile of survey respondents.

Figure 9 shows that survey respondents find most, or all assets/features of Woods Hole are important, but some have irreplaceable historical value such as the Woods Hole Library, Woods Hole Community Hall, Children's School of Science, Woods Hole Historical Museum, Waterfront Park and sculptures and the NPR building. Other mentioned the yacht club, Nobska Point, and the intrinsic nature of daily life, friends, history, access to outdoors and the Harbors.

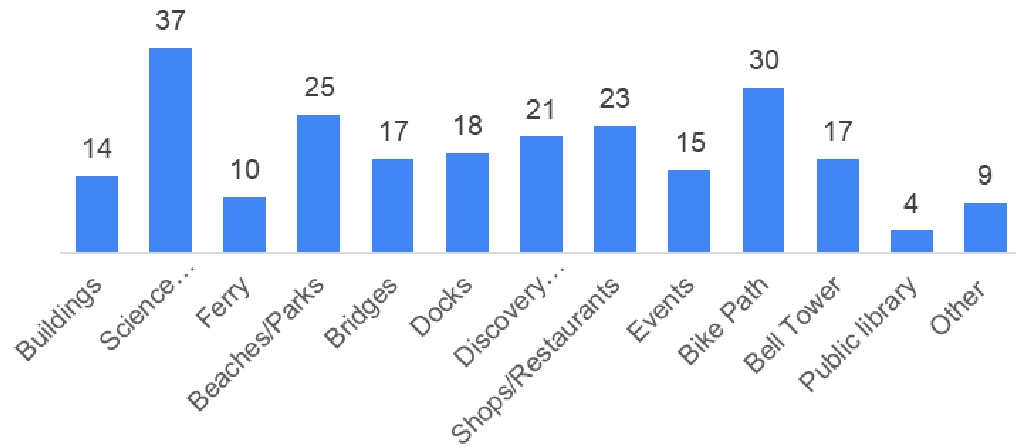


Figure 9. Most important features of Woods Hole.

Additional results from the public survey include:

- 66% of survey respondents indicated they have experienced high tide flooding or coastal storm flooding in Woods Hole.
- Woods Hole Yacht Club and associated docks, beaches, and eel pond are a few areas that have been impacted by tidal flooding. Coastal storm flooding has impacted Gardiner Rd, Millfield Street and Mill Pond.
- Survey respondents also had a strong preference for nature-based solutions in adaptation planning while retreat and taking no action were undesirable approaches (Figure 10).

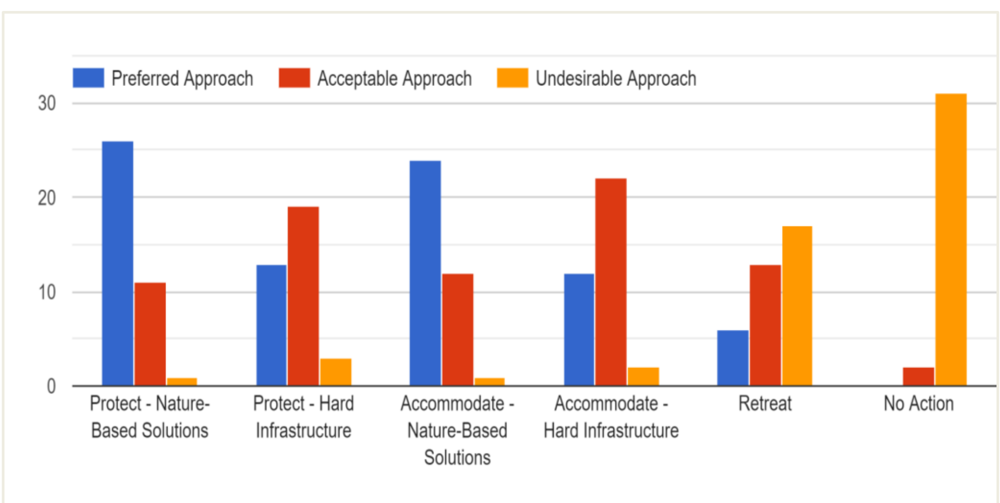


Figure 10. Preferred adaptation strategies for Woods Hole.

One common theme throughout the public survey was Woods Hole's unique and historical character that gives Woods Hole its identity- mainly the scientific community, history, natural environment, and community connectivity.

3.4 DETERMINATION OF ADAPTATION THEMES

Based on the feedback from Community Workshop #1 and associated public comment tools, and the stakeholder interviews and public survey, the project team proposed four themes to guide adaptation planning. These four themes were designed to cover the range of options available and be responsive to stated community preferences. The adaptation themes were reviewed, revised, and approved by the project Steering Committee.

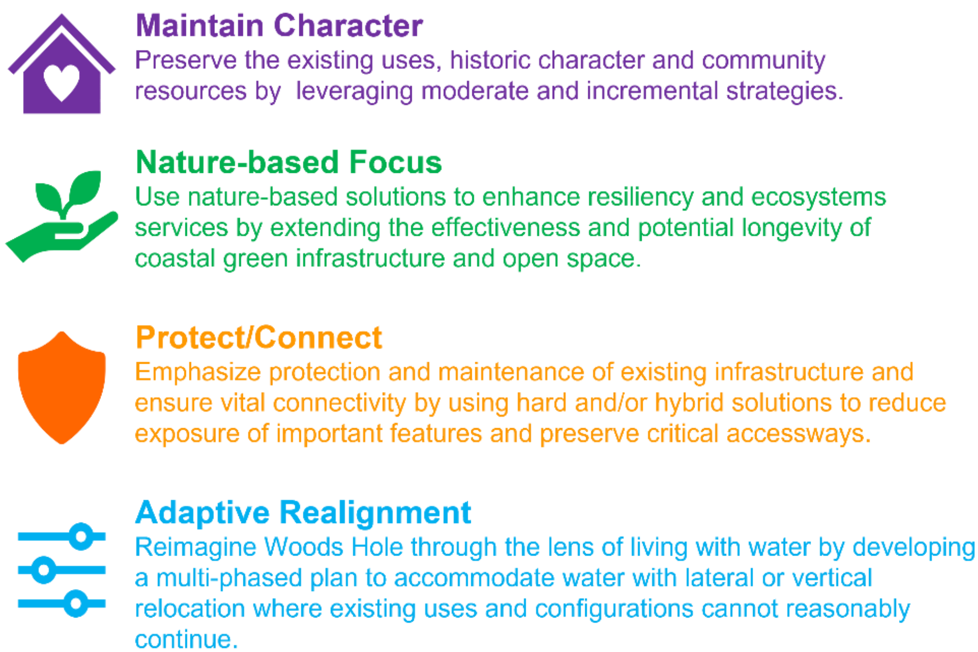


Figure 11. Adaptation themes developed for Sandwich Village.

As presented in Figure 11, the themes are:

Maintain Character

- Goal: Preserve the existing uses, historic character, and community resources
- Strategy: Leverage moderate and incremental strategies to steward the seaside community and the blue economy village identity
- Representative Actions: Incorporate wet floodproofing, deployable site protection strategies, building systems protection

Nature-based Focus

- Goal: Use nature-based solutions to enhance resiliency and ecosystem services

- Strategy: Where feasible, extend the effectiveness and potential longevity of coastal green infrastructure and open space by facilitating the preservation, restoration, and migration of natural resource systems
- Representative Actions: Incorporate salt marsh migration/restoration, beach/dune nourishment, living shorelines

Protect/Connect

- Goal: Emphasize protection and maintenance of existing infrastructure and ensure vital connectivity
- Strategy: Use hard and/or hybrid infrastructure solutions to reduce exposure of important features (municipal infrastructure, waterfront scientific assets, businesses and the residential community) and preserve critical accessways (within Woods Hole and to the waterfront)
- Representative Actions: Incorporate seawalls, bulkheads, flood walls, landscaped berms and terracing, elevation of land/roads/buildings/infrastructure, dry floodproofing

Adaptive Realignment

- Goal: Reimagine Woods Hole through the lens of living with water
- Strategy: Where existing uses and configurations cannot reasonably continue (increasing cost/risk from daily tides or common storms), develop a multi-phased plan to accommodate water with lateral or vertical relocation based on shared understanding of risk tolerance
- Representative Actions: Consider strategic elevation/relocation of buildings/infrastructure, change in use or program, undevelopment (retreat/buyout) for resilient open space

These four adaptation themes served as an organizing framework for potential adaptation actions developed in the next phase (Section 4.0) of the project. While not every theme was applicable to every part of the study area, the possibility of a range of approaches defined by these themes was considered in brainstorming potential strategies for each area and asset.

4.0 DEVELOPMENT OF POTENTIAL ACTIONS AND TIMEFRAMES

Having developed an understanding of the assets, features, amenities and functions valued by the community, and having distilled the goals and preferences for approaches to coastal resilience as currently stated by the community into adaptation themes, the next step in the project was to identify a full range of adaptation actions to address coastal flooding of the various elements of Woods Hole which are vulnerable, including buildings, roadways and natural resources. The range of adaptation actions were reviewed and approved by the project steering committee and evaluated in terms of effectiveness over time at addressing changing climate conditions in the coastal environment.

4.1 THEMED ADAPTATION ACTION METHODOLOGIES

The process for identifying and evaluating potential adaptation actions in the study area was both top-down and bottom up. In some areas, certain projects with coastal resiliency benefits have either been posited by the community or even investigated in an engineering feasibility study. Those project with some history of community discussion and ideation were included for consideration as a potential adaptation action in this process. Additionally, a bottom-up process was employed in which coastal resilience planners and engineers reviewed the results of the extended community vulnerability assessment for Woods Hole and generated ideas for adaptation actions to address the documented vulnerabilities across a range of assets (buildings, roads, natural resources).

Potential adaptation actions were categorized according to their thematic approach (see Section 3.4) and evaluated in terms of their effectiveness over time, based on explicitly stated engineering and planning assumptions regarding their configuration. Potential adaptation action ideas were generated from the perspective of basic engineering feasibility and constructability (i.e., is it physically possible). It was assumed that basic implementation hurdles (e.g., tapering in elevational elements to meet existing grades) could be solved in a more detailed future design process if/when a project advanced, but there were some general planning assumptions (e.g., do not build a seawall greater than 42 inches above grade to maintain views) that imposed constraints on certain potential actions with the explicit goal of avoiding significant disruption to the community character and experience.

Some of these potential actions may not be permittable under current regulatory schemes; however, since this is the foundational work for a long-term planning project, it was important to acknowledge the possibility of future changes to regulatory structures to facilitate resiliency measures. That said, based on feedback from the community and project partners, the process did not advance any potential adaptation actions that would significantly alter the environment and/or community.

4.1.1 Evaluation of Adaptation Action Effectiveness

It was important to understand the effectiveness of each potential adaptation action over time to weigh options for each asset. To accomplish this, coastal resilience planners and engineers reviewed ground surface elevations, proposed adaptation action dimensions (height or target elevation) and projected MC-FRM water surface elevations (WSEs).

To determine whether a potential adaptation action could provide protection/resiliency for a future 1% (100-year) coastal storm, the design parameters were compared to the projected 1% WSE (refer to Section 2.2 for definition of WSEs) for that area on the 2030, 2050 and 2070 planning horizons. Maps showing these projected 1% WSEs in the study area are presented in Appendix A for reference.

