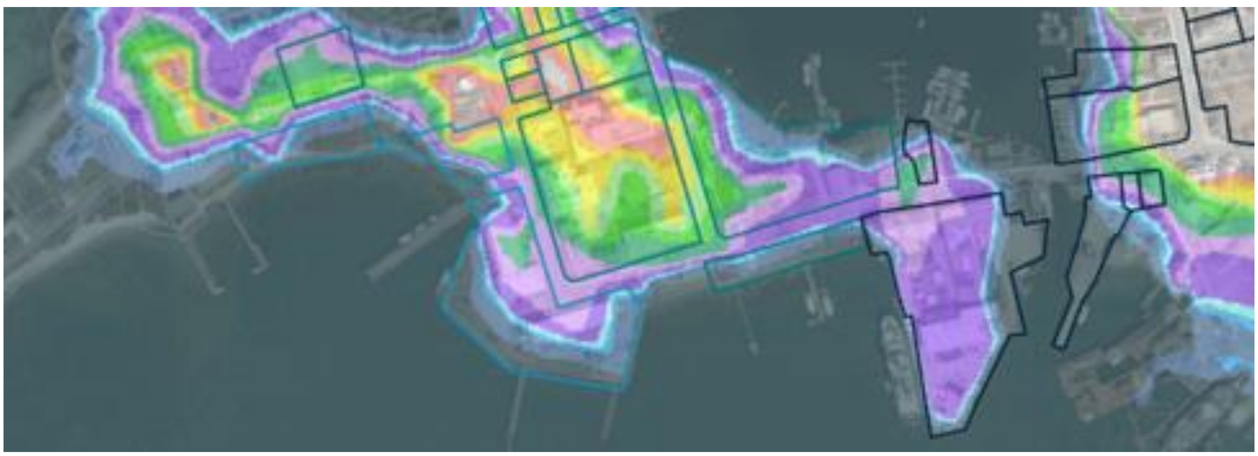
Woods Hole Village
Climate Change Vulnerability Assessment and Adaptation Plan



October 2020

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

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

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Prepared for:

Woods Hole Oceanographic Institution
86 Water Street
Woods Hole, MA 02543

Marine Biological Laboratory
7 MBL Street
Woods Hole, MA 02543

NOAA Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543

Prepared by:
Joseph Famely and Kirk Bosma, P.E.
Woods Hole Group, Inc.
A CLS Company
107 Waterhouse Road
Bourne, MA 02532 USA
(508) 540-8080

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EXECUTIVE SUMMARY

Woods Hole, Massachusetts is home to world renowned scientific organizations, a vibrant business and residential community, and serves as a vital link to Martha's Vineyard. With a mission-focused need to be proximate to the water's edge, the Woods Hole campuses of the Woods Hole Oceanographic Institution (WHOI), the Marine Biological Laboratory (MBL), and the National Oceanic and Atmospheric Administration's Northeast Fisheries Science Center (NOAA) initiated the development of a long-range framework to prepare for sea level rise and increasing extreme weather events. A cooperative effort is underway to assess these threats and jointly develop solutions which frame a range of responses for the broader Woods Hole community.

WHOI, MBL, and NOAA worked with Woods Hole Group to prepare the Woods Hole Climate Change Vulnerability Assessment and Adaptation Plan. The climate change vulnerability assessment considered both periodic and episodic impacts of sea level rise and coastal storms. Periodic impacts include nuisance flooding of developed areas and infrastructure due to the shifting tidal range, coastal wetlands migration/loss in undeveloped areas due to the shifting tidal range, and potential erosion of natural shorelines due to repetitive storm damage. Episodic impacts include risk of flooding to developed areas and infrastructure during more frequent and more intense coastal storms with greater potential for impact due to sea level rise.

Nuisance flooding was evaluated using the most up-to-date relative sea level rise projections developed for the Commonwealth of Massachusetts (DeConto and Kopp, 2017). The approach employed a probabilistic assessment of future relative sea level rise under two greenhouse gas concentration scenarios (RCP 8.5 and RCP 4.5), and two approaches for projecting ice sheet loss and its effects – expert elicitation and process-based numerical model simulations. From among four representative scenarios (Intermediate, Intermediate-High, High, and Extreme), the Commonwealth selected the "High" scenario for planning purposes. The "High" sea level rise scenario is extremely unlikely to be exceeded (99.5%) under RCP 8.5, unlikely to be exceeded (83%) under RCP 8.5 when accounting for ice sheet loss, and extremely unlikely to be exceeded (95%) under RCP 4.5 when accounting for ice sheet loss. Based on local tidal benchmark projections developed from this sea level rise scenario, institutional assets will be increasingly exposed to nuisance flooding over time (13 by 2050, 78 by the end of the century), which would significantly interfere with normal use of research facilities.

Coastal wetlands migration due to the shifting tidal range was evaluated using the statewide modeling conducted by Woods Hole Group on behalf of the Massachusetts Office of Coastal Zone Management using the Sea Level Rise Affecting Marshes Model. This model accounts for the rising tidal range and computes potential habitat change based on existing vegetation, topography, marsh accretion rates, and potential for erosion. Based on this modeling, up to 50 acres of upland area may be lost within the Woods Hole Village study area to wetland migration by the end of the century, while large expanses of existing wetlands will transition to open water north of Eel Pond. Salt marsh habitat is projected to expand in the coming decades but may give way to tidal flats and open water as sea level rise progresses past 2050.

The potential erosion of natural shorelines due to repetitive storm damage was evaluated for natural shorelines in the study area using existing rates of short-term (1978 – 2013) shoreline change produced by USGS and the Massachusetts Office of Coastal Zone Management. Future shoreline positions (2030, 2050 and 2070) were projected landward or seaward based on representative rates of erosion or accretion (respectively) from the Massachusetts Shoreline Change Project. Results of this analysis showed that current rates of shoreline change in the areas of Woods Hole's natural shorelines do not pose significant threats to infrastructure or development.

Woods Hole Group applied the storm surge projections from the Massachusetts Coast Flood Risk Model (MC-FRM) to evaluate vulnerable WHOI, MBL and NOAA assets and Woods Hole Village. MC-FRM, the standard for coastal climate change planning in the Commonwealth, was used to assess impacts under present day conditions as well as projected future storm surge inundation for 2030, 2050, and 2070. The asset-specific vulnerability assessment process implemented a risk-based approach/framework similar to the Town of Falmouth's Climate Change Vulnerability Assessment. The asset inventory documented 36 WHOI assets, 54 MBL assets and 28 NOAA assets (including buildings, parking lots, docks, docks, cranes, generators, fuel tanks and other equipment) and their critical thresholds for flooding impacts. Assets were then internally scored with a customized asset rating scheme to capture the organizational, financial and temporal impacts of flood loss as well as the relative importance of each institutional asset to achieving the mission objectives of each organization – Research & Applied Science, Operations & Economic Activity, and Education & Outreach.

The MC-FRM results and asset-specific vulnerability assessments provided a broad perspective on community impacts and an in-depth understanding of organizational impacts anticipated from climate-related coastal hazards in Woods Hole. MC-FRM projections indicate that the coastal storm surge from a 1% event in 2050 could potentially impact 80% of WHOI's evaluated assets, 87% of MBL's evaluated assets, and 93% of NOAA's evaluated assets.

Using information on asset vulnerability (probability of inundation) and importance (consequence), a risk assessment score was developed for each asset in each planning horizon (Present, 2030, 2050 and 2070). The results of the risk assessment provide a roadmap for WHOI, MBL and NOAA to strategically prioritize and implement adaptation over time, incorporating coastal resilience into long-term planning, and more immediately incorporating long-range thinking into near-term investments.

Woods Hole Group prepared adaptation and resilience plans at the asset-level, district-level, and community level to facilitate planning for future conditions in Woods Hole.

Asset-level strategies, intended to reduce flood damage to individual buildings and equipment, ranged from changes in asset operations/use, to elevating mechanical equipment, to various interventions for wet or dry floodproofing and elevating structures.

District-level strategies were developed for each organization focusing on key groups of buildings. The district-level strategies for WHOI, MBL and NOAA focus on critical campus areas and leverage modular and phased-in flood protection elements (such as modular walls, door and window barriers, deployable barriers or rising gates, and in some cases elevated decking) to achieve the tandem goals of flood protection and accessible waterfront operations.

Sea level rise and storm surge present both existential and operational threats to Woods Hole Village's marine science facilities as well as to the commercial and residential infrastructure within the Village. Often it is not viable or sustainable to adapt assets to sea level rise and/or storm surge in a vacuum. It can also be more efficient and have greater benefit to deploy adaptation solutions on a wider scale to address shared risk rather than addressing each specific flood vulnerability on a case by case basis. Considering these issues and acknowledging ongoing coastal resilience planning in the Town of Falmouth, Woods Hole Group developed three conceptual community-level strategies to explore adaptation options for Woods Hole Village along three themes: Protect / Migrate / Transform. These adaptation strategies are intended to initiate discussions and visioning exercises among the Woods Hole community and with the Town of Falmouth. Elements of each may be more practicable or desirable for different areas and stakeholders.

- The *Protect* strategy focuses on keeping storm surge and nuisance flooding out of existing developed and undeveloped areas of Woods Hole Village.

- The *Migrate* strategy condenses nuisance flooding protection into a strategic core of Woods Hole Village, while planning for phased relocation as lower lying areas transition with sea level rise.

- The *Transform* strategy reconfigures Woods Hole Village to respond to projected long-term change and aligns with existing recommendations for adaptation in the Town of Falmouth's coastal resilience program.

The Woods Hole Village CCVA documented significant vulnerability to sea level rise and storm surge among WHOI/MBL/NOAA assets as well as throughout much of the Woods Hole Village area. By design, working waterfront facilities must be constructed at the water's edge and allow for easy access to vessels as well as fixed assets. Due to the necessity of water access to support marine science and future shifts in the tidal prism, all three organizations will face operational challenges as sea level rise progresses. Over the long term, many parts of Woods Hole Village will also have to deal with nuisance flooding and habitat shifts that may make living or working in some areas difficult.

In order to adapt to climate change effectively and efficiently, it is crucial to coordinate with the Town of Falmouth's ongoing coastal resilience work. As additional planning around sea level rise and storm surge evolves throughout Woods Hole Village, it will be important to update vulnerability assessments with the best available scientific developments as they become available. This will require an exchange of information among WHOI, MBL, NOAA, the Town of Falmouth, Woods Hole Group, and the Commonwealth of Massachusetts.

The three scientific institutions that commissioned this study have a long history of observing environmental conditions and crafting management recommendations based on scientific investigation. WHOI, MBL and NOAA also have critical research efforts underway in the field of climate science. The threats of sea level rise and storm surge present an existential challenge for Woods Hole, but therein lies an opportunity to leverage scientific advancement, creativity, and cooperation for the continuance of inquiry at the water's edge and beyond.

1.0 INTRODUCTION AND PROJECT GOALS

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 Village. 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 Village more generally.

Woods Hole Group is an environmental consulting firm with roots in the Woods Hole scientific community. An outgrowth of WHOI, Woods Hole Group was formed to apply scientific principles in oceanography and coastal processes to solve on-the-ground problems, and now consists of four major business units – Environment & Climate Consulting, Sustainable Fisheries, Energy & Mining, and Satellite Telemetry. Woods Hole Group's consulting group specializes in coastal planning, climate change vulnerability assessment and adaptation planning, and modeling the risks to coastal communities and infrastructure from sea level rise and storm surge.

WHOI, MBL and NOAA commissioned Woods Hole Group to conduct this climate change vulnerability assessment (CCVA) and adaptation plan to provide data on likely scenarios and degrees of potential impact in vulnerable areas, and to assist in the development and prioritization of strategies to minimize risks to infrastructure, facilities, and the community. The specific climate-related hazards addressed in this vulnerability assessment are sea level rise and storm surge inundation, as well as related habitat change and erosion for undeveloped areas. Working with asset managers from each organization, Woods Hole Group developed asset-specific probabilistic risk assessments considering exposure to sea level rise and storm surge (using the Massachusetts Coast Flood Risk Model 'MC-FRM') and the relative importance of each asset to each research organization's operations and mission. This granular risk assessment data formed the basis of prioritization and developing adaptation recommendations.

The overall goal of the vulnerability assessment and adaptation plan is to jointly develop a suite of asset-level, district-level, and community-level strategies that can form the basis for future discussion and planning, ultimately resulting in the long-term viability and resilience of Woods Hole's scientific organizations, working waterfronts, and the community itself. Beyond the scope of this study, the vision is for WHOI, MBL and NOAA to partner amongst themselves, with other Woods Hole Village entities and organizations, and with the Town of Falmouth to keep Woods Hole working.

The CCVA was conducted by Woods Hole Group climate change planners, coastal engineers and modelers, in collaboration with representatives from facilities and operations at WHOI/MBL/NOAA. Members of the Woods Hole Village CCVA working group included:

Woods Hole Oceanographic Institution
Rob Munier - Vice President for Marine Facilities and Operations
Leslie-Ann McGee - CWATER Program Manager
Assistant Director at the Center for Marine Robotics
Rick Galat - Senior Facilities Engineer

Marine Biological Laboratory
Paul Speer - Chief Operating Officer
Marie Russell - Director of Facilities and Services

NOAA Northeast Fisheries Science Center
Nathan Keith - Research Vessel Operations Coordinator

DSK | Dewing Schmid Kearns Architects + Planners
Jim Newton - Senior Planner

Woods Hole Group
Kirk Bosma - Senior Coastal Engineer / Innovation Director
Joseph Famely - Senior Environmental Scientist

Throughout the CCVA process, the working group reviewed work products and provided input on the selection of planning scenarios, identification of assets and development of critical elevations, evaluation of asset impact consequence to the organization, and prioritization of adaptation strategies.

2.0 VULNERABILITY ASSESSMENT DATA AND METHODS

A series of analyses were conducted to determine the vulnerabilities of natural resources and institutional assets (fixed assets and facilities) to sea level rise, habitat conversion, landform change, and storm surge inundation. Different analyses were required to understand vulnerabilities of varying types of resources including wide-reaching salt marshes, working waterfront areas, and site-specific facilities and equipment.

This assessment layered state of the science climate change projections available from the Commonwealth of Massachusetts with additional locally customized analyses. These data sources and analyses are described in the following sections. The data sources for coastal wetland projections and coastal inundation projections are identical to those currently used in the Town of Falmouth's Climate Change Vulnerability Assessment (Woods Hole Group, 2020) and coastal resilience program, enabling alignment between the Town and WHOI/MBL/NOAA on climate adaptation plans.

The projections in this report are based on some of the most recent developments in the science of climate change but are not guaranteed predictions of future events. It is recommended that these results be updated over time as science, data and modeling techniques advance.

2.1 COASTAL WETLAND MODELING

Increasing water levels caused by sea level rise will be the dominant influence on the future location and condition of wetland resources. The results of this ecological assessment and modeling effort are used to answer several important questions specific to coastal marsh systems and sea level rise (independent of storm surge). For example, results are used to assess if specific marsh systems have adequate space to migrate landward in response to the changing climate or if their migration may be hampered by topographic features or infrastructure and developed areas. The results are also used to determine the timeframe that a marsh's accretion rate can no longer be expected to keep up with the rate of sea-level rise, or over what timeframe specific resource areas within a marsh are expected to transition (e.g., high marsh to low marsh, or low marsh to tidal flats, etc.) due to climate change. By identifying a likely time frame for these changes, coastal managers can plan their monitoring and conservation effects to be most effective. Additionally, these model results can be used to guide long-term institutional/campus planning to anticipate where water-dependent uses may occur in the future and where water-incompatible uses should not remain.

The assessment of natural resource impacts from sea level rise in Woods Hole Village relies on statewide modeling conducted by Woods Hole Group on behalf of the Massachusetts Office of Coastal Zone Management (Woods Hole Group, 2016), which uses the Sea Level Rise Affecting Marshes Model (SLAMM). In addition to the effects of inundation, second-order effects occurring due to changes in the spatial relationship of various coastal processes are taken into account with this type of modeling. For example, if the fetch for wind-driven waves is greater than 9 km, the model assumes moderate erosion. However, if the area is exposed to the open ocean, severe erosion of wetlands is assumed. Full discussion of marsh migration modeling methodology is provided in the statewide report "Modeling the Effects of Sea-Level Rise on Coastal Wetlands" (Woods Hole Group, 2016).

High resolution elevation data may be the most important SLAMM model data requirement, since the elevation data demarcate not only where saltwater penetration is expected, but also the frequency of flooding for wetlands and marshes when combined with tidal range data. Input elevation data also helps define the lower elevation range for beaches, wetlands and tidal flats, which dictates when they should be converted to a different land-cover type or open water due to an increased frequency of flooding. For the Woods Hole area, the 2011 USGS LiDAR flight was used. To reduce processing time within the SLAMM model, areas of higher elevation within each regional panel that are unlikely to be affected by coastal processes, such as sea level rise, were excluded prior to processing. All areas above an elevation of 60 ft. (NAVD88) were clipped from the input files.

Accretion, or the deposition and build-up of sediment, is an important process because it may help counter permanent inundation of marshes and beaches from long-term sea level rise, so the model was run in two ways:

1) In areas where there are no observed accretion data, the model is run with an accretion rate equivalent to the historic SLR rate, which is a very reasonable assumption given measured accretion rates in the mid-Atlantic and northeast.
2) In areas where there are observed accretion data, the model is run with the observed data AND with an accretion rate equivalent to the historic SLR rate.

SLAMM was intentionally run first without the limitation that impervious surfaces (roads, parking lots, etc.) would not be subject to change to see how and where the marshes and other natural resources would migrate, if there was no restriction to their migration. As such, the ecological modeling assumes that existing infrastructure may not remain in place. The mapping results therefore do not reflect certain realities. An additional post-processing step can be applied to overlay the impervious layer to indicate developed areas that are not expected to naturally transition to wetlands.

Appendix A provides the wetland classification areas for 2011, 2030, 2050, 2070 and 2100 based on the SLAMM modeling using the "High" SLR projection scenario. Existing infrastructure (impervious area) can be overlaid on the SLAMM modeling results for further analysis, since the model does not consider limits to migration imposed by existing infrastructure.

2.2 SHORELINE CHANGE

Shoreline erosion and accretion is a natural coastal process affecting unarmored shorelines through the evolution of coastal processes. Shorelines can change seasonally as high energy winter waves pull sediment off beaches into nearshore zones and lower energy summer waves transport it back and rebuild the beach. Shorelines may also change due to shifts in the tidal prism (sea level rise) or due to storm impacts. Given the anticipated impacts of climate change, shoreline erosion is likely to continue, and potentially increase in severity over time.

The primary source of shoreline change data available for the state of Massachusetts is the Massachusetts Office of Coastal Zone Management Shoreline Change Project (MSCP). The MSCP includes digitized historic shorelines depicting the local high-water line at approximately high tide. The historical shorelines are digitized from a variety of sources including Coast and Geodetic Survey (now the National Geodetic Survey) T-sheets, aerial and satellite imagery, and LiDAR topographic surveys. The MSCP demonstrates how the shoreline of Massachusetts has evolved from the early 1800s up to 2014. Rates of shoreline position change (the average distance the shoreline has moved in any year) are calculated along transects spaced approximately 50 meters apart along the entire coastline of the State. Long-term and Short-term rates are calculated covering the last approximately ~150 years of change and ~30 years of change, respectively. The rates are calculated using a linear regression methodology, and uncertainty values are available for each rate. The project was originally created in 1989 to identify erosion prone areas along the Massachusetts coastline (Benoit, 1989). The project was then updated in 2001 and 2013 (Thieler et al., 2001 and Thieler et al., 2013) to update the original analysis with shoreline position data created using more recent orthoimagery and LiDAR datasets. In 2019 an additional project update was conducted to add two additional shoreline position datasets from LiDAR data collected between 2010 and 2014 (Himmelstoss et al., 2019).

One method to predict how shorelines across Woods Hole may look in the future is to assume a constant rate of change into the future based on what has been observed in the past. This approach has limitations including that it does not account for any variations in rates of shoreline change that may be expected with accelerated rates of rising sea levels. Additionally, this approach cannot account for variations in material type or availability of sediment that may alter rates of change as shorelines and landscapes are altered in the future. However, this generalized approach as well as a careful examination of the landscape may provide an indication of areas and infrastructure that are at risk from erosion as well as what future shorelines may look like. To demonstrate how natural shorelines in Woods Hole Village may evolve in the future (based on short term rates of shoreline change obtained from the MSCP), the most recent shoreline created by the MSCP (2013 in Woods Hole) was transposed a shore-normal distance equal to the rate of change multiplied by the future projection period. Future shorelines were only extrapolated for the natural portions of the Woods Hole coastline, and were stopped at any engineered barrier (such as a seawall or rock revetment) due to the limitations of this methodology in determining how such structures may behave in the future.

Appendix B provides the projected natural shorelines for Woods Hole Village using the MSCP rates.

Another proxy for the evolution of shorelines is to delineate projected tidal benchmarks on the existing topography. This method, which does not account for erosion but rather focuses on sea level rise, uses existing topographic models (LiDAR) to symbolize future tidal benchmark elevations on the landscape through a GIS analysis. The tidal benchmark projections used for this analysis are discussed in Section 2.3.1.

2.3 COASTAL INUNDATION MODELING

The Massachusetts Coastal Flood Risk Model (MC-FRM) developed by the Woods Hole Group is the most comprehensive and sophisticated model available for anticipating how climate change (specifically sea level rise and coastal storm events) will influence future coastal flood risks in Massachusetts coastal communities (MassDOT, 2019 in publication). MC-FRM was developed for the Massachusetts Department of Transportation (MassDOT) to assess potential flooding vulnerabilities to highways and other transportation infrastructure throughout the coastline of Massachusetts. The model is based on mathematical representations of the hydrodynamic processes that affect water levels along the coast, including tides, waves, winds, storm surge, sea level rise, wave set-up, wave run-up and overtopping, etc. These processes were modeled at a high enough resolution to identify site-specific locations in Woods Hole that are vulnerable and may require adaptation responses.

The model is based upon a numerical mesh that provides a digital representation of the geometry of the physical environment. The numerical mesh represents the bathymetry and topography (elevations) of the land, ocean, rivers, and bays at high resolution in order to predict the physical movement of water during coastal storm events (nor'easters, hurricanes, etc.). The model mesh creates discrete nodes at which the governing equations of water flow can be solved. While the model mesh encompasses the entire Atlantic Ocean, the resolution of the model gets finer – meaning the nodes get closer together – as the mesh gets closer to the shoreline. The mesh for the Woods Hole Village study area is shown in Figure 2-1, overlaid on an aerial image. The MC-FRM mesh has a resolution of 10 meters or less between nodal points, and sometimes as low as 2-3 meters to capture important changes in topography and physical processes related to storm dynamics. It includes areas of open water, estuaries, bays, rivers, and upland subject to present and future flooding.

Figure 2-1 Massachusetts Coast Flood Risk Model mesh in Woods Hole Village study area

The MC-FRM is comprised of a tight coupling of the Advanced CIRCulation (ADCIRC) model, which calculates the water levels and velocities, and the UNSWAN model (Unstructured Simulated Waves Nearshore), which calculates wave generation and transformation. These two models dynamically exchange information on physical processes every time step of the model simulation. This allows MC-FRM to provide an accurate representation of the resulting wave surface elevation, waves, winds, and flooding at each node, over each time step, in the model domain. The MC-FRM also includes the addition of wave run-up and overtopping at major coastal structures across the Commonwealth. This added module dynamically calculates the volume of seawater that advances landward over the coastal structure over time. The volume is calculated over each time step and allowed to flow over the landscape. MC-FRM was calibrated and validated to normal tidal conditions (at observation stations from the Caribbean Islands to Canada), as well as to historic storm events that impacted the coastline of Massachusetts (e.g., Hurricane Bob, Perfect Storm, Blizzard of 1978, etc.) Complete details on the development of the Massachusetts Coastal Flood Risk Model (MC-FRM) can be found in MassDOT (2019, in publication).

2.3.1 Sea Level Rise Scenarios

NOAA has been recording tidal observations since 1932 at Tide Gauge No. 8447930 in Woods Hole, Massachusetts (Figure 2-2). Over the 87-year period of verified data through 2019, relative sea level at this station has risen approximately 25.4 cm (2.92 mm/year, with a 95% confidence interval of +/ 0.17 mm/yr). This rate of sea level rise is expected to increase in the future due to a volumetric expansion of the oceans coupled with glacial ice melt as a result of climate change, coupled with local subsidence.

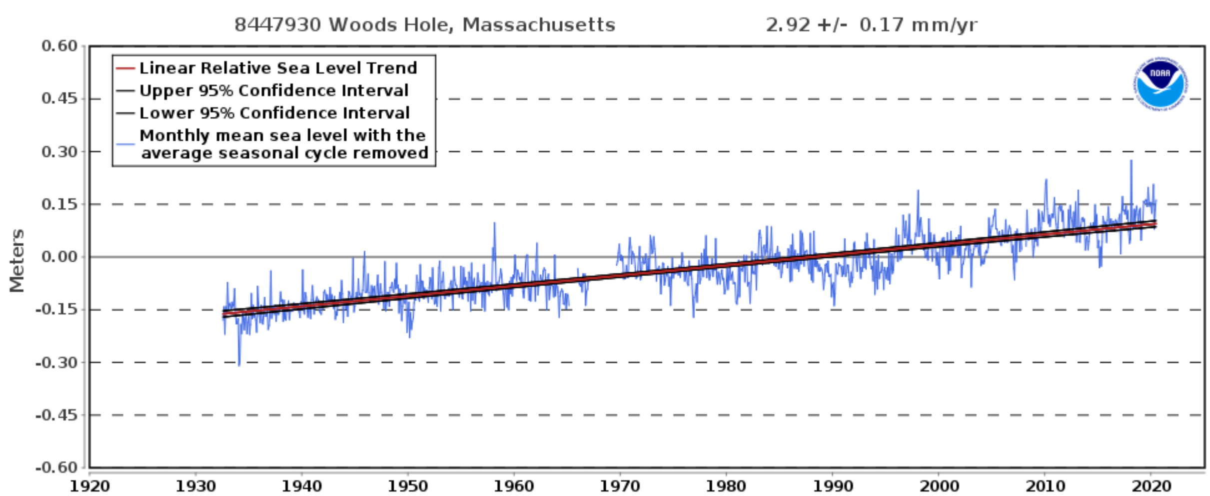


Figure 2-2 Historical relative sea level trend – Station 8447930 (Woods Hole)

The Commonwealth of Massachusetts has developed downscaled local climate change projections based on a range of medium (RCP 4.5) to high (RCP 8.5) greenhouse gas emissions scenarios (Figure 2-3), which are available on the Massachusetts Climate Change Clearinghouse (resilientMA).

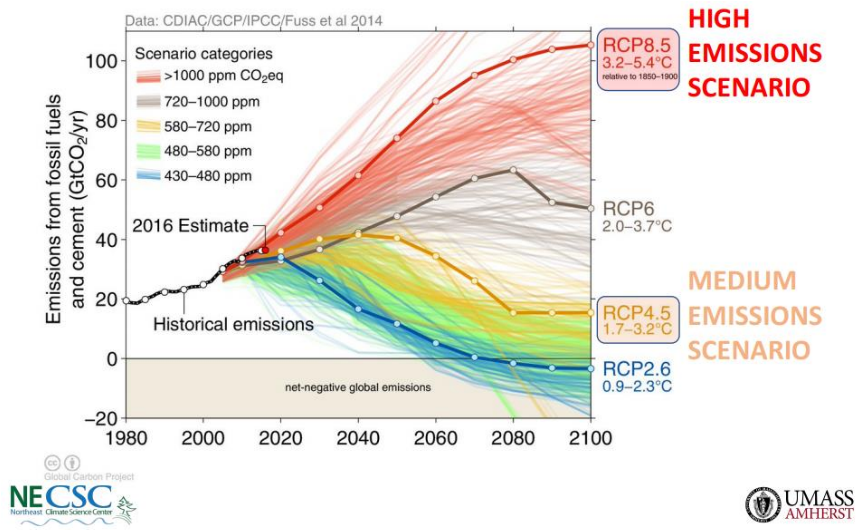


Figure 2-3 Greenhouse gas emissions scenarios used in resilient MA climate projections

This project utilizes the most up-to-date relative sea level rise (RSLR reflects global sea level rise adjusted for local land subsidence and changes in ocean circulation) projections developed for the Commonwealth of Massachusetts (DeConto and Kopp, 2017). The approach employed a probabilistic assessment of future relative sea level rise under two (2) greenhouse gas concentration scenarios (RCP 8.5 and RCP 4.5), and two (2) methods for projecting ice sheet loss and its effects – expert elicitation (Kopp et al., 2014) and process-based numerical model simulations (Deconto and Pollard, 2016; Kopp et al., 2017). Conditional probability distributions were integrated into four representative scenarios (Intermediate, Intermediate-High, High, and Extreme), and the Commonwealth selected the “High” scenario for planning purposes.

This “High” sea level rise scenario is:

- extremely unlikely to be exceeded (99.5%) under RCP 8.5,
- unlikely to be exceeded (83%) under RCP 8.5 when accounting for ice sheet loss, and
- extremely unlikely to be exceeded (95%) under RCP 4.5 when accounting for ice sheet loss.

The “High” scenario projections developed for MC-FRM (Figure 2-4) and applied to the NOAA tide gage at Woods Hole (Table 2-1) are the basis for MC-FRM inputs and this project’s nuisance flooding evaluation.

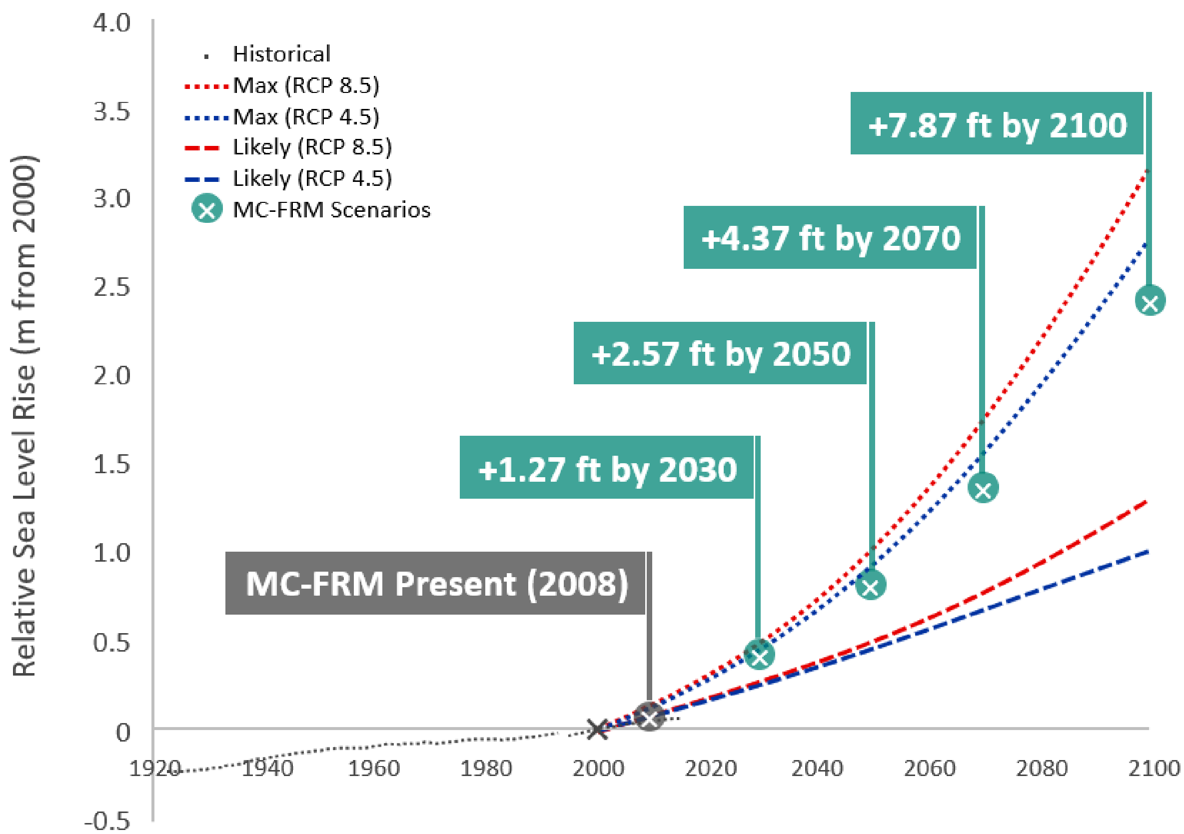


Figure 2-4 Relative sea level rise projections

To inform asset management and campus planning for this project, four distinct time horizons were selected: 2030 (near-term), 2050 (mid-term), 2070 (long-term), and 2100 (beyond). Sea level rise projections were available for 2100, but MC-FRM storm surge projections were not available for 2100 at the time of this project. Using a common set of climate change planning horizons and modeling results also allowed the study to align with the Town of Falmouth's coastal resiliency planning (Woods Hole Group, 2020) and other state and regional studies.

To estimate the amount of SLR that may occur by 2030, 2050, 2070, and 2100 locally in Woods Hole, the project team used the relative sea-level rise projections discussed above (DeConto and Kopp, 2017) which draw on long-term water level datasets from a series of tide gages around the state (including Woods Hole). To compare future mean sea level to "present day" conditions, a starting elevation for mean sea level must be calculated. A tidal-epoch, a 19-year time period, is traditionally used to calculate tidal datums. For this study, the 19-year tidal-epoch with a midpoint year of 2008 (i.e., 1999-2017) was used to calculate a starting elevation for mean sea level. Based on this methodology, the mean sea level in Woods Hole in the year 2008 was at an elevation of -0.17 feet (NAVD88). This 2008 starting elevation of -0.17 feet (NAVD88) can then be used to compare to projected relative mean sea-level elevations under various scenarios, and to develop future tidal benchmarks (Table 2-1). Note that the values in Table 2-1 are elevations of the projected tidal benchmarks at various times relative to a vertical datum of NAVD88, not the magnitude of change in elevation. These tidal benchmarks apply only to the Woods Hole Village study area waterfront on Great Harbor and Vineyard Sound.

Table 2-1 Present Day and Projected Future Tidal Benchmarks for Woods Hole Village

Tidal Benchmark	Elevation (feet, NAVD88)					
	1983-2001 Epoch	1999-2017 Epoch	2030	2050	2070	2100
Highest Annual Tide	1.86	2.07	3.3	4.6	6.4	9.9
Mean Higher High Water	0.84	1.05	2.3	3.6	5.4	8.9
Mean High Water	0.56	0.79	2.1	3.4	5.2	8.7
Mean Sea Level	-0.38	-0.17	1.1	2.4	4.2	7.7
Mean Low Water	-1.23	-1.02	0.25	1.5	3.3	6.8

The science of sea level rise projections is continually evolving. The sea level rise projections used in this assessment represent the best available science, but inherently carry some level of uncertainty. Parallel to this project, WHOI commissioned a Flood Risk and Dock Elevation Study to evaluate design parameters for the replacement of the Iselin Dock. This study (Moffatt & Nichol, 2020) provides an in-depth review of "shallow" and "deep" uncertainty in the context of sea level rise projections. Shallow uncertainty refers to conditions where outcomes are predictable within the range of variability in a known system and can be captured by a single probability distribution. Deep uncertainty refers to conditions where outcomes are not reliably predictable due to remaining gaps in understanding of the governing systems. It was concluded that sea level rise projections retain "shallow" uncertainty out to 2050 because there is scientific consensus regarding thermal expansion and other near-term factors, but beyond 2050 the projections are subject to "deep" uncertainty due to the evolving understanding of ice sheet melt and its effects and feedback mechanisms.

For this reason, the sea level rise projections used for this study may be treated as ranges of possible impacts over periods of time. Conservatively selecting the "High" scenario (MC-FRM Scenario in Figure 2-4) allows for the evaluation of inundation risk probabilities under other scenarios due to the bracketed nature of the results. For example, the "High" results in 2030 are approximately equivalent to "Intermediate/Likely" results in 2050, and the "High" results in 2050 are approximately equivalent to the "Intermediate/Likely" results in 2070. In this way, the selected scenarios provide an upper bound of potential risk. This approach enables projections to be used as guidelines for investment decisions based on the knowledge to date, while providing flexibility to accommodate these uncertainties.