At some point as climate conditions evolved, proposed actions may not be able to deal with 1% WSEs, but the adaptation may still provide protection/resiliency for lower level (higher probability) future storms. To evaluate the protective benefit of the potential adaptation strategy beyond the 1% WSE, the design parameters were compared to the full range of projected WSEs from the MC-FRM ACFEP curve. These curves were extracted from the model for various exposure areas in the Phase 1 and Phase 2 assessments and are presented in those reports (Woods Hole Group 2020a and 2022). If a proposed strategy could not provide protection/resiliency for at least a 50% ACFEP level, it was determined that the strategy would no longer be deemed effective for storm surge flood protection at that time horizon (assumed frequency of flooding would be undesirable from a storm protection perspective).

Beyond storm protection, some adaptation strategies may provide protection/resiliency for tidal inundation, even as sea level rise progresses. To evaluate the effectiveness of each potential adaptation for addressing tidal inundation and sea level rise, the design parameters and project configuration were compared to the projected mean high water tidal benchmark elevations for Woods Hole (see Section 2.1).

4.1.2 Coastal Management Areas

Because solutions vary in their scope and effectiveness, it was useful to divide the study area into coastal management areas. These geographic assessment units were developed from a combination of established neighborhood areas and a review of future flood extents. This allows solutions to be more easily organized and tailored to the local context, including existing elevation, projected magnitude of flooding and surrounding uses. Figure 12 shows the coastal management areas. Note that upland portions of the ResilientWoodsHole study area are not included in the coastal management areas because they are not expected to be exposed to be exposed to future sea level rise or storms surge.

Figure 12. Coastal Management Areas

4.2 ADAPTATION ACTIONS BY MANAGEMENT AREA

This section presents a series of tables describing the array of potential adaptation strategies that could be implemented within each coastal management area. Each table of potential strategies is sorted by adaptation theme and provides basic information about each strategy's design and configuration. Appendix B provides a series of maps diagramming the various adaptation strategies by theme for each management area. These maps correspond to the tables presented in the following sections.

4.2.1 Gansett

Table 4. Potential adaptation strategies for Gansett management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% Storm Protection	Reduced Storm Protection	Tidal Effectiveness
Deployable barriers (48 in) at lower Ganset Rd	X				2022	-	2022-2070	n/a
Beach nourishment and dune enhancement at lower Gansett Rd landing		X			2022	-	2022-2070	2070-2100
Modular seawall (to 42 in) at lower Ganset Rd landing			X		2022	-	2022-2070	2070-2100
Raise parking lot and road at lower Ganset Rd landing and tie back to high ground			X		2022	2022-2070	2070 +	n/a
Construct bridge at lower Ganset Rd				X	2022	2022+	n/a	n/a
Reroute lower Ganset Rd to west to reduce storm impacts				X	2022	2022+	n/a	n/a
Reroute lower Ganset Rd to west to reduce tidal impacts				X	2022	-	-	2070+

A range of potential adaptation actions were explored for the Gansett management area. These strategies are detailed in Table 4 and summarized spatially in Appendix B. Due to the elevated nature of most of the Gansett management area, adaptation strategies focused only on the low-lying portion of northern Gansett Road adjacent to the landing and association dock on Quissett Harbor. This area is projected to experience increasing storm surge inundation and some potential tidal inundation (in the long-term). The strategies investigated for this area included deployable flood barriers, elevated dune features, constructed walls or ground, a bridge spanning the vulnerable area, and potentially rerouting the roadway.

4.2.2 Mill Pond

Table 5. Potential adaptation strategies for Mill Pond management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% Storm Protection	Reduced Storm Protection	Tidal Effectiveness
Deployable flood protection strategies for low lying Millfield St and Gardiner Rd homes and identify location for communal storage					2022	-	2022-2050	n/a
Wet floodproof low lying homes. No longer effective if 1st floor impated by flooding (Threshold is ~18" above grade). Only viable for homes at the top of Park Rd and in the middle of Millfield at Bell Tower Lane.					2022	-	2022-2030	n/a
Dune construction modification to seawall at Gardiner Rd and tie into high ground at ~10 ft NAVD88.					2022	-	2022-2070	2070+
Improve tidal connection between Eel Pond and Mill Pond for future salt marsh migration and drainage. May reduce some low level flooding over Millfield Road but not effective for larger storms or SLR.					2022	-	2022-2030	2030-2070
Elevate low lying Millfield and Gardiner corridor (parcels and roads) and rebuild homes w/ some elevation. Assume elevating low corridor to ~10 ft NAVD88.					2022	2022-2030	2030-2070	2070-2100
Raise seawall at Gardiner Rd and install drainage outlet for wetland. Tie into high ground at ~10 ft NAVD88. Drainage does not add storm protection but reduces residence time if overtopped.					2022	-	2022-2070	2070-2100
Dry floodproof and/or elevate Park Rd Sewer Lift Station.					2022	2022-2070	2070+	n/a
Construct a 3 ft landscape berm or elevated bulkhead system to tie into existing neighborhood high spots currently at ~7 ft NAVD88. Only viable for Millfield backyards.					2022	-	2022-2050	2050-2100
Modify seawall at Gardiner Rd to enhance post-storm drainage. Drainage does not add storm protection but reduces residence time if overtopped.					2022	-	2022-2050	2050-2070
Elevate low lying homes (Millfield/Gardiner) no more than 10 ft above ground level. No longer viable if tidal inundation occurs.					2022	2022-2050	2050-2070	n/a
Relocate low lying homes out of tidal inundation zone, abandon part/all of Gardiner/Millfield, repurpose land (including Woods Hole Park) for flood storage and resilient open space					2070	n/a	2022-2070	2070+

A range of potential adaptation actions were explored for the Mill Pond management area. These strategies are detailed in Table 5 and summarized spatially in Appendix B. Vulnerability in the Mill

Pond management area is related to three primary flood pathways – overtopping of the sea wall at Gardiner Road, overtopping of low-lying segments of Millfield Street, and overtopping of the Stoney Beach dune with flood conveyance down Spencer Baird Road. Storm exposure is expected to increase with climate change, and tidal inundation is also a concern for many properties adjacent to Mill Pond and the associated wetland complex in the mid- to long-term. The strategies investigated for this area included deployable barriers, wet floodproofing (residential), enhanced tidal connections and drainage, elevated dune features, constructed walls or ground, dry floodproofing (sewer lift station), elevating structures, and potential long-term retreat.

4.2.3 Spencer Baird

Table 6. Potential adaptation strategies for Spencer Baird management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% Storm Protection	Reduced Storm Protection	Tidal Effectiveness
Coordinate deployable flood protection strategies for low lying homes and identify location for communal storage	■				2022	-	2022-2070	n/a
Wet floodproof low lying homes. No longer effective if 1st floor impated by flooding (Threshold is ~18" above grade)	■				2022	-	2022-2050	n/a
Beach nourishment and dune enhancement at Stoney Beach. Tie into existing neighborhood high spots of ~10 ft NAVD88.		■			2022	-	2022-2070	2070-2100
Elevate existing Buzzards Bay seawalls to ~10 ft NAVD88 tyinginto existing neighborhood high spots.			■		2022	-	2022-2070	2070-2100
Elevate low lying corridor (parcels and roads) along Gosnold Rd, Spencer Baird Rd and Albtross to ~12 ft NAVD88, and rebuild homes with increased elevation.			■		2022	2022-2070	2070+	n/a
Elevate low lying homes no more than 10 ft above ground level.				■	2022	2022-2050	2050-2070	n/a
Relocate low lying homes out of tidal inundation zone, repurpose land for flood storage and resilient open space				■	2070	n/a	2022-2070	2070+

A range of potential adaptation actions were explored for the Spencer Baird management area. These strategies are detailed in Table 6 and summarized spatially in Appendix B. Vulnerability in the Spencer Baird management area is related to two primary flood pathways – overtopping of the Stoney Beach dune and flood conveyance down Spencer Baird from overtopping of Eel Pond or Mill Pond. Some additional exposure may also result from wave runup and overtopping at Bar Neck Road from Great Harbor. Storm exposure is expected to increase with climate change, and tidal inundation is also a concern for low-lying properties on Spencer Baird Road and Gosnold

Road in the long-term. The strategies investigated for this area included deployable barriers, wet floodproofing (residential), elevated dune features, constructed walls or ground, elevating structures, and potential long-term retreat.

4.2.4 Penzance Point

Table 7. Potential adaptation strategies for Penzance Point management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% Storm Protection	Reduced Storm Protection	Tidal Effectiveness
Coordinate deployable flood protection strategies for low lying homes	X				2022	-	2022-2070	n/a
Wet floodproof low lying homes. No longer effective if 1st floor impacted by flooding (Threshold is ~18" above grade)	X				2022	-	2022-2050	n/a
Beach nourishment and dune enhancement or living shoreline sideslope treatments for low lying segments of Bar Neck Rd and Penzance Rd. Tied into existing neighborhood high spots at ~10 ft NAVD88		X			2022	-	2022-2070	2070-2100
Elevate low lying segments of Bar Neck Rd and Penzance Rd no more than 3 ft over time.			X		2022	-	2022-2070	2070-2100
Elevate low lying homes no more than 10ft above ground level.				X	2022	2022-2070	-	n/a
Move low lying structures away from tidal inundation zone				X	2070	n/a	2022-2070	2070+

A range of potential adaptation actions were explored for the Penzance Point management area. These strategies are detailed in Table 7 and summarized spatially in Appendix B. Vulnerability in the Penzance Point management area is related to direct coastal inundation at low-lying portions of the peninsula, primarily the causeway access where the former island was connected to Woods Hole, and low-lying parcels and road segments toward the point. Storm exposure is expected to increase with climate change, and tidal inundation is a concern for road segments and a few properties in the long-term. The strategies investigated for this area included deployable barriers, wet floodproofing (residential), elevated dune features, constructed ground, elevating structures, and potential long-term retreat.

4.2.5 Eel Pond

Table 8. Potential adaptation strategies for Eel Pond management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% Storm Protection	Reduced Storm Protection	Tidal Effectiveness
Deployable flood protection strategies for low lying Millfield St homes and SW Eel Pond/Water St. Identify location for communal storage.					2022	2022-2030	2030-2070	n/a
Wet floodproof low lying homes. No longer effective if 1st floor impated by flooding (Threshold is ~18" above grade)					2022	-	2022-2050	n/a
Elevate School St and increase culvert size. Tie into highpoints along school street at ~`13.6 ft NAVD88 (Option: undevelop driveway/parking lot east of Vincent House for marsh migration, move parking to Maury Ln)					2022	2022-2070	2070+	n/a
Upsize Culvert while maintaining existing road elevation (Critical low spot along school street is ~5.6 ft NAVD88)					2022	-	2022-2050	2050-2100
Dry floodproofing (scientific/commerical). Assume all buildings can be dry floodproof to 1% storm event. No longer effective if tidal inundation occurs					2022	2022-2100	n/a	n/a
Elevate Eel Pond seawalls and bulkheads by ~42" bringing new critical elevation to ~8.5 ft NAVD88 (scientific/commercial/residential)					2022	2022-2050	2050-2070	2070-2100
Elevate low lying Millfield corridor (parcels and roads) and rebuild homes with increased elevation. Bring low corridor to ~10 ft NAVD88.					2022	2022-2030	2030-2070	2070-2100
Elevate Water St and businesses no higher than ~9.5 ft NAVD88.					2022	2022-2050	2050-2070	2070+
Construct flood control barrier at Eel Pond Channel at 7.75 ft NAVD88. Flanking pathways should be considered if installed.					2022	-	2022-2050	n/a
Elevate mechanical equipment and reprogram 1st floors to accommodate flooding (scientific). Assumes 1st floors are 10ft high on ~6.5 ft NAVD88 decks. Not impacted until WSE of ~16.5 ft NAD88 and no longer effective if tidal inundation occurs					2022	2022-2100	n/a	n/a
Move non-water dependent science operations, undevelop facilities, and develop elevated Eel Pond Park					2022	2022-2070	2070+	n/a
Elevate low lying homes (Millfield) no more than 10 ft above grade and no longer effective if tidal inundation occurs.					2022	2022-2070	n/a	n/a
Relocate low lying Millfield Rd homes out of tidal inundation zone and repurpose land for flood storage and resilient open space					2070	n/a	2022-2070	2070+

A range of potential adaptation actions were explored for the Eel Pond management area. These strategies are detailed in Table 8 and summarized spatially in Appendix B. Vulnerability in the Eel Pond management area is related to two primary flood pathways – overtopping of the Eel Pond bulkheaded shoreline and overtopping of low-lying segments of Millfield Street. Secondary flood exposure may also come from wave overtopping from Great Harbor at the waterfront along Water Street. Storm exposure is expected to increase with climate change, and tidal inundation is also a concern for (residential, MBL and commercial) properties adjacent to Eel Pond in the long-term. The strategies investigated for this area included deployable barriers, wet floodproofing (residential), enhanced tidal connections and drainage, constructed walls or ground, dry floodproofing (non-residential), a tide gate on Eel Pond, elevating structures, relocating non-water dependent research activities, and potential long-term retreat.

4.2.6 Waterfront

Table 9. Potential adaptation strategies for Waterfront management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% Storm Protection	Reduced Storm Protection	Tidal Effectiveness
Deployable flood protection strategies for science and community (WHCA/Fire) structures					2022	2022-2050	2050-2100	n/a
Wet floodproof community facilties (WHCA, Fire Station) No longer effective if 1st floor impacted by flooding (Threshold is WSE >3 ft above grade)					2022	2022-2050	2050-2070	n/a
Develop living shoreline at Bar Neck Rd approximately 3ft above low spot to preserve harbor views.					2050	2050-2070	2070+	n/a
Dry floodproofing (scientific & sewer pump). Assume all buildings can be dry floodproof to 1% storm event. No longer effective if tidal inundation occurs					2022	2022-2100	n/a	n/a
Install Water St and Albatross Rd sidewalk/waterfront wall with rising gate at boatramp, integrated with CWATER and NOAA strategies. Assume wall is 3ft starting at ~6.5 ft NAVD88 and tied to high point north of NOAA cottage.					2022	2022-2050	2050-2070	n/a
Elevate NOAA bulkhead to reduce tidal inundation impacts.					2070	-	-	2070+
Elevate Waterfront Park with alignment to NOAA parcel. Assume two 24" tiers in park elevation to maintain sightlines bringing elevation to ~12 ft NAVD88.					2022	2022-2070	2070+	n/a
Elevate Water St and Albatross St no higher than 9.5 ft NAVD88.					2022	2022-2050	2050-2070	2070+
Elevate mechanical equipment and reprogram 1st floors to accommodate flooding (scientific). Assumes 1st floors are 10ft high on ~6.5 ft NAVD88 decks. Not impacted until WSE of ~16.5 ft NAVD88 and no longer effective if tidal inundation occurs					2022	2022-2100	n/a	n/a
Move non-water dependent science operations, undevelop facilities and expand elevated Waterfront Park.					2022	2022-2070	2070+	n/a

A range of potential adaptation actions were explored for the Waterfront management area. These strategies are detailed in Table 9 and summarized spatially in Appendix B. Vulnerability in the Waterfront management area is related to direct exposure to Great Harbor and some potential flood conveyance from overtopping along Eel Pond. Given the developed nature of the Waterfront area, mostly comprised of bulkheaded shoreline, sea level rise is not generally a concern except for NOAA's working deck/parking area in the long-term. The strategies investigated for this area included deployable barriers, wet floodproofing (non-residential), elevated coastal bank features, constructed walls or ground, dry floodproofing (non-residential), elevating structures, and relocating non-water dependent research activities.

4.2.7 Juniper Point

Table 10. Potential adaptation strategies for Juniper Point management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% storm protection	Reduced Storm Protection	Tidal Effectiveness
Deployable flood protection strategies for low lying homes, bikepath at Crane Rd, Luscombe/Railroad Ave	■				2022	2022-2050	2050-2100	n/a
Wet floodproof low lying homes. No longer effective if 1st floor impated by flooding (Threshold is ~18" above grade)	■				2022	2022-2030	2030-2050	n/a
Beach nourishment and dune enhancement at Hinkley Rd. Existing high spot on dune is ~6.5 ft NAVD88. Not much room to do more.		■			2022	-	2022-2030	2030-2100
Dry floodproof USCG and Commerical structures. Assume all buildings can be dry floodproof to 1% storm event. No longer effective if tidal inundation occurs			■		2022	2022-2070	n/a	n/a
Elevate seawalls (residential) & **bulkheads** (USCG, SSA, commercial), including roads (Little Harbor and Hinckley). Elevate seawall/bulkheads no more than 3 ft to reach ~7ft NAVD88.			■		2022	-	2022-2070	2070-2100
Elevate roads (Little Harbor Rd, Hinckley Rd, Luscombe Ave, Railroad Ave). Tie in to existing high ground at ~9ft NAVD88			■		2022	2022-2030	2030-2070	2070+
Elevate structures (USCG, commercial, residential) no more than 10 ft above ground level.				■	2022	2022-2070	n/a	n/a
Reroute Little Harbor Rd and Hinckley Rd. Connect using high spine of the point south of Juniper Pt. Limited by 11 ft NAVD88 elevation near perched wetland.				■	2022	2022-2050	2050+	n/a
Pull development from waterfront back to Luscombe Ave and created tiered resilient open space on water side				■	2070	2070+	n/a	n/a

A range of potential adaptation actions were explored for the Juniper Point management area. These strategies are detailed in Table 10 and summarized spatially in Appendix B. Vulnerability in the Juniper Point management area is related to direct coastal inundation at low-lying portions of the peninsula, primarily the USCG station on Little Harbor, low-lying segments of Hinckley Road, and the commercial corridor along Great Harbor south of the drawbridge. Storm exposure is expected to increase with climate change, and tidal inundation is a concern for Hinckley Road, USCG and a few Luscombe Avenue commercial properties in the long-term. The strategies investigated for this area included deployable barriers, wet floodproofing (residential), elevated dune features, constructed walls or ground, dry floodproofing (non-residential), elevating structures, rerouting roads and potential (limited) long-term retreat.

4.2.8 Nobska Point

Table 11. Potential adaptation strategies for Nobska Point management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% Storm Protection	Reduced Storm Protection	Tidal Effectiveness
Coordinate deployable flood protection strategies for low lying homes	■				2022	2022-2050	2050-2100	n/a
Wet floodproof low lying homes. No longer effective if 1st floor impated by flooding (Threshold is ~18" above grade)	■				2022	2022-2030	2030-2070	n/a
Coastal bank and dune enhancement to ~10 ft NAVD88 to tie into existing neighborhood high spots at Nobska Beach and Lower Nobska Rd.		■			2022	2022-2050	2050-2100	2100+
Elevate Church St and lower Nobska Rd to ~10ft NAVD88 tying into existing road high spots.			■		2022	2022-2050	2050-2100	2100+
Reroute Nobska Rd to higher ground for reducing storm impacts. Assumes moving west to meet 14ft NAVD88 grade from Nobskat Point. Still requires a bridge or elevation to connect north area over wetland.				■	2022	2022+	n/a	n/a
Move low lying outbuildings landward to eliminate tidal inundation impacts.				■	2070	-	-	2070+
Elevate low lying homes to no more than 10 ft above grade.				■	2022	2022-2070	2070+	n/a

A range of potential adaptation actions were explored for the Nobska Point management area. These strategies are detailed in Table 11 and summarized spatially in Appendix B. Vulnerability in the Nobska Point management area is related to direct coastal inundation at low-lying portions of the peninsula, primarily through the coastal ponds on either side of the point. Storm exposure is expected to increase with climate change, and tidal inundation is not generally a concern for the area except a few small low-lying outbuildings in the long-term. The strategies investigated for this area included deployable barriers, wet floodproofing (residential), elevated dune and coastal bank features, constructed ground, dry floodproofing (non-residential), elevating or moving structures, and rerouting roads.

4.2.9 Fay Road

Table 12. Potential adaptation strategies for Fay Road management area.

Potential Adaptation Action	Theme				Estimated Time Frame			
	Maintain	Nature-Based	Protect/ Connect	Adaptive Realignment	Initiate Strategy	1% Storm Protection	Reduced Storm Protection	Tidal Effectiveness
Coordinate deployable flood protection strategies for low lying homes	X				2050	2050-2100	2100+	n/a
Wet floodproof low lying homes. No longer effective if 1st floor impated by flooding (Threshold is ~18" above grade)	X				2050	2050-2070	2070+	n/a
Coastal bank and dune enhancement to ~15 ft NAVD88 to tie into existing neighborhood high spots		X			2050	2050-2100	2100+	n/a
Construct a ~5 ft landscape berm or terrace to tie into existing neighborhood high spots currently at ~10 ft NAVD88.			X		2050	2050-2100	2100+	n/a
Elevate roadway to ~15ft NAVD88 tying into exsiting high grade areas along Fay Rd.			X		2050	2050-2100	2100+	n/a
Elevate low lying homes to no more than 10ft above ground level.				X	2070	2070-2100+	n/a	n/a

A range of potential adaptation actions were explored for the Fay Road management area. These strategies are detailed in Table 12 and summarized spatially in Appendix B. Due to the elevated nature of most of the Fay Road management area, adaptation strategies focused on a few potentially exposed properties and a low-lying segment of northern Fay Road. This area is projected to experience increasing storm surge inundation, but tidal inundation is not a concern. The strategies investigated for this area included deployable flood barriers, wet floodproofing (residential), elevated dune and coastal bank features, constructed ground, and elevating structures.

5.0 DEVELOPMENT OF DYNAMIC ADAPTATION PATHWAYS

Following development and evaluation of the range of adaptation options, the next step in the planning process was to begin the exploration of potential phasing of strategies with dynamic adaptation pathways. Dynamic adaptation pathways planning is an approach for exploring and sequencing adaptation options over time in a way that acknowledges deep uncertainty (deficiency of agreement on or knowledge of how likely various future scenarios are) in climate projections, and allows decision makers to establish a flexible plan that achieves community goals while being responsive to changing conditions/projections.

This framework enables communities to prepare a range of responses to potential future conditions, while preparing to implement solutions (or change approach) informed by tipping points and knowledge of the capacity of each adaptation option.

5.1 DYNAMIC ADAPTATION PATHWAYS

Dynamic adaptation pathways can provide a unique and powerful visualization of the potential adaptation actions previously presented in this study, including the range of potential actions available to reduce the flood vulnerability of a particular asset or group of assets, key water level and temporal thresholds, and decision points. While these dynamic adaptation pathways figures appear complex, once understood, they can be valuable decision tools.

A key to interpreting the dynamic adaptation pathways figures is presented in Figure 13. The pathways associated with each action are color-coded by theme (Maintain Character = purple, Nature-based Focus = green, Protect/Connect = orange, Adaptive Realignment = blue). As you move left to right along a pathway for a particular action, at key time steps you will encounter a "transfer station." These transfer stations represent decision points and opportunities to transition or shift to a different action (i.e., move up or down along one of the vertical paths when a change in approach is decided upon due to variations in community desires, climatic conditions, or overall municipal policies).