2.3.2 Storm Events and Wave Run-up

The storm climatology parameters in MC-FRM include wind directions and speeds, radius of maximum winds, pressure fields, and forward track. MC-FRM requires storm input data to run storm surge simulations and generate flooding results. Without input data, MC-FRM cannot determine which areas of Woods Hole Village will likely be exposed to coastal flooding in the near-term, mid-term and long-term future, as much of the study area's flood risk profile is dependent on storms.

As part of the development of MC-FRM, a large statistically robust sample of storms, including tropical (hurricanes) and extratropical (nor'easters) storms, was developed specifically for the coast of Massachusetts existing and future climatologies. This storm data set includes historic storm events, as well as future storm conditions, and was used to assess coastal flooding risks in the Present, 2030, 2050 and 2070. Figure 2-5 shows a representation of the tropical storm tracks representing some of the tropical storms used in MC-FRM.

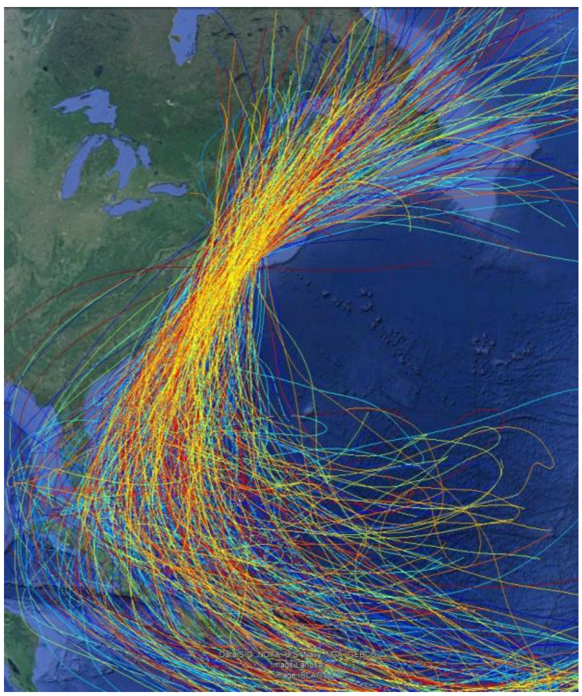


Figure 2-5 Tropical storm tracks in MC-FRM statistical analysis

To assess coastal flooding risks in 2070, a different sample of storms reflecting a late 21st century climatology was used. This storm sample includes some very powerful hurricanes, for example, reflecting projections that tropical storms will be more intense on average in the second half of the century assuming that air and ocean temperatures are significantly higher than in the past. This set of storm input data was created by MIT professor Dr. Kerry Emmanuel based on climate projections.

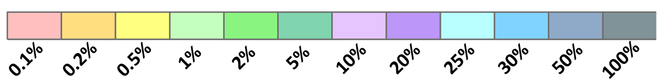
Fully optimized Monte Carlo simulations were run in MC-FRM using the respective storm sets and SLR projections for present and future conditions. Importantly, these simulations included the tide cycle as a dynamic element of the model. The same storm surge can result in very different flooding outcomes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

2.3.3 MC-FRM Outputs

The results of MC-FRM simulations for Present, 2030, 2050 and 2070 were used to generate two types of coastal flooding maps for the Woods Hole Village study area: Coastal Flood Exceedance Probability (CFEP) maps and depth of flooding maps. Each of these maps are described in more detail below.

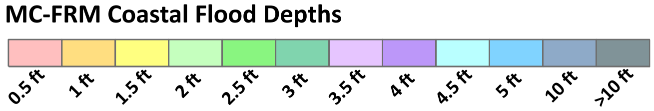
- Coastal Flood Exceedance Probability: CFEP maps provide the annual chance of inundation from coastal storm surge across the landscape. These maps show interpolated results of the MC-FRM nodal calculations, and can be used as a screening/planning tool and to inform engineering design criteria since they provide the probability of an event occurring in this changing regime, such as the “new” 1 in 100 year flood event (1% probability). Inundation probabilities are represented as follows:

MC-FRM Coastal Flood Exceedance Probabilities



- Coastal Flood Depth: Depth maps indicate the scale of inundation above the land surface produced by a given probability level event. These maps are developed by subtracting the land surface elevation from the water surface elevation at each model node and interpolating the results of these MC-FRM intra-nodal elevation comparisons. Depth maps are also useful as a screening/planning tool and to inform engineering design criteria since they provide an indication of the severity of flooding under various conditions. For this study, Coastal Flood Depth maps were produced for the 1% (100-year return period) and 0.1% (1000-year return period) CFEP levels. Inundation depths are represented as follows:

MC-FRM Coastal Flood Depths



MC-FRM coastal flood maps, including both flood exceedance probabilities and flood depths, are included in Appendix C.

2.3.4 Model Disclaimer

The flood maps and probabilistic data presented in this report are derived from output of MC-FRM for sea level rise and coastal storm simulations. These maps and data are provided without any guarantees or warranty. This information is not intended for use as a flood insurance determination, nor should it be directly related to FEMA FIRM maps or data since these data and FEMA data are for different purposes. This information cannot be used for the purpose of boundary resolution or location.

This public information should be accepted and used by the recipient with the understanding that the maps and data received were developed and collected for future flooding analyses purposes only. No liability is assumed as to the accuracy, sufficiency or suitability of the information contained herein for any other particular use. While every effort has been made to assure the accuracy and correctness of the data presented, it is acknowledged that inherent mapping inaccuracies are present due to interpolation between MC-FRM calculation nodes. Any reliance upon the maps or data presented herein used to make decisions or conclusions is at the sole discretion and risk of the user. This information is provided with the understanding that these data are not guaranteed to be accurate, correct or complete and assumes no responsibility for errors or omissions. Data and documents may not be the most currently available data, and the data is subject to constant change given the changing climate.

Assets located near boundaries of a probability zone may or may not be within the probability zone due to mapping inaccuracies and interpolation between model nodes. MC-FRM nodal spacing varies throughout the Woods Hole Village study area. The GIS rasters interpolate the values between model nodes and therefore create probabilities that may be inaccurate between model nodes. Care should be taken when using the raster data to evaluate site-specific properties or locations.

The probability maps should not be applied at such a granular level as to assess the fate of individual buildings or properties. Rather, they should be used as a tool to identify areas that may be vulnerable to flooding. Once those areas are identified, detailed information for individual buildings or other infrastructure can then be extracted from the closest model nodes. This approach (detailed in Section 2.4) has been used on many previous vulnerability assessments, including for MassDOT, and is the approach being used for this project. Nodal data are more accurate on a property scale than interpolated values shown on the maps.

2.4 ASSET-SPECIFIC RISK ASSESSMENT

A risk assessment methodology was utilized to generate risk scores for each asset and assist WHOI, MBL and NOAA with prioritization of capital projects and long-term campus and adaptation planning. The risk assessment process leveraged the probabilistic results from MC-FRM and is described in the following subsections.

2.4.1 Screening of Critical Assets Subject to Flooding

The project team developed an inventory of institutional assets for WHOI, MBL and NOAA that included buildings, associated infrastructure components (e.g. generators, fuel tanks, electrical equipment, fixed cranes), parking lots, and coastal infrastructure (docks and piers) on the Woods Hole Village campuses of each organization. While MBL and NOAA property in Woods Hole fall entirely within the zone of potential flooding, some parts of WHOI's campus are elevated and not vulnerable to future flooding. Before engaging in asset-specific analyses, the project team pre-screened assets to reduce unnecessary investigations. Any asset that did not intersect with the extent of the MC-FRM model mesh was dropped from the vulnerability and risk assessment. Figure 2-6 shows the asset screening process.

Figure 2-6 MC-FRM extent of model mesh used to select WHOI/MBL/NOAA assets for vulnerability assessment

2.4.2 Critical Elevation Determination

Critical elevations are defined as the elevation at which flood water will cause the asset to cease to function as intended or sustain significant damage. The critical elevation for a building may be the first floor, or a basement window sill elevation (above which water can enter the basement and damage critical mechanical equipment). In another case, the critical elevation could be the bottom of a critical electrical transformer or electrical panel, above which flood water would damage the equipment and shut down the facility or equipment. For other assets, such parking lots and open space, the critical elevation is the ground elevation.

The project team derived critical elevations from existing documentation wherever available. Existing documentation included facility plans (in consultation with facilities staff and architectural team) and FEMA Elevation Certificates. For facilities and equipment without existing information, Woods Hole Group performed site visits to document critical elevations. For WHOI assets, the critical elevations were surveyed in the field by WHOI's on-call surveyor. For MBL and NOAA, Woods Hole Group collected field measurements from the ground surface and developed critical elevations from these measurements using a desktop analysis of existing elevation data (LiDAR).

A full review of facility drawings, material testing, survey or analysis of a structure's ability to withstand the projected hydrostatic forces due to flooding were not completed for this Study. The findings include certain assumptions based on reasonable engineering judgment as to the ability of buildings and facilities to resist the projected hydrostatic forces due to flooding. These assumptions will require additional verification and customization during the design phase of individual projects.

The derivation of each asset's critical elevation is described in the asset tables (Appendix D).

2.4.3 Extraction of Probability of Exceedance Data

Probability of exceedance data – the probability that storm surge will exceed the critical elevation of the asset – was developed for each asset for Present, 2030, 2050 and 2070 planning horizons. Since WHOI/MBL/NOAA assets are located throughout the Woods Hole Village study area, they are exposed to different CFEP profiles, depending on location. Therefore, the project team identified representative MC-FRM nodes (a node is a point in the model at which the governing equations are solved) to analyze asset exposure in a spatially discrete manner. Woods Hole Group reviewed nodal CFEP distribution curves in the vicinity of study assets (see Figure 2-1 for distribution of all nodal points in the study area) to select a subset of individual nodes that best represent the flood exposure profiles for assets in different regions of Woods Hole Village. Figure 2-7 shows the areas and assets covered by each of the five (5) representative MC-FRM nodes. Figures 2-8 through 2-12 present the CFEP distribution curves for each of these nodes.

Asset critical elevations were compared to water surface elevations (WSE) from the corresponding CFEP distribution curve to extract the probability of coastal flooding exceeding the critical elevation for each asset. Figure 2-13 provides an example of the asset-specific exposure probability assessment process.

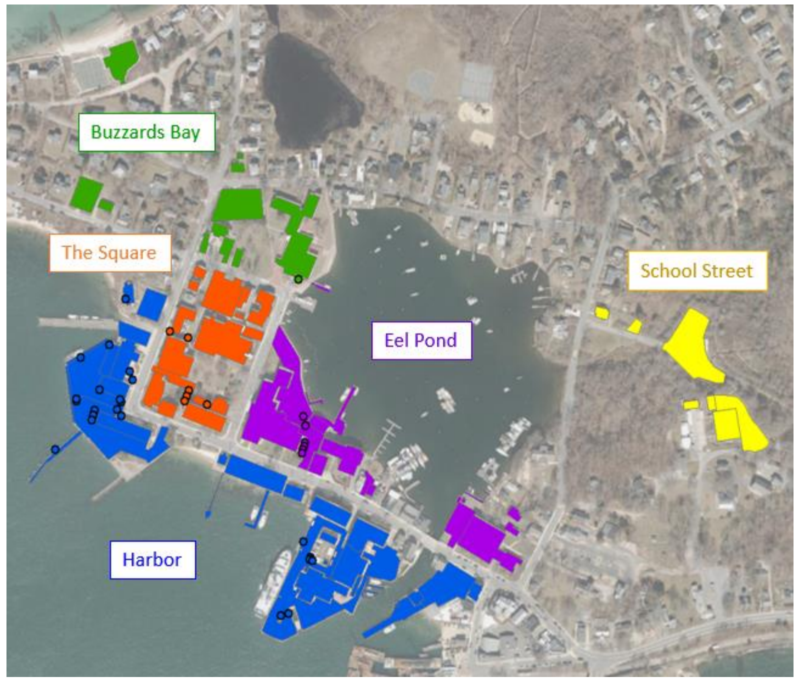


Figure 2-7 MC-FRM representative nodal distribution

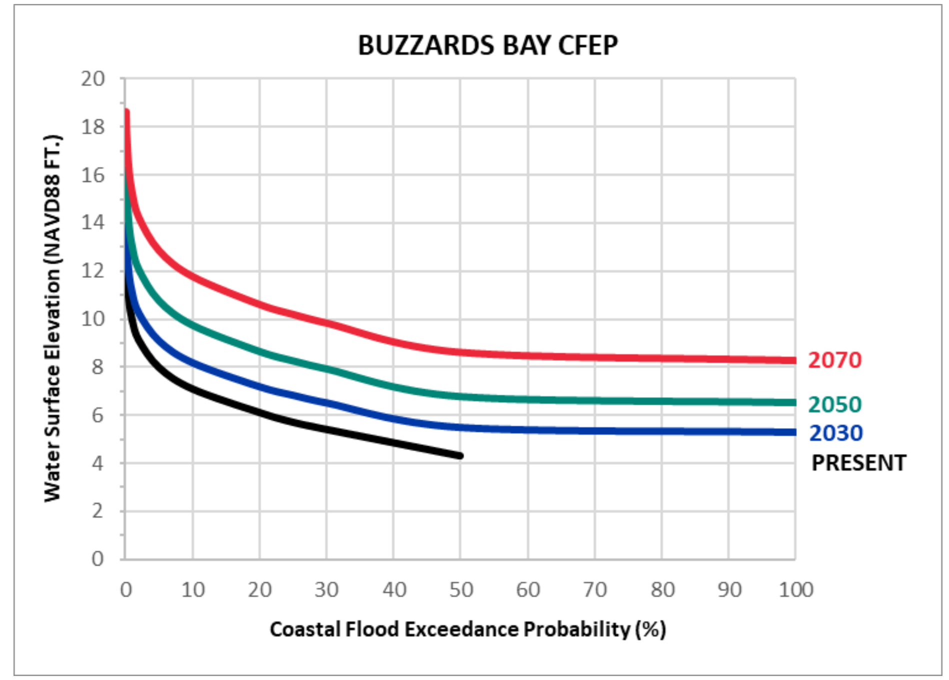


Figure 2-8 MC-FRM node – Buzzards Bay

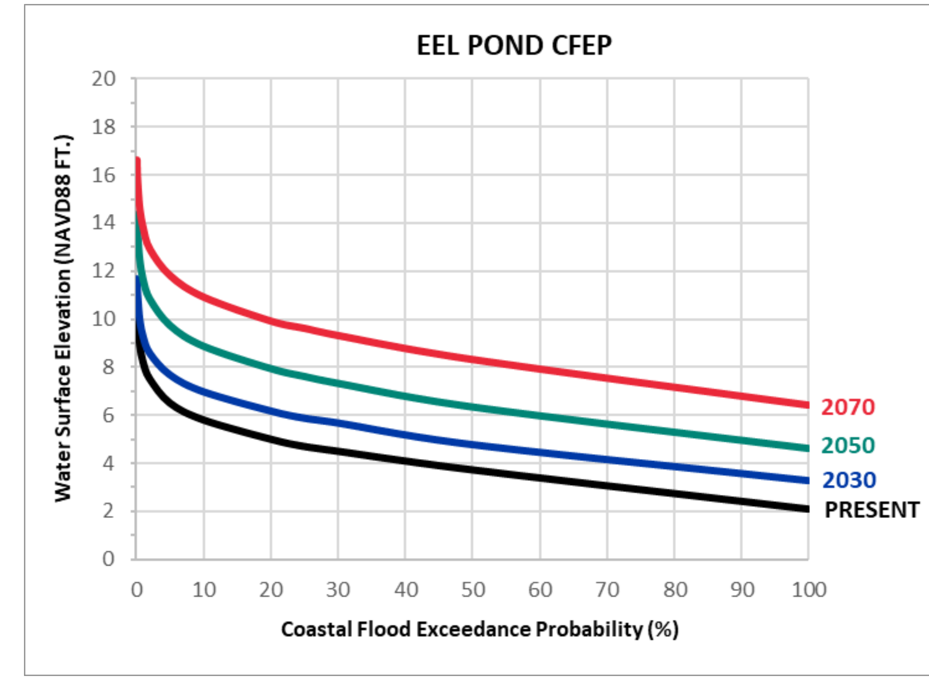


Figure 2-9 MC-FRM node – Eel Pond

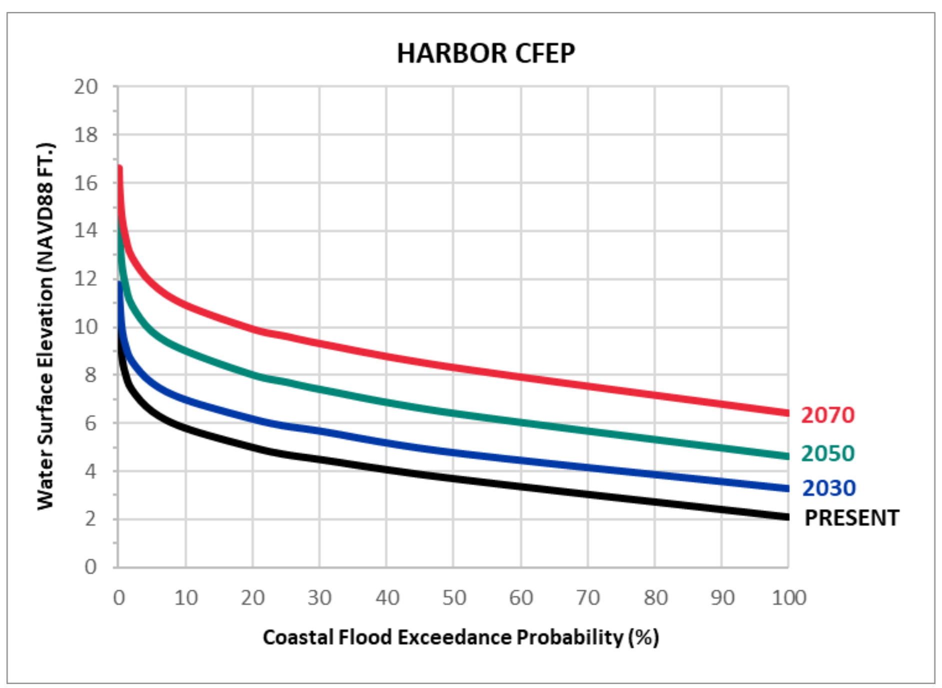


Figure 2-10 MC-FRM node – Harbor

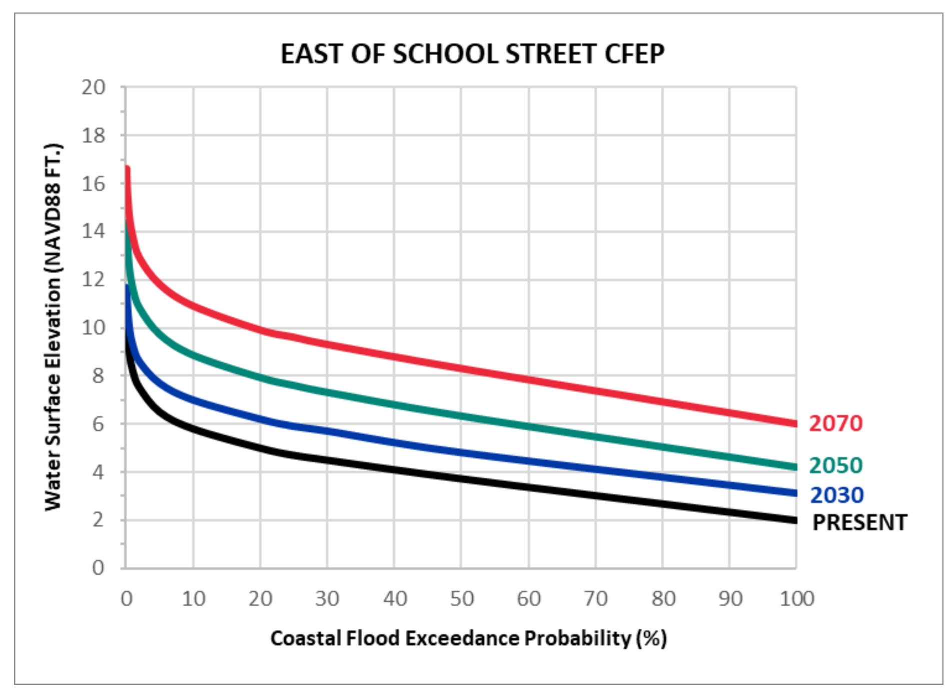


Figure 2-11 MC-FRM node – School Street

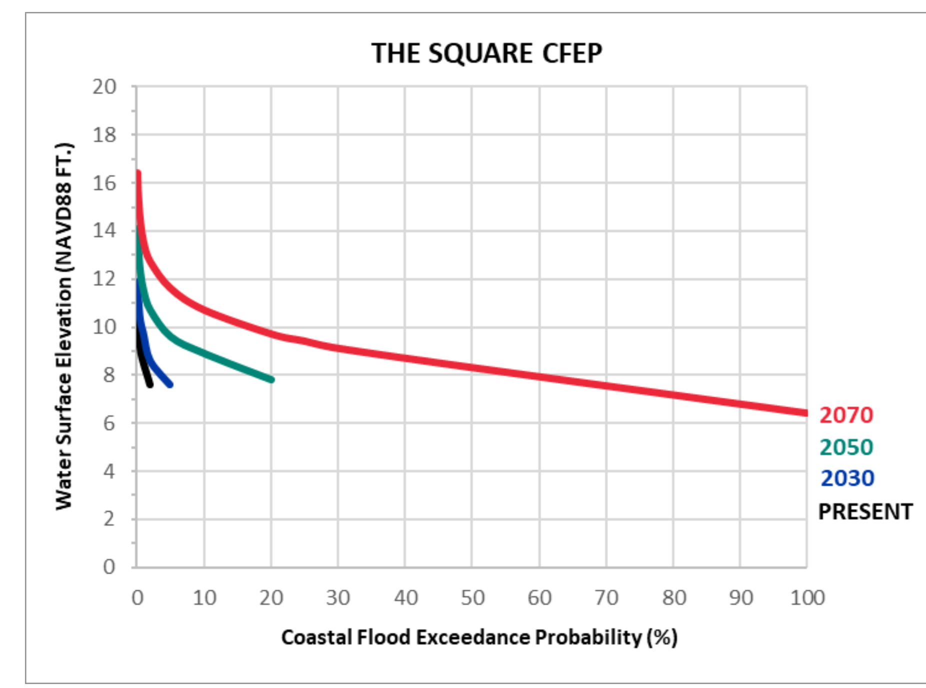


Figure 2-12 MC-FRM node – The Square

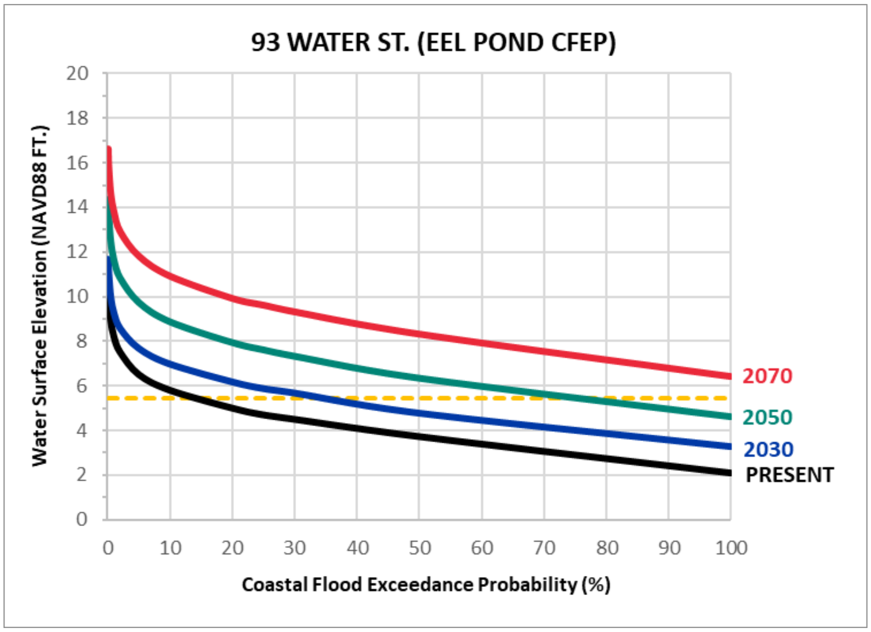


Figure 2-13 Asset-level exposure assessment example (WHOI Information Office)

Probabilities of exceeding each asset's critical elevation during each planning horizon are documented in the asset tables in Appendix D.

2.4.4 Development of Consequence Scores

The consequence scoring methodology and results are important tools for asset managers to discuss, build consensus on, and ultimately use for decision-making. They help answer the questions of which facilities and infrastructure components are most important for the institution to maintain in the context of flooding, and why. This process breaks down the higher-level concept of consequence into more easily defined scoring categories and scales, and in doing so, can lead to useful results comparing seemingly disparate systems. An iterative process of adjusting ratings for individual assets relative to others helps calibrate the scores and rankings to better reflect institutional values and ultimately provides better inputs to the risk assessment. Institutional values influence the priority assigned to investments of time and money, and the same is true for adaptation investment.

The consequence of failure for each asset subject to potential flooding (at or above the critical elevation) was rated on a scale of 0 through 4 (from low to high consequence) for six different potential impacts in accordance with the guide shown in Table 2-2. In collaboration with the research institutions sponsoring this study, Woods Hole Group developed a custom consequence scoring matrix focused on two types of impacts from asset loss/damage – direct impacts to operations and finances, and mission impairment impacts (derived from commonalities among the mission statements of each institution). Direct impacts included the spatial/organizational extent of service loss, the duration of service loss (time for recovery/repair/replacement), and the cost of damage (cost of recovery/repair/replacement). Mission impairment impacts included the effect of asset loss on the organization's ability to continue research and applied science, to support daily operations and revenue generating activities, and to advance education and outreach initiatives. The operational definitions of the consequence scoring scheme are provided on page 19.

Table 2-2 Asset consequence scoring matrix

Rating	Direct Impacts			Mission Impairment		
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach
4	Organization	>30 d	>$10M	Severe	Severe	Severe
3	Campus	15-30 d	$1M-$10M	High	High	High
2	Facility	8-14 d	$150K-$1M	Moderate	Moderate	Moderate
1	System	1-7 d	$10K-$150K	Low	Low	Low
0	Component	<1 d	<$10K	None	None	None

Each impact is rated separately, then a composite Consequence of Failure score is calculated by summing the individual scores, dividing by 24 (the highest total possible), and normalizing to 100 using the following equation:

$$\text{Composite Consequence of Failure Score } = \frac{\sum \text{all six ratings}}{24} \text{x } 100$$

Consequence scores for each asset were developed by facilities management and/or administrative staff from each organization. To ensure a consistent understanding and application of the scoring categories within each type of potential impact, Woods Hole Group provided operational definitions of each scoring category and conducted a training/discussion session for the organizations.

Composite consequence scores can be as low as 0 and as high as 100. The higher the rating, the greater the impact of asset inundation to the organization.

Individual and composite consequence scores for each asset are documented in the asset tables in Appendix D and are also presented on the map in Figure 2-14.

(Direct) Service Loss Extent

4	Organization	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) to the entire scientific organization. Organization-level impairment halts vital activities that are essential to the organization's overall function, and potentially has cascading impacts to the Town of Falmouth and/or the broader scientific community.*
3	Campus	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) throughout the organization's Woods Hole campus. Campus-level impairment impedes activity throughout the organization's footprint in Woods Hole, and may have broader implications for the Village.*
2	Facility	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) to an entire building or waterfront facility. Facility-level impairment limits the ability of a building or dock to effectively support its intended functions.*
1	System	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) to an entire system or group of assets performing a common function. System-level impairment impedes the normal function of the asset, but does not have cascading impacts to other systems or operations.*
0	Component	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) to an individual component or part of the asset. Component-level impairment does not extend beyond the immediately affected equipment.*

(Direct) Service Loss Duration(Direct)

4	>30 d	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) that can be restored to function, by repair or replacement, but will take over one month to implement.*
3	15-30 d	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) that can be restored to function, by repair or replacement, within one month.*
2	8-14 d	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) that can be restored to function, by repair or replacement, within two weeks.*
1	1-7 d	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) that can be restored to function, by repair or replacement, within one week.*
0	≤1 d	*Inundation of the asset at (or above) the critical elevation results in impact (incapacity/damage/destruction) that either self-corrects after storm surge recedes, or can be restored to function within one day.*

Cost of Damage

4	>$10M	*Inundation of the asset at (or above) the critical elevation results in damage or destruction that can be repaired or replaced, but for over $10,000,000.*
3	$1M-$10M	*Inundation of the asset at (or above) the critical elevation results in damage or destruction that can be repaired or replaced for less than $10,000,000.*
2	$150K-$1M	*Inundation of the asset at (or above) the critical elevation results in damage or destruction that can be repaired or replaced for less than $1,000,000.*
1	$10K-$150K	*Inundation of the asset at (or above) the critical elevation results in damage or destruction that can be repaired or replaced for less than $150,000.*
0	<$10K	*Inundation of the asset at (or above) the critical elevation results in damage or destruction that can be repaired or replaced for less than $10,000.*

(Mission) Research & Applied Science

4	Severe	*Inundation of the asset at (or above) the critical elevation totally incapacitates the organization's ability to conduct research and/or apply scientific findings to natural resource management. Such loss of functionality puts funding, institutional reputation and/or scientific progress at risk, and may also impact the research of other entities.*
3	High	*Inundation of the asset at (or above) the critical elevation impedes the organization's ability to conduct research or apply scientific findings to natural resource management. Some functions are not able to proceed, other functions experience significant reductions in capacity/efficiency.*
2	Moderate	*Inundation of the asset at (or above) the critical elevation significantly impairs the organization's ability to conduct research or apply scientific findings to natural resource management. Such functions are able to proceed, but at noticeably reduced capacity/efficiency.*
1	Low	*Inundation of the asset at (or above) the critical elevation slightly impairs the organization's ability to conduct research or apply scientific findings to natural resource management. Such functions are able to proceed, but at somewhat reduced capacity/efficiency.*
0	None	*Inundation of the asset at (or above) the critical elevation does not affect the organization's ability to conduct research or apply scientific findings to natural resource management.*

(Mission) Operations & Economic Activity

4	Severe	*Inundation of the asset at (or above) the critical elevation totally incapacitates the organization's operations or economic activity (revenue generation). Such loss of functionality has cross-cutting impacts on the organization's ability to conduct business, and may have cascading impacts on the operations of other institutions (and the revenue streams these activities generate).*
3	High	*Inundation of the asset at (or above) the critical elevation impedes the organization's operations or economic activity (revenue generation). Some functions are not able to proceed, other functions experience significant reductions in capacity/efficiency.*
2	Moderate	*Inundation of the asset at (or above) the critical elevation significantly impairs the organization's operations or economic activity (revenue generation). Such functions are able to proceed, but at noticeably reduced capacity/efficiency.*
1	Low	*Inundation of the asset at (or above) the critical elevation slightly impairs the organization's operations or economic activity (revenue generation). Such functions are able to proceed, but at somewhat reduced capacity/efficiency.*
0	None	*Inundation of the asset at (or above) the critical elevation does not affect the organization's operations or economic activity (revenue generation).*

(Mission) Education & Outreach

4	Severe	*Inundation of the asset at (or above) the critical elevation totally incapacitates the organization's education and outreach activities. Such loss of functionality has cross-cutting impacts on the organization's ability to conduct education/outreach, and may have cascading impacts on the education/outreach initiatives of other institutions and/or the broader community.*
3	High	*Inundation of the asset at (or above) the critical elevation impedes the organization's education and outreach activities. Some programs are not able to proceed, other programs experience significant reductions in capacity/efficiency.*
2	Moderate	*Inundation of the asset at (or above) the critical elevation significantly impairs the organization's education and outreach activities. Such functions are able to proceed, but at noticeably reduced capacity/efficiency.*
1	Low	*Inundation of the asset at (or above) the critical elevation slightly impairs the organization's education and outreach activities. Such functions are able to proceed, but at somewhat reduced capacity/efficiency.*
0	None	*Inundation of the asset at (or above) the critical elevation does not affect the organization's education and outreach activities.*

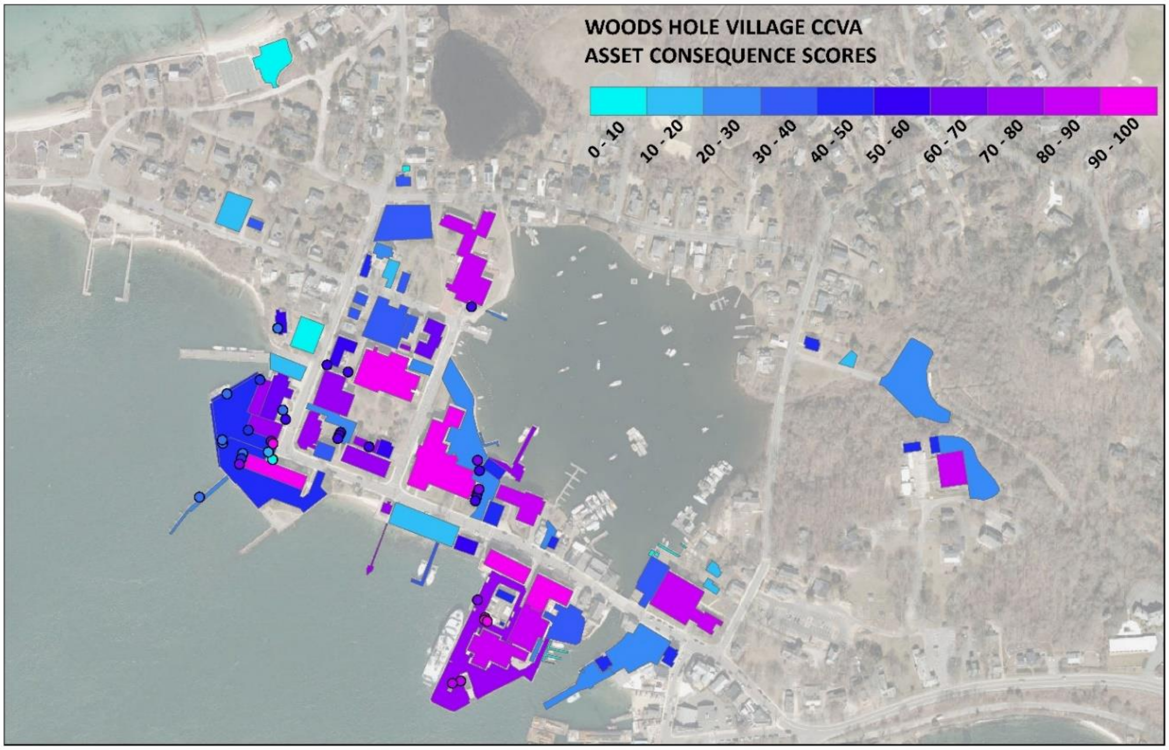


Figure 2-14 Asset-consequence scores

2.4.5 Risk Calculations and Rankings

A risk assessment was completed to determine the specific, asset-level vulnerabilities of institutional assets. Risk is defined as the probability of an asset flooding, multiplied by the consequence of that asset failing or ceasing to function as intended. A risk score was calculated for each asset subject to flooding in each time horizon using the following equation:

$$R_{tn} = P_{tn} \times C_{tn}$$

Where:
R_{tn} = *Risk Score at a given time horizon*
P_{tn} = *Probability of Exceedance at a given time horizon*
C_{tn} = *Consequence of Failure rating at a given time horizon*
tn = Time horizon n (Present, 2030, 2050 or 2070)

Using risk to assess the vulnerability of infrastructure allows one to take into account both how likely a damaging flood event is, and what the consequence of that damaging flood is to the institution. These risk scores can be ranked to assist each organization with the prioritization of adaptation investments over time.

Risk scores for each asset are documented in the asset tables in Appendix D.

3.0 VULNERABILITY ASSESSMENT RESULTS

The vulnerability assessment was prepared using the methods described in Section 2 and was guided by discussions with administrators and facilities managers representing WHOI, MBL and NOAA. It should be noted that in assessing future coastal conditions, the representatives from each institution noted that some facilities have already been impacted by sea level rise coastal storms, mostly owing to their location at the waterfront. This highlights one of the inherent tensions of climate change planning for working waterfronts, where having easy access to the water's edge is necessary to maintain operations but also exposes facilities and assets to coastal flooding.