In many cases, the most beneficial and cost-effective approach to protecting an asset is to phase in different actions over time or consider shifting the use of a specific asset over time. Rising water levels prompt additional actions or an alteration in the way an asset may be used in the future. Actions that are effective for addressing the projected 1% WSE are indicated by a thick solid colored line. In some cases, an adaptation may not provide the same amount of storm protection over time; therefore, the diagram may transition to a thick dashed colored line (indicative of reduced storm performance). Although these transitions to reduced levels of protectiveness indicate changes in performance, they still represent choices for adaptation planning and are marked by transfer stations on the diagram. If the community decides that a reduced state of performance is not acceptable for a certain asset or group of assets, it can choose an alternate path (another adaptation strategy) that satisfies community goals (if available).

Admittedly, adaptation actions cannot solve every flooding problem for all potential future storm surge water levels. Tipping points, when an action can no longer function as intended, are indicated by a black vertical bar. When this occurs, the thick solid or dashed colored line representing an action will either end at that tipping point terminal (i.e., that action is no longer effective), or the line will continue past the tipping point terminal as a thin dashed line. The thin dashed line in this case indicates a change in function for that action – the action is able to provide a solution for tidal inundation. For example, an action that originally provided protection from storm damage flooding in the 2030 or 2050 timeframe, may only provide protection from daily tidal flooding in the more distant future as water levels increase.

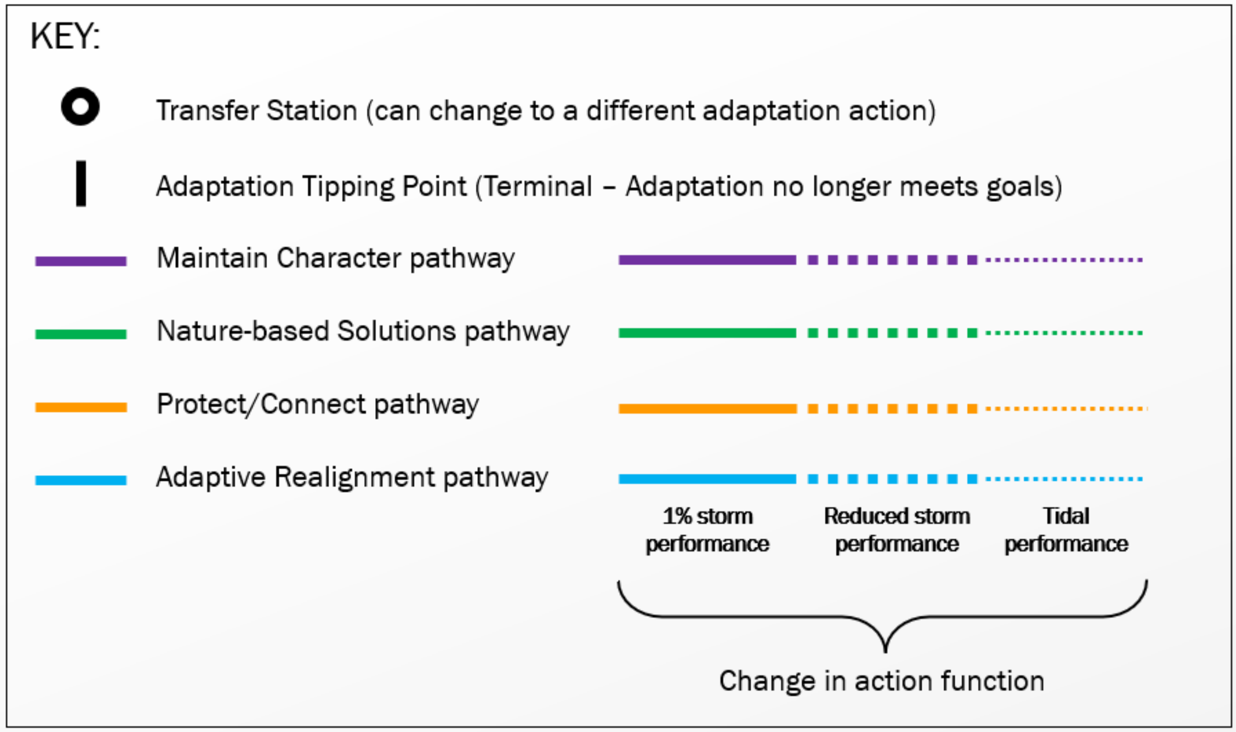


Figure 13. Key to interpreting Dynamic Adaptation Pathways

Another feature to consider when interpreting the dynamic adaptation pathways figures is whether a path is light (partially transparent line) or bold (fully opaque). Pathways depicted as partially transparent lines are technically possible but either not yet required (due to the contemporaneous flood exposure profile) or not recommended. This will occur if an action is unwarranted at a particular water level. For example, one could implement wet or dry floodproofing measures in a building with moderate elevation in 2030, but it would be an unjustified expense if the projected 1% WSE does not expose the structure until 2070. These paths could still be selected at an earlier time than required; however, if sea level rise does not occur at the rate projected, then this adaptation may not ever be required. However, if there is high confidence that a change is needed, then perhaps following a lightly shaded line is a proactive adaptation that may be warranted (in these situations, careful alignment of the design life of the adaptation with the projected exposure period is important).

Finally, at the bottom of each figure are three threshold lines (Figure 14): the amount of sea level rise in feet; and at what outyear that amount of sea level rise is expected to occur given a high sea level rise scenario (i.e., RCP 8.5) or an intermediate sea level rise scenario (i.e., RCP 4.5). The bottom two lines provide a range of actionable timelines for when each action may be needed and effective. The top line, indicating the total amount of sea level rise in feet, can be compared to actual measured water levels over time to track whether climate change impacts are proceeding closer to the high or intermediate-low scenario. Based on actual water level trends, planned timeframes for implementation can be adjusted accordingly. For the purposes of the discussion below, however, all timelines will be discussed related to the high sea level rise projections (RCP 8.5) in terms of out years.

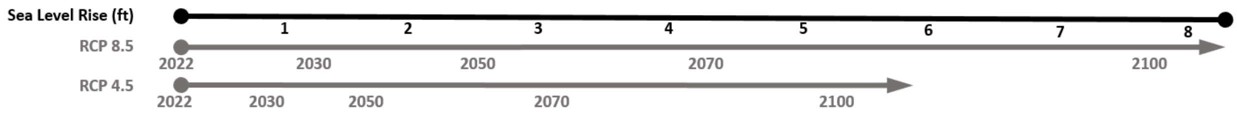


Figure 14. Key for interpreting actionable timelines for each adaptation pathway.

5.2 DYNAMIC ADAPTATION PATHWAYS BY MANAGEMENT AREA

Potential adaptation actions for each coastal management area (presented in Section 4.2) were then developed in diagrammatic form. The following sections show the dynamic adaptation pathways diagrams that resulted from the development and analysis of strategies.

5.2.1 Gansett

The range of viable options for the Gansett management area to address flooding concerns is diagrammed in Figure 15.

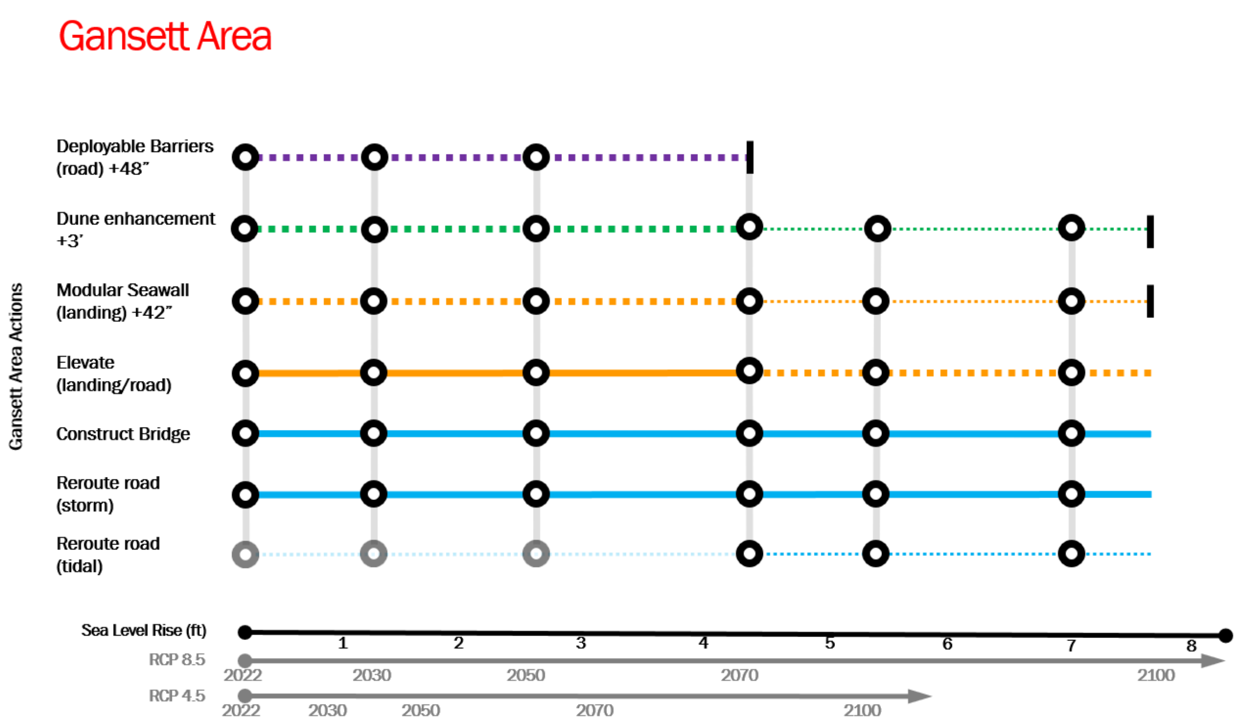


Figure 15. Dynamic Adaptation Pathways for Gansett management area.

A potential pathway to address storm flooding concerns at lower Gansett Road could be:

- 2022: deployable barriers
- INTERIM: design/permitting/implement next phase

- 2030: dune enhancement to provide moderate storm protection
- INTERIM: design/permitting/implement next phase
- 2070: elevate landing and road segment to provide moderate storm protection

5.2.2 Mill Pond

The range of viable options for the Mill Pond management area to address flooding concerns is diagrammed in Figure 16.

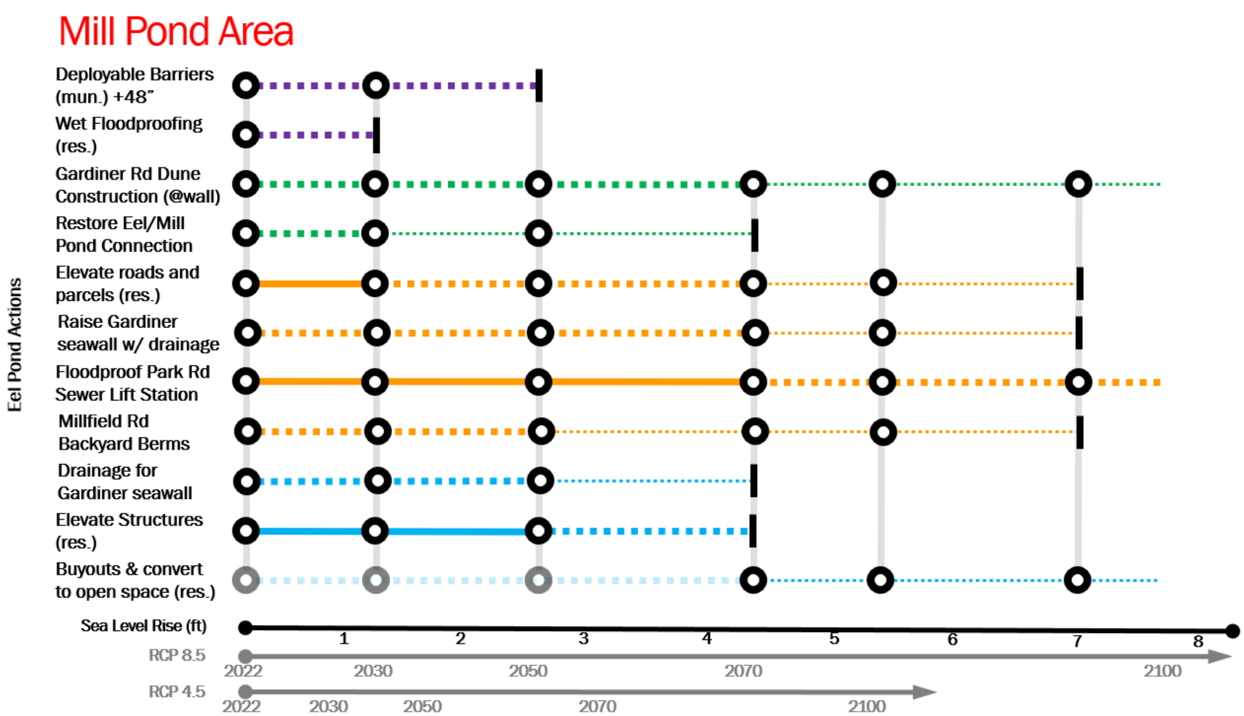


Figure 16. Dynamic Adaptation Pathways for Mill Pond management area.

A potential pathway to address storm flooding concerns (and later only tidal flooding concerns) at Mill Pond low-lying homes could be:

- 2022: deployable barriers
- INTERIM: design/permitting/implement next phase
- 2030: raise Gardiner Road seawall and install drainage
- INTERIM: ensure concurrent solutions for Spencer Baird and Eel Pond pathways
- 2100: buyouts and convert to open space

5.2.3 Spencer Baird

The range of viable options for the Spencer Baird management area to address flooding concerns is diagrammed in Figure 17.

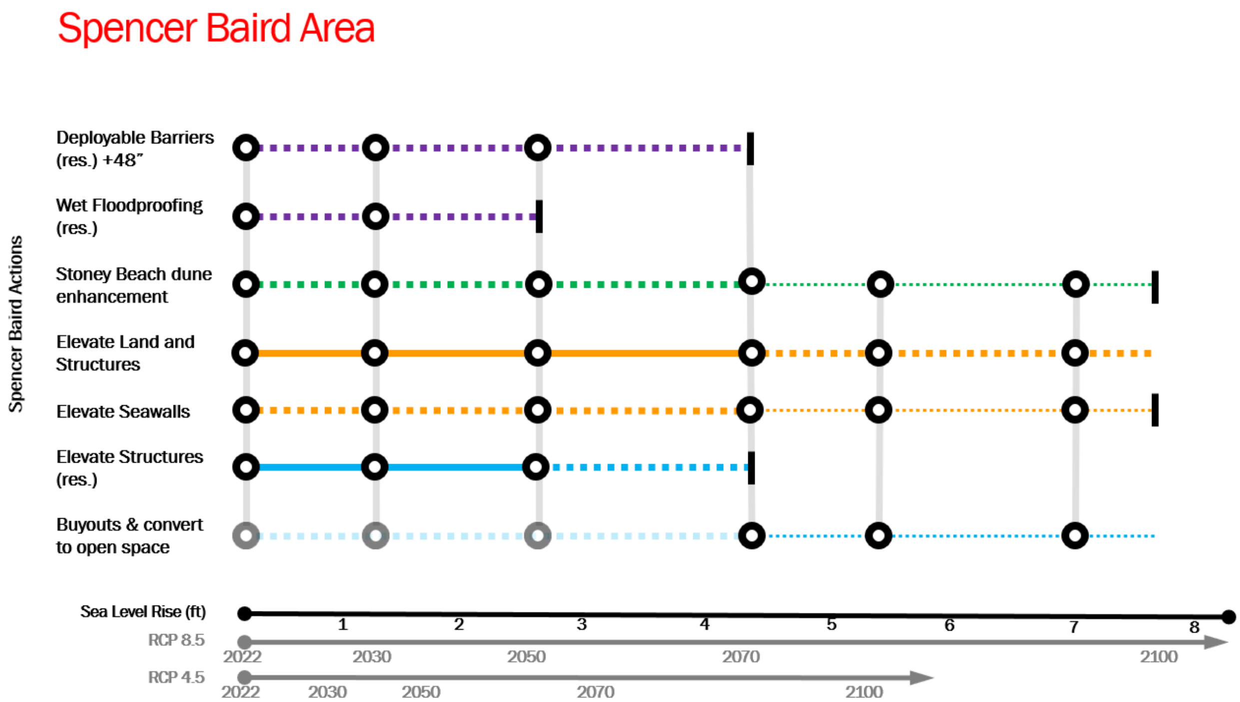


Figure 17. Dynamic Adaptation Pathways for Spencer Baird management area.

A potential pathway to address storm flooding concerns (and later only tidal flooding concerns) at Spencer Baird low-lying homes could be:

- 2022: deployable barriers
- INTERIM: design/permitting/implement next phase
- 2030: Elevate structures
- INTERIM: ensure concurrent solutions for Mill Pond and Eel Pond pathways
- 2070: Stoney Beach dune enhancement

5.2.4 Penzance Point

The range of viable options for the Penzance Point management area to address flooding concerns is diagrammed in Figure 18.

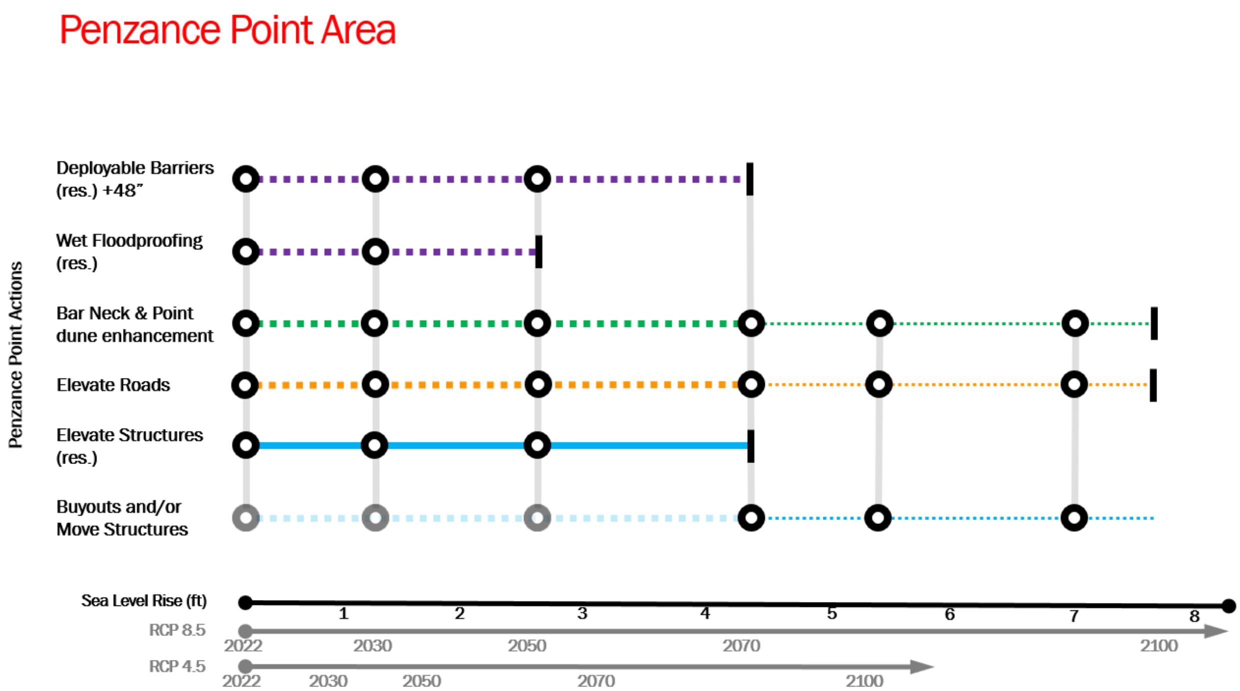


Figure 18. **Dynamic Adaptation Pathways for Penzance Point management area.**

A potential pathway to address storm flooding concerns (and later only tidal flooding concerns) at Penzance Point low-lying homes could be:

- 2022: wet floodproofing
- INTERIM: design/permitting/implement next phase
- 2030: Elevate structures
- 2070: buyouts and convert to open space

5.2.5 Eel Pond

The range of viable options for the Eel Pond management area to address flooding concerns is diagrammed in Figure 19.

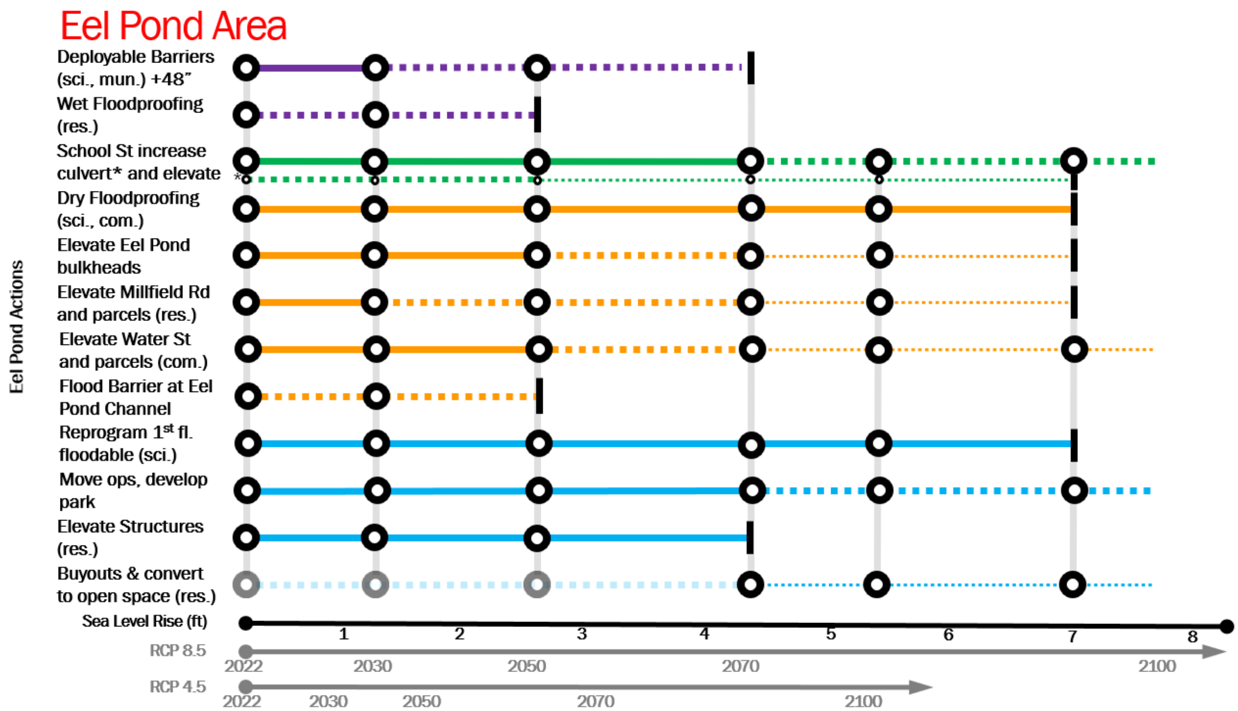


Figure 19. Dynamic Adaptation Pathways for Eel Pond management area.

A potential pathway to address storm and tidal flooding concerns at Eel Pond low-lying scientific facilities could be:

- 2022: deployable barriers or wet floodproofing (depending on facility exposure)
- 2050: dry floodproofing
- INTERIM: design/permitting/implement next phase
- 2070: elevate Eel Pond bulkhead

5.2.6 Waterfront

The range of viable options for the Waterfront management area to address flooding concerns is diagrammed in Figure 20.