3.1 COASTAL WETLAND MIGRATION

Wetlands provide numerous valuable ecosystem services, from fisheries habitat, to carbon sequestration and storm damage protection. Although not as pervasive in the developed portions of Woods Hole Village, they are an important component of the Woods Hole landscape with the pocket beaches and the expansive wetland area adjacent to Mill Pond and Woods Hole Park. These resource areas are vulnerable to sea level rise, and local vulnerabilities were assessed by comparing SLAMM results between planning horizons to quantify projected habitat change.

Areas of each type of wetland classification in the Woods Hole Village study area over time are mapped the figures provided in Appendix A and summarized in Table 3-1. Within the study area delineated for this assessment, projections indicate that Woods Hole Village could potentially experience a loss of up to 50 acres of upland habitat and 16 acres of wetlands to tidal influence by the end of the century, and an equivalent area of conversion to open water.

Table 3-1 Wetland area projections for Woods Hole Village study area

	Area (acres)				
	Present	2030	2050	2070	2100
Upland	114.5	111.9	107.9	91.7	65.0
Nontidal Swamp	3.2	3.1	3.0	0.6	0.4
Transitional Marsh/Scrub-Shrub	8.4	1.5	0.9	6.4	0.4
Regularly Flooded Marsh	0.8	10.0	5.7	2.6	1.9
Estuarine Beach/Tidal Flat	0.5	0.9	9.9	9.6	8.9
Ocean Beach	5.6	5.3	7.5	14.7	26.0
Estuarine Open Water	18.2	18.2	18.6	27.1	41.7
Open Ocean	48.4	50.4	51.1	52.8	61.3
Irregularly Flooded Marsh	2.5	3.7	0.8	0.1	0.1
Tidal Swamp	3.8	0.9	0.5	0.3	0.1

Overall, the projections for wetlands trends in the Woods Hole Village study area indicate that there may be a near term gain in salt marsh (both low and high marsh) habitat, but as sea level continues to rise by 2050 and beyond, the low-lying areas of Woods Hole Village will experience a gradual loss of salt marsh (Figure 3-1) and conversion to a shifting mix of beach, tidal flat, and open water (Figure 3-2). This trend is most robust for the wetland area adjacent to Mill Pond and Woods Hole Park. Over the mid-term, the area east of School Street should transition to salt marsh but may eventually also convert to open water over the long term. Other notable long term projections for Woods Hole Village include the potential for tidal inundation (nuisance flooding) across much of the waterfront parcels south of Water Street and west of Luscombe Avenue (extending from the NOAA campus to the Steamship Authority lots) as well as along the edges of Eel Pond. Additionally, projections for 2100 indicate that much of the area north of Eel Pond to Buzzards Bay (currently the wetland areas adjacent to Woods Hole Park) may convert to open water, creating a second inlet equivalent in size to Eel Pond. If sea level rise modifies the landscape of Woods Hole Village to this extent, there would be cascading impacts to daily use and access – especially along Millfield Street, Gardiner Road, and Spencer Baird Road.

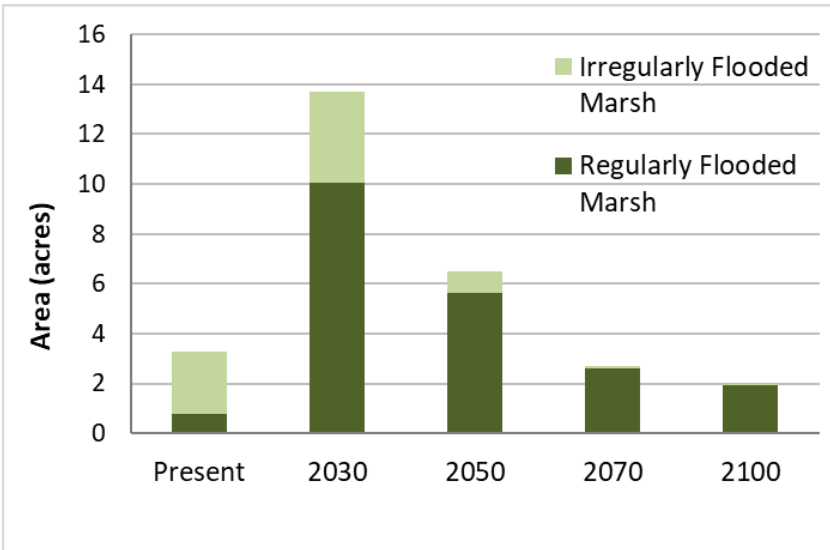


Figure 3-1 SLAMM salt marsh projections for Woods Hole Village study area

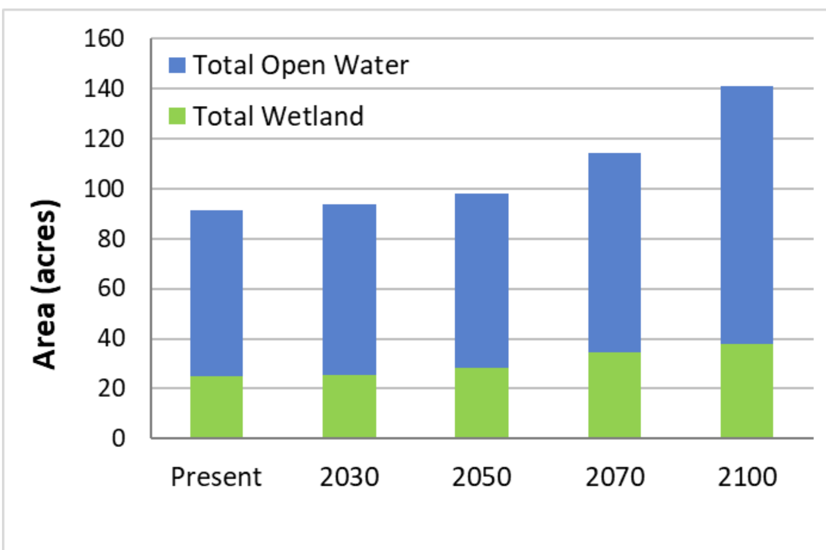


Figure 3-2 SLAMM total wetland and open water projections for Woods Hole Village study area

3.2 IMPACTS OF LONG-TERM CHANGE

Sea level rise, associated shifts in habitat and tidal benchmarks, and erosion of natural shorelines all present long-term existential challenges to Woods Hole Village – including its research organizations with working waterfronts as well as its commercial and residential districts. Long-term change from shoreline erosion can undermine structural foundations or change the usability of waterfront areas. Sea level rise may also greatly influence the usability of developed and working waterfront areas, as well as inundate roads and open space – creating challenges for circulation and use. The following sections discuss the findings of these long-term change investigations.

3.2.1 Issues Related to Projected Future Shorelines

Maps provided in Appendix B (B-1 through B-5) show the projected shorelines for natural shorelines in Woods Hole Village based on MSCP short term rates of change. The baseline shoreline is represented as a green line and is identified as the present shoreline in each figure. Future shoreline positions are identified as yellow, blue, and red lines for the expected 2030, 2050, and 2070 positions, respectively. Each figure also shows the short-term rate of change that was utilized based on the MSCP study for each portion of natural shoreline. Positive rates indicate expected accretional rates, while negative rates indicate erosional rates.

Five (5) figures were created to show the results of this analysis. Each figure has an inset map which shows the respective location within Woods Hole Village. The figures start along the Buzzards Bay shoreline of Woods Hole Village at Stony Beach and continue southwards along Great Harbor to the Steamship Authority facility. Figure B-1 (Stony Beach and adjacent properties) shows rates ranging from +0.10 ft/yr (accretion) to -0.23 ft/yr (erosion). All portions of the shoreline within Figure B-1 are erosional except for Stony Beach between the two groins. Figure B-2 shows an expected rate of +0.36 ft/yr (accretion) along the northern shoreline of Barneck Road, and rates between -0.16 and -0.26 ft/yr (erosion) along the southern shoreline of Barneck Road. Figure B-3 shows rates ranging from -0.20 ft/yr to -0.23 ft/yr (erosion) in the vicinity of the Woods Hole Yacht Club. Figure B-4 shows a rate of -0.42 ft/yr (erosion) at the pocket beach fronting the Town of Falmouth sewer pump station. Since this pocket beach is backed by a large seawall, the shoreline does not migrate inland of this hard structure. Figure B-5 shows an area of shoreline with a projected rate of +0.30 ft/yr (accretion) abutting a groin just south of the Steamship Authority parking lot, and an erosional area with a rate of -0.39 ft/yr to the south. The future shorelines shown within these figures may only be valid representations if the processes that have occurred in the short-term period analyzed by the MSCP remain constant into the future.

None of the projected shorelines based on local rates of erosion appear to interfere with any development in Woods Hole Village. Additionally, most of the Woods Hole Village waterfront areas coincide with developed shorelines (bulkheads, seawalls, revetments, etc.) where shoreline change is not an issue.

3.2.2 Issues Related to Nuisance Flooding

Structured waterfront areas of Woods Hole Village may not be significantly influenced by shoreline change or coastal processes, but long-term shifts in tidal benchmarks due to sea level rise can create nuisance flooding issues which may severely encroach on existing assets and the usability of the working waterfront.

Figure 3-3 shows the spatial extent of existing and projected future Mean Higher High Water (MHHW) for Woods Hole Village, based on local sea level rise projections for Great Harbor (Table 2-1), and how these areas of potential future nuisance flooding intersect with WHOI/MBL/NOAA property in Woods Hole Village. Although the tidal benchmark projections (which were developed specifically for the Great Harbor waterfront) have not been locally scaled to reflect the geometry of Eel Pond or processes affecting Buzzards Bay, they are applied to these areas as a close approximation for planning purposes. Subsequent releases of MC-FRM will include locally adjusted high-water lines.

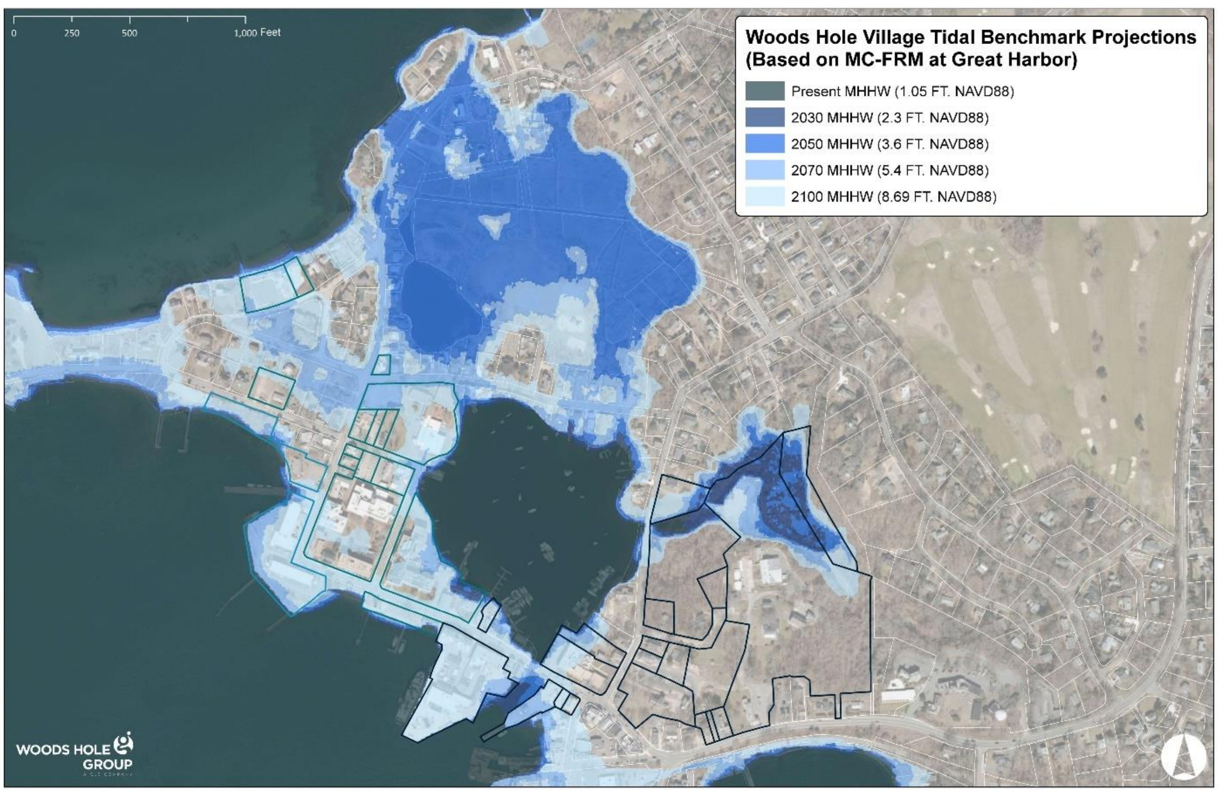


Figure 3-3 Present Day and Projected Future Mean Higher High Water for Woods Hole Village

Based on this assessment, the following facilities could experience nuisance flooding issues:

By 2030

WHOI: None anticipated
MBL: None anticipated
NOAA: None anticipated

By 2050

WHOI: School Street Parking Areas
MBL: MRC
NOAA: None anticipated

By 2070

WHOI: Iselin Parking, Dyers, Redfield Parking
MBL: CSF, Lillie Parking, Swope Parking
NOAA: Aquarium/Maintenance/Gear Parking, Main Office Parking, Cottage Parking

By 2100

WHOI: Information Office, Smith, Bigelow, Iselin, Redfield, Sugar Shack, 38 Water St.
MBL: Swope, Crane, Carpentry, Ebert, Starr, ESL, Rowe, Loeb, Lillie, Candle, Pump House, MBL Club, Stoney Beach
NOAA: Aquarium/Maintenance/Gear Building, Main Office Building

Throughout Woods Hole Village, tidal inundation could also present access issues for the following roadways:

By 2030

None anticipated

By 2050

Gardiner Road

By 2070

Albatross Street, Spencer Baird Road, Millfield Road, Gosnold Road, MBL Street, North Street

By 2100

Water Street, School Street, Luscombe Avenue

Additionally, the asset tables in Appendix D provide a screening level assessment of each asset's critical elevation compared to the projected Highest Annual Tide (HAT) benchmark to develop an understanding of first exposure of assets to tidal flooding. No assets are vulnerable to HAT inundation above the critical elevation under present conditions. Projected 2030 HAT exceeds the critical elevation for 1/36 WHOI assets (dock on Eel Pond), 2/54 MBL assets (docks on Eel Pond), and 0/28 NOAA assets. Projected 2050 HAT exceeds the critical elevation for 7/36 WHOI assets, 3/54 MBL assets, and 3/28 NOAA assets. Projected 2070 HAT exceeds the critical elevation for 16/36 WHOI assets, 14/54 MBL assets, and 7/28 NOAA assets. Projected 2100 HAT exceeds the critical elevation for 25/36 WHOI assets, 32/54 MBL assets, and 21/28 NOAA assets.

Note that although these projections represent the state of the science and the best available local downscaling of global climate models, there is uncertainty in these sea level rise projections, especially when looking further into the future. As organizations involved in climate research and marine science, WHOI/MBL/NOAA should continue to monitor sea level rise trends and update projections as the science evolves.

3.3 COASTAL FLOOD EXCEEDANCE PROBABILITY AND DEPTH PROJECTIONS

Episodic impacts from more frequent and more intense coastal storms, as opposed to the periodic nature of nuisance flooding, present a significant threat to the infrastructure that supports all these important activities and uses in Woods Hole.

This section provides an overview of the vulnerability assessment performed for Woods Hole Village looking to the next 50 years. This vulnerability assessment is based on the MC-FRM projections, which are presented in Appendix C.

Having been developed around the waterfront of Great Harbor and Eel Pond, Woods Hole Village is generally at low elevation, and therefore vulnerable to coastal flooding. Some portions of the study area (notably WHOI's campus east of School Street and north of Woods Hole Road, but to some extent the MBL parcels near the intersection of North Street and Albatross Street) are elevated, affording them some level of protection from storm surge. The rest of Woods Hole Village, including all of NOAA's property, the majority of MBL's holdings, and WHOI's waterfront facilities, are vulnerable to storm surge under current conditions and will be increasingly exposed as sea level rises and storms intensify.

Due to the significant change in elevation east of School Street and Buzzards Bay Avenue, the extent of storm surge is not projected to change very much in the study area over time. Review of the CFEP maps (Appendix C) indicates that flood probability increases over time throughout Woods Hole Village, and that eventually even the higher spine in the vicinity of North Street and Albatross Street could be exposed to a 1% chance event by 2070. Flood probabilities at campus locations along Albatross Street (NOAA), Water Street (MBL and WHOI) and Eel Pond (MBL and WHOI) are currently in the range of 5-10%, but could increase to 10-20% by 2030, to 50-100% by 2050, and to 100% by 2070. These projections suggest that, given the assumptions of MC-FRM, much of Woods Hole Village could be inundated by the annual (100% chance event) storm by 2070.

Depths of flooding in a 1% chance event (Appendix C) under current conditions are more severe in the low-lying residential and open space areas north of Millfield Street than in the built-up portions held by the research institutions. However, a 1% chance event today could produce flooding on the order of 2-3 feet across NOAA's campus, WHOI's Iselin Dock and in the vicinity of MBL's Candle House, MRC and CSF. By 2030, a 1% storm could produce flooding on the order of 3-4 feet at these facilities. In 2050 and 2070, 1% chance events could produce flooding in the range of 10 feet or greater.

Depths of flooding in a 0.1% chance event (Appendix C) would be significant (10 feet or more) even under current conditions. Such high intensity (and low probability) events may be useful to think about in terms of emergency planning, but are not likely to be productive for adaptation planning where organizations must prioritize investments in actions to build resilience in the face of more probable events.

Review of the MC-FRM maps (Appendix C) also highlights the importance of access in the Woods Hole Village study area. These projections indicate that roads serving the various WHOI/MBL/NOAA facilities in Woods Hole may be inundated and impassable during present and future storms. Particularly vulnerable roads that also provide critical access for WHOI/MBL/NOAA facilities include Water Street, Albatross Street and Millfield Road. Also, of concern are secondary streets within the campuses (MBL Street, North Street, Luscombe Avenue) and the low-lying portion of School Street fronting Eel Pond). MassDOT considers roads impassable by passenger vehicles at 6 inches of flooding. Municipal emergency vehicles (e.g. fire trucks) may not be able to proceed along roads with greater than 18 inches of flooding. These potential access issues highlight the importance of working with the Town of Falmouth to ensure all adaptation measures are coordinated and aligned in terms of their goals.

3.4 INSTITUTIONAL ASSET RISK

A total of 118 institutional assets were evaluated in the risk assessment. The results of the risk assessment are provided in Appendix D tables, which are divided by institution and sorted in descending order of Present-Day risk. In general, the highest risk institutional assets were WHOI's waterfront operational facilities, NOAA's waterfront operational facilities, and MBL's Eel Pond facilities. Present Day, 2030, 2050, and 2070 asset risks in the Woods Hole Village study area are represented in Figures 3-4 through 3-7.

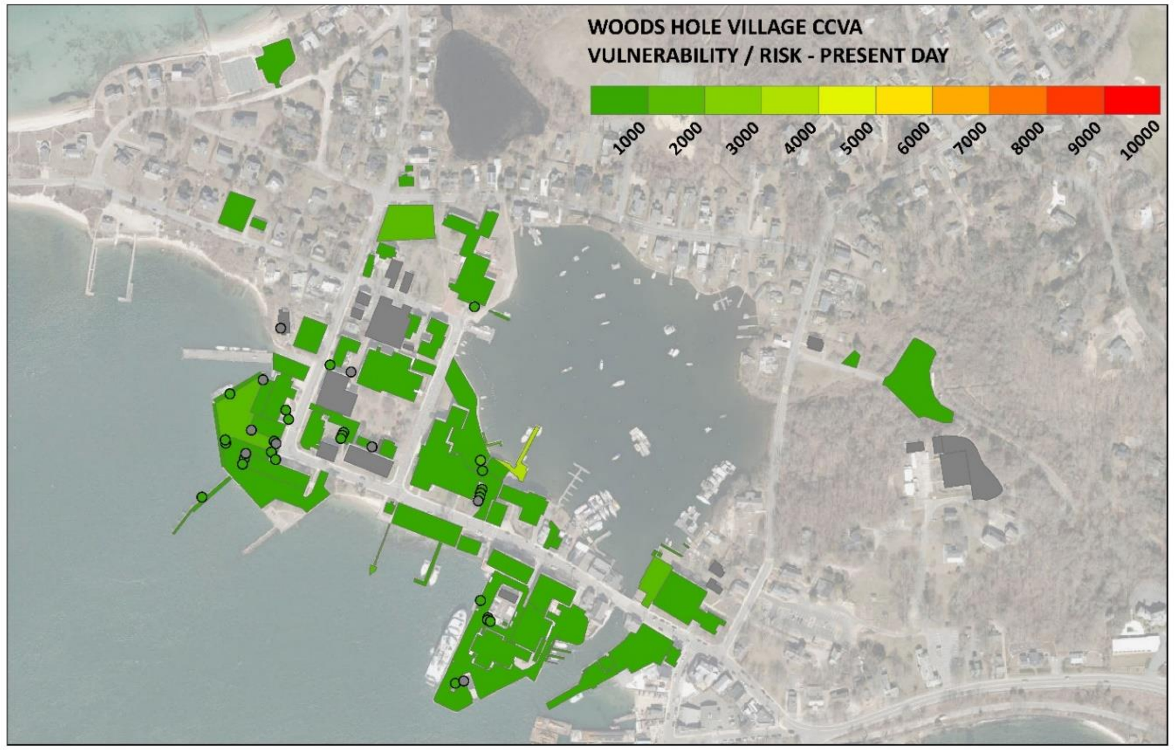


Figure 3-4 Present Day asset specific risk results

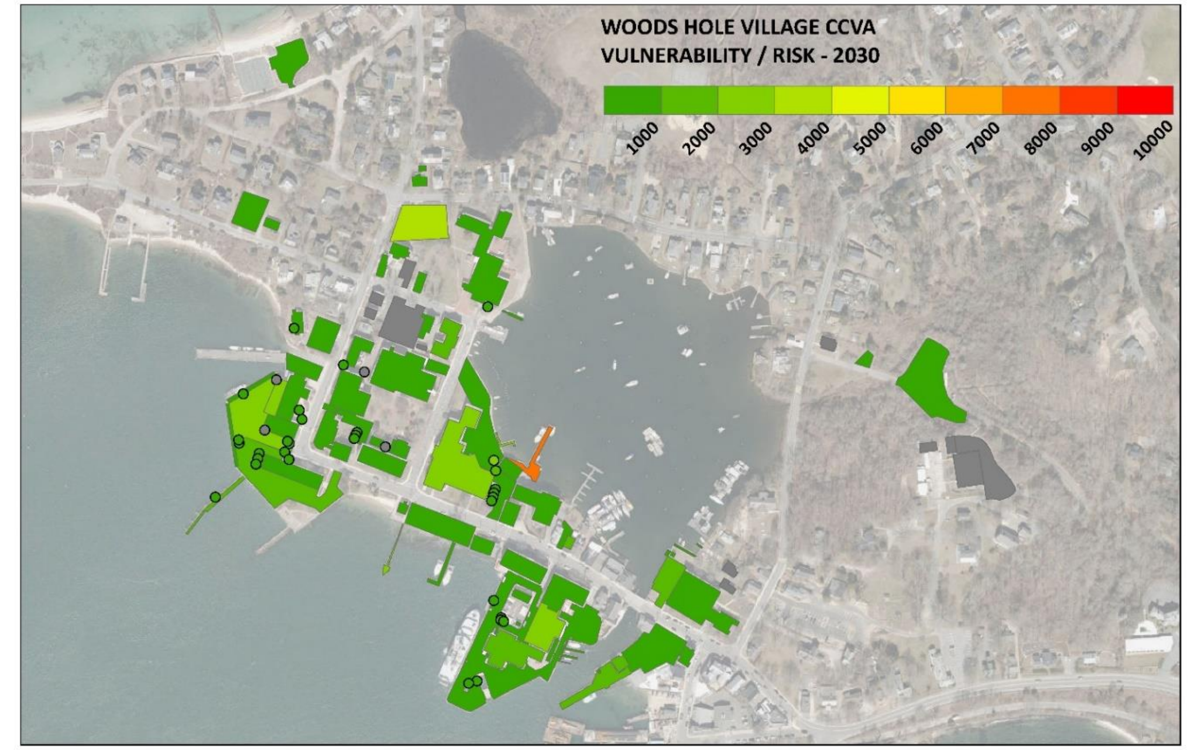


Figure 3-5 2030 asset specific risk results

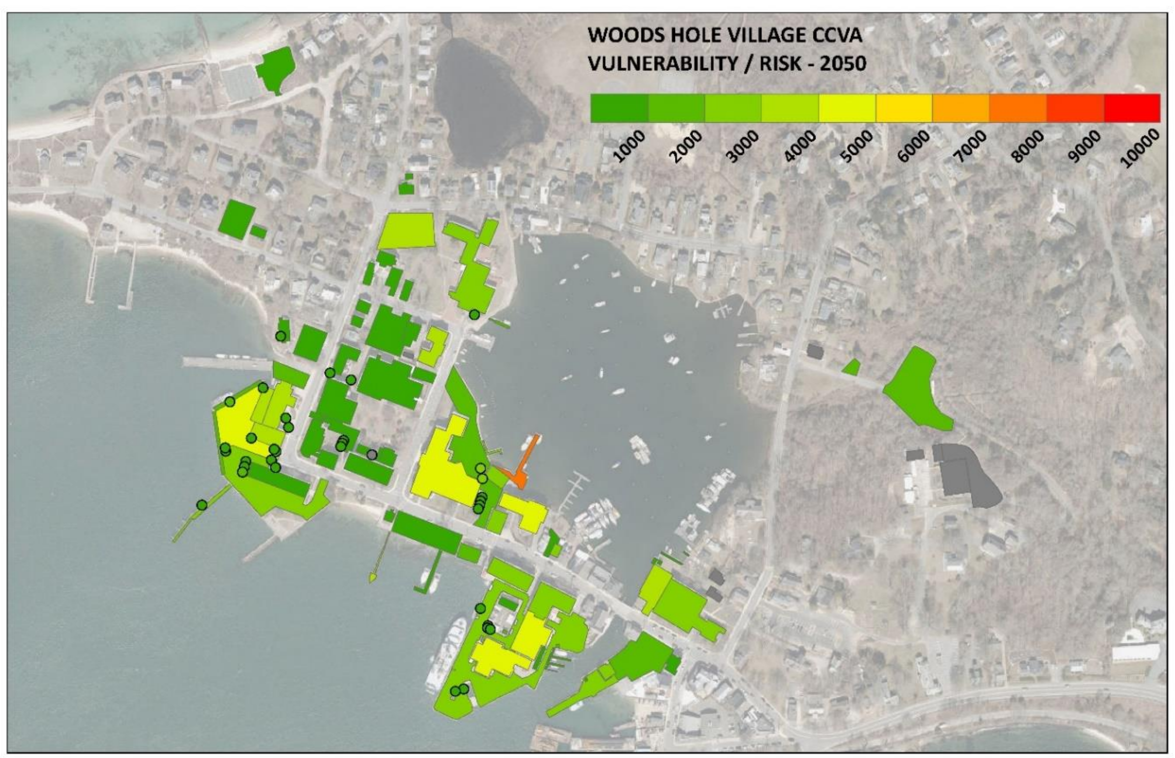


Figure 3-6 2050 asset specific risk results

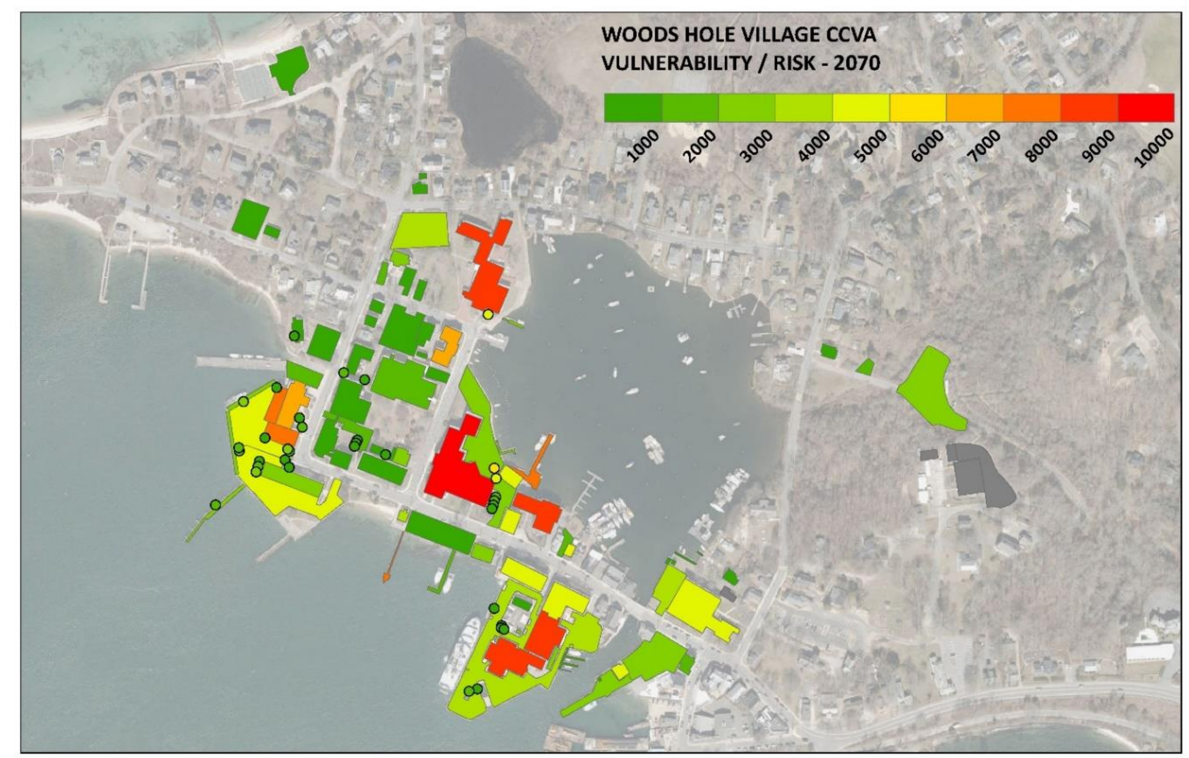


Figure 3-7 2070 asset specific risk results

3.4.1 WHOI Assets

Appendix D-1 provides the asset specific risk assessment results for WHOI's 36 assets evaluated in this study. Figures 3-8 through 3-11 provide the asset specific risk assessment process for WHOI's assets (Water Street assets shown in figures) under Present Day, 2030, 2050, and 2070 conditions.

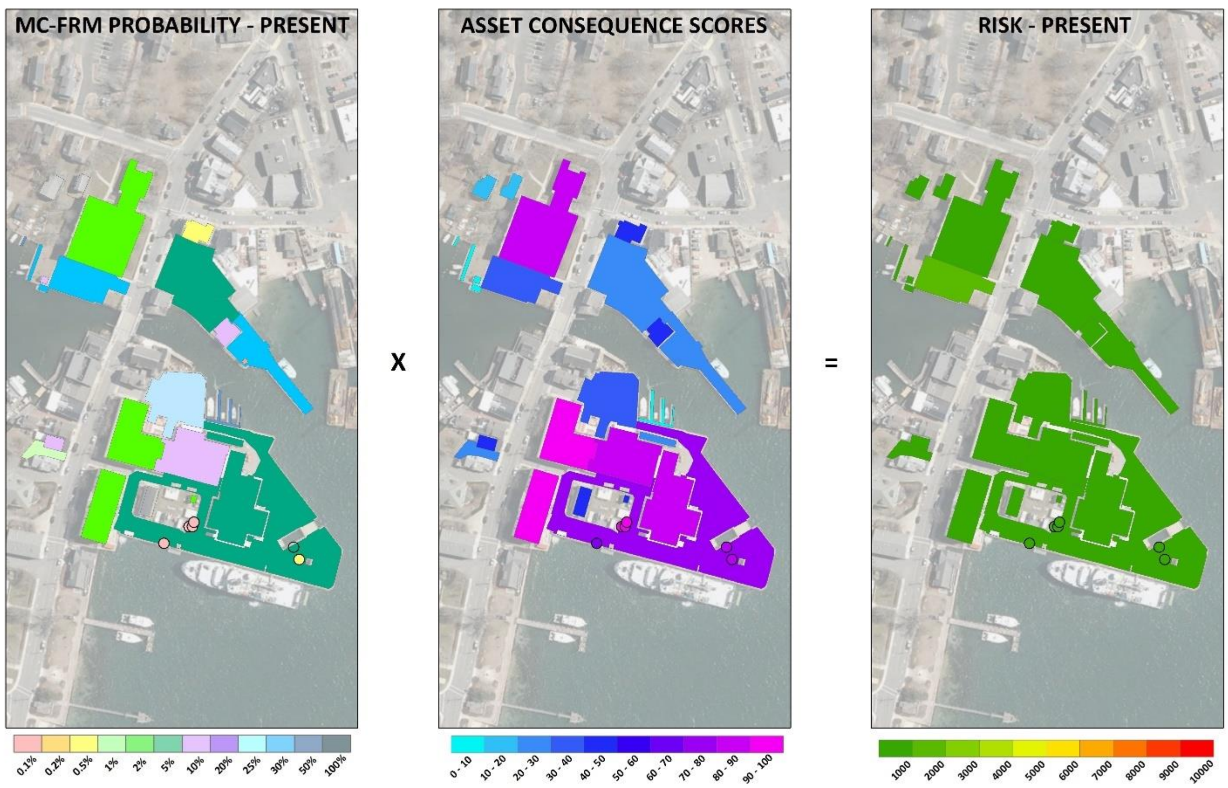


Figure 3-8 WHOI asset risk assessment - Present

Based on Present Day conditions, the Top 10 WHOI assets at risk to storm surge are:

1) Redfield Parking
2) Iselin Parking
3) Smith-Iselin Connector
4) 49 School Street Parking
5) Dyers Dock
6) Information Office (93 Water Street)
7) Dyers Hangar
8) Iselin
9) Finger Pier
10) Iselin Dock

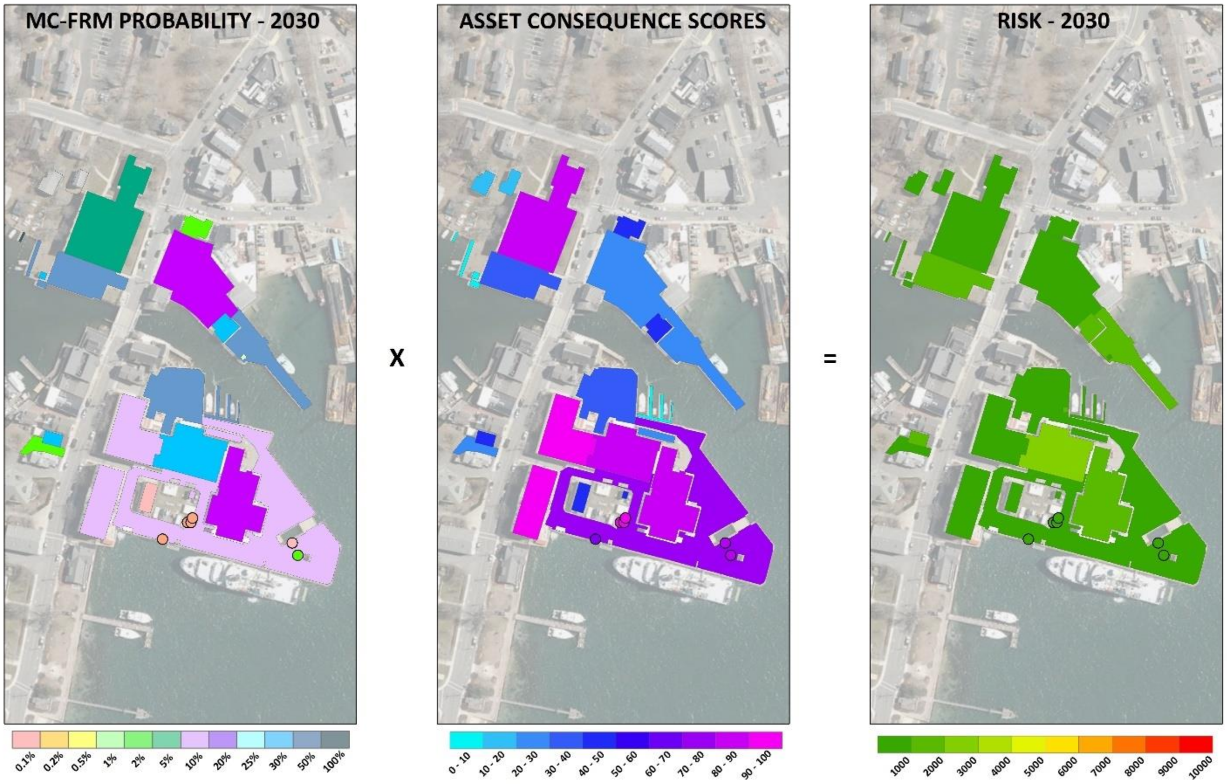


Figure 3-9 WHOI asset risk assessment - 2030

Based on 2030 conditions, the Top 10 WHOI assets at risk to storm surge are:

1) Smith-Iselin Connector
2) Redfield Parking
3) Iselin Parking
4) Iselin
5) Information Office (93 Water Street)
6) Dyers Hangar
7) Dyers Dock
8) Smith
9) Bigelow
10) School Street Parking

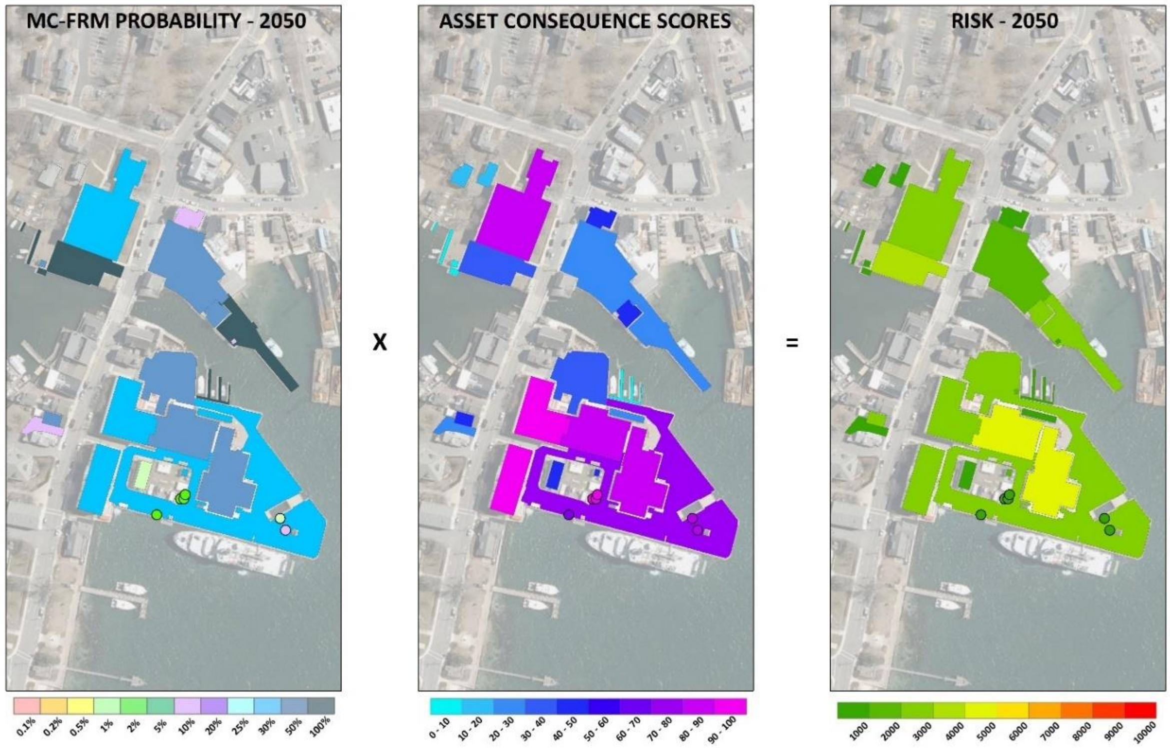


Figure 3-10 WHOI asset risk assessment - 2050

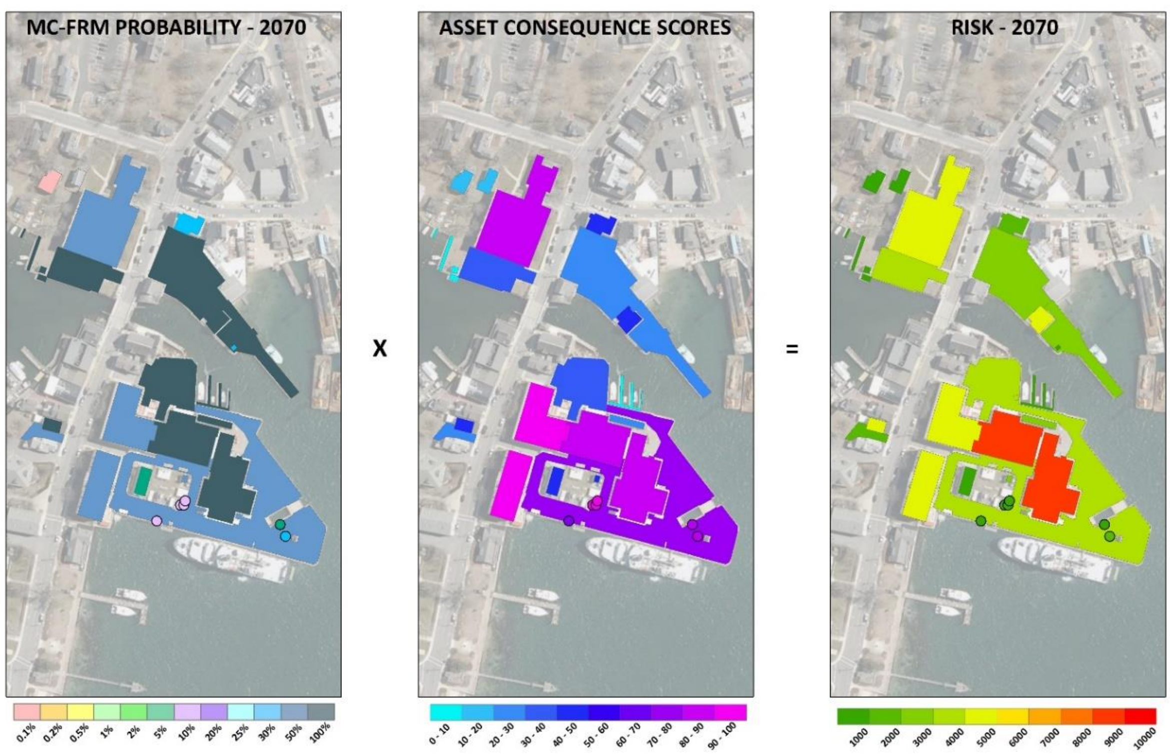


Figure 3-11 WHOI asset risk assessment - 2070

The risk assessment assumes that certain assets associated with WHOI's CWATER project at the Iselin Marine Facility will be replaced or relocated during the facility's reconstruction project and, therefore, were not included in the 2050 or 2070 asset level risk calculations. Based on 2050 and 2070 conditions, the Top 10 WHOI assets at risk to storm surge are:

1) Redfield Parking
2) Smith
3) Bigelow
4) Information Office (93 Water Street)
5) Redfield
6) Dyers Hangar
7) Dyers Dock
8) 49 School Street Parking
9) School Street Parking
10) Dyers Parking

Appendix E-1 provides asset profiles (including impact probability, depth above the critical elevation, consequence scoring, and risk assessment results) for 15 priority WHOI assets.

3.4.2 MBL Assets

Appendix D-2 provides the asset specific risk assessment results for MBL's 45 assets evaluated in this study. Figures 3-12 through 3-15 provide the asset specific risk assessment process for MBL's assets (except Smith Cottage and Stoney Beach) under Present Day, 2030, 2050, and 2070 conditions.

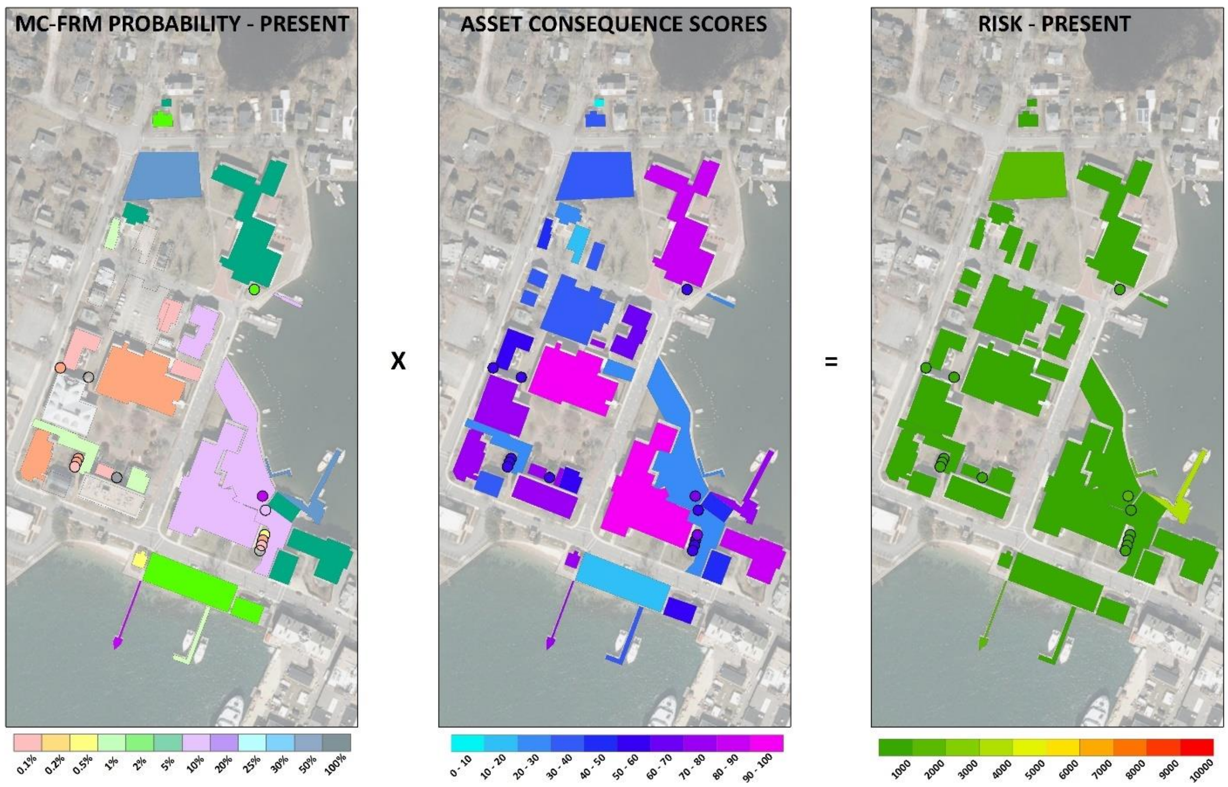


Figure 3-12 MBL asset risk assessment - Present

Based on Present Day conditions, the Top 10 MBL assets at risk to storm surge are:

1) MRC Dock
2) Swope Parking
3) Seawater Dock
4) MRC Fuel Tank
5) Dinghy Dock
6) Lillie Laboratory
7) Ebert Hall
8) Marine Resources Center
9) Swope Building
10) Lillie Fuel Tank

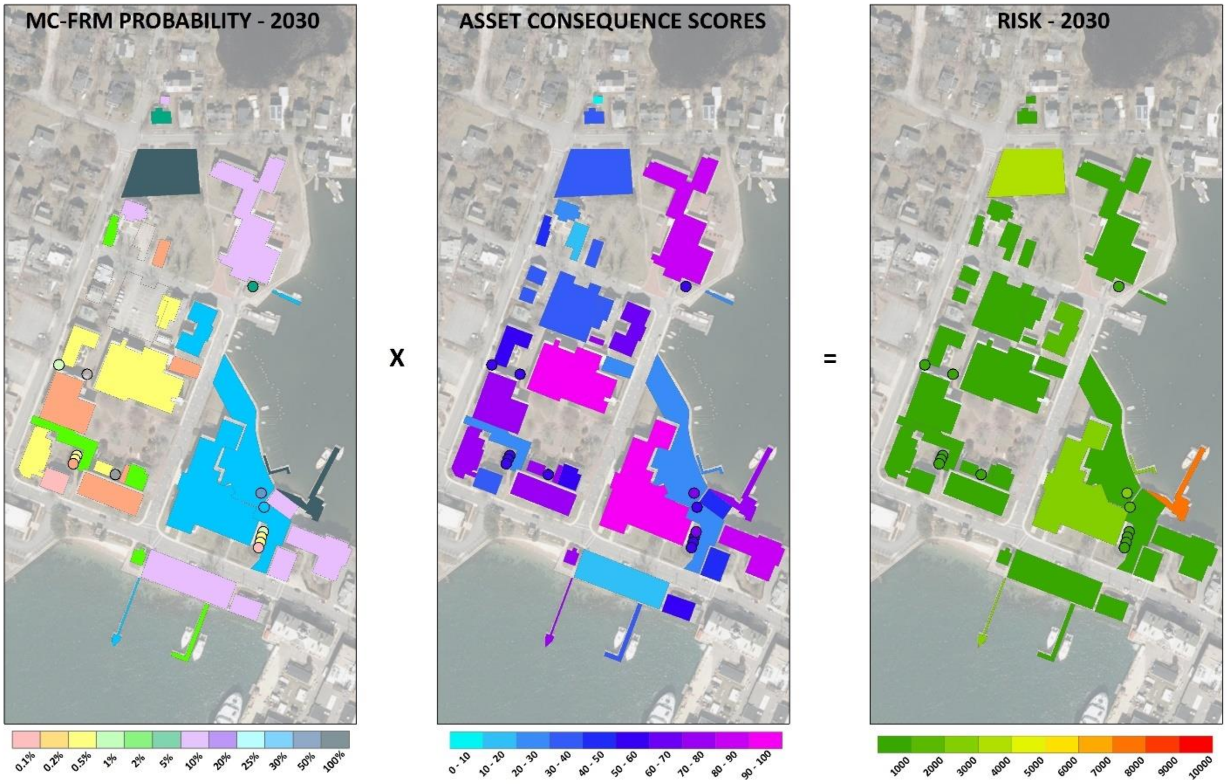


Figure 3-13 MBL asset risk assessment - 2030

Based on 2030 conditions, the Top 10 MBL assets at risk to storm surge are:

1) MRC Dock
2) Swope Parking
3) Lillie Laboratory
4) MRC Fuel Tank
5) Seawater Dock
6) Dinghy Dock
7) Ebert Hall
8) Lillie Fuel Tank
9) Swope Dock
10) Lillie Parking

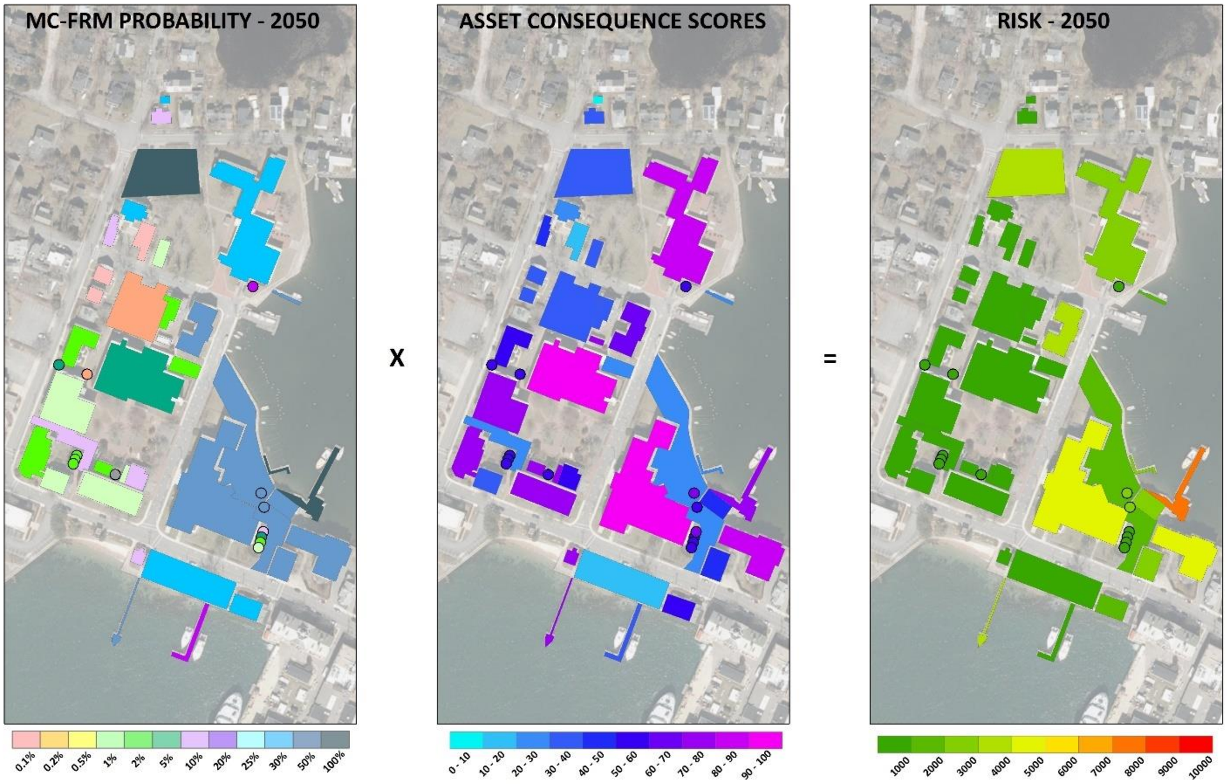


Figure 3-14 MBL asset risk assessment - 2050

Based on 2050 conditions, the Top 10 MBL assets at risk to storm surge are:

1) MRC Dock
2) Lillie Laboratory
3) Marine Resources Center
4) Seawater Dock
5) Swope Parking
6) Ebert Hall
7) MRC Fuel Tank
8) Swope Building
9) Candle House
10) Lillie Fuel Tank / Collection Support Facility

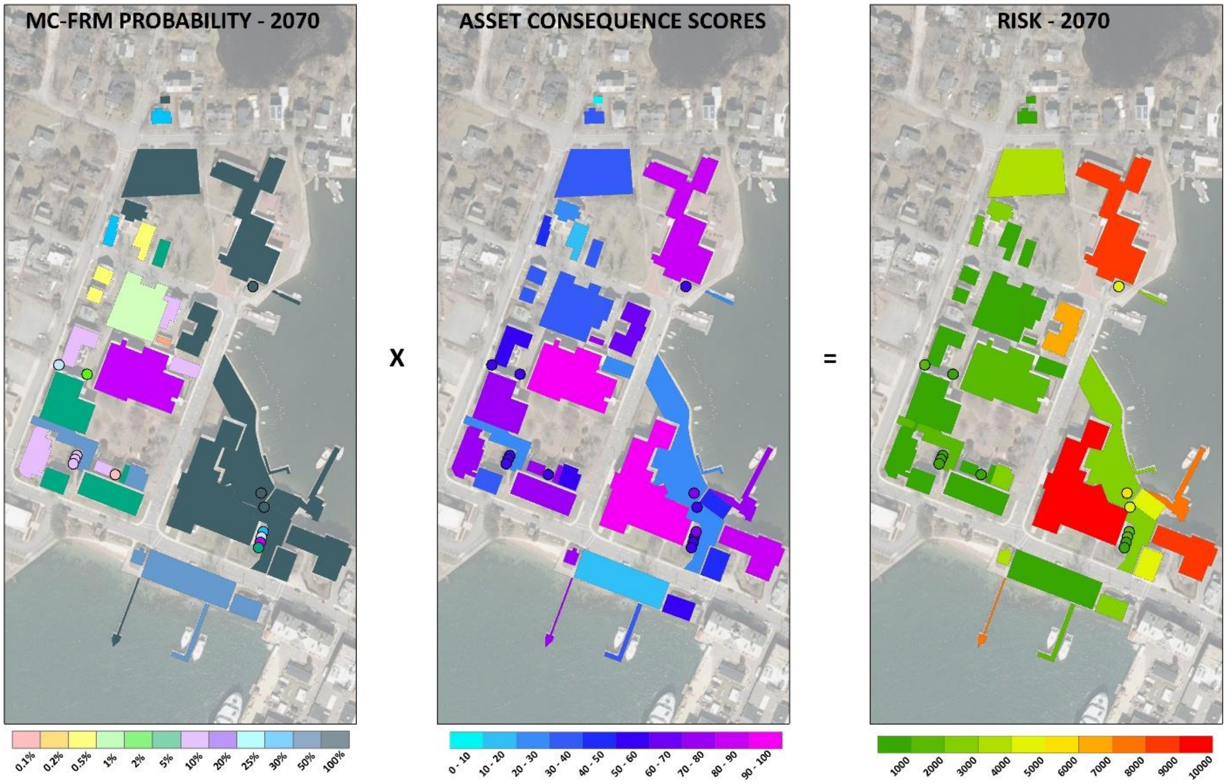


Figure 3-15 MBL asset risk assessment - 2070

Based on 2070 conditions, the Top 10 MBL assets at risk to storm surge are:

1) Lillie Laboratory
2) Marine Resources Center
3) Swope Building
4) MRC Dock
5) Seawater Dock
6) Ebert Hall
7) MRC Fuel Tank
8) Candle House
9) Lillie Fuel Tank
10) Collection Support Facility / Swope Generator

Appendix E-2 provides asset profiles (including impact probability, depth above the critical elevation, consequence scoring, and risk assessment results) for 15 priority MBL assets.

3.4.3 NOAA Assets

Appendix D-3 provides the asset specific risk assessment results for NOAA's 28 assets evaluated in this study. Figures 3-16 through 3-19 provide the asset specific risk assessment process for NOAA's assets under Present Day, 2030, 2050, and 2070 conditions.

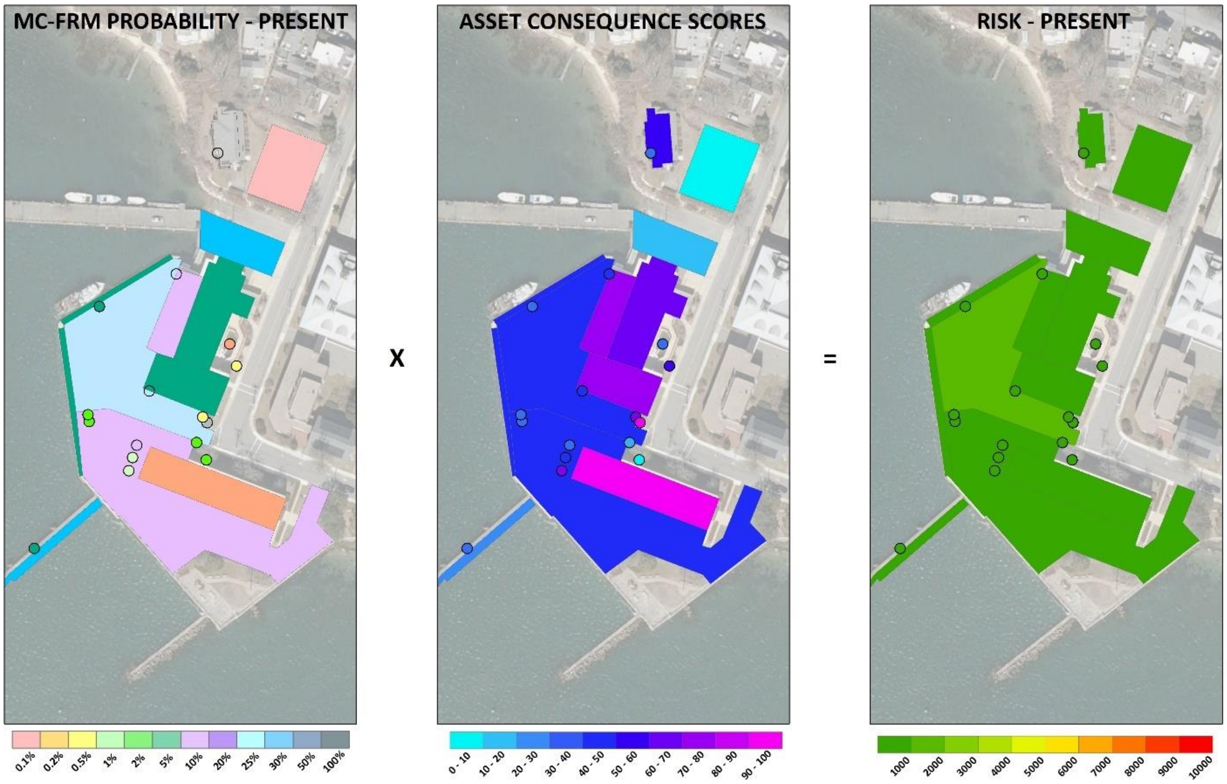


Figure 3-16 NOAA asset risk assessment - Present

Based on Present Day conditions, the Top 10 NOAA assets at risk to storm surge are:

1) Maintenance/Gear Parking
2) 250' Wooden Finger Pier
3) Gear Shed
4) Aquarium Parking
5) Main Office Parking
6) Maintenance Garage
7) Aquarium Building
8) Small Vessel Berthing (160ft)
9) Large Vessel Berthing (200ft)
10) 50A Electrical Service - Small Vessel Bulkhead / Electrical Service – Pier

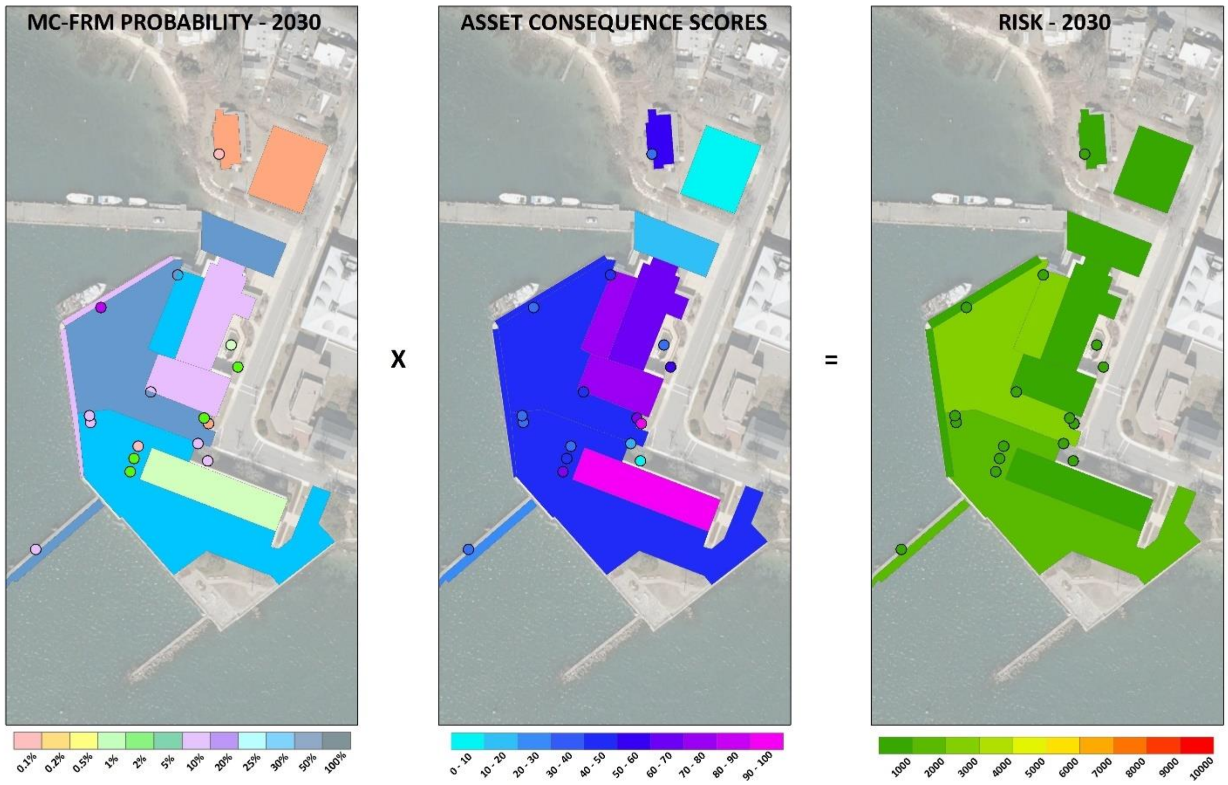


Figure 3-17 NOAA asset risk assessment - 2030

Based on 2030 conditions, the Top 10 NOAA assets at risk to storm surge are:

1) Maintenance/Gear Parking
2) Gear Shed
3) Main Office Parking
4) 250' Wooden Finger Pier
5) Aquarium Parking
6) Maintenance Garage
7) Aquarium Building
8) 50A Electrical Service - Small Vessel Bulkhead
9) Small Vessel Berthing (160ft)
10) Large Vessel Berthing (200ft)

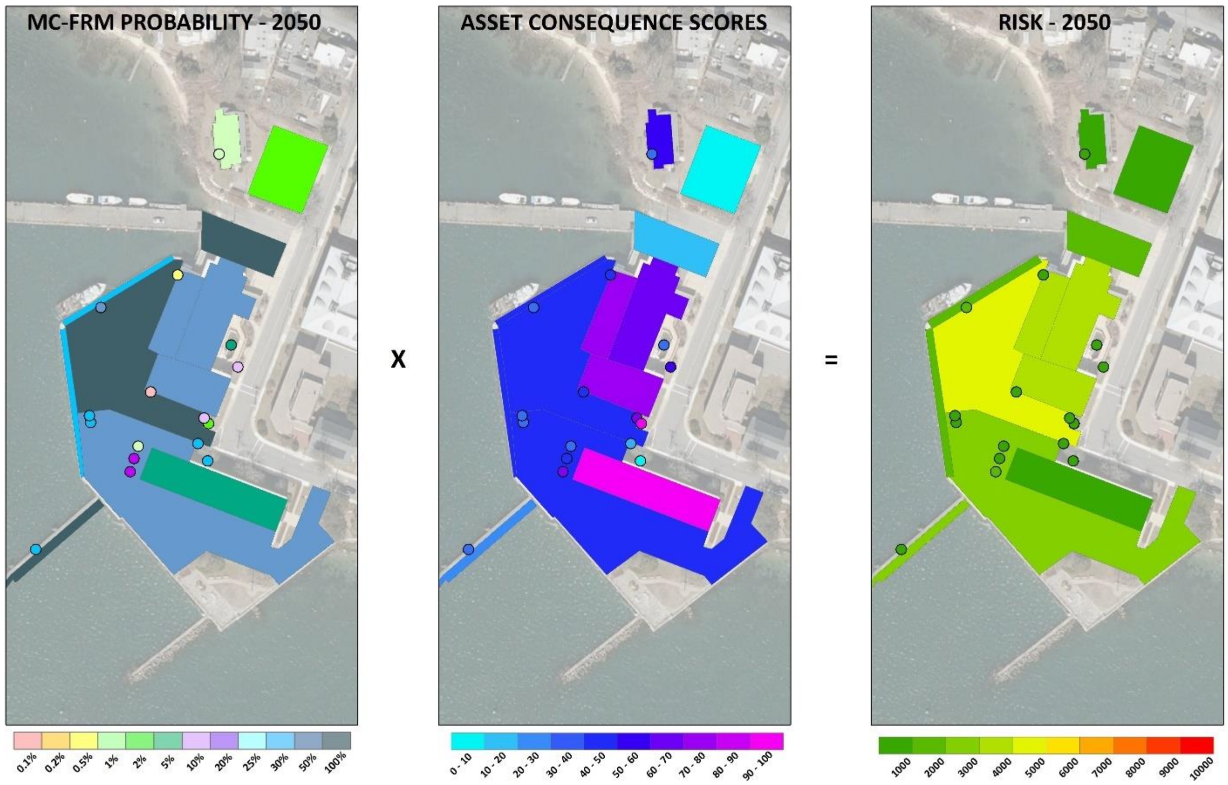


Figure 3-18 NOAA asset risk assessment - 2050

Based on 2050 conditions, the Top 10 NOAA assets at risk to storm surge are:

1) Maintenance/Gear Parking
2) Maintenance Garage
3) Gear Shed
4) Aquarium Building
5) 250' Wooden Finger Pier
6) Main Office Parking
7) Aquarium Parking
8) Small Vessel Berthing (160ft)
9) Large Vessel Berthing (200ft)
10) 50A Electrical Service - Small Vessel Bulkhead

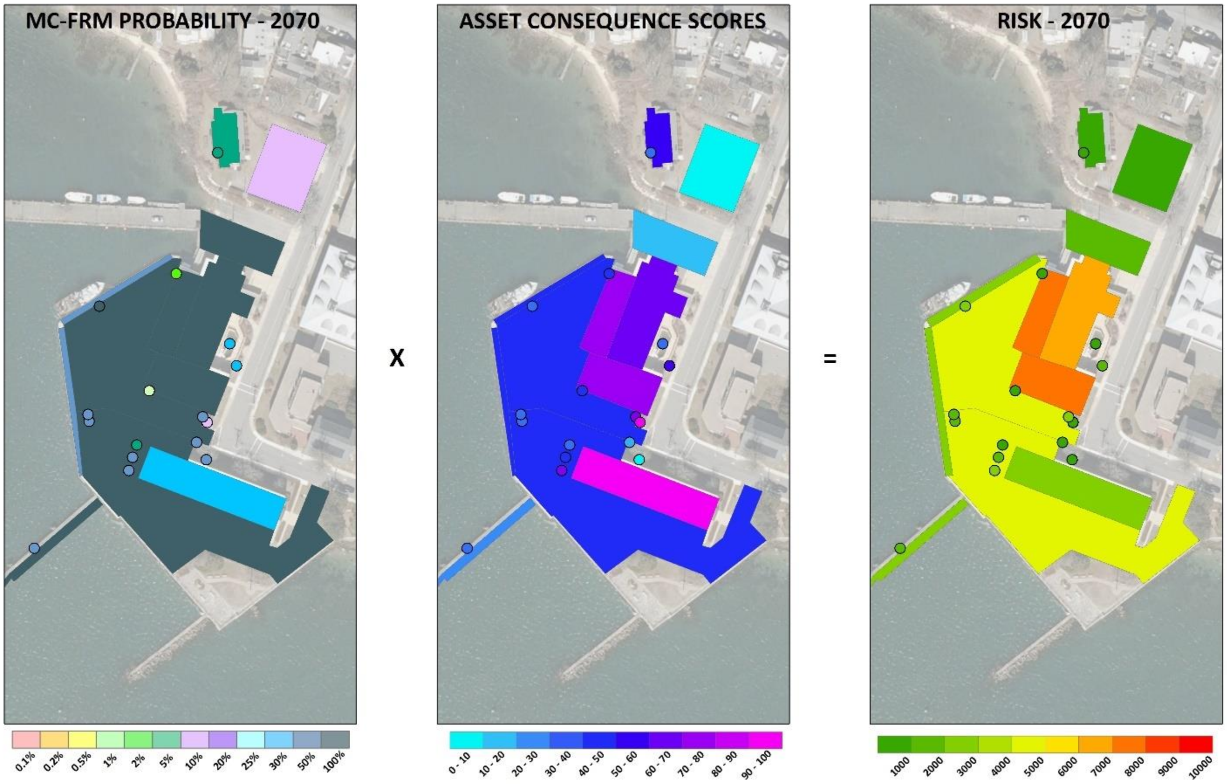


Figure 3-19 NOAA asset risk assessment - 2070

Based on 2070 conditions, the Top 10 NOAA assets at risk to storm surge are:

1) Maintenance Garage
2) Gear Shed
3) Aquarium Building
4) Maintenance/Gear Parking
5) Main Office Parking
6) 50A Electrical Service - Small Vessel Bulkhead
7) Seawater Pump House
8) Main Office
9) Aquarium Complex Transformer
10) 250' Wooden Finger Pier / Small Vessel Berthing (160ft) / Large Vessel Berthing (200ft)

Appendix E-3 provides asset profiles (including impact probability, depth above the critical elevation, consequence scoring, and risk assessment results) for 15 priority NOAA assets.

4.0 ADAPTATION STRATEGIES

At a conceptual level, there are generally five (5) categories of adaptation strategies to reduce the vulnerability of assets in the coastal zone to sea level rise and storm surge. While numerous implementation approaches are available and vary by context and goal, they all are rooted in one of the following strategies (graphics from CoastAdapt / National Climate Change Adaptation Research Facility):

AVOID – Keep new development away from areas of current and future risk. This may not be applicable to working waterfronts but could be used to guide facilities planning for non-water-dependent uses. This strategy assumes that upland areas have been identified and can be designated as receiving areas for facilities and uses currently located in vulnerable parts of Woods Hole Village. Both WHOI and MBL have campuses and additional land holdings in higher elevation parts of Woods Hole as well as at the Sippewissett Campus. NOAA, however, does not have land outside of the zone vulnerable to storm surge (although the Cottage parcel is generally above the projected area of tidal inundation).