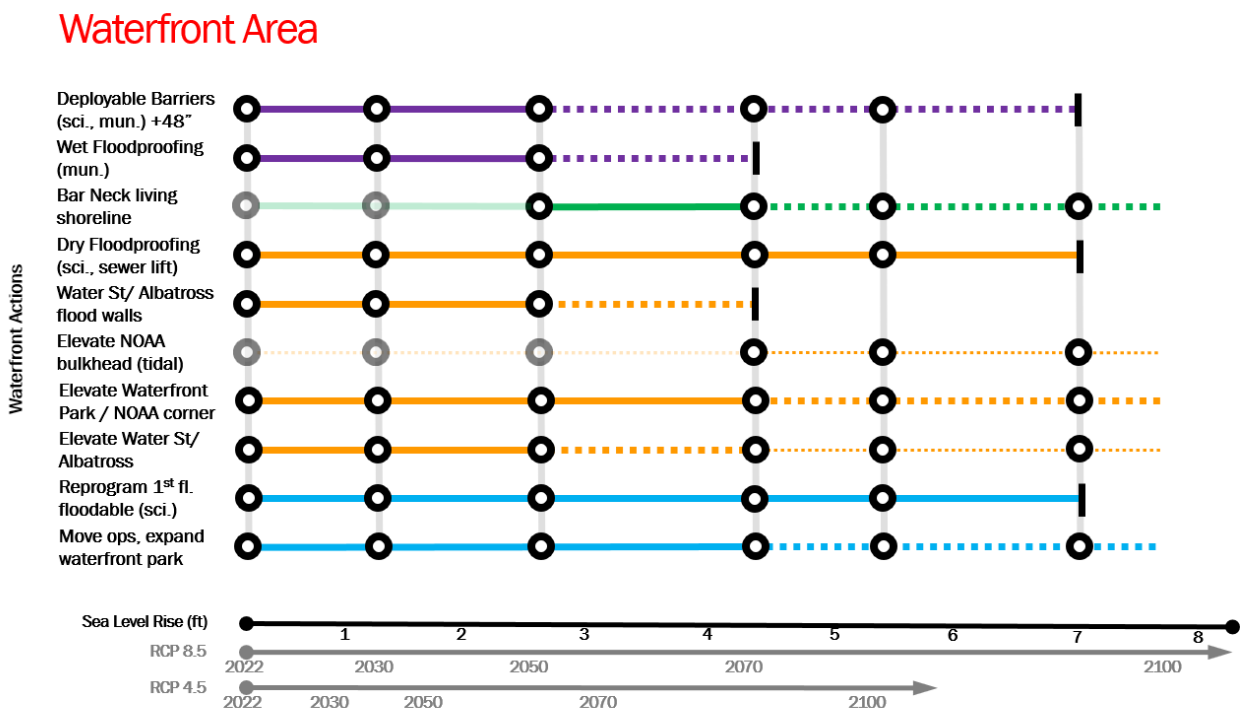


Figure 20. Dynamic Adaptation Pathways for Waterfront management area.

A potential pathway to address storm and tidal flooding concerns at Water Street and Albatross Street could be:

- 2022: design/permitting/implement next phase
- 2030: flood walls and integrated deployables
- INTERIM: design/permitting/implement next phase
- 2070: elevate roadways

5.2.7 Juniper Point

The range of viable options for the Juniper Point management area to address flooding concerns is diagrammed in Figure 21.

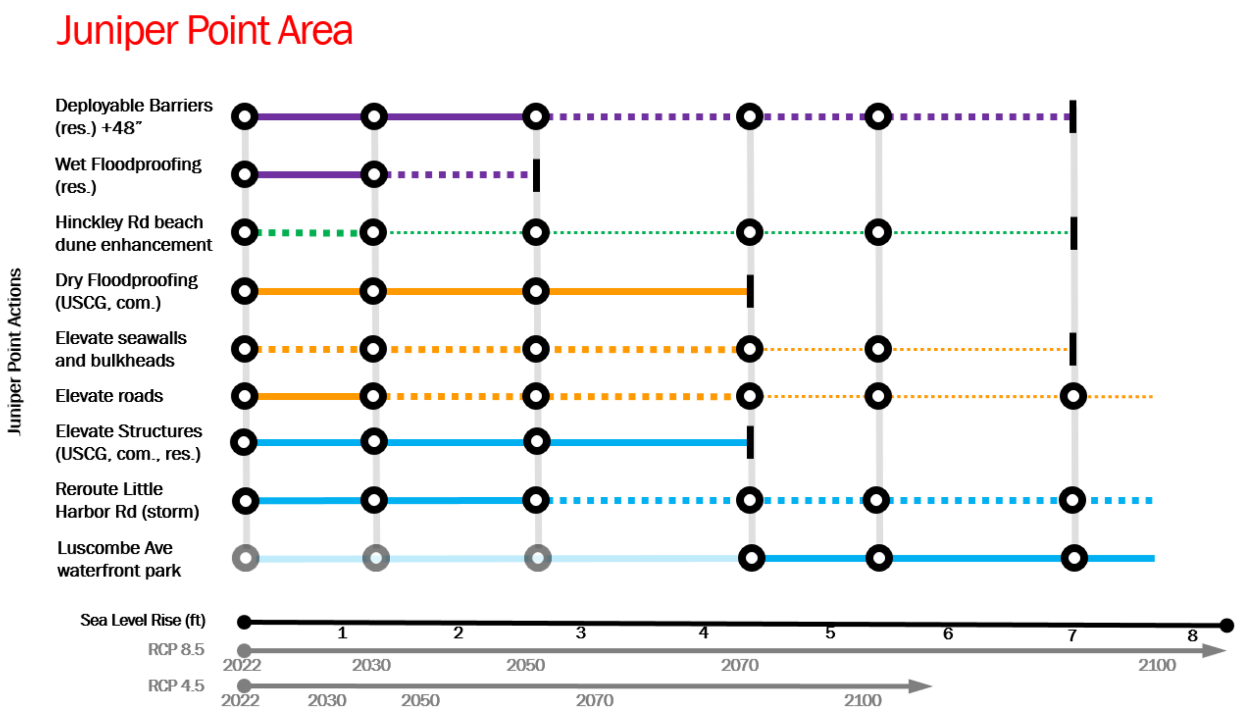


Figure 21. Dynamic Adaptation Pathways for Juniper Point management area.

A potential pathway to address storm and tidal flooding concerns at the non-elevated USCG Woods Hole Station buildings could be:

- 2022: deployable barriers
- 2030: dry floodproofing maintenance hangars, elevate other facilities
- INTERIM: design/permitting/implement next phase
- 2070: elevate bulkhead

5.2.8 Nobska Point

The range of viable options for the Nobska Point management area to address flooding concerns is diagrammed in Figure 22.

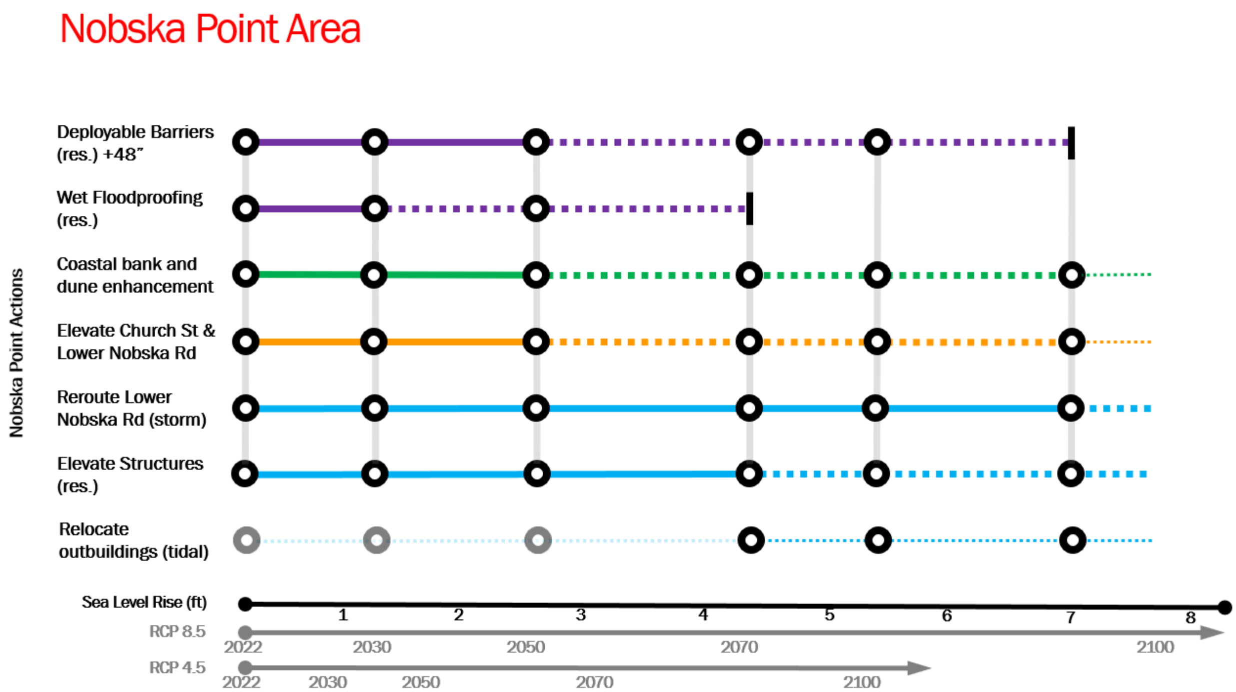


Figure 22. Dynamic Adaptation Pathways for Nobska Point management area.

A potential pathway to address storm (and eventual tidal) flooding concerns at the Church Street causeway between Nobska Pond and Nobska Beach could be:

- 2022: no action (reroute traffic in event of a storm)
- INTERIM: design/permitting/implement next phase
- 2030: coastal bank and dune enhancement in front of Church Street causeway
- 2050: renourishment as needed
- 2070: renourishment as needed

5.2.9 Fay Road

The range of viable options for the Fay Road management area to address flooding concerns is diagrammed in Figure 23.