ACCOMMODATE – Continue to occupy the same area but modify assets to enhance their flood tolerance and resilience. Structures and infrastructure may be elevated above a design flood elevation that may be tied to a certain level of risk tolerance (e.g. a future 1% chance event), and wet floodproofed to allow water to pass through without damage to systems or structures. In some cases, at working waterfronts, adjustments to accommodate sea level rise may be necessary to maintain access to the water, but facilities can be designed to be resilient to storm surge.

PROTECT – Continue to occupy the same area but modify assets or surroundings to keep flood waters out. Such measures may include building-level dry floodproofing techniques such as façade sealing, window and door barriers, and deployable barriers. Additionally, flood protection may be applied at a landscape scale using hard structures (e.g. modular seawalls) or soft solutions (e.g. dunes and vegetated berms)

ADVANCE – Land reclamation may be used in extenuating circumstances to build seaward protection (hard structures or soft solutions) where other options are limited. This strategy is generally very costly and has significant environmental impacts, making it difficult (if not impossible) to permit.

RETREAT – Move existing at-risk assets to higher ground to reduce exposure to flooding. As discussed in the "Avoid" strategy, this strategy assumes that upland areas have been identified and can be designated as receiving areas for facilities and uses currently located in vulnerable parts of Woods Hole Village. Relocation may be infeasible for water-dependent uses, and requires upland sending areas for non-water-dependent uses. Pulling development back from vulnerable areas not only reduces risk, but also allows for wetland migration as sea levels rise. This strategy, by abandoning some land at the water's edge, may also provide an opportunity to build a regional protection strategy for other landward assets that may be vulnerable under future conditions.

4.1 ASSET-LEVEL STRATEGIES

A variety of options exist for asset-specific (buildings or mechanical infrastructure components) adaptations. These strategies may be applied as needed to vulnerable WHOI/MBL/NOAA facilities as well as to other assets in Woods Hole Village, following further site-specific investigations and suitability analyses. These asset-specific strategies are intended to reduce damages caused by flooding and range from major building modifications to interior modifications. These general asset adaptation strategies include:

- *Full Building Elevation*: If a building or structure has a high probability of flood inundation, consideration should be given to elevating the entire structure above the projected target flood elevation to avoid critical damage from sea level rise and storm surge. Depending on the construction type and architectural style of the structure, it could be elevated on stilts or pilings (allowing water to pass under the structure without causing structural damage) or on a solid concrete foundation. Any elevation project will require the installation of additional stairs or a ramp to access the new elevated entryway.

- *Interior Elevation*: If a building or structure has a high probability of flood inundation, but full building elevation is not possible, consideration could instead be given to elevating just the first floor from the interior. This strategy is most appropriate for buildings constructed of a non-porous, flood-resistant material (e.g., masonry), where the most significant risk comes from flood water entering the structure through openings in the building (e.g., doorways, windows, etc.). This is a particularly attractive option when there is a strong desire to maintain the existing aesthetic of the building's exterior, such as with historic preservation sites. However, interior elevation only works if there is an adequate floor to floor height to accommodate the floor elevation.

- *Dry Floodproofing*: Dry floodproofing involves using multiple strategies to ensure that no flood water enters through the exterior of the building, the basement, or any of the building's openings. This might involve installing deployable flood shields at any doors or windows below the projected target flood elevation. Traditional flood shields require permanent hardware to be installed on the frame of the opening so that barriers can be easily deployed prior to a flood event. Dry floodproofing can also involve sealing the existing exterior façade of the building with an impervious coating that stops floodwaters from penetrating pre-existing porous materials.

- *Wet Floodproofing*: Unlike dry floodproofing, wet floodproofing does not aim to stop water from entering a building or structure. Instead, it aims to reduce flood damages by allowing flood water to pass through the structure so that the forces of the water on the building's exterior do not cause significant damage to the structure itself. Because of this, wet floodproofing requires retrofitting the building's interior with 'floodable' materials and protecting mechanical and utility equipment so that these components will not suffer permanent damage when water passes through.

- *Mechanical Systems*: Whenever possible, mechanical systems should be elevated above the projected target flood elevation. For low flood inundation probabilities, or if it is not feasible to relocate the mechanical system outside of the lower level, systems should be elevated on a platform to protect from subgrade flooding. Systems should always be anchored so as not to shift during a flood event, damaging other areas.

The asset tables in Appendix D provide near-term and long-term conceptual level asset-specific recommendations for each WHOI/MBL/NOAA asset evaluated in this vulnerability assessment. The recommendations consider each asset's current and future exposure to tidal inundation as well as to storm surge. In general, the asset level strategies focus on Protection strategies (such as building dry floodproofing measures) and elevating mechanical/electrical equipment in the near-term, and pivot to larger scale interventions like facility redesign (with elevation) or retreat in the long-term. Also, some asset-level adaptation strategies are operational in nature – i.e. prohibit use of low-lying parking areas during storms or secure/move vulnerable equipment on waterfront work areas ahead of a storm. In these cases, the asset should be usable once the storm surge inundation recedes.

Over the long-term, as more facilities become vulnerable to storm surge, WHOI/MBL/NOAA may consider reducing risk simply by changing the use of a facility or keeping vulnerable equipment above a design flood elevation.

For instance, WHOI's Dyer's Hangar is a moderate risk asset with a critical elevation at grade with Dyer's Dock. The building houses office space for Facilities and Services, which is not a water-dependent use. If those offices were relocated, floodproofing at Dyer's Hangar might not need to be a priority investment.

Additionally, MBL's Carpentry Shop is a moderate risk asset in the long-term because its critical elevation is the basement floor at grade with Swope Parking. If MBL relocated carpentry activities/equipment and elevated the building systems, the first floor of the facility would not be vulnerable even in severe future storms.

Finally, NOAA's Gear Shed is vulnerable to storm surge in the near term because equipment is stored on the floor. The usable lifespan of the Gear Shed could be prolonged without significant investment in floodproofing just by changing storage practices to keep all items above a design flood elevation.

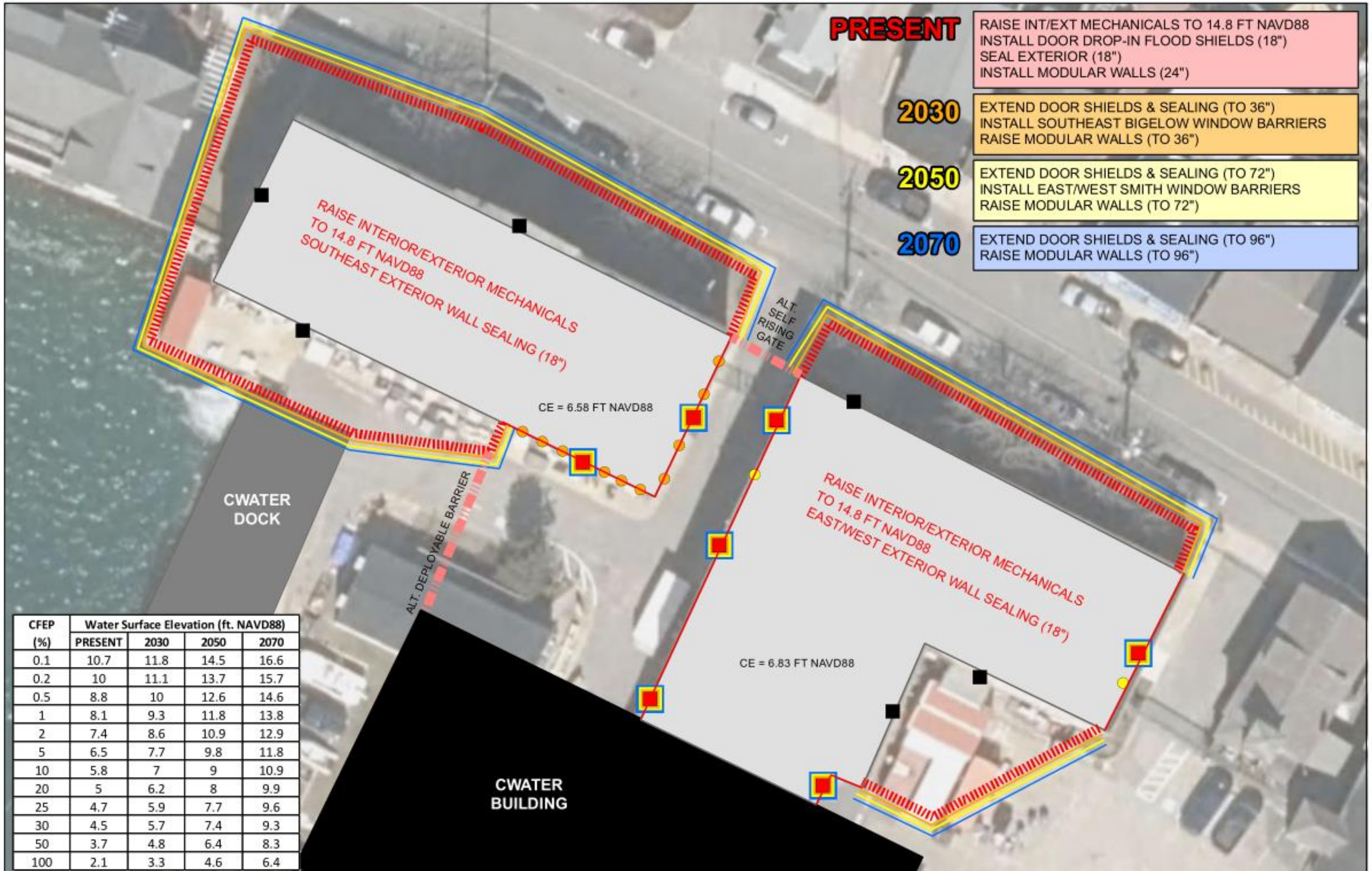
4.2 DISTRICT-LEVEL STRATEGIES

Implementing individual adaptation actions for each asset in a large waterfront institution such as WHOI, MBL or NOAA is not likely to be a sustainable or cost-effective approach. Rather, each organization should look for opportunities to protect/adapt clusters of high-risk assets with district-level strategies for those facilities that are well-positioned for long-term use (i.e. able to adjust to sea level rise while maintaining full function, and able to implement modular adaptations for storm surge over time as necessary). Each organization reviewed asset risk tables and maps and identified groups of assets that could be addressed together in an efficient manner. The campuses (districts) identified by each organization were: WHOI's Iselin Marine Facility, MBL's Lillie/CSF/MRC/Candle Complex, and NOAA's Aquarium/Maintenance/Gear Complex.

4.2.1 WHOI Complex – Iselin Marine Facility

WHOI's Iselin Marine Facility comprises the Iselin Dock and multiple facilities on and adjacent to the dock. WHOI is presently designing a new complex to replace the existing dock as well as the Iselin Building, the Smith-Iselin Connector, the Flume, the Iselin Sewer Pump Shed, and Bigelow Trailer. What will remain north of the planned new Iselin Dock and CWATER building are two buildings along Water Street – Smith and Bigelow.

With Iselin and CWATER poised to serve the next century of ocean science, the Smith and Bigelow facilities had high risk scores among the remaining post-CWATER assets. Recognizing an opportunity to build on the resilient design of CWATER, WHOI decided to advance a district-level adaptation plan for these facilities. The conceptual level adaptation plan for the Iselin Marine Facility is shown in Figure 4-1.



CFEP (%)	Water Surface Elevation (ft. NAVD88)			
	PRESENT	2030	2050	2070
0.1	10.7	11.8	14.5	16.6
0.2	10	11.1	13.7	15.7
0.5	8.8	10	12.6	14.6
1	8.1	9.3	11.8	13.8
2	7.4	8.6	10.9	12.9
5	6.5	7.7	9.8	11.8
10	5.8	7	9	10.9
20	5	6.2	8	9.9
25	4.7	5.9	7.7	9.6
30	4.5	5.7	7.4	9.3
50	3.7	4.8	6.4	8.3
100	2.1	3.3	4.6	6.4

Figure 4-1 District-level adaptation plan – WHOI Iselin Marine Facili

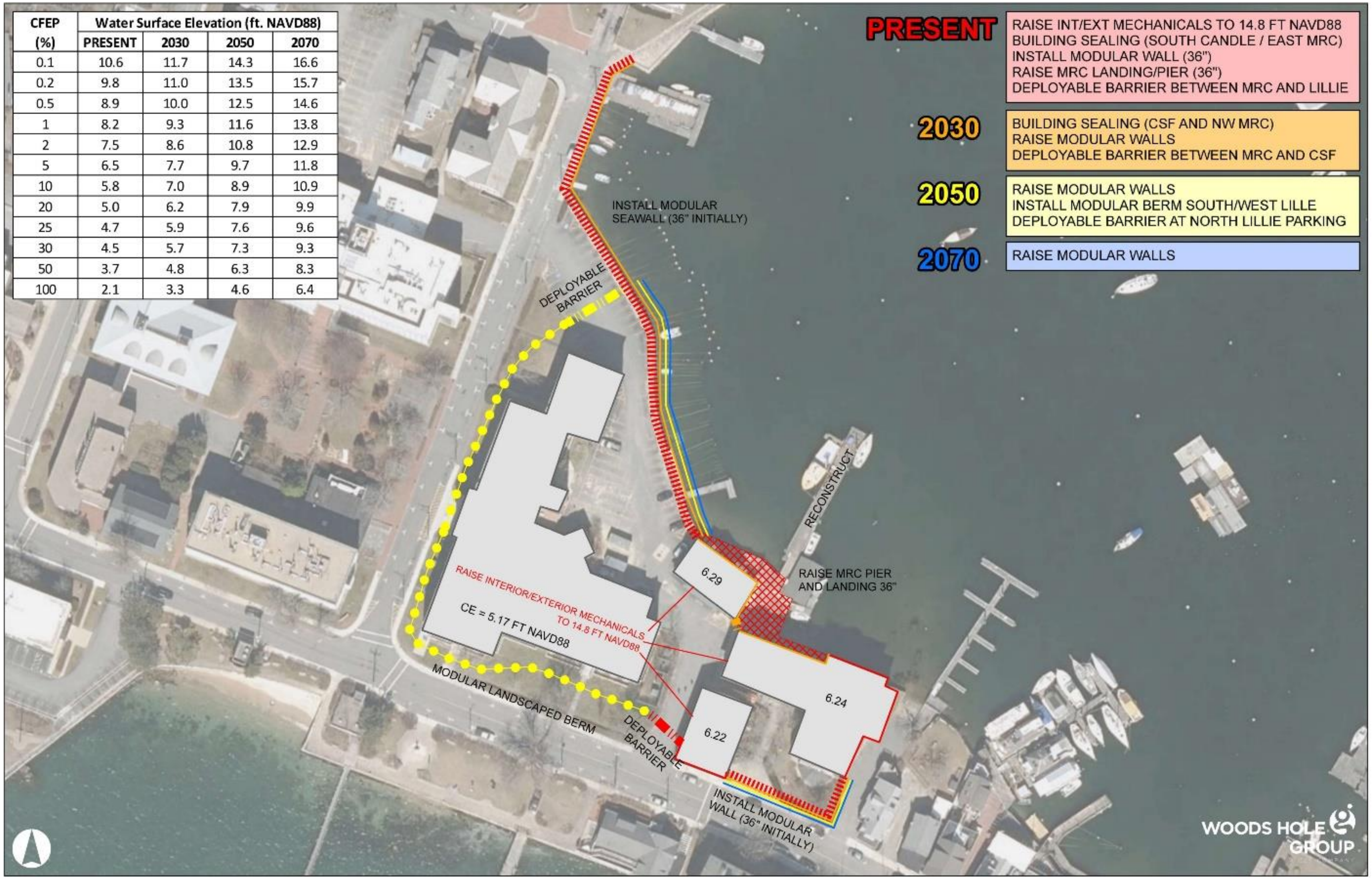
The concept for this WHOI district strategy is to protect critical infrastructure from storm surge (to the 1% CFEP water surface elevation projected over time) in an incremental and modular way, starting with present needs and adjusting over time. The design is intended to be integrated with CWATER. Under present conditions, there is a need to address storm surge from the Harbor, which is achieved by a combination of building dry-floodproofing (façade sealing and door barriers) and modular walls (creating courtyards around most of Bigelow, the Water Street side of Smith, and the southeast corner of Smith). These recommendations sought to minimize individual window and door flood shield treatments while preserving the access way between the buildings for Iselin Dock traffic. There is also an alternative proposed for a deployable barrier between Bigelow and CWATER, and a rising gate at Water Street to further reduce building treatments. Over time, the modular walls and any building treatments (façade sealant, window and door flood shields) would need to be adjusted for additional flood protection (phasing is color keyed on Figure 4-1). These elements would be designed for modularity to accept additional protection over time, as needed.

The goal of this adaptation plan is to maintain existing uses and align with CWATER project while offering incremental flood protection for these existing facilities. Over the long term (potentially 2100) there may need to be a consideration for tidal inundation, which would also by necessity require coordination with the Town of Falmouth on Water Street.

4.2.2 MBL Complex – Eel Pond Triangle

MBL's high risk Eel Pond facilities between Water Street and MBL Street include Lillie Laboratory, the Collection Support Facility, the Marine Resource Center (and pier), Candle House, and a host of adjacent building-associated infrastructure (fuel tanks, electrical equipment). These facilities border the southwestern edge of Eel Pond and are set behind or on a seawall.

This group of collocated assets returned some of the highest risk scores in the MBL assessment and are also vulnerable to future tidal inundation due to sea level rise. Recognizing a need to maintain a critical waterfront core of its campus, MBL decided to advance a district-level adaptation plan for these facilities. The conceptual level adaptation plan for the Eel Pond Triangle Complex is shown in Figure 4-2.



CFEP (%)	Water Surface Elevation (ft. NAVD88) PRESENT	2030	2050	2070
0.1	10.6	11.7	14.3	16.6
0.2	9.8	11.0	13.5	15.7
0.5	8.9	10.0	12.5	14.6
1	8.2	9.3	11.6	13.8
2	7.5	8.6	10.8	12.9
5	6.5	7.7	9.7	11.8
10	5.8	7.0	8.9	10.9
20	5.0	6.2	7.9	9.9
25	4.7	5.9	7.6	9.6
30	4.5	5.7	7.3	9.3
50	3.7	4.8	6.3	8.3
100	2.1	3.3	4.6	6.4

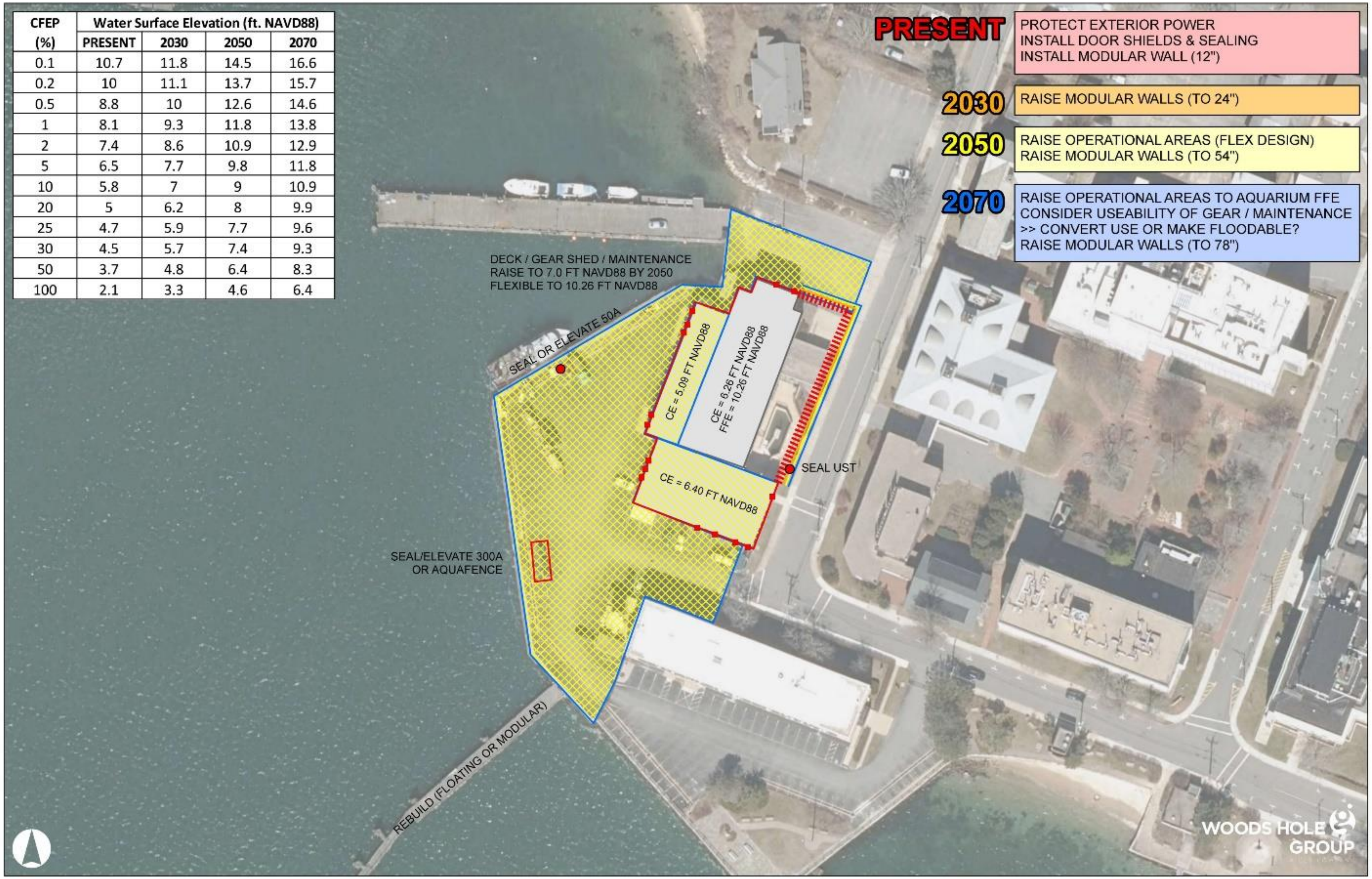
Figure 4-2 **District-level adaptation plan – MBL Eel Pond Triangle Complex**

The concept for this MBL district strategy is to protect critical infrastructure from storm surge (to the 1% CFEP water surface elevation projected over time) in an incremental and modular way, starting with present needs and adjusting over time. Under present conditions, there is a need to address flooding from Eel Pond, which is addressed by a combination of building dry-floodproofing (façade sealing) and modular walls/ bulkheads). Additionally, a deployable flood barrier at the Water Street entrance blocks present day storm surge coming from the Harbor. By 2030, extension of building dry-floodproofing measures and modular walls may be necessary, plus a deployable barrier between MRC and CSF to block an additional Eel Pond flood pathway. By 2050, further extension of building dry-floodproofing and modular walls may be required. Additionally, 2050 storm surge may overtop the higher landscaped area along the south and west façade of Lillie, which would necessitate further elevation of the landscaped berm around Lillie and deployable barrier or self-rising gate across the parking lot near MBL Street. Over the long term, further modular additions may be required for storm surge, as well as a re-assessment of accessibility issues at MRC Dock considering sea level rise.

4.2.3 NOAA Complex – Working Waterfront

NOAA's high-risk Working Waterfront facilities include vessel berthings, the Aquarium building, the Gear Shed, the Maintenance Shed, and several associated infrastructure components (vessel power supplies, generator, transformer, seal pool exhibit). These facilities are set between the Harbor and the southern end of Albatross Street.

This group of collocated assets returned the highest risk scores in the NOAA assessment, and are also vulnerable to future tidal inundation due to sea level rise. Recognizing a need to maintain a critical working waterfront, NOAA decided to advance a district-level adaptation plan for these facilities. The conceptual level adaptation plan for the NOAA Working Waterfront Complex is shown in Figure 4-3.



CFEP (%)	Water Surface Elevation (ft. NAVD88) PRESENT	2030	2050	2070
0.1	10.7	11.8	14.5	16.6
0.2	10	11.1	13.7	15.7
0.5	8.8	10	12.6	14.6
1	8.1	9.3	11.8	13.8
2	7.4	8.6	10.9	12.9
5	6.5	7.7	9.8	11.8
10	5.8	7	9	10.9
20	5	6.2	8	9.9
25	4.7	5.9	7.7	9.6
30	4.5	5.7	7.4	9.3
50	3.7	4.8	6.4	8.3
100	2.1	3.3	4.6	6.4

Figure 4-3 District-level adaptation plan – NOAA Working Waterfront Complex

The concept for this NOAA district strategy is to protect critical infrastructure from storm surge (to the 1% CFEP water surface elevation projected over time) in an incremental and modular way, starting with present needs and adjusting over time. Under present conditions, there is a need to address storm surge from the Harbor impacting vessel power infrastructure and flooding the Gear Shed and Maintenance Shed. Protecting the vessel power can be accomplished by elevating the posts, sealing the boxes, or deploying temporary flood barriers. Limiting storm surge inundation at the building and seal pool exhibit can be achieved by a combination of building dry-floodproofing (façade sealing and door barriers) and a modular wall around the front entrance area. By 2030, additional storm surge levels may require additional building dry-floodproofing and elevation of the modular wall. By 2050, projected tidal inundation could pose operational issues for these facilities, so elevation of the operational areas (bulkheads, decking/lot, floors of the Maintenance and Gear facilities) may be required in addition to further enhancements to storm surge protection measures (dry-floodproofing and modular wall). By 2070, additional tidal inundation may make it necessary to investigate the feasibility of additional elevation of the operational areas equaling the Aquarium's first floor elevation. If raising the floors of the Gear and Maintenance Sheds to accommodate sea level rise at the working waterfront presents operational challenges to these facilities, it may be advisable to consider reconstructing the facility in the mid-term. Given the sensitivity of these facilities to sea level rise, it is recommended that NOAA continue to monitor and adjust as necessary, with a goal of accommodating sea level rise and daily waterfront access over the long term while remaining resilient to storm inundation.

4.3 WOODS HOLE COMMUNITY-LEVEL STRATEGIES

Sea level rise and storm surge present both existential and operational threats to Woods Hole Village's marine science facilities as well as to the commercial and residential infrastructure within the Village. Often it is not viable or sustainable to adapt assets to sea level rise and/or storm surge in a vacuum. For example, it does not make sense to implement building/facility level floodproofing or elevation to a 2050 1% DFE if the roadway used to access that facility experiences tidal inundation by 2050. It can also be more efficient and have greater benefit to deploy adaptation solutions on a wider scale to address shared risk rather than addressing each specific flood vulnerability on a case by case basis. Considering these issues and acknowledging ongoing coastal resilience planning in the Town of Falmouth (Woods Hole Group, 2020), Woods Hole Group developed three conceptual community-level strategies to explore adaptation options for Woods Hole Village (as a whole) along three themes: Protect / Migrate / Transform.

Ultimately, the final plan for Woods Hole Village may be a hybrid of these (and potentially other) strategies developed from a shared vision among WHOI, MBL, NOAA, the Town of Falmouth, and the broader community. The following community-level adaptation strategies are intended to initiate these discussions and visioning exercises.

4.3.1 Protect Approach

The Protect strategy (Figure 4-4) focuses on keeping storm surge and nuisance flooding out of existing developed and undeveloped areas of Woods Hole Village.

Working primarily at the water's edge, this strategy leverages modular green (elevated coastal dunes and terraced open space) and gray infrastructure (seawalls, bulkheads and elevated roadways) to keep storm surge (to the 1% CFEP water surface elevation projected over time) out. Certain areas of Woods Hole Village operate as working waterfronts, and therefore require unencumbered access to the water. In these areas, modular elevation of the grade may be phased in over time (adaptive management approach provided plans account for adjustability over time) to keep pace with sea level rise. Working waterfront areas would need to be designed to accommodate storm inundation and would likely incorporate storm protection elements for the community behind them. Hard structures in the Village center would give way to elevated dunes to the northwest, tied into roadway elevation to the north, and eventually intersecting higher grades along Gardiner Road. A rising gate at the Woods Hole Boat Ramp would automatically block storm surge from getting to Albatross Street. Similarly, deployable barriers would be required at Iselin Marine Facility and at the Steamship Authority underpass to prevent these areas from becoming flood conveyance pathways. All elements of the Protect strategy should be designed to be modular and adjustable over time so that they are not overbuilt at first but are still able to respond to a changing climate.

4.3.2 Migrate Approach

The Migrate strategy (Figure 4-5) condenses nuisance flooding protection into a strategic core of Woods Hole Village, while planning for phased relocation as lower lying areas transition with sea level rise.

This strategy uses minimal phased-in modular interventions around the core of Woods Hole Village to respond to sea level rise and preserve the daily usability of facilities and commercial areas for as long as practicable. For areas in the Village where interim or modular solutions are more difficult to implement in the face of nuisance flooding, a gradual relocation of residences, businesses and facilities may be necessary. Areas of near-/mid-/long-term migration are referenced to the shifting tidal benchmark projections, and an adaptive management approach should be adopted with trigger points for pulling back from certain at-risk areas. Access to the Village core is preserved by strategic roadway elevation projects. Within the Village core, a series of modular seawalls provide phased protection from nuisance flooding. Over the mid- to long-term, sea level rise may disturb some facilities to a degree that would otherwise require significant investment in reconstruction. For these areas, it is suggested that adaptation investments focus on preserving water-dependent uses, and WHOI/MBL/NOAA should each identify receiving areas for their exposed non-water-dependent uses. If NOAA cannot identify a viable alternative location, it would have to adopt a reconstruction plan to elevate facilities (as in other Community-level strategies and similar to the proposed project for WHOI's Iselin Dock). Additionally, all facilities in the Village that do not relocate would have to implement adaptation strategies to deal with projected storm surge. For planning purposes, the diagram provides a guide for when each facility is vulnerable to projected 1% event inundation at or above the critical elevation.

4.3.3 Transform Approach

The Transform strategy (Figure 4-6) reconfigures Woods Hole Village to respond to projected long-term change and aligns with existing recommendations for adaptation in the Town of Falmouth's coastal resilience program (Woods Hole Group, 2020).

This strategy adopts a 'design-with-nature' approach to anticipate and plan for areas where sea level rise may encroach on development and shift wetland habitats. The most significant change in this plan is the reorientation of Eel Pond with an inlet to Buzzards Bay through existing low-lying areas. This approach allows Eel Pond to be closed on the south side to facilitate storm surge protection projects along Water Street. Along the New Harbor area, areas for salt marsh migration have been identified that align with SLAMM projections. Additionally, living with water areas indicate portions of Woods Hole Village that may not be protected by this strategy and may have to adapt to periodic or episodic flooding. Material produced in the development of the New Harbor may be beneficially reused for developing terraced modular greenspaces along Water Street, or to supply the necessary grade elevations for the road spine and associated network of land. Loss of the Woods Hole boat ramp to terraced modular storm protection elements is offset by a new boat ramp at Woods Hole Park within the New Harbor area. Finally, the working waterfront facilities at WHOI and NOAA would be redeveloped with appropriate plans for modular elevation and adaptive management and could be tied into the elevated road spine.

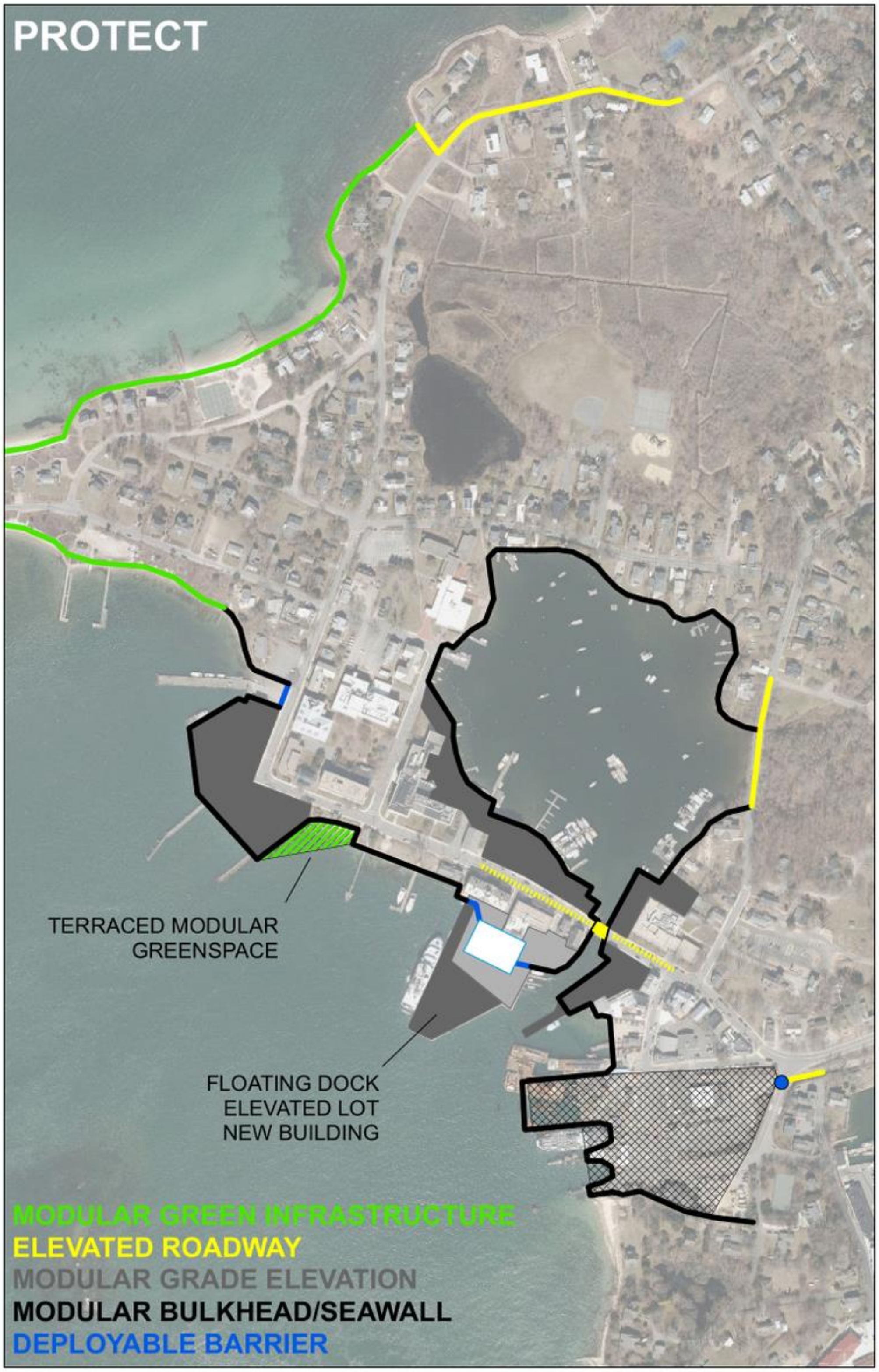


Figure 4-4 Community-level adaptation plan – PROTECT

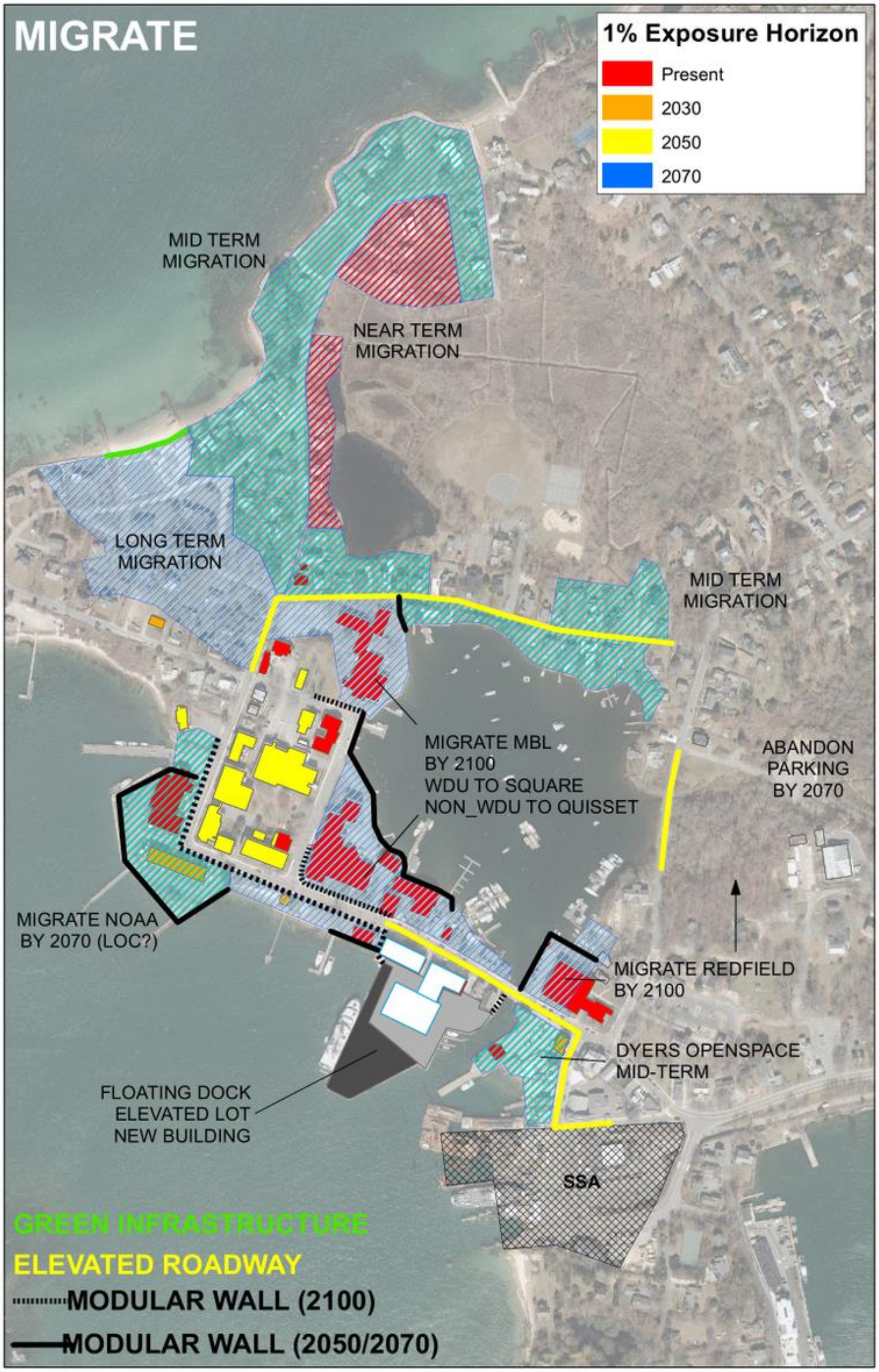


Figure 4-5 Community-level adaptation plan – Migrate

Figure 4-6 Community-level adaptation plan – Transform

5.0 SUMMARY AND NEXT STEPS

The Woods Hole Village CCVA documented significant vulnerability to sea level rise and storm surge among WHOI/MBL/NOAA assets as well as throughout much of the Woods Hole Village area.

Many working waterfront areas will have to contend with access and usability issues as tidal prisms shift upwards. Of the 118 institutional assets evaluated in this study, 3 could experience tidal flooding by 2030, 13 by 2050, 37 by 2070, and 78 by 2100. By design, working waterfront facilities must be constructed at the water's edge and allow for easy access to vessels as well as fixed assets; due to the necessity of water access to support marine science and future shifts in the tidal prism, all three organizations will face operational challenges as sea level rise progresses. Over the long term, many parts of Woods Hole Village will also have to deal with nuisance flooding and habitat shifts that may make living or working in some areas difficult.

Based on comparisons of asset critical elevations to coastal flood exceedance probability water surface elevations extracted from MC-FRM, nearly all 118 institutional assets investigated in the CCVA are vulnerable to storm surge either under present or future climate conditions. WHOI's facilities at the top of Challenger Drive have sufficient elevation and should not be exposed to any storm surge at least through 2070. MBL facilities near the intersection of North Street and Albatross Street benefit from higher landform elevations and are only vulnerable to low probability events at later planning horizons. Much of NOAA's campus is exposed to storm surge under present conditions, however the Cottage does benefit from a modest landform elevation which reduces probability of inundation and delays vulnerability. Also, some of NOAA's infrastructure components have high critical elevations (e.g. the freezers' blowers are almost eight feet above grade) making them less vulnerable to storm damage.

WHOI, MBL and NOAA carefully considered the consequences of asset damage/loss resulting from flooding. Each asset was scored based on how flooding above the critical elevation would impact each organization's function, finances, and ability to carry out their common missions of research and applied science, operations and revenue generating activities, and education/outreach.

The risk assessment process integrated the probabilistic climate change projections and granular assets impact probabilities with consequence scoring and provides each research organization with a risk profile that facilitates prioritizing and phasing adaptation responses over time. The risk assessment results focused district-level adaptation planning on three locations where high-risk assets are concentrated – WHOI's Iselin Marine Facility, MBL's Eel Pond Triangle, and NOAA's Working Waterfront Complex. These district-level solutions are conceptual in nature and are intended to both start conversations around campus planning in the face of climate change, and to serve as models of layered and modular approaches to resilient design for working waterfronts for additional planning at each organization.

Additional conceptual adaptation designs were prepared for Woods Hole Village as a whole, acknowledging both the interdependencies of the three research organizations and the Village, as well as the potential need for large-scale solutions for these low-lying areas. In order to adapt to climate change effectively and efficiently, it is crucial for all district- and community-level solutions to coordinate efforts with the Town of Falmouth, which has commenced its own Town-wide coastal resilience initiative (Woods Hole Group, 2020) based on the same MC-FRM projections and a similar risk assessment framework.

As additional planning around sea level rise and storm surge evolves throughout Woods Hole Village, it will be important to update vulnerability assessments with the best available scientific developments as they become available. This will require an exchange of information among WHOI, MBL, NOAA, the Town of Falmouth, Woods Hole Group, and the Commonwealth of Massachusetts. The Massachusetts Executive Office of Energy and Environmental Affairs' Resilient Massachusetts Action Team (RMAT) is in the process of releasing climate resilience design guidelines and standards, which will be a key resource in the future design and campus planning for each research organization.

Aside from these broader recommendations and resources, the next steps for each research organization should include:

- Review the risk assessment results and asset-specific recommendations in detail and identify low-hanging fruit – small adaptation projects for individual assets that have near-term vulnerability and higher risk, which are not likely to be addressed by a broader solution. Any action asset managers can take to make critical elevations higher than what they are currently will reduce that asset's risk over time.
- Integrate asset-level adaptations into existing schedules for anticipated asset maintenance and replacement, as feasible.
- Refine the district-level solution and look for opportunities to align with campus planning.
- Realign facility uses such that only water-dependent uses are located in waterfront (and therefore vulnerable) areas. Identify upland receiving areas for non-water dependent uses.
- Develop an implementation roadmap for institutional resilience, including trigger points and flexible/alternate pathways.
- Create interpretive educational installations using the organization's CCVA results to inform internal and external education and outreach on climate change impacts.

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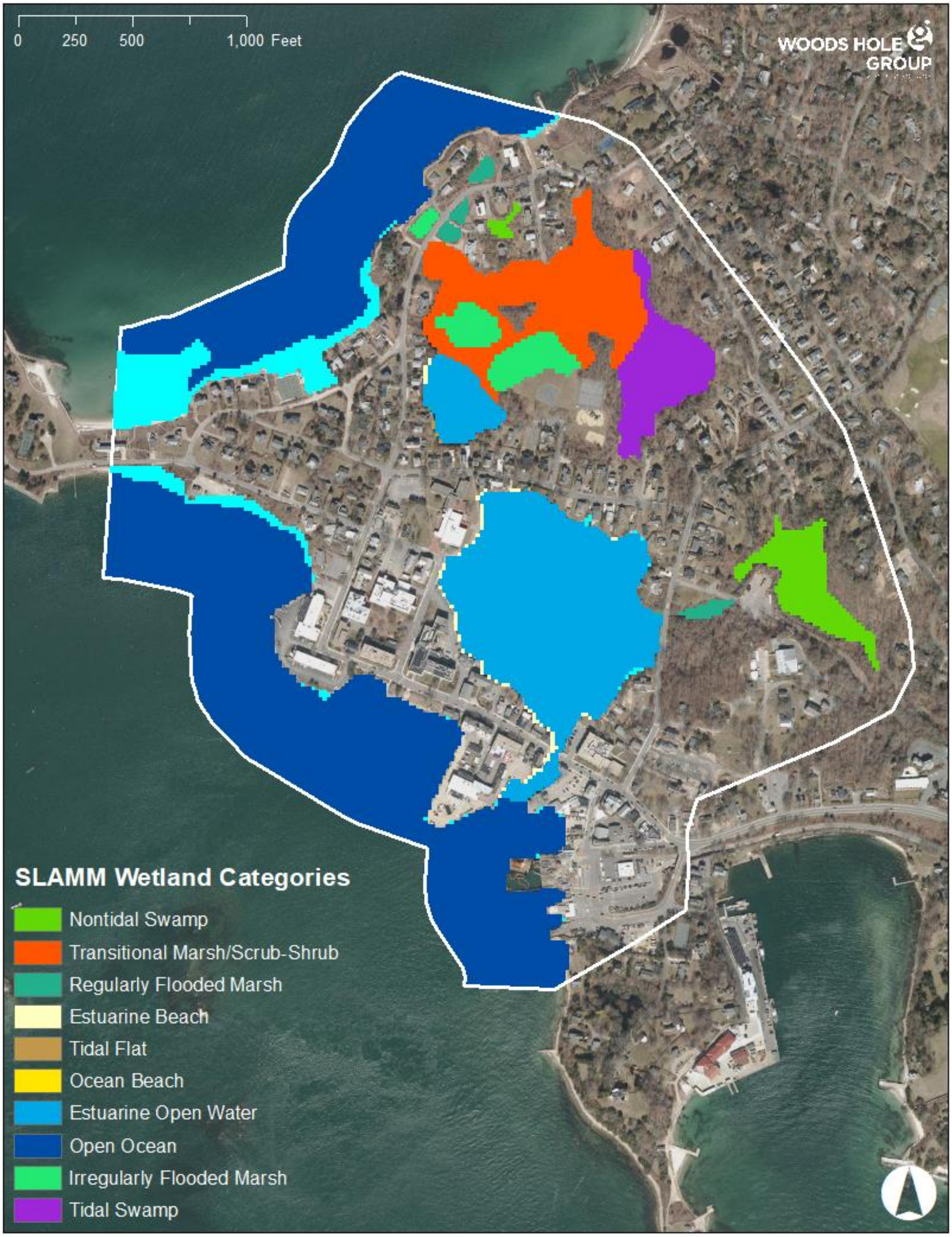
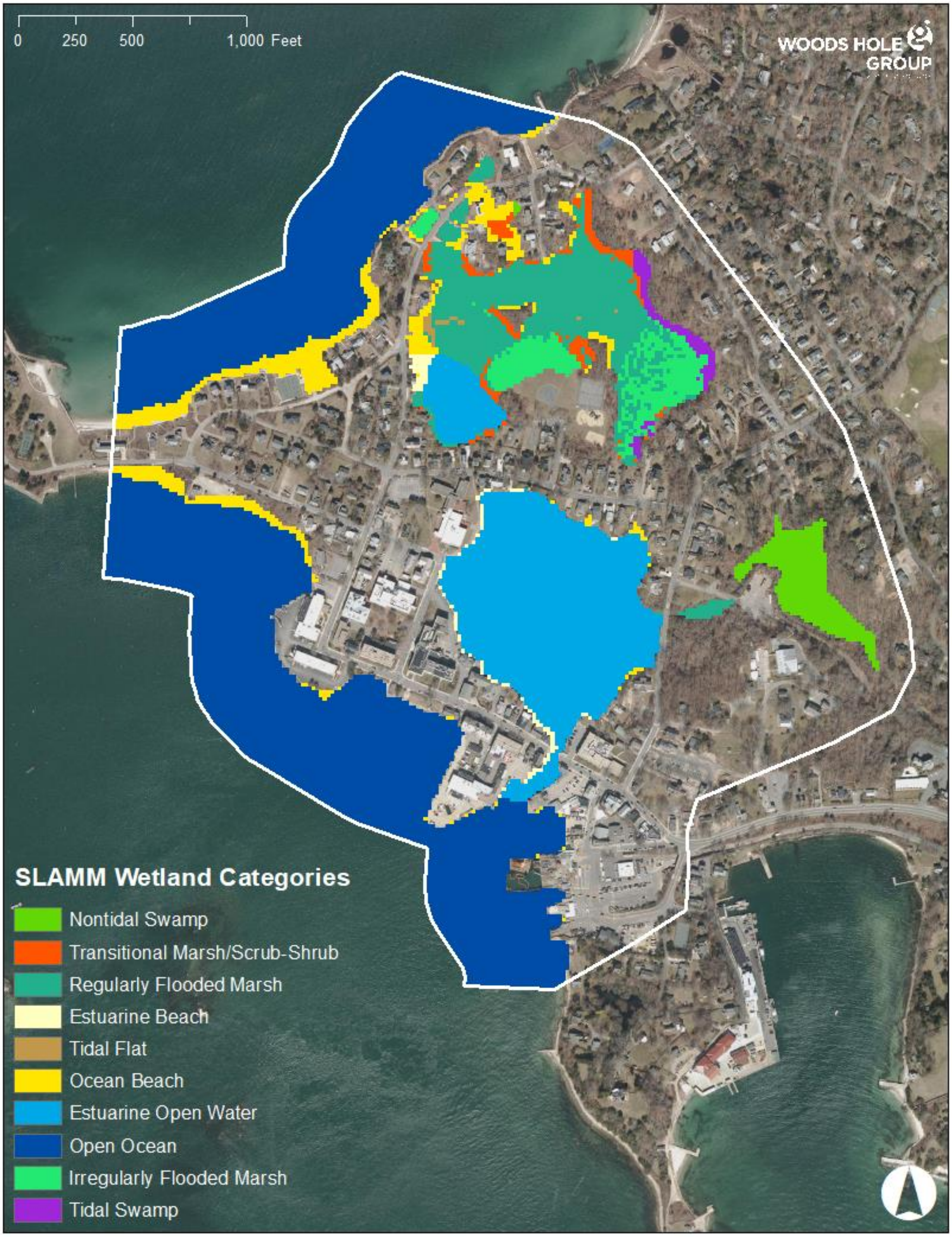
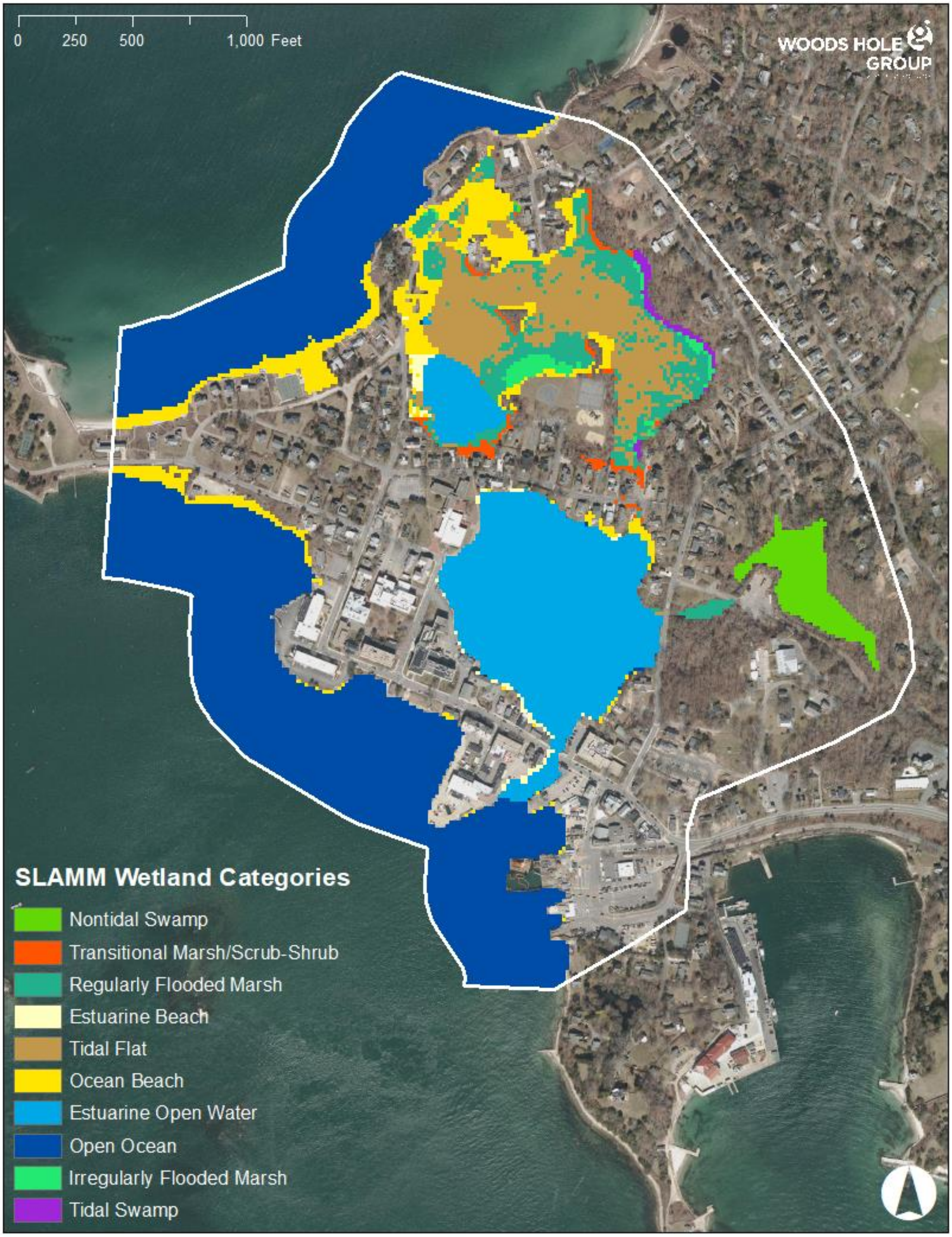
APPENDIX A COASTAL WETLAND MODELING



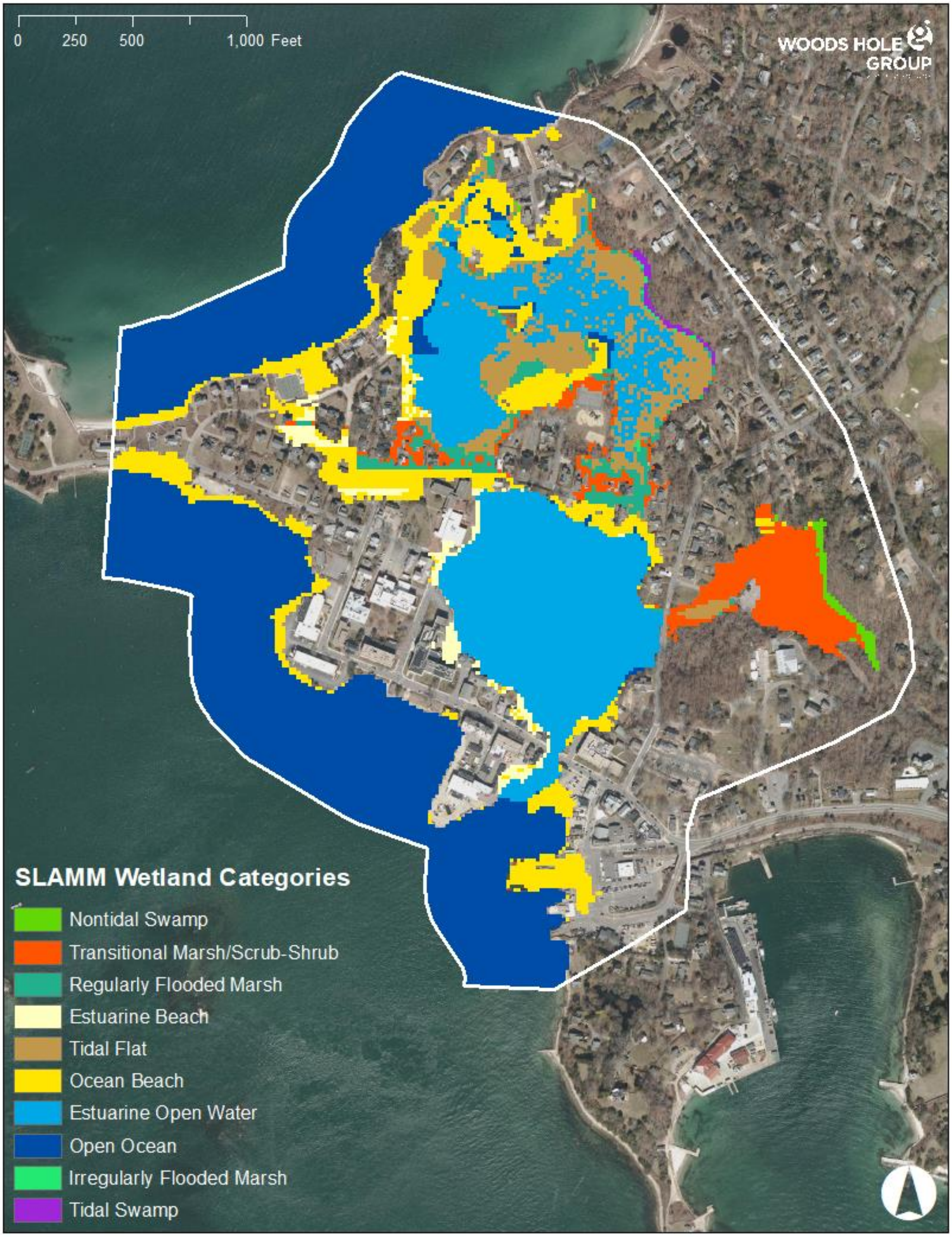
A-1 Present Day Wetlands Condition



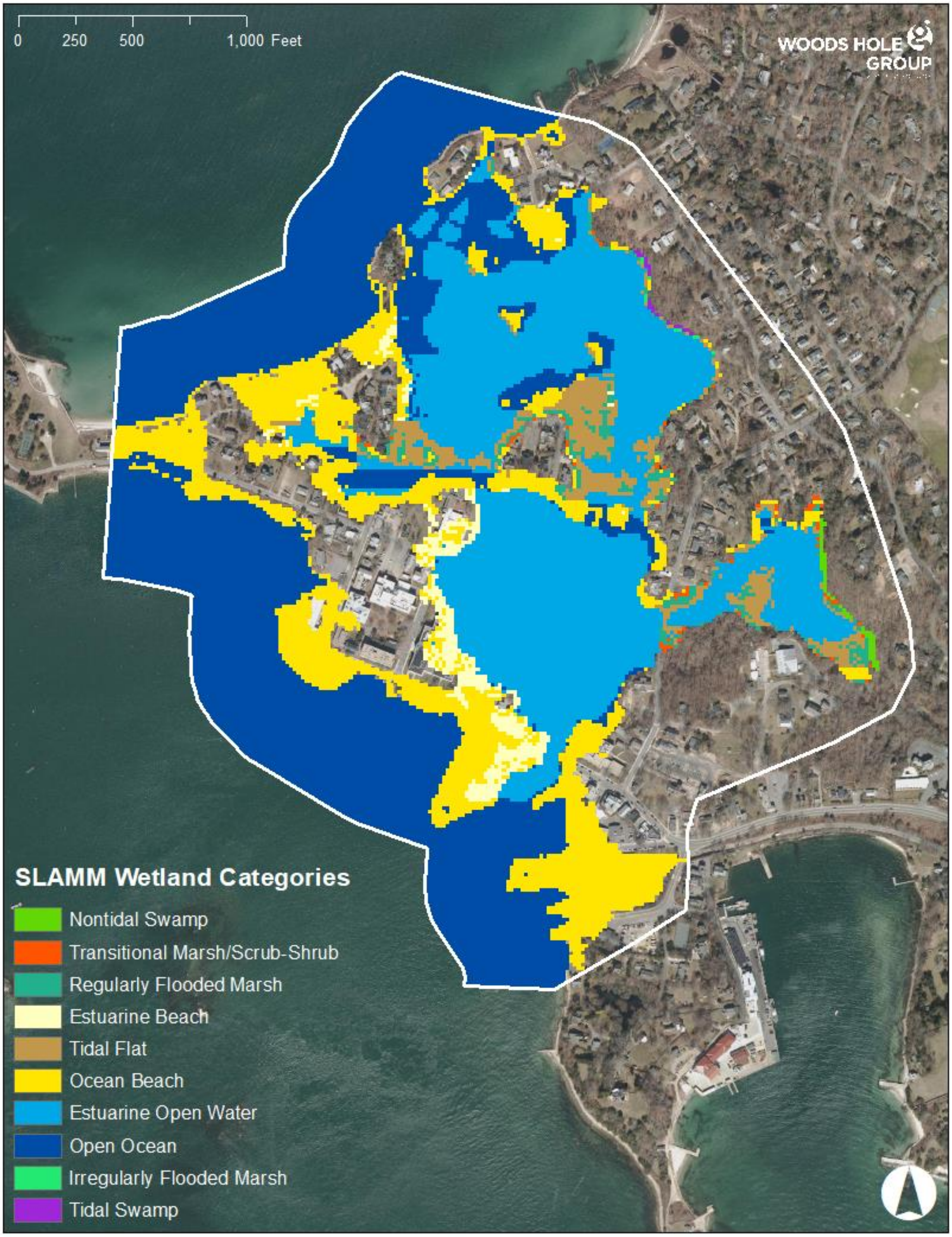
A-2 2030 (near-term) Wetlands Condition



A-3 2050 (mid-term) Wetlands Condition

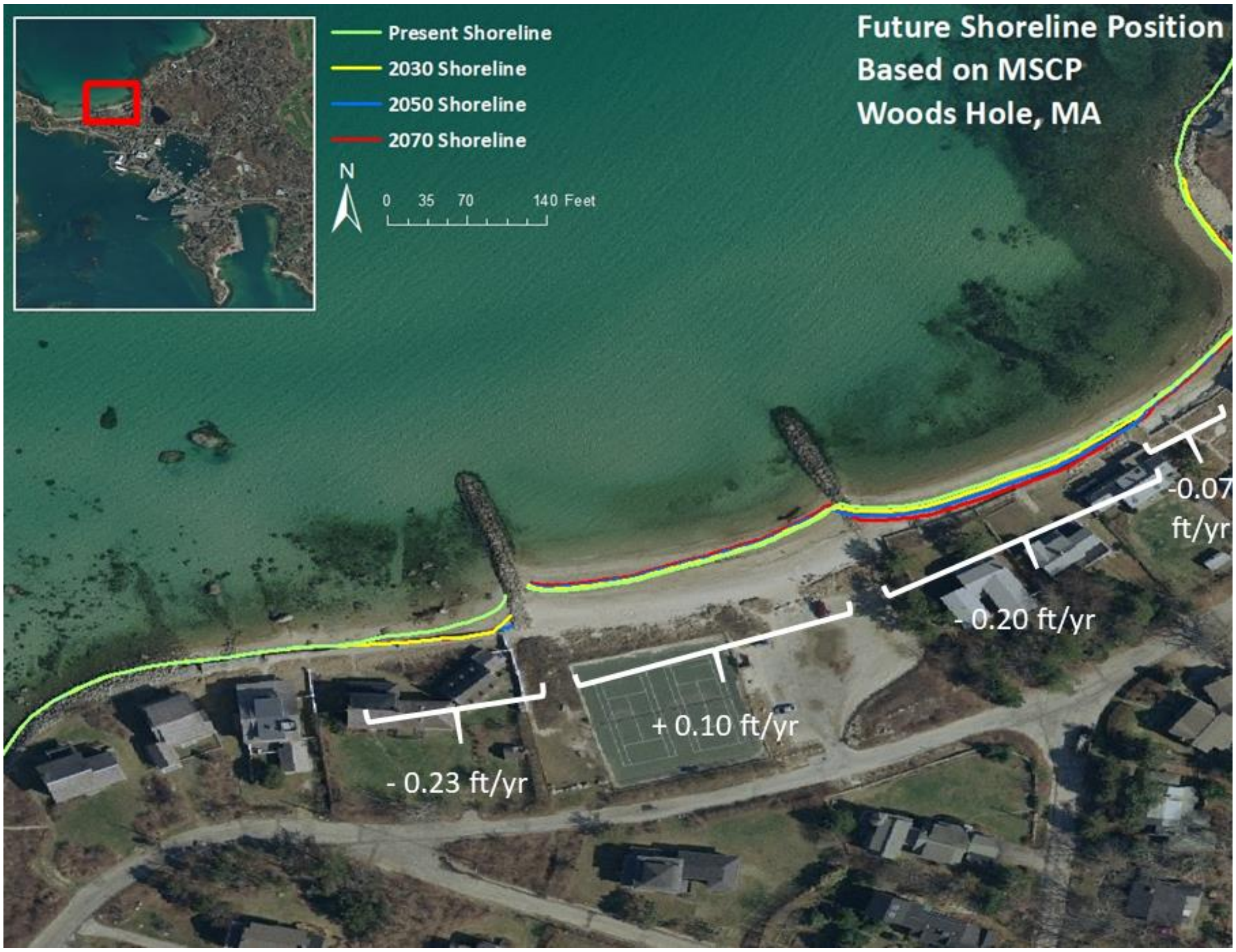


A-4 2070 (long-term) Wetlands Condition

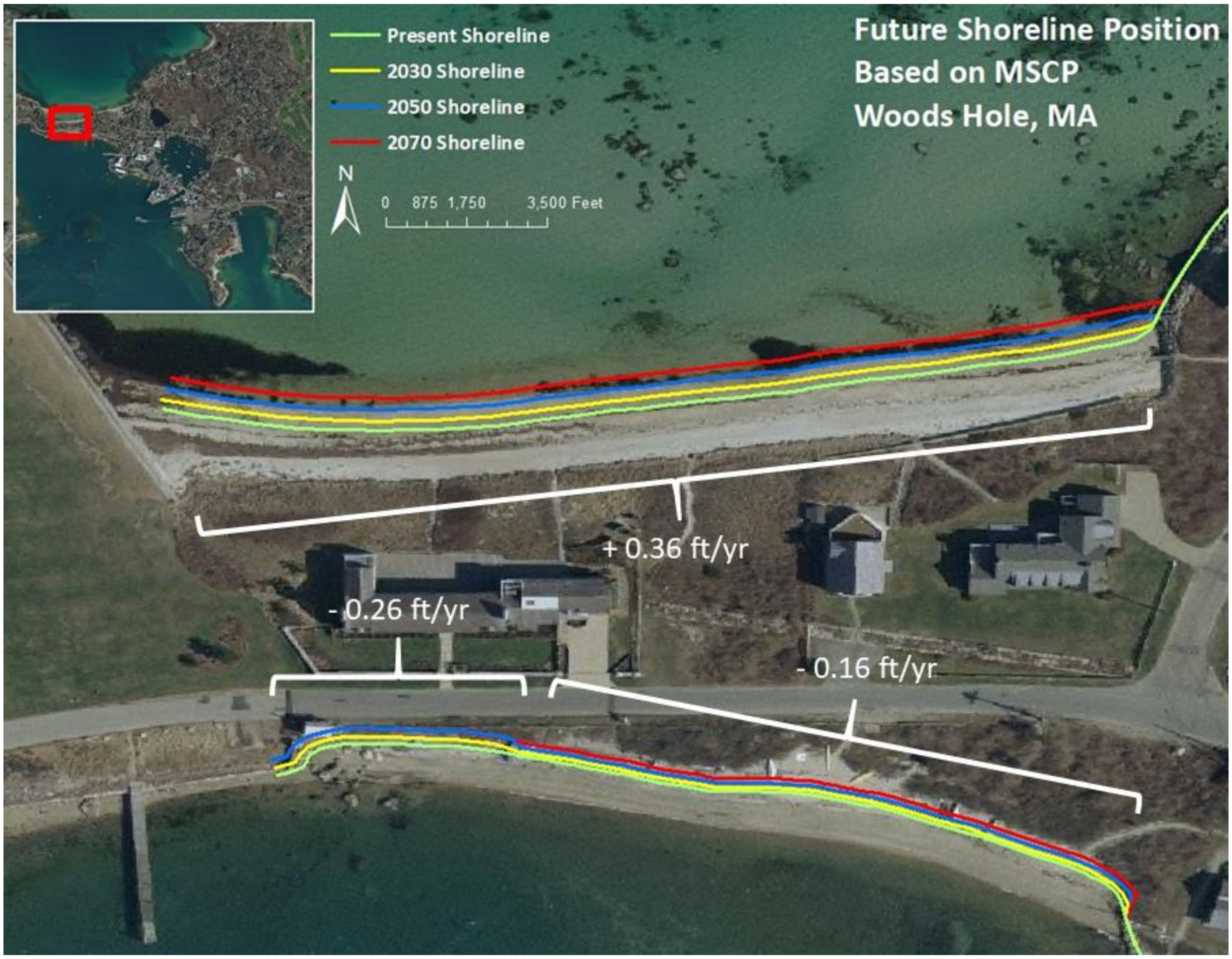


A-5 2100 (beyond) Wetlands Condition

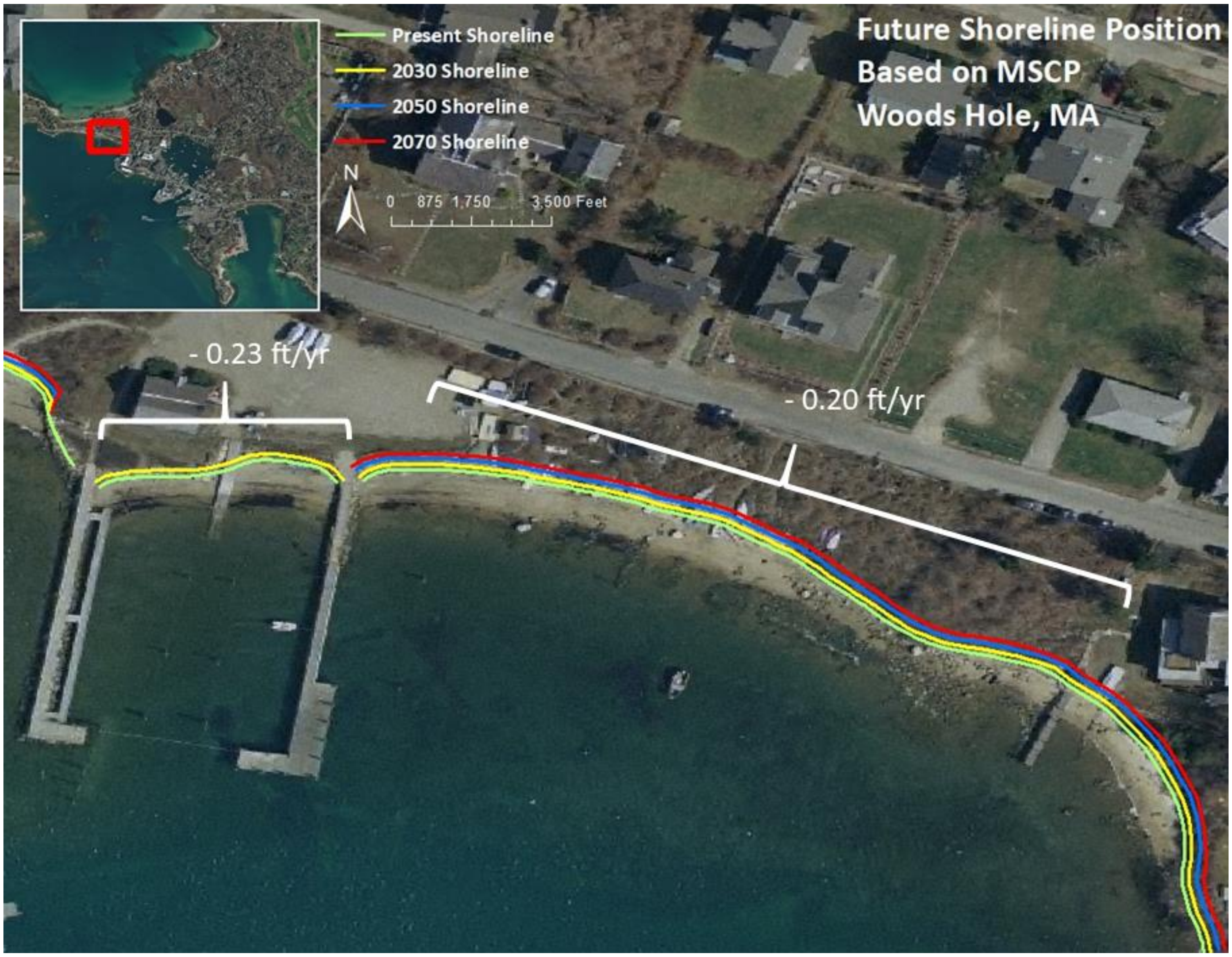
APPENDIX B NATURAL SHORELINE PROJECTIONS