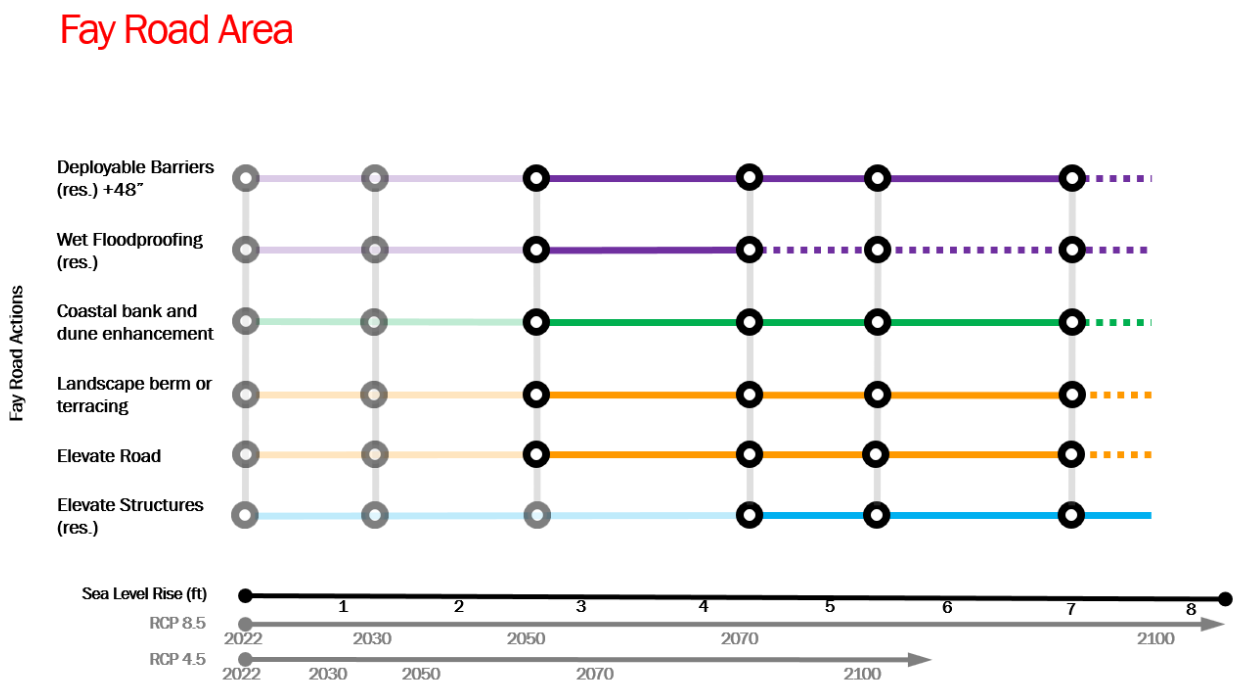


Figure 23. Dynamic Adaptation Pathways for Fay Road management area.

A potential pathway to address storm flooding concerns at Fay Road homes could be:

- 2022: no action required
- 2030: no action required
- 2050: wet floodproofing
- INTERIM: design/permitting/implement next phase
- 2070: install protective landscape berms
- INTERIM: design/permitting/implement next phase
- 2100: elevate structures

5.3 COMMUNITY WORKSHOP #2

The Phase 3 Community Vision Workshop #2 was scheduled for May 19, 2022 as an in-person workshop at the Gus Canty Community Center in Falmouth, MA. The intention of the workshop was to present an executive summary of the extended vulnerability assessments, introduce adaptation concepts and explain the use and function of the Dynamic Adaptation Pathways developed for Woods Hole. The workshop concluded with rotating stations where attendees could investigate and provide feedback on adaptation strategies for each management area.

As part of the rotating stations, attendees used feedback forms to indicate whether they were residents or business owners in each specific area and if they approved or disapproved of each adaptation strategy for each management area. Lastly, attendees were encouraged to provide comments and/or present new alternative strategies not yet identified.

In general, most attendees favored Maintain and Nature-Based themed adaptation strategies while Adaptative Realignment strategies like buyouts and elevating structures were less favorable. The Mill Pond Management area had the most participant feedback and attendees gave mostly approval ratings for all strategies developed for Mill Pond.

Appendix C contains the feedback summary results and scanned copies of all feedback forms for each management area.

Following the workshop, feedback and/or suggestions for alternative adaptation strategies were incorporated into the final version of the adaptation strategy tables, thematic maps, and Dynamic Adaptation Pathway diagrams.

The materials used for the Community Workshop including the thematic maps, Dynamic Adaptation Pathway diagrams, and feedback forms were uploaded to ResilientWoodsHole's website: Community Workshop #2 Materials. This gave and will continue to give stakeholders who could not attend the workshop the opportunity to provide comments and feedback on the various adaptation strategies.

6.0 ADDITIONAL CONSIDERATIONS

During the adaptation pathways planning process, stakeholders stated various concerns about climate-related hazards and impacts that were outside the scope of this assessment. Although these potential impacts could not be formally analyzed in the current assessment, the project team felt these concerns – which revolved around utilities – were important to include in this planning document since they have a direct link to the daily livability and resilience of Woods Hole over the long-term.

6.1 WASTEWATER

There are two types of systems for dealing with wastewater present in Woods Hole – sewer and septic. Both are potentially impacted by climate change and present a risk to Woods Hole.

In general, Woods Hole's already low-lying residential areas and Village commercial/ institutional properties are connected to the sewer system. This system includes municipal lift stations at Park Road, Water Street, and a private pump station at the Coast Guard station. All sewage is conveyed through this system to the force main that runs along the bike path from Woods Hole towards the Palmer Avenue lift station. Climate related concern for the long-term viability of this system include storm surge vulnerabilities of the lift stations in Woods Hole as well as system infiltration (from rising groundwater tables, increased precipitation-based flooding and increased coastal storm surge) through defects in pipes, unsealed manholes or illegal connections. Through a MVP Action Grant, Town of Falmouth is concurrently investigating options for adapting lift stations to current and future coastal storm surge via floodproofing or elevation, and considering alternatives for converting the low-lying residential area around Mill Pond (that relies on the Park Road lift station) to a low pressure system with grinder pumps (which has other resiliency concerns due to reliance on electricity for operation). It is recommended that additional system analysis consider long-term sea level rise and its impact on groundwater elevation, sewer system infiltration, and general neighborhood viability as plans and investments are made in system adaptation. Over the long-term, sea level rise may render some of the lowest lying residential areas in Woods Hole uninhabitable, depending on pathways ultimately selected for these areas. If this occurs, then the sewer system in these areas would likely be abandoned and further upgrade unnecessary.

Upland residential areas outside the Village and low-lying Mill Pond areas (including Gansett Point, Penzance Point, most of Juniper Point, Nobska Point, and the Fay Road area) rely on individual septic systems. These systems have a variety of impacts on the coastal environment and their function can be impaired by rising groundwater levels. Some low-lying homes not already part of the sewer system may be impacted by rising groundwater levels and possibly even saltwater infiltration. Future options may include connection to the sewer system (though the Town is presently limited by capacity and discharge permits) or conversion to tight tanks. Further analysis of the potential for sea level rise to alter groundwater levels and impact these systems will be helpful for long-term planning. Septic systems in the elevated portions of Woods Hole not at risk to coastal inundation or groundwater rise may not need to convert for resiliency reasons, but the Town's ongoing work with respect to water quality may eventually necessitate conversion to alternative septic systems or connection to an expanded sewer system.

6.2 STORMWATER

Stormwater drainage infrastructure exists throughout much of the Woods Hole area, especially in the more densely developed Village area. For upland components of this drainage infrastructure (generally composed of catch basins, pipes and leaching pits), the primary climate related impact will be increased loading from larger precipitation events (heavy rainfall). If the leaching pits also intersect with areas of rising groundwater levels, drainage capacity may be further impacted and some roads/properties may flood with stormwater.

For those stormwater components near the coast connecting to outfalls on Eel Pond, Great Harbor or Little Harbor, storm surge and sea level rise may further impact drainage capacity. If water levels associated with coastal storms or tidal conditions create tailwater conditions at these outfalls with sufficient hydraulic head, there may be stormwater backups in these more developed areas of the Village as well.

Further assessment of projected future precipitation, and its interaction with the stormwater system and (where relevant) coastal water levels will help Woods Hole plan for this climate impact.

6.3 DRINKING WATER

The Town of Falmouth supplies drinking water to all developed properties in Woods Hole. Water supply comes from upland reservoirs and wells, which have not been projected to be exposed to coastal inundation or saltwater intrusion. The distribution system of water mains and private connection lines is, however, potentially vulnerable to seepage and corrosion from exposure to increasing salinity and rising groundwater levels in the low-lying coastal areas. Further investigation of rising groundwater tables and saltwater intrusion will inform planning and adaptation in this regard.

6.4 NATURAL GAS

While heating fuels such as oil and propane are locally delivered and the storage tanks can generally be integrated into building level flood protection strategies, natural gas is distributed by a private utility through a system of pipelines (which are generally underground at the local scale). National Grid was not engaged in this project but should be consulted regarding future resiliency work in Woods Hole. Natural gas lines buried underground in low-lying areas of Woods Hole may be subject to more frequent exposure to inundation, including salt water, as groundwater tables rise. As with other underground infrastructure discussed above, further investigation of rising groundwater tables and saltwater exposure will be helpful for planning and adaptation.

6.5 ELECTRICITY

Electricity is also distributed by a private utility. Eversource was not engaged in this project but should be consulted regarding future resiliency work in Woods Hole. The system for electrical distribution in Woods Hole primarily consists of overhead power lines. The project team was not aware of any substations in the potentially vulnerable coastal portions of Woods Hole, so the primary known hazard that frequently affects power supply is wind and subsequent tree damage. Downed trees and power outages often coincide with coastal storms (which are projected to increase in frequency and intensity with climate change), but can also occur under other high wind conditions in this region. The project team was made aware of ongoing discussions between Eversource, WHOI and MBL regarding improving power reliability and recovery times for Woods Hole. As this work evolves, short term reliability gains may be realized by enhanced tree trimming, but the community can also investigate the potential for generators, renewables and/or microgrids to bolster resilience.

7.0 NEXT STEPS FOR ADAPTATION PATHWAYS

Given the size, complexity, and number of different types of assets to consider in an adaptation pathways planning project for a neighborhood, the project team concluded that even after significant outreach and engagement via public survey, stakeholder interviews and two public workshops, the project and all the potential adaptation actions/phasing/pathways require additional evaluation, and community vetting/discussion. The community and steering committee acknowledged this work is the beginning of a long process of engagement and discussion, overlayed by an adaptive management approach whereby adaptation approaches can and should respond to changing conditions. It was deemed premature to select a preferred adaptation pathway for any management area or group of assets.

7.1 ADDITIONAL EVALUATION

Through this project, a range of potential adaptation actions have been developed for assets (buildings, roadways, open space and natural resources, etc.) throughout the Woods Hole study area. Potential adaptation actions in this project have been evaluated for their flood performance (1% annual chance storm, lower-level storms, tidal conditions) over time, which is a benefit documented by the timelines in the pathways tables (Tables 4-12), maps and diagrams (Appendix B).

Besides flood protection, adaptations may also have co-benefits as well as drawbacks. All potential adaptation actions will have an economic cost, which could be the responsibility of the Town or private interests, depending on the asset. To support future decision making and eventual selection of a preferred adaptation pathway, the community will need to understand all these factors in more detail.

As the project team and steering committee considers this work to be a living document, a crucial next step to facilitate community discussion and comparison of alternatives for like assets will be to develop a full matrix of benefits, drawbacks and costs for each adaptation action and potential pathway. The ResilientWoodsHole project team plans to meet regularly with representatives from each of the management areas to discuss and vet alternatives based on this information.

Table 13 and Figure 24 show examples of these evaluation tools.

Table 13. Example Adaptation Action Evaluation Matrix for Spencer Baird Management Area.