B-1 Shoreline Projections – Gosnold Road

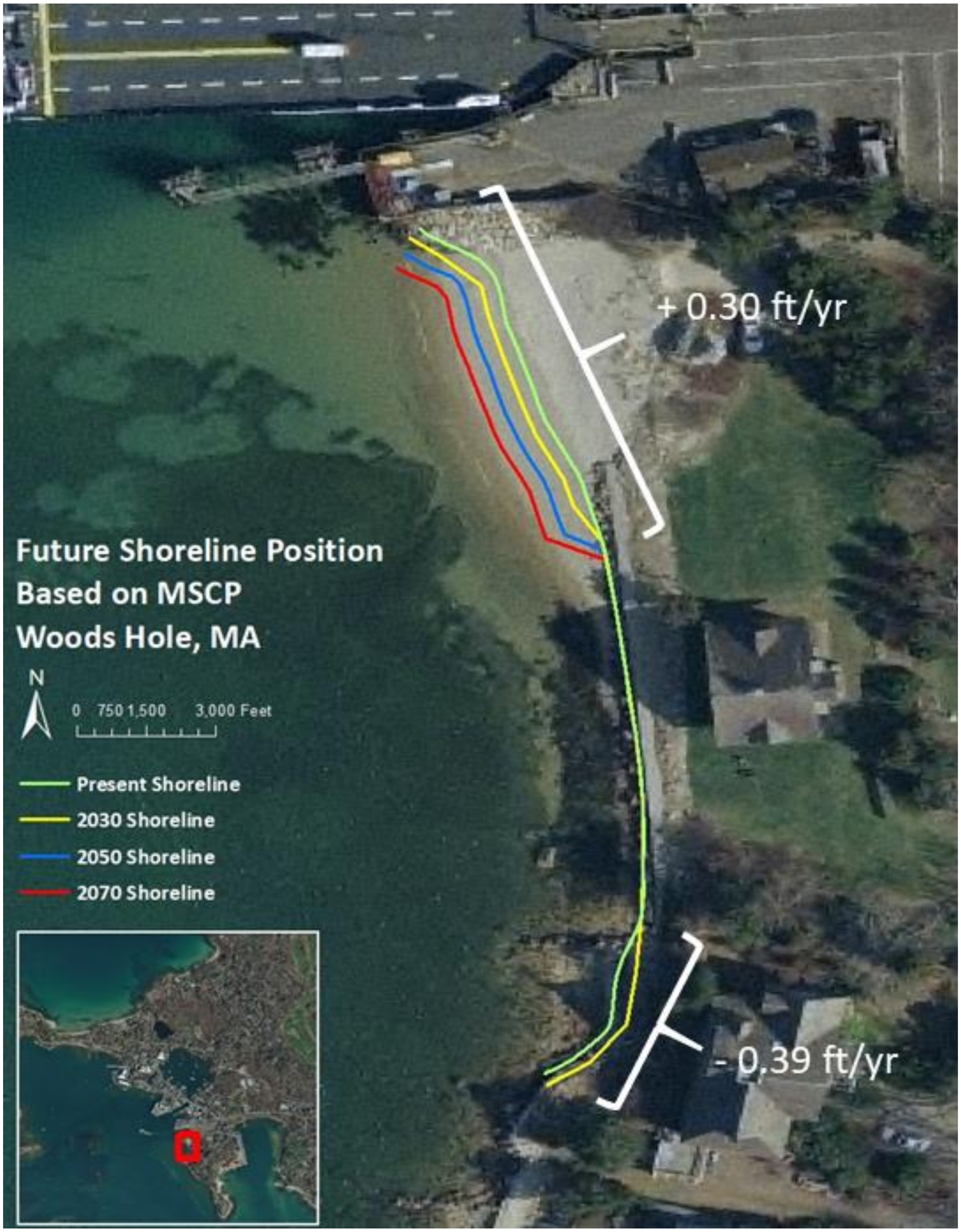


B-2 Shoreline Projections – Bar Neck Road (West)



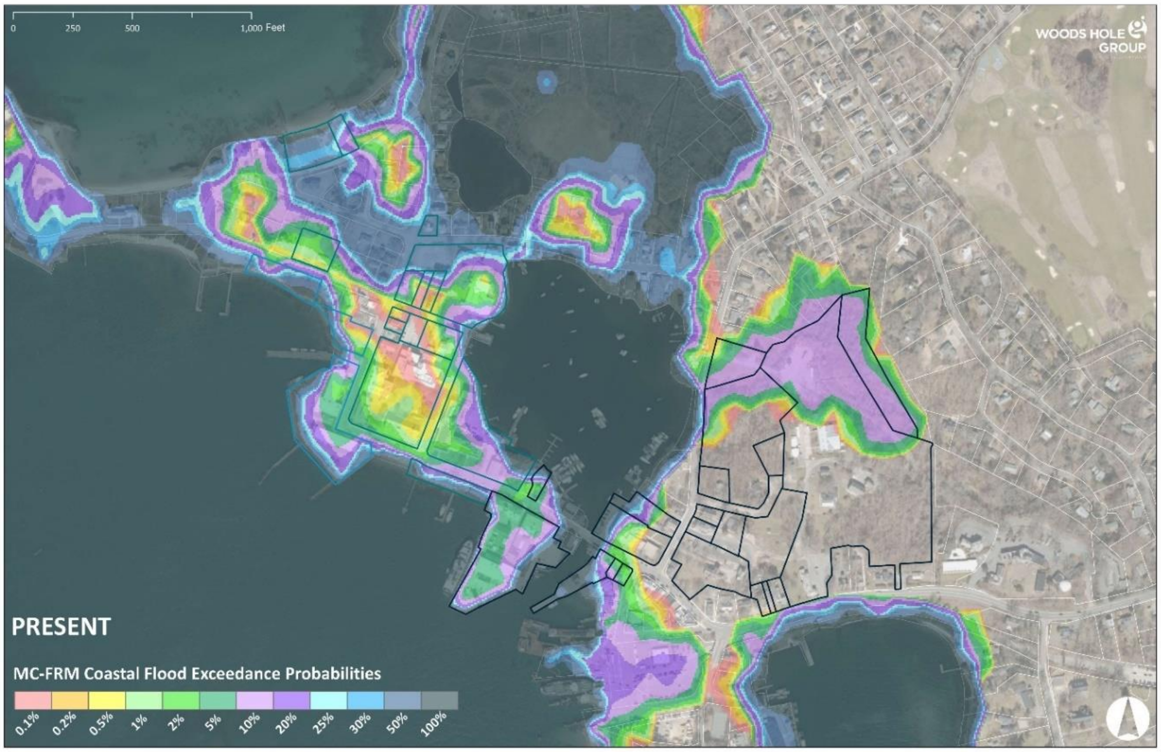
B-3 Shoreline Projections – Bar Neck Road (East)

B-4 Shoreline Projections – Water Street

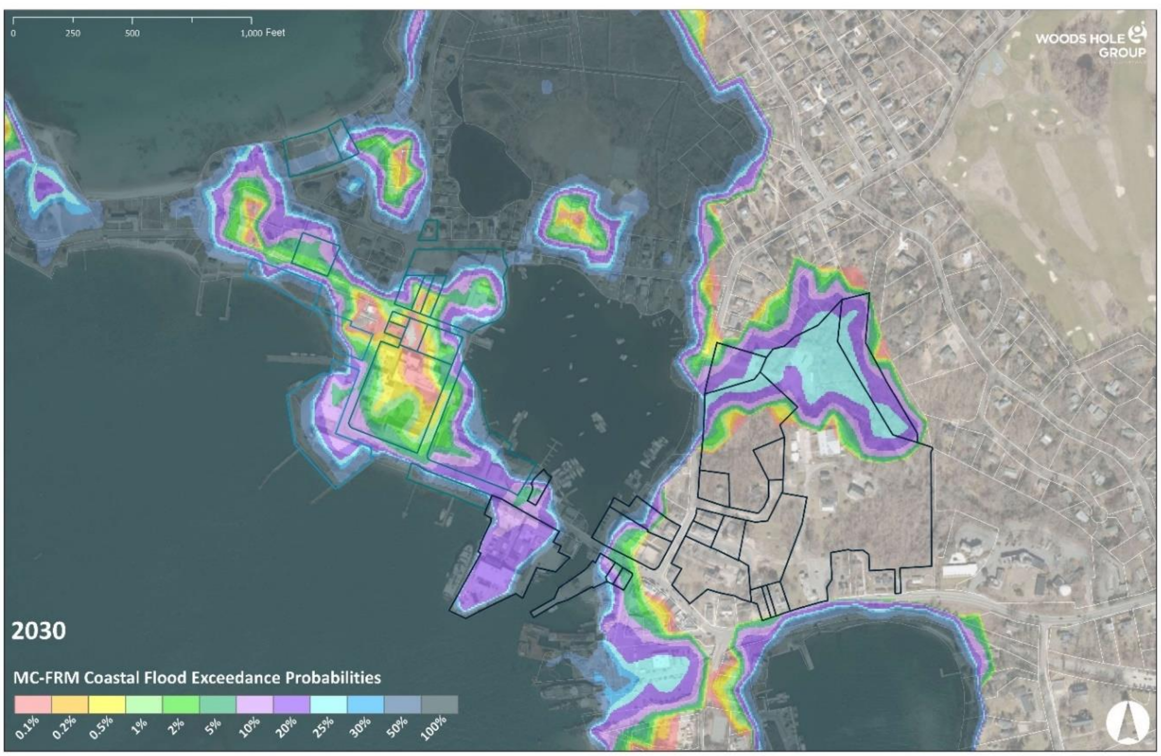


B-5 Shoreline Projections – South of Cowdry Road

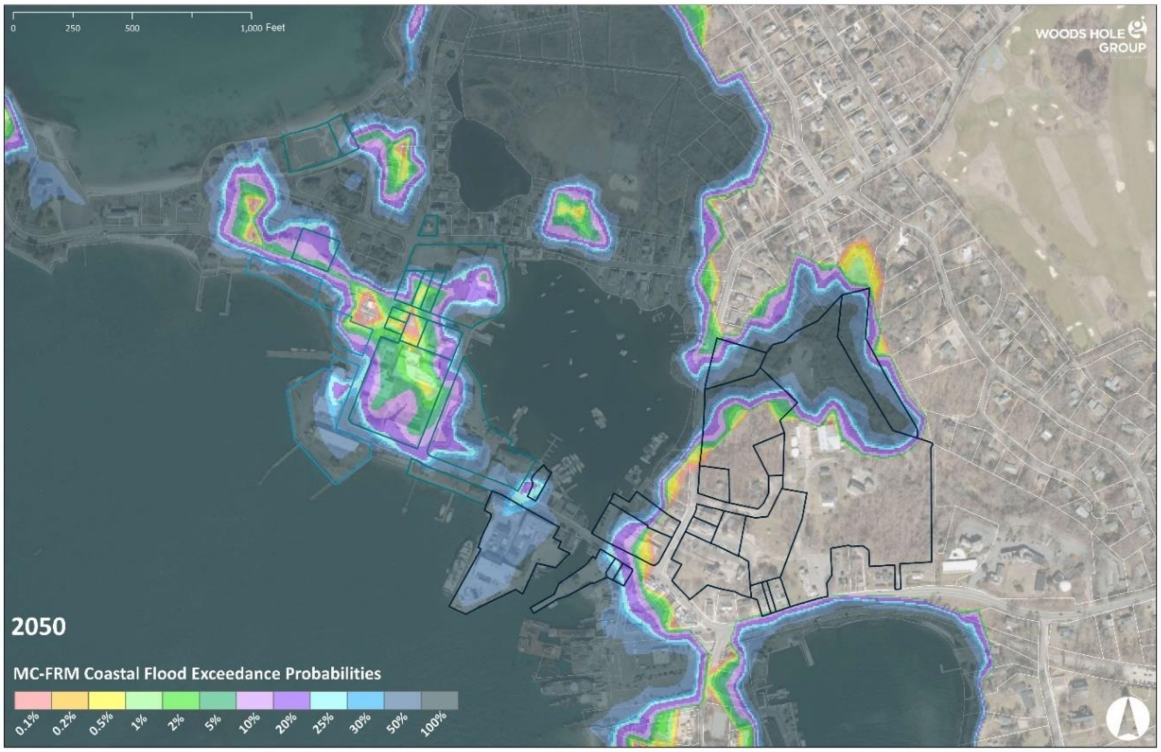
APPENDIX C MC-FRM RESULTS



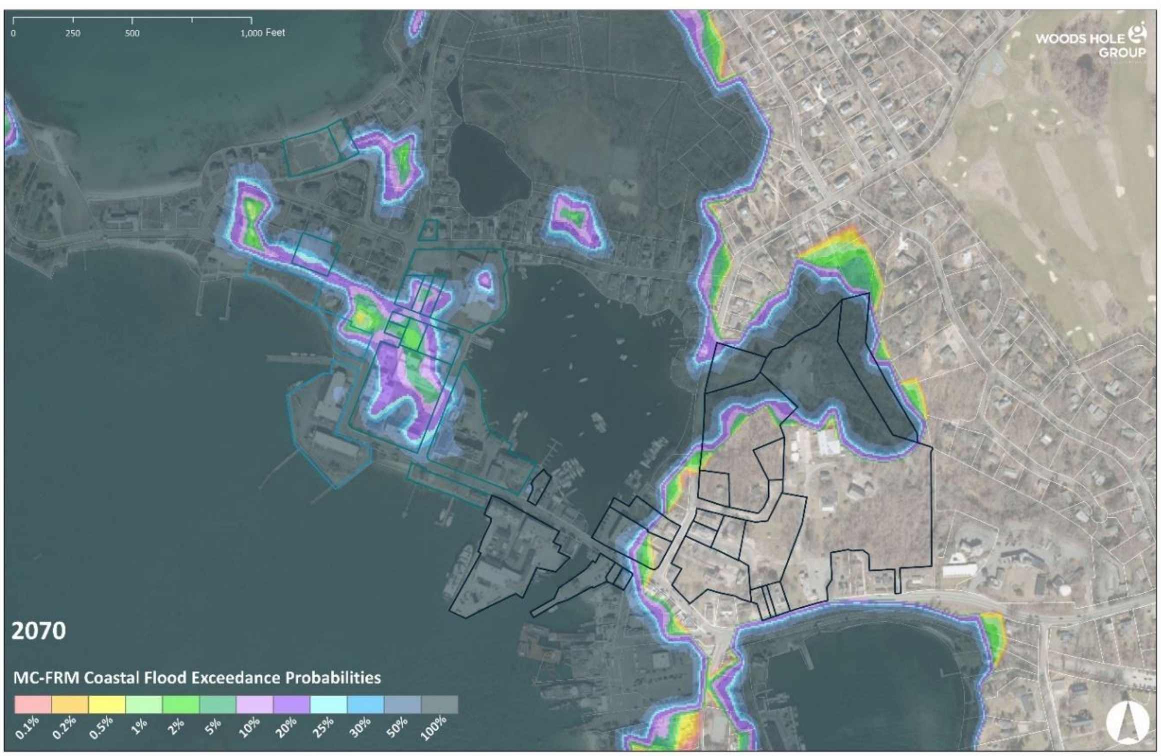
C-1 Present Day MC-FRM Inundation Probability



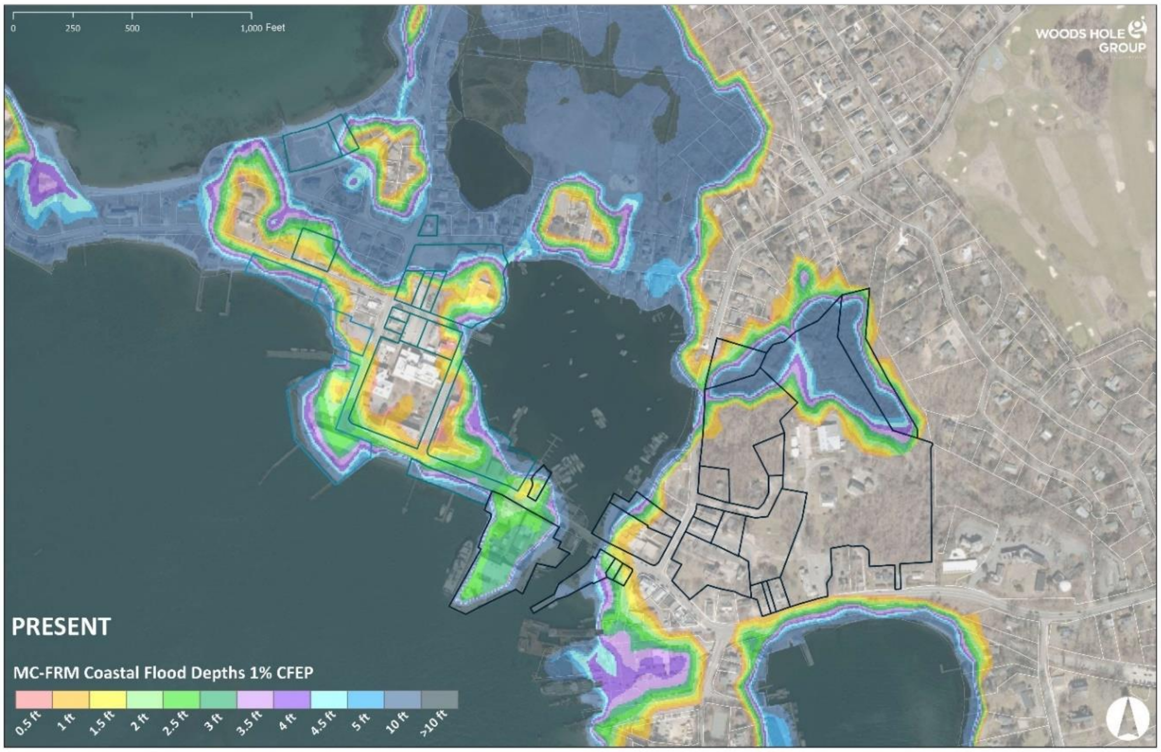
C-2 2030 (near-term) MC-FRM Inundation Probability



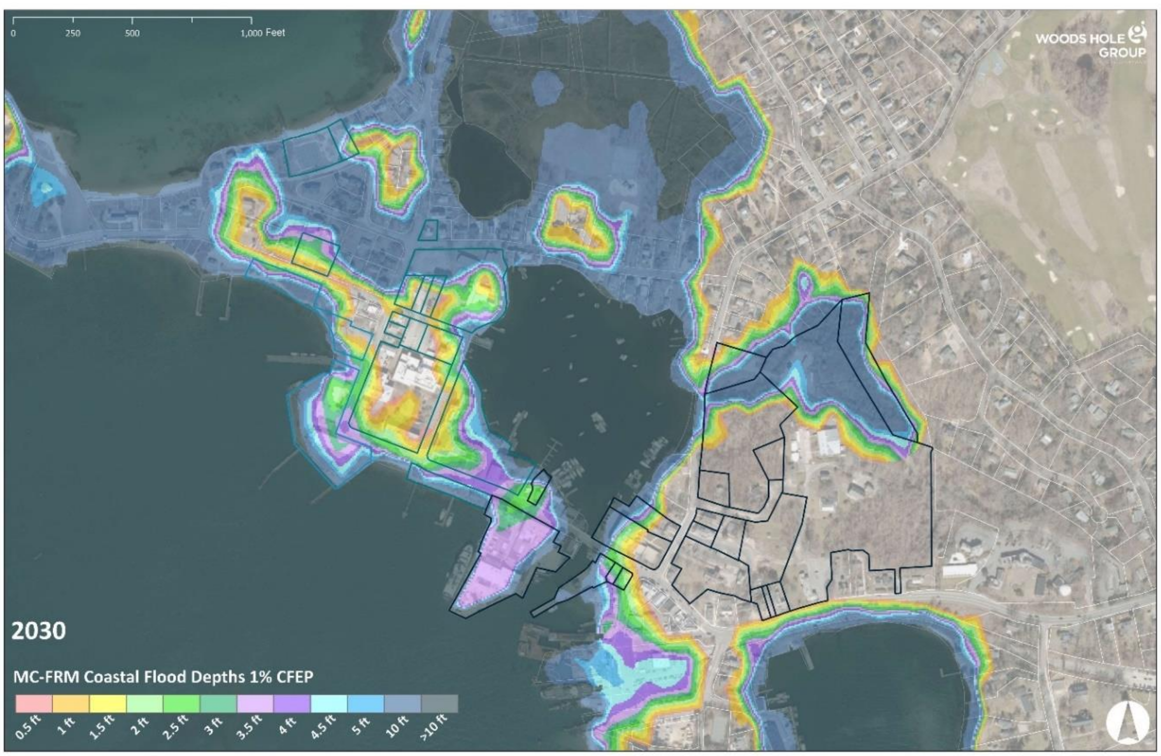
C-3 2050 (mid-term) MC-FRM Inundation Probability



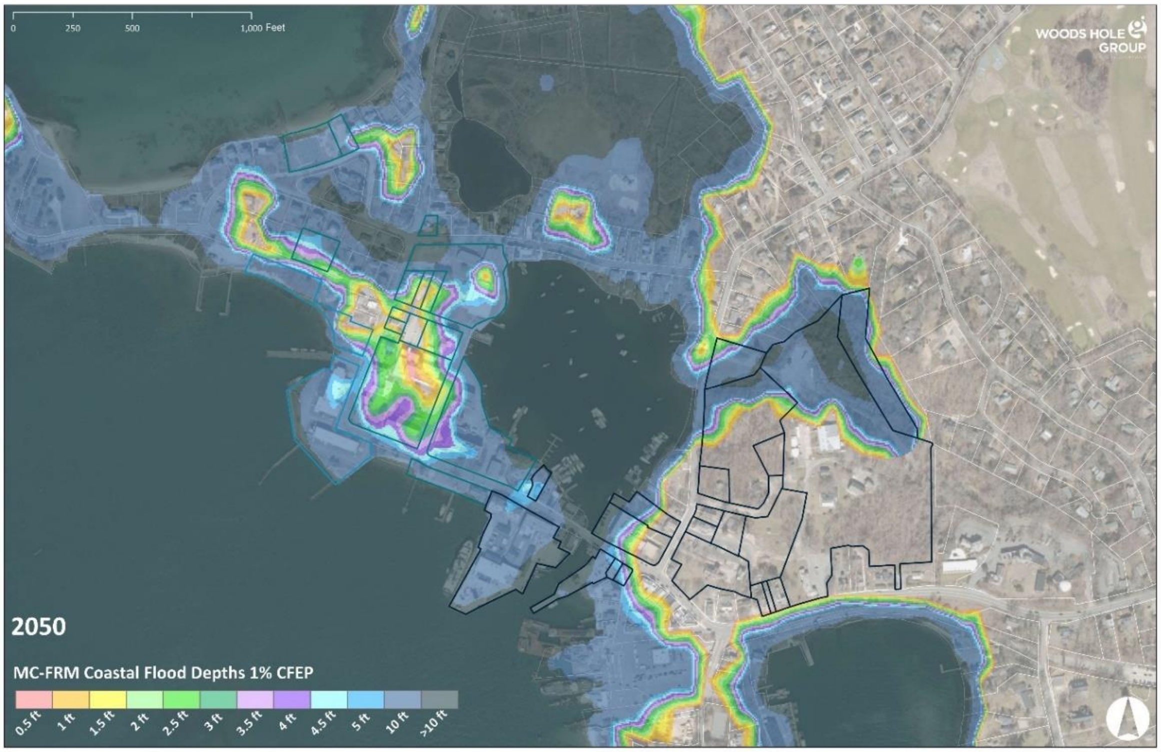
C-4 2070 (long-term) MC-FRM Inundation Probability



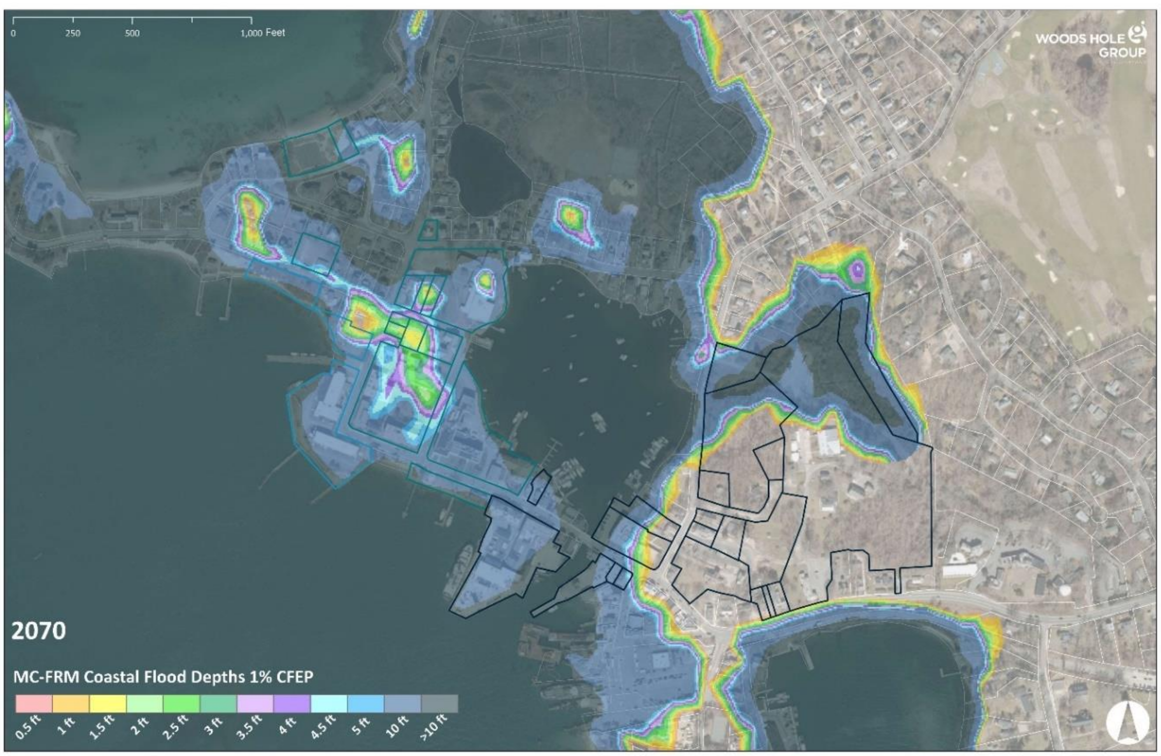
C-5 Present Day MC-FRM 1% Event Inundation Depth



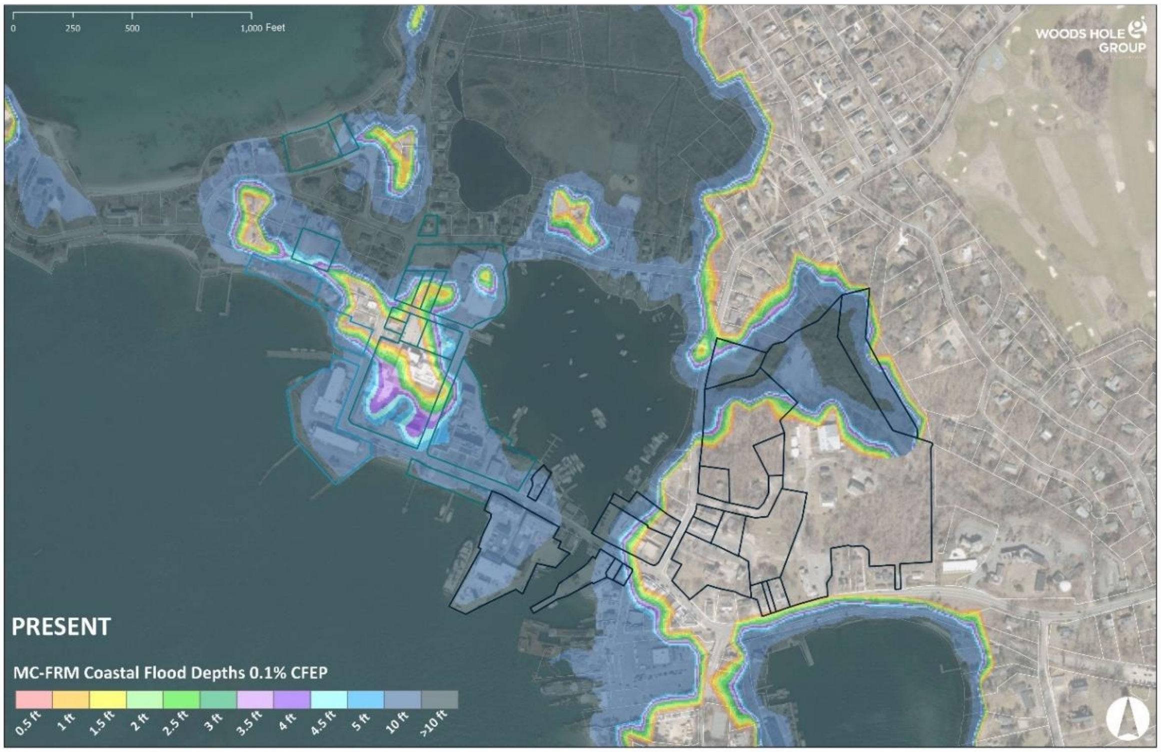
C-6 2030 (near-term) MC-FRM 1% Event Inundation Depth



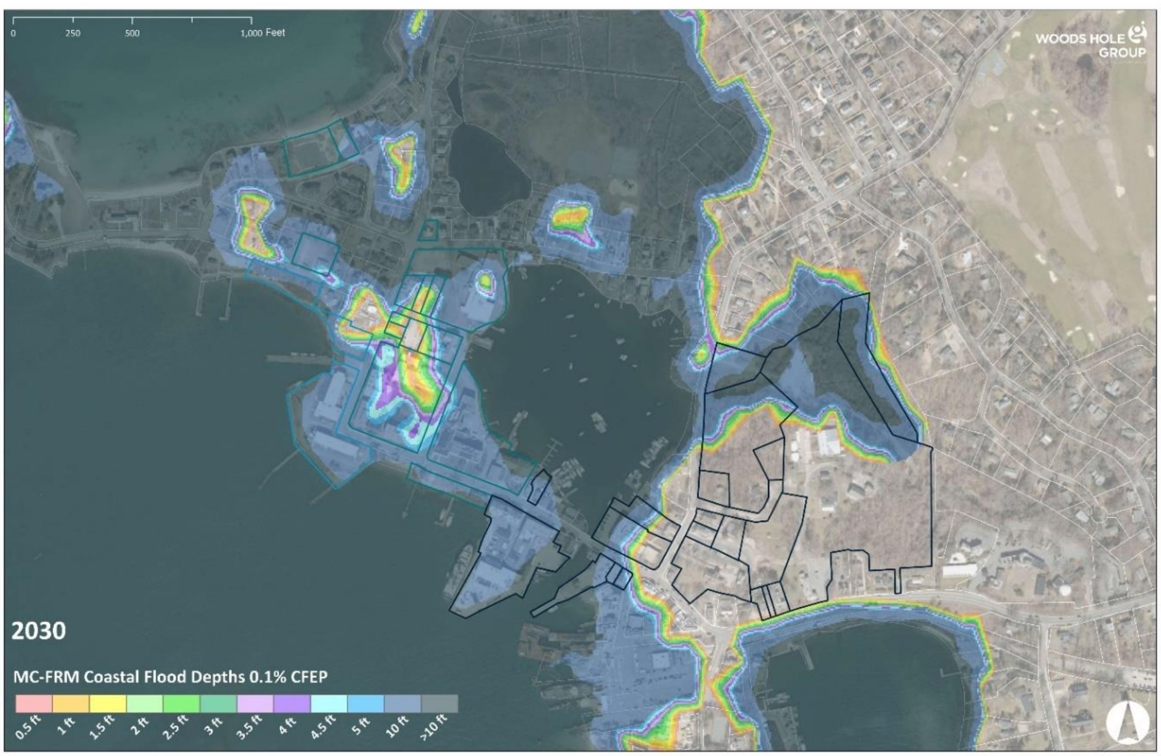
C-7 2050 (mid-term) MC-FRM 1% Event Inundation Depth



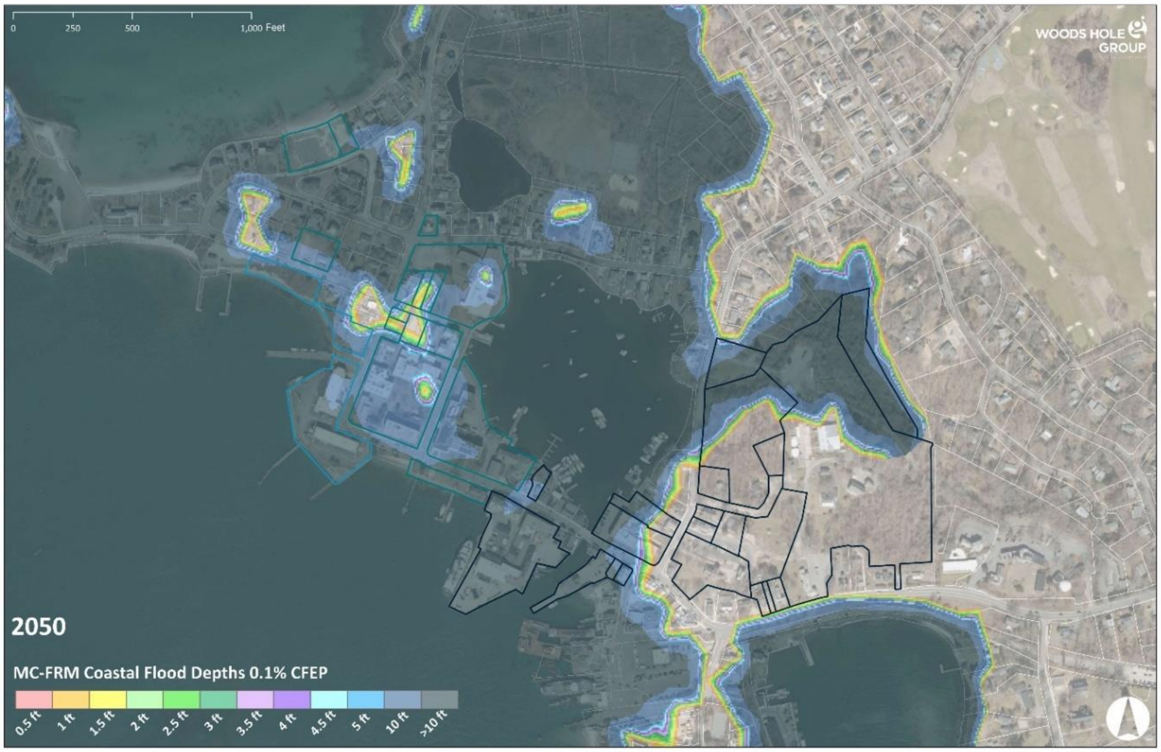
C-8 2070 (long-term) MC-FRM 1% Event Inundation Depth