Potential Actions	Theme	Estimated Cost	Target Effects	Drawbacks
Coordinate deployable flood protection strategies for low lying homes and identify location for communal storage		+	Maintains access and connectivity without altering local configuration	Not a solution for larger storms or daily flooding conditions; possible redirection of floodwaters; requires storage and coordination/timing for deployment
Wet floodproof low lying homes. No longer effective if 1st floor impacted by flooding (Threshold is ~18" above grade)		+	Reduces impacts/costs of storm damage without altering local configuration	Does not address large storm surge unless paired with elevation; may require post-storm pumpout
Beach nourishment and dune enhancement at Stoney Beach. Tie into existing neighborhood high spots of ~10 ft NAVD88.		+ +	Preserves and enhances ecosystem services and access to beach; provides protection for moderate storms and tidal flooding	Effectiveness limited by elevation of existing adjacent land; future ongoing maintenance
Elevate low lying corridor (parcels and roads) along Gosnold Rd, Spencer Baird Rd and Albatross to ~12 ft NAVD88, and rebuild homes with increased elevation		+ + + + +	Protects structures and roadways from flooding in the short- to mid-term; Maintains neighborhood access and connectivity	Expensive, impactful, logistically difficult; fill in areas subject to coastal storm flowage is discouraged by regulatory agencies
Elevate existing Buzzards Bay seawalls to ~10 ft NAVD88 tying into existing neighborhood high spots.		+ + +	Protection from smaller storms and daily flooding	Impacts coastal processes, may interrupt ocean views, may require maintenance in high energy settings
Elevate low lying homes no more than 10 ft above ground level.		+ +	Reduces or eliminates flood risk to homes during storms	Alters community character; future tidal flooding may still impact usability
Relocate low lying homes out of tidal inundation zone, repurpose land for flood storage and resilient open space		+ + + +	Removes vulnerable assets from high-risk area; creates beneficial new use	Loss of residential neighborhood

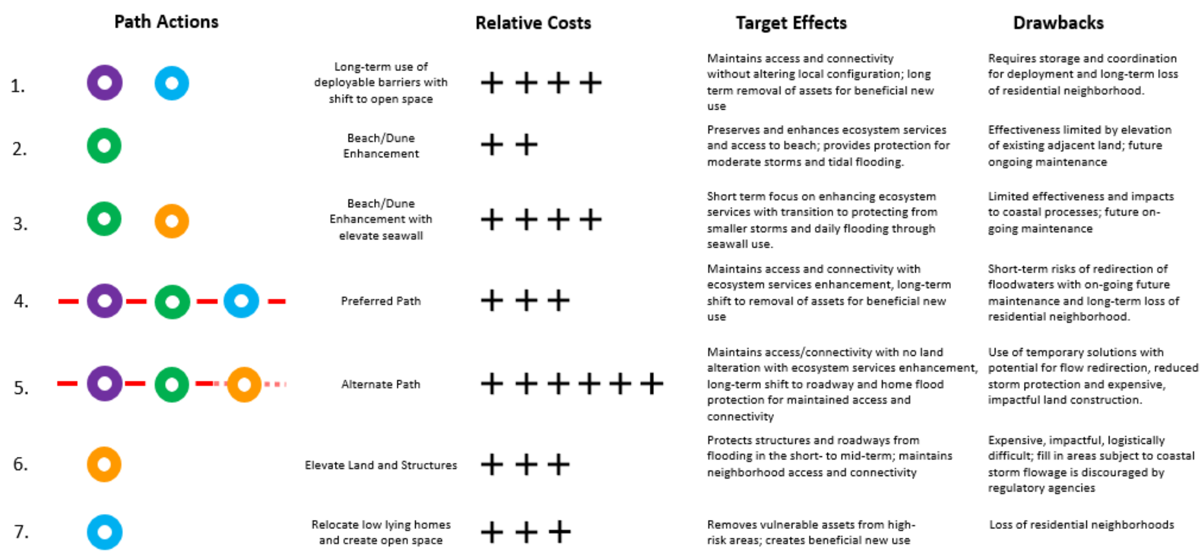


Figure 24. Example Pathways Scorecard for Spencer Baird Management Area

7.2 PHASING AND IMPLEMENTATION PLAN

Based on the additional evaluation and community conversations, a recommended phased approach will be developed for each group of assets in the management areas. This combination of actions aims to address resiliency concerns as well as community preferences over time, balancing benefits, impacts and cost. As stated before, dynamic adaptation pathways planning is designed to be an adaptive management approach to resilience. Therefore, even if a phasing and implementation plan (with preferred pathway) is selected, there may be alternates or adjustments to the strategy over time based on evolving conditions and changing community goals.

A recommended phased approach will not imply approval of or commitment to implement these actions by the Town or private entities, but rather an outline for achieving a stated vision of resilience over time in Woods Hole. Bas ed on the mix of public and private actions required for this area, funding mechanisms will need to be explored. Preliminarily, these could include grants, bonds, municipal capital expenditures, institutional capital expenditures, private investment, public-private partnerships, and perhaps the creation of tax increment financing zone for coastal resilience.

This study is intended to provide Woods Hole with a series of alternatives to consider. It should also be noted that although estimated time frames for action are presented here, these are based on the future water levels projected under a high sea level rise scenario. While the sea level rise model used in this study is highly vetted and considered the state standard for sea level rise planning in Massachusetts, it does represent a high, and therefore rather conservative, sea level rise scenario. The project team acknowledges that sea level rise may proceed slower (or faster) in the future. For this reason, multiple timeframes (based on the RCP 4.5 and RCP 8.5 emissions projections) are presented in the pathways diagrams, in addition to thresholds based on the actual change in sea level rise that would trigger various actions. Through future monitoring of water level changes, timelines can be adjusted accordingly.

Figure 25 shows an example of a phased implementation plan.

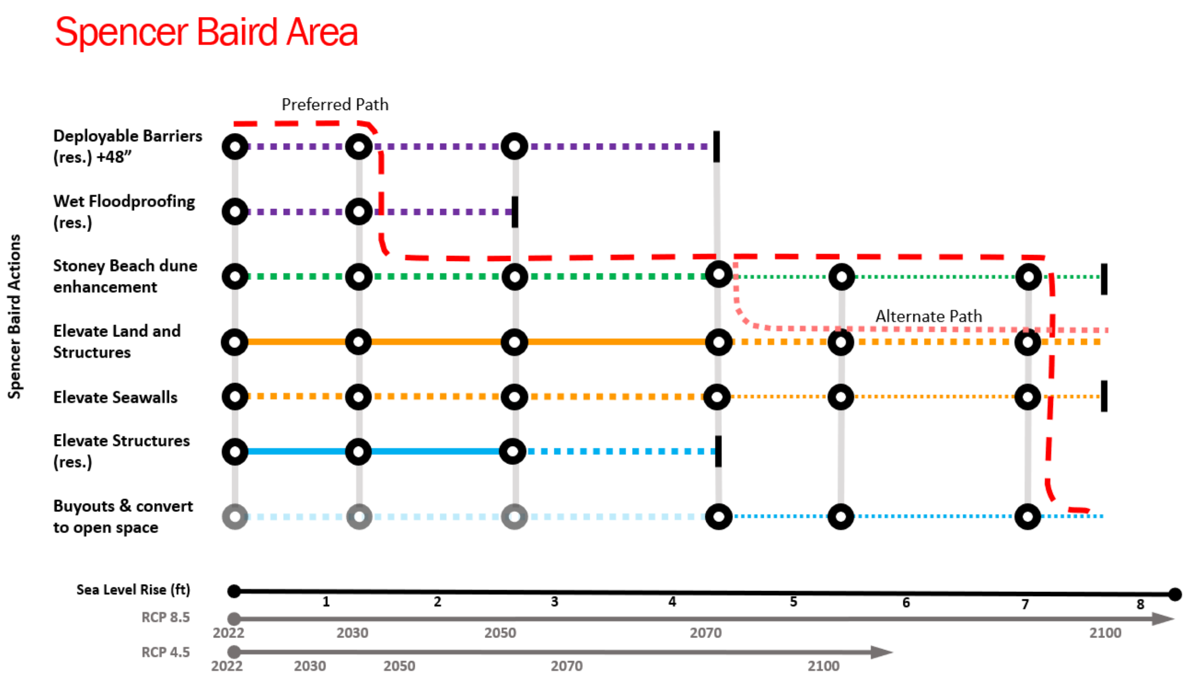


Figure 25. Example Phased Implementation Plan for Spencer Baird Management Area

8.0 NEXT STEPS FOR RESILIENTWOODSHOLE

The FY22 CZM Coastal Resilience Grant provided significant momentum to the ResilientWoodsHole initiative. In addition to the advancement of technical work and stakeholder outreach outlined in this report, ResilientWoodsHole made notable progress on partnerships with the Town and local community. Going forward, ResilientWoodsHole will continue to mature these partnerships as well as further advance the development of adaptation projects and community conversations.

WHOI, MBL and NOAA are developing a communications and engagement strategy to raise the profile of this initiative, both locally and more widely, and ensure the project's momentum and continuity. ResilientWoodsHole will build on its existing website and explore a variety of additional platforms (including local festivals, WHOI/MBL/NOAA visitor centers, social media, news outlets, public radio, academic journals, professional conferences) to reach and engage these audiences.

Project partners are recommending proactive initiatives for ResilientWoodsHole Phase 4. ResilientWoodsHole should next act on short-, mid- and long-term adaptation strategies developed in this (Phase 3) and prior phases of the project. The work ahead would address physical assets, natural resources and community engagement. Specifically, these next steps would include:

- Design, procure and deploy flood protection systems for critical high risk publicly accessible WHOI, MBL, and NOAA facilities. These no-regrets implementations could also serve as adaptation demonstration projects for the local community and other blue economy waterfronts;
- Conduct a feasibility and alternatives assessment for using nature-based solutions to address significant flood pathways affecting the Woods Hole community; and
- Continue and expand conversations with the Woods Hole business and residential community on vulnerability and adaptation by:
    - organizing regular meetings with representatives from each of the coastal management areas identified in the Phase 3 process to continue locally vetting adaptation options and implementation plans;
    - utilizing social media to reach additional stakeholders, including underserved and diverse communities;
    - creating a series of podcasts about climate vulnerabilities, resiliency efforts and opportunities in Woods Hole; and
    - producing an accessible Woods Hole Climate Walking Tour for all visitor types to physically connect with the issues facing Woods Hole.

Finally, in the context of further exploring alternatives for addressing Woods Hole's major flood pathways and sustaining community collaboration, ResilientWoodsHole should also consider further investigation of potential flood mitigation strategies for the Mill Pond Wetland Complex (some adaptation alternatives under consideration were included in the pathways for Mill Pond, Sections 4.2.2 and 5.2.2). This low-lying area is vulnerable to flooding from precipitation and coastal storms – affecting homes, roadways, MBL and St. Joseph's Church facilities, a sewer lift station and the community park. Coastal flooding in this area can come both from Buzzards Bay and from Eel Pond (overtopping Millfield Street) and can be impounded by a number of engineered structures in the area, including a seawall at Gardiner Road and multiple culverts under Gardiner Road and Millfield Street. Investigation of the potential to improve tidal flushing (and restore/improve salt marsh habitat), enhance floodwater drainage, and even reduce flooding from storm surge and wave overtopping may leverage historical hydraulic studies of the area with new information and link to more recent climate projections (used in the ResilientWoodsHole project). ResilientWoodsHole's multi-stakeholder approach provides a unique opportunity to advance conversations and study on this complex and significant flood pathway.

9.0 REFERENCES

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

Falmouth Coastal Resiliency Action Committee. 2021. Coastal Resiliency Action Committee Final Report. https://www.falmouthma.gov/1263/Coastal-Resiliency-Action-Committee-Fina.

MassDOT. 2019 (in publication). Massachusetts Coast Flood Risk Model.

Woods Hole Group. 2020a. Woods Hole Village Climate Change Vulnerability Assessment and Adaptation Plan. https://resilientwoodshole.org/wp-content/uploads/sites/44/2022/01/RWH-Phase-1-Report-WoodsHoleVillageCCVA.pdf.

Woods Hole Group. 2020b. Falmouth Climate Change Vulnerability Assessment and Adaptation Plan. https://www.falmouthma.gov/1053/Falmouth-Climate-ChangeVulnerability-As.

Woods Hole Group. 2020c. Coastal Resilience Planning for the Surf Drive Area. https://www.falmouthma.gov/1052/Coastal-Resilience-Planning-Surf-Drive-A.

Woods Hole Group. 2022. ResilientWoodsHole Phase 2 Report. https://resilientwoodshole.org/wp-content/uploads/sites/44/2022/02/ResilientWoodsHole_Phase2Report.pdf.