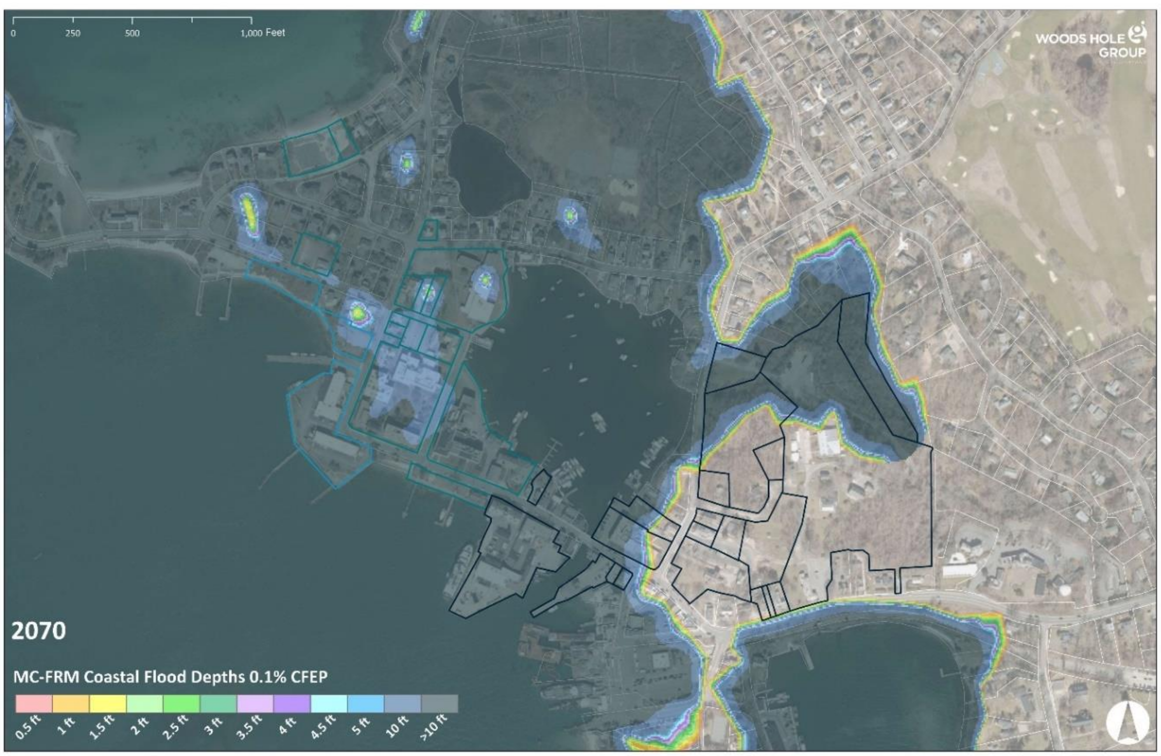
C-9 Present Day MC-FRM 0.1% Event Inundation Depth



C-10 2030 (near-term) MC-FRM 0.1% Event Inundation Depth



C-11 2050 (mid-term) MC-FRM 0.1% Event Inundation Depth



C-12 2070 (long-term) MC-FRM 0.1% Event Inundation Depth

APPENDIX D ASSET SPECIFIC RISK ASSESSMENT TABLES

D-1 WHOI Asset Level Risk Assessment and Adaptation Strategies

Type	Name	Extent	Duration	Cost	Research	Operations	Education	SUM	CONSQ	CE_ftNAVD	CE_Desc	NODE	Prob_PDAY	Prob_2030	Prob_2050	Prob_2070	Risk_PDAY	Risk_2030	Risk_2050	Risk_2070	Near-Term Plan	Long-Term Plan
Parking Lots and Parks	Redfield Parking	3	1	0	2	3	0	9	38	4.46	average elevation in footprint (LiDAR)	Eel Pond	30	50	100	100	1125	1875	3750	3750	Operational (no parking during storms)	Retreat*
Parking Lots and Parks	Iselin Parking	3	1	0	2	3	0	9	38	4.61	representative elevation cuts off dock access at Flume (prior survey)	Harbor	25	50	50	100	938	1875	1875	3750	No Action	CWATER Design
Buildings	Smith-Iselin Connector	4	4	3	4	4	2	21	88	5.63	rigging garage door Room 116 West Door (prior survey)	Harbor	10	30	50	100	875	2625	4375	8750	Deployable door barriers	CWATER Design
Parking Lots and Parks	49 School Street Parking	2	1	0	1	0	0	4	17	3.50	average elevation in footprint (LiDAR)	East of School St.	50	50	100	100	834	834	1667	1667	Operational (no parking during storms)	Retreat*
Coastal Infrastructure	Dyers Dock	1	1	1	1	1	0	5	21	4.45	top of decking (surveyed)	Harbor	30	50	100	100	625	1042	2083	2083	Floodproof power hookups	Redesign Dyers Facility*
Buildings	Information Office (93 Water Street)	2	3	1	1	1	4	12	50	5.45	sill of basement vent in alley (surveyed)	Eel Pond	10	30	50	100	500	1500	2500	5000	Floodproof building + door barriers (or relocate)	Monitor FFE exposure
Buildings	Dyers Hangar	2	3	2	2	2	0	11	46	5.26	FFE (surveyed)	Harbor	10	30	50	100	458	1375	2292	4583	Floodproof building + door barriers (or relocate)	Redesign Dyers Facility*
Buildings	Iselin	4	4	3	3	4	2	20	83	6.08	North Alvin high bay 130D Door - systems at grade Room 138 (prior survey)	Harbor	5	20	50	100	417	1667	4167	8333	Deployable door barriers	CWATER Design
Coastal Infrastructure	Finger Pier	1	1	0	0	0	0	2	8	3.55	top of decking (surveyed)	Harbor	50	50	100	100	417	417	833	833	Floodproof electrical systems	CWATER Design
Coastal Infrastructure	Iselin Dock	4	2	2	3	4	3	18	75	6.50	representative of deck at lower operation area (from M&N)	Harbor	5	10	30	50	375	750	2250	3750	Operational (secure equipment prior to storms)	CWATER Design
Parking Lots and Parks	School Street Parking	3	1	0	2	1	0	7	29	5.09	average elevation in footprint (LiDAR)	East of School St.	10	30	50	100	292	875	1459	2917	Operational (no parking during storms)	Retreat*
Coastal Infrastructure	Redfield Dock 1	0	1	0	0	0	0	1	4	2.28	ramp pivot point at grade	Eel Pond	50	100	100	100	209	417	417	417	Operational (remove prior to storms)	Relocate or remove*
Buildings	Smith	4	4	4	4	4	4	24	100	6.83	Lab 115 Door - systems at grad Room 108 (prior survey)	Harbor	2	10	30	50	200	1000	3000	5000	Deployable barriers, elevate mechanicals	Renovate or re-program 1st floor
Buildings	Bigelow	4	4	4	4	4	2	22	92	6.58	W06 Door - systems below grade G12/G1 (prior survey)	Harbor	2	10	30	50	183	917	2750	4584	Deployable barriers, elevate mechanicals	Renovate or re-program 1st floor
Buildings	Redfield	4	4	3	3	4	2	20	83	7.28	West Loading Door W06 - systems below brade Room 143 (surveyed)	Eel Pond	2	5	30	50	167	417	2500	4167	Deployable barriers, elevate mechanicals	Renovate or re-program 1st floor
Parking Lots and Parks	Dyers Parking	3	1	0	2	1	0	7	29	5.91	average elevation in footprint (LiDAR)	Harbor	5	20	50	100	146	583	1459	2917	Operational (no parking during storms)	Redesign Dyers Facility*
Coastal Infrastructure	Redfield Dock 3	0	1	0	0	0	0	1	4	4.33	top of bulkhead (surveyed)	Eel Pond	30	50	100	100	125	209	417	417	Operational (remove prior to storms)	Relocate or remove*
Coastal Infrastructure	Redfield Dock 2	0	1	0	0	0	0	1	4	4.34	top of bulkhead (surveyed)	Eel Pond	30	50	100	100	125	209	417	417	Operational (remove prior to storms)	Relocate or remove*
Buildings	Flume	0	2	1	1	1	1	6	25	6.39	Western alley door - systems at grade (prior survey)	Harbor	5	10	30	100	125	250	750	2500	Deployable door barriers	CWATER Design
Buildings	Iselin Sewer Pump Shed	2	3	1	3	3	0	12	50	6.79	pump chamber metal hatch (prior survey)	Harbor	2	10	30	50	100	500	1500	2500	Seal hatch, elevate or floodproof controls	CWATER Design
Buildings	Recreational Boat Shed	0	2	0	0	0	0	2	8	5.11	grade (surveyed)	Eel Pond	10	30	50	100	83	250	417	833	Remove any chemicals	Relocate or remove
Infrastructure	Small Test Well Jib Crane	4	3	2	3	3	0	15	63	8.58	safety switch - 4.83' flange bolt head + 45"" (surveyed)	Harbor	0.5	2	10	30	31	125	625	1875	Elevate safety switch	CWATER Design
Parking Lots and Parks	Information Office Parking	2	1	0	1	0	2	6	25	8.18	average elevation in footprint (LiDAR)	Eel Pond	1	2	10	50	25	50	250	1250	Operational (no parking during storms)	Operational (no parking during storms)
Buildings	38 Water Street	2	4	2	2	2	0	12	50	8.60	rear bulkhead threshold (surveyed)	Harbor	0.5	2	10	30	25	100	500	1500	Deployable barriers, floodproof basement	Monitor FFE exposure
Infrastructure	Iselin Transformers 1/2/3	4	4	2	4	4	0	18	75	10.31	pad (surveyed) 1&3=10.31 / 2=10.68	Harbor	0.1	0.2	2	10	8	15	150	750	No Action	CWATER Design
Infrastructure	REMUS Jib Crane	3	3	2	3	3	0	14	58	10.67	safety switch - 6.34' flange bolt head + 52"" (surveyed)	Harbor	0.1	0.2	2	10	6	12	117	583	Elevate safety switch	CWATER Design
Buildings	Dyers Dock Electrical Shed	0	2	0	1	1	1	5	21	8.90	grade + 3ft to systems (prior survey)	Harbor	0.2	1	10	30	4	21	208	625	Floodproof electrical systems	Redesign with Dyers Dock (nuisance flooding issues)
Infrastructure	Large Test Well Jib Crane	4	3	2	3	3	0	15	63	11.53	safety switch - 7.95' flange bolt head + 43"" (surveyed)	Harbor	0	0.1	1	5	0	6	63	313	No Action	CWATER Design
Buildings	Bigelow Trailer	2	3	2	2	1	0	10	42	11.77	FFE (surveyed)	Harbor	0	0.1	1	5	0	4	42	208	No Action	CWATER Design
Buildings	49 School Street	2	3	2	1	1	1	10	42	14.72	rear bulkhead threshold (surveyed)	East of School St.	0	0	0	0.2	0	0	0	8	No Action	Floodproof basement or deployable barrier
Buildings	Sugar Shack	0	2	1	0	0	0	3	13	16.26	FFE lower section above storage (surveyed)	Eel Pond	0	0	0	0.1	0	0	0	1	Relocate non-essential basement storage	Floodable basement
Buildings	Swift Barn	0	2	1	0	0	0	3	13	19.50	FFE (surveyed)	Eel Pond	0	0	0	0	0	0	0	0	No Action	Floodable basement

* current design vulnerable to nuisance flooding

2030	2050	2070	2100

Nuisance flooding key (HAT > CE)

D-2 MBL Asset Level Risk Assessment and Adaptation Strategies

Type	Name	Extent	Duration	Cost	Research	Operations	Education	SUM	CONSQ	CE_ftNAVD	CE_Desc	NODE	Prob_PDAY	Prob_2030	Prob_2050	Prob_2070	Risk_PDAY	Risk_2030	Risk_2050	Risk_2070	Near-Term Plan	Long-Term Plan
Coastal Infrastructure	MRC Dock	4	4	3	3	3	2	19	79	2.46	top of ramp (adjacent parking lot elevation)	Eel Pond	50	100	100	100	3959	7917	7917	7917	Operational (remove ramp prior to storm), check range of electrical connections	Redesign with MRC facility
Parking Lots and Parks	Swope Parking	3	1	1	1	1	1	8	33	4.03	average elevation in footprint (LiDAR)	Buzzards Bay	50	100	100	100	1667	3333	3333	3333	Operational (no parking during storms)	Retreat*
Coastal Infrastructure	Seawater Dock	4	4	2	3	3	2	18	75	4.82	deck (adjacent park terrace - 42"") + 12"" to electrical box	Harbor	20	30	50	100	1500	2250	3750	7500	Elevate electrical box	Redesign*
Infrastructure	MRC Fuel Tank	2	2	2	3	2	2	13	54	4.80	grade from LiDAR	Eel Pond	20	50	50	100	1083	2709	2709	5417	Seal hatches	Relocate tank*
Coastal Infrastructure	Dinghy Dock	1	3	0	0	1	0	5	21	2.25	top of ramp (adjacent parking lot elevation - 25"")	Eel Pond	50	100	100	100	1042	2083	2083	2083	Operational (remove ramp prior to storm)	Redesign or retreat*
Buildings	Lillie Laboratory	4	4	4	4	4	3	23	96	5.17	loading dock slab entry from 2017 ELV CERT	Eel Pond	10	30	50	100	958	2875	4792	9583	Building floodproofing (Eel Pond side), elevate mechanicals	Redesign*
Buildings	Ebert Hall	3	3	2	1	3	3	15	63	5.33	grade from LiDAR at north sidewalk (path to basement doors)	Eel Pond	10	30	50	100	625	1875	3125	6250	Elevate mechanicals or floodproof basement	Redesign or retreat*
Buildings	Marine Resources Center	4	2	2	4	4	4	20	83	6.24	TBF from 2017 ELV CERT	Eel Pond	5	10	50	100	417	833	4167	8333	Building floodproofing	Redesign*
Buildings	Swope Building	3	4	3	2	4	4	20	83	7.60	loading dock and FFE from 2017 ELV CERT	Buzzards Bay	5	10	30	100	417	833	2500	8333	Deployable basement bay/door barriers	Elevate mechanicals, reprogram floodable 1st floor
Infrastructure	Lillie Fuel Tank	2	1	1	3	2	1	10	42	5.30	grade from LiDAR	Eel Pond	10	30	50	100	417	1250	2084	4167	Seal hatches	Relocate tank*
Coastal Infrastructure	Swope Dock	1	4	1	0	1	0	7	29	5.43	top of ramp (adjacent terrace elevation)	Eel Pond	10	30	50	100	292	875	1459	2917	Operational (remove ramp prior to storm)	Redesign or retreat*
Parking Lots and Parks	Lillie Parking	3	1	1	1	1	0	7	29	5.64	average elevation in footprint (LiDAR)	Eel Pond	10	30	50	100	292	875	1459	2917	Operational (no parking during storms)	Elevate/protect with facility redesign*
Buildings	Candle House	2	2	2	1	2	2	11	46	6.22	TBF from 2017 ELV CERT	Eel Pond	5	10	50	100	229	458	2292	4583	Deployable bay/door barriers or floodable 1st floor	Redesign or retreat*
Buildings	Collection Support Facility	2	2	2	1	2	1	10	42	6.29	slab (alt 10.8 generator fuel pump) from 2017 ELV CERT	Eel Pond	5	10	50	100	208	417	2084	4167	Deployable bay/door barriers or floodable 1st floor	Redesign or retreat*
Buildings	Carpentry Shop	2	1	2	0	1	0	6	25	7.62	top of bottom floor (basement entry) 8.5 NGVD29 2001 ELV CERT	Buzzards Bay	5	10	30	100	125	250	750	2500	Deployable basement bay/door barriers	Relocate carpentry operations, monitor 1st floor exposure
Buildings	MBL Club	2	4	3	0	2	2	13	54	6.94	finish floor from 2017 ELV CERT	Harbor	2	10	30	50	108	542	1625	2709	Deployable door barriers and floodproofing	Reprogram 1st floor or relocate operations
Parking Lots and Parks	Stoney Beach Parking	1	1	0	0	0	0	2	8	6.19	average elevation in footprint (LiDAR)	Buzzards Bay	10	30	100	100	83	250	833	833	Post-storm recovery of sand to beach	Dune restoration and walkover*
Infrastructure	Swope Generator	2	1	1	3	2	1	10	42	8.30	A/C Pad from 2017 topo plan (confirmed LiDAR)	Buzzards Bay	2	5	20	100	83	208	833	4167	Monitor exposure	Elevate pad
Buildings	Crane House	2	2	2	0	1	1	8	33	9.00	first floor and equipment from 2017 ELV CERT	Buzzards Bay	2	5	10	30	67	167	333	1000	Monitor exposure	Elevate mechanicals
Buildings	Rowe Auditorium	4	3	2	2	1	2	14	58	7.87	grade from LiDAR at NW corner entry	The Square	1	2	10	50	58	117	583	2917	Deployable door barrier	Coordinate with Rowe Laboratory
Buildings	Broderick House	2	3	2	1	1	1	10	42	9.70	Lower entry (Albatross St.) threshold from 2017 ELV CERT	Buzzards Bay	1	2	10	30	42	83	417	1250	Monitor exposure	Deployable door barrier or elevate mechanicals
Coastal Infrastructure	Klimm Dock	1	4	2	0	2	0	9	38	7.84	deck (adjacent park terrace) + 20"" to electrical box	Harbor	1	2	20	50	38	75	750	1875	Monitor exposure	Seal electrical boxes
Buildings	Pump House	3	3	2	3	3	3	17	71	8.28	Front entry from 2017 ELV CERT	Harbor	0.5	2	10	50	35	142	708	3542	Monitor exposure	Elevate pad
Infrastructure	MRC Transformer	2	2	2	3	2	2	13	54	8.71	grade from LiDAR + 5"" to plinth	Eel Pond	0.5	1	10	30	27	54	542	1625	Monitor exposure	Elevate pad
Parking Lots and Parks	Waterfront Park	1	1	1	0	0	0	3	13	6.86	average elevation in footprint (LiDAR)	Harbor	2	10	30	50	25	125	375	625	No Action	No Action
Parking Lots and Parks	Quad Parking	2	1	2	1	0	0	6	25	7.91	average elevation in footprint (LiDAR)	The Square	1	2	10	50	25	50	250	1250	Operational (no parking during storms)	Operational (no parking during storms)
Buildings	Crane House Garage	0	0	1	0	0	0	1	4	7.40	slab of detached garage from Crane House 2017 ELV CERT	Buzzards Bay	5	10	30	100	21	42	125	417	No Action	Allow to flood or retreat
Buildings	Loeb Laboratory	4	4	4	3	4	4	23	96	9.61	sidewalk grade from LiDAR at front entry (path to basement windows)	Eel Pond	0.2	0.5	5	20	19	48	479	1917	Monitor exposure	Adjustable wall at sidewalk + deployable door barriers
Buildings	Environmental Services Laboratory	3	3	3	4	3	1	17	71	9.98	first floor elevation from 2017 ELV CERT	The Square	0.2	0.5	2	10	14	35	142	708	Monitor exposure	Deployable door barriers, elevate mechanicals
Infrastructure	Junction Box (Rowe/Homestead/ESL/Loeb)	2	1	1	3	2	3	12	50	9.75	grade from LiDAR + 4"" to plinth	The Square	0.2	0.5	2	10	10	25	100	500	Monitor exposure	Elevate pad
Infrastructure	Meter Box (Rowe/Homestead/ESL/Loeb)	2	1	1	3	2	3	12	50	9.91	grade from LiDAR + 4"" to plinth	The Square	0.2	0.5	2	10	10	25	100	500	Monitor exposure	Elevate pad
Infrastructure	Starr Electric Switch Box	2	1	1	3	2	2	11	46	9.16	grade from LiDAR	The Square	0.2	1	5	25	9	46	229	1146	Monitor exposure	Elevate pad

* current design vulnerable to nuisance flooding

2030	2050	2070	2100

Nuisance flooding key (HAT > CE)

See Proprietary Note on Title Page

D-2 MBL Asset Level Risk Assessment and Adaptation Strategies (cont.)

Type	Name	Extent	Duration	Cost	Research	Operations	Education	SUM	CONSQ	CE_ftNAVD	CE_Desc	NODE	Prob_PDAY	Prob_2030	Prob_2050	Prob_2070	Risk_PDAY	Risk_2030	Risk_2050	Risk_2070	Near-Term Plan	Long-Term Plan
Infrastructure	Junction Box (Lillie/MRC)	2	1	1	3	2	2	11	46	9.33	grade from LiDAR + 4"" to plinth	Eel Pond	0.2	0.5	5	25	9	23	229	1146	Monitor exposure	Elevate pad
Buildings	Rowe Chiller Building	2	4	3	4	3	2	18	75	10.03	grade from LiDAR at SW corner + 24"" to slab	The Square	0.1	0.5	2	10	8	38	150	750	Monitor exposure	Deployable door barriers
Buildings	Smith Cottage	2	3	2	0	1	1	9	38	11.05	grade from LiDAR (approx FFE and A/C pad)	Buzzards Bay	0.2	1	2	10	8	38	75	375	No Action	Elevate mechanicals
Parking Lots and Parks	Bar Neck Parking	1	1	0	0	1	0	3	13	9.98	average elevation in footprint (LiDAR)	Buzzards Bay	0.5	2	5	25	6	25	63	313	Operational (no parking during storms)	Operational (no parking during storms)
Buildings	Brick Apartment Building	3	2	1	2	2	3	13	54	10.07	grade from LiDAR at sidewalk (steps down to basement door)	The Square	0.1	0.5	2	10	5	27	108	542	Seal basement door	Monitor first floor exposure
Infrastructure	Transformer Feeds (Rowe/Homestead/ESL/Loeb)	2	1	1	3	2	3	12	50	10.70	grade from LiDAR + 6"" to plinth	The Square	0.1	0.2	2	10	5	10	100	500	Monitor exposure	Elevate pad
Infrastructure	Lillie Transformer	2	1	1	3	2	2	11	46	9.89	grade from LiDAR (plinth at grade on west edge)	Eel Pond	0.1	0.5	2	20	5	23	92	917	Monitor exposure	Elevate pad
Buildings	Drew House	2	2	1	1	1	2	9	38	10.10	LAG (east alley door threshold) from 2017 ELV CERT	The Square	0.1	0.5	2	10	4	19	75	375	Seal basement alley door	Seal basement windows
Parking Lots and Parks	Loeb Loading Dock	2	1	1	1	0	1	6	25	10.36	average elevation in footprint (LiDAR)	The Square	0.1	0.2	2	10	3	5	50	250	Operational (no deliveries during storms)	Operational (no deliveries during storms)
Buildings	Rowe Laboratory	4	3	3	4	3	2	19	79	10.79	first floor elevation from 2017 ELV CERT	The Square	0	0.2	1	5	0	16	79	396	No Action	Deployable door barriers, elevate mechanicals
Buildings	Rowe Generator Building	2	4	3	4	3	1	17	71	10.79	first floor elevation from 2017 ELV CERT (Rowe Laboratory)	The Square	0	0.2	1	5	0	14	71	354	No Action	Deployable door barriers, floodproof vents
Buildings	Starr Laboratory	3	3	3	3	3	3	18	75	10.85	TBF slab from 2017 ELV CERT	The Square	0	0.2	1	5	0	15	75	375	No Action	Deployable door barriers
Buildings	Homestead	2	2	2	0	1	2	9	38	11.47	grade from LiDAR at W side brick courtyard + 20"" to FFE	The Square	0	0.1	1	5	0	4	38	188	No Action	Deployable door barriers
Buildings	11 North Street	2	3	1	0	1	1	8	33	12.80	grade from LiDAR at sidewalk (pathway to basement door)	Buzzards Bay	0	0.2	1	5	0	7	33	167	No Action	Monitor exposure
Buildings	David House	2	2	1	1	1	2	9	38	13.62	grade from LiDAR between David/Veeder (basement windows - breaker boxes)	The Square	0	0	0.1	0.5	0	0	4	19	No Action	Monitor exposure
Buildings	Veeder House	2	2	1	1	1	2	9	38	13.62	grade from LiDAR between David/Veeder (basement windows - breaker boxes)	The Square	0	0	0.1	0.5	0	0	4	19	No Action	Monitor exposure
Buildings	Loeb Generator Building	2	4	3	3	2	3	17	71	15.08	grade from LiDAR at west + 13"" to floor	The Square	0	0	0	0.2	0	0	0	14	No Action	Monitor exposure
Infrastructure	Meter Box (Lillie/MRC)	2	1	1	3	2	2	11	46	11.37	grade from LiDAR + 13"" to plinth	Eel Pond	0	0.1	1	5	0	5	46	229	No Action	Elevate pad
Infrastructure	Starr Transformer	2	1	1	3	2	2	11	46	12.39	grade from LiDAR	The Square	0	0	0.2	2	0	0	9	92	No Action	Elevate pad
Parking Lots and Parks	Loeb Parking	3	1	1	1	1	1	8	33	13.05	average elevation in footprint (LiDAR)	The Square	0	0	0.2	1	0	0	7	33	No Action	Operational (no deliveries during storms)
Infrastructure	Rowe Fuel Tank	1	2	2	3	2	0	10	42	15.65	grade from LiDAR + 75"" to top of tank	The Square	0	0	0	0.1	0	0	0	4	No Action	No Action
Parking Lots and Parks	Broderick Parking	2	1	1	0	0	0	4	17	15.93	average elevation in footprint (LiDAR)	Buzzards Bay	0	0	0.1	0.5	0	0	2	8	No Action	No Action

* current design vulnerable to nuisance flooding

2030	2050	2070	2100

Nuisance flooding key (HAT > CE)

D-3 NOAA Asset Level Risk Assessment and Adaptation Strategies

Type	Name	Extent	Duration	Cost	Research	Operations	Education	SUM	CONSQ	CE_ftNAVD	CE_Desc	NODE	Prob_PDAY	Prob_2030	Prob_2050	Prob_2070	Risk_PDAY	Risk_2030	Risk_2050	Risk_2070	Near-Term Plan	Long-Term Plan
Parking Lots and Parks	Maintenance/Gear Parking	2	0	2	2	2	3	11	46	4.54	average elevation in footprint (LiDAR)	Harbor	25	50	100	100	1146	2292	4583	4583	Operational (no parking during storms)	Elevate/protect with facility redesign*
Coastal Infrastructure	250' Wooden Finger Pier	0	4	2	0	0	0	6	25	4.43	grade at parking lot (LiDAR)	Harbor	30	50	100	100	750	1250	2500	2500	No Action (not currently in use)	Redesign*
Buildings	Gear Shed	2	4	4	3	3	1	17	71	5.09	grade at bay door (LiDAR)	Harbor	10	30	50	100	708	2125	3542	7083	Deployable door/bay barriers	Relocate operations or redesign facility*
Parking Lots and Parks	Aquarium Parking	0	0	1	0	0	3	4	17	4.33	average elevation in footprint (LiDAR)	Harbor	30	50	100	100	500	834	1667	1667	Operational (no parking during storms)	Elevate with facility redesign*
Parking Lots and Parks	Main Office Parking	2	0	1	2	2	3	10	42	5.65	average elevation in footprint (LiDAR)	Harbor	10	30	50	100	417	1250	2084	4167	Operational (no parking during storms)	Elevate with facility redesign*
Buildings	Maintenance Garage	3	4	4	3	3	1	18	75	6.40	grade at bay door (LiDAR)	Harbor	5	10	50	100	375	750	3750	7500	Deployable door/bay barriers	Relocate operations or redesign facility
Buildings	Aquarium Building	2	4	4	1	2	3	16	67	6.26	Gear Shed Slab + 14"" to basement vent shaft (alt = Gear Shed Slab +62"" FF	Harbor	5	10	50	100	333	667	3334	6667	Reroute vent shaft + deployable door barri	Monitor FFE exposure
Coastal Infrastructure	Small Vessel Berthing (160ft)	2	4	2	2	1	1	12	50	6.43	grade at parking lot (LiDAR) + 24""	Harbor	5	10	30	50	250	500	1500	2500	Operational (no berthing during storm)	Operational (no berthing during storm)
Coastal Infrastructure	Large Vessel Berthing (200ft)	2	4	2	2	1	1	12	50	6.43	grade at parking lot (LiDAR) + 24""	Harbor	5	10	30	50	250	500	1500	2500	Operational (no berthing during storm)	Operational (no berthing during storm)
Infrastructure	50A Electrical Service - Small Vessel Bulkhead	1	4	1	0	1	0	7	29	5.99	grade at parking lot (LiDAR) + 18"" to box	Harbor	5	20	50	100	146	583	1459	2917	Seal or elevate	Seal or elevate*
Infrastructure	Electrical Service - Pier	1	4	1	0	1	0	7	29	6.43	Finger Pier decking + 24"" to box	Harbor	5	10	30	50	146	292	875	1459	No Action (not currently in use)	Elevate if pier redesigned
Infrastructure	300A Electrical Service - Large Vessel Bulkhead S	1	4	1	0	1	0	7	29	6.91	grade at parking lot (LiDAR) + 29""	Harbor	2	10	30	50	58	292	875	1459	Seal or elevate	Seal or elevate
Infrastructure	300A Electrical Service - Large Vessel Bulkhead N	1	4	1	0	1	0	7	29	6.91	grade at parking lot (LiDAR) + 29""	Harbor	2	10	30	50	58	292	875	1459	Seal or elevate	Seal or elevate
Infrastructure	Seawater Pump House	2	4	1	1	3	3	14	58	7.71	grade at parking lot SE corner (LiDAR) + 15"" to pump plinth	Harbor	1	2	20	50	58	117	1167	2917	Deployable door barrier, seal foundation	Monitor wall connection exposures
Infrastructure	Automatic Chop Gate	1	2	1	0	0	0	4	17	6.65	grade at parking lot (LiDAR) + 7""	Harbor	2	10	30	50	33	167	500	834	Seal box if possible	Elevate controls
Infrastructure	Make Up Seawater Tower	0	1	2	1	1	3	8	33	7.71	same as Seawater Pump House (linked infrastructure)	Harbor	1	2	20	50	33	67	667	1667	See Pump House	See Pump House
Infrastructure	Aquarium Complex Transformer	2	3	2	2	2	2	13	54	8.23	grade at parking lot (LiDAR) + 24"" to box	Harbor	0.5	2	10	50	27	108	542	2708	Check connection seals on pad	Replace/elevate at end of service life
Infrastructure	UST	3	1	0	3	1	3	11	46	8.34	grade (LiDAR)	Harbor	0.5	2	10	30	23	92	458	1375	Seal hatches	Maintain seals on hatches
Buildings	Main Office	3	4	4	4	4	3	22	92	9.13	grade at frontdoor driveway (LiDAR) + 17"" FFE (alt = load dock grade +20""	Harbor	0.2	1	5	30	18	92	458	2750	Deployable door barriers	Renovate or re-program 1st floor
Infrastructure	Main Office A/C Units	0	1	1	0	0	0	2	8	6.96	grade (LiDAR)	Harbor	2	10	30	50	17	83	250	417	Deployable barrier	Elevate mechanicals
Infrastructure	Seal Pool Exhibit	1	1	2	0	0	3	7	29	9.05	grade at sidewalk (LiDAR) + 20""	Harbor	0.2	1	5	30	6	29	146	875	Deployable barrier	Monitor wall overtopping exposure
Parking Lots and Parks	Cottage Parking	0	0	1	0	0	0	1	4	10.26	average elevation in footprint (LiDAR)	Harbor	0.1	0.2	2	10	0	1	8	42	Operational (no parking during storms)	Operational (no parking during storms)
Infrastructure	Engine Generator	3	4	2	3	3	3	18	75	10.90	grade at parking lot (LiDAR) + 56""	Harbor	0	0.2	2	10	0	15	150	750	Check connection seals on pad	Replace/elevate at end of service life
Buildings	Cottage (Lab / Offices)	2	4	2	2	2	1	13	54	10.99	grade at bulkhead SE corner (LiDAR)	Harbor	0	0.2	1	5	0	11	54	271	No Action	Elevate mechanicals or floodproof basement
Infrastructure	Cottage Generator	2	2	1	1	1	0	7	29	11.23	grade (LiDAR)	Harbor	0	0.1	1	5	0	3	29	146	No Action	Replace/elevate at end of service life
Infrastructure	Hazmat Storage Sheds	1	2	1	0	1	0	5	21	11.67	grade at parking lot N side (LiDAR) + 77"" to fan vent	Harbor	0	0.1	1	5	0	2	21	104	Check door and connection seals	Replace/elevate at end of service life
Infrastructure	Exterior Freezer 1	1	4	1	1	1	0	8	33	12.10	grade at parking lot (LiDAR) + 94"" to blowers	Harbor	0	0	0.5	2	0	0	17	67	Check door and connection seals	Replace/elevate at end of service life
Infrastructure	Exterior Freezer 3	1	4	1	1	1	0	8	33	13.74	grade at parking lot (LiDAR) + 92"" to blowers	Harbor	0	0	0.1	1	0	0	3	33	Check door and connection seals	Replace/elevate at end of service life

* current design vulnerable to nuisance flooding

2030	2050	2070	2100

Nuisance flooding key (HAT > CE)

See Proprietary Note on Title Page

APPENDIX E ASSET RISK PROFILES

E-1 WHOI Asset Risk Profiles

Smith-Iselin Connector

Asset Type: Buildings

Critical Elevation (CE): 5.63 FT. NAVD88

Threshold Description:

Rigging garage door Room 116 West Door (prior survey)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	5.07	11.8	6.17	14.5	8.87	16.6	10.97
0.2	10	4.37	11.1	5.47	13.7	8.07	15.7	10.07
0.5	8.8	3.17	10	4.37	12.6	6.97	14.6	8.97
1	8.1	2.47	9.3	3.67	11.8	6.17	13.8	8.17
2	7.4	1.77	8.6	2.97	10.9	5.27	12.9	7.27
5	6.5	0.87	7.7	2.07	9.8	4.17	11.8	6.17
10	5.8	0.17	7	1.37	9	3.37	10.9	5.27
20	5	-	6.2	0.57	8	2.37	9.9	4.27
25	4.7	-	5.9	0.27	7.7	2.07	9.6	3.97
30	4.5	-	5.7	0.07	7.4	1.77	9.3	3.67
50	3.7	-	4.8	-	6.4	0.77	8.3	2.67
100	2.1	-	3.3	-	4.6	-	6.4	0.77

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	4	4	3	4	4	2	21	88

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	10	88	875	3/36
2030	30		2625	1/36
2050	50		4375	-
2070	100		8750	-

WOODS HOLE GROUP
A CLS COMPANY

Dyers Dock

Asset Type: Coastal Infrastructure

Critical Elevation (CE): 4.45 FT. NAVD88

Threshold Description:

Top of decking (surveyed)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	6.25	11.8	7.35	14.5	10.05	16.6	12.15
0.2	10	5.55	11.1	6.65	13.7	9.25	15.7	11.25
0.5	8.8	4.35	10	5.55	12.6	8.15	14.6	10.15
1	8.1	3.65	9.3	4.85	11.8	7.35	13.8	9.35
2	7.4	2.95	8.6	4.15	10.9	6.45	12.9	8.45
5	6.5	2.05	7.7	3.25	9.8	5.35	11.8	7.35
10	5.8	1.35	7	2.55	9	4.55	10.9	6.45
20	5	0.55	6.2	1.75	8	3.55	9.9	5.45
25	4.7	0.25	5.9	1.45	7.7	3.25	9.6	5.15
30	4.5	0.05	5.7	1.25	7.4	2.95	9.3	4.85
50	3.7	-	4.8	0.35	6.4	1.95	8.3	3.85
100	2.1	-	3.3	-	4.6	0.15	6.4	1.95

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	1	1	1	1	1	0	5	21

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	30	21	625	5/36
2030	50		1042	7/36
2050	100		2083	7/24
2070	100		2083	9/24

WOODS HOLE GROUP
A CLS COMPANY

Information Office (93 Water Street)

Asset Type: Buildings

Critical Elevation (CE): 5.45 FT. NAVD88

Threshold Description:

Sill of basement vent in alley (surveyed)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	5.1	11.7	6.3	14.3	8.9	16.6	11.2
0.2	9.8	4.4	11.0	5.6	13.5	8.1	15.7	10.3
0.5	8.9	3.5	10.0	4.6	12.5	7.0	14.6	9.2
1	8.2	2.8	9.3	3.9	11.6	6.2	13.8	8.4
2	7.5	2.1	8.6	3.2	10.8	5.4	12.9	7.5
5	6.5	1.1	7.7	2.3	9.7	4.3	11.8	6.4
10	5.8	0.4	7.0	1.6	8.9	3.4	10.9	5.5
20	5.0	-	6.2	0.8	7.9	2.5	9.9	4.5
25	4.7	-	5.9	0.5	7.6	2.1	9.6	4.2
30	4.5	-	5.7	0.3	7.3	1.9	9.3	3.9
50	3.7	-	4.8	-	6.3	0.9	8.3	2.9
100	2.1	-	3.3	-	4.6	-	6.4	1.0

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	3	1	1	1	4	12	50

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	10	50	500	6/36
2030	30		1500	5/36
2050	50		2500	4/24
2070	100		5000	2/24

WOODS HOLE GROUP

A CLS COMPANY

Dyers Hangar

Asset Type: Buildings

Critical Elevation (CE): 5.26 FT. NAVD88

Threshold Description:

FFE (surveyed)

Probability of Exceedance Summary Table

Probability	Present Flood Elevation	Present Depth Over CE	2030 Flood Elevation	2030 Depth Over CE	2050 Flood Elevation	2050 Depth Over CE	2070 Flood Elevation	2070 Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	5.44	11.8	6.54	14.5	9.24	16.6	11.34
0.2	10	4.74	11.1	5.84	13.7	8.44	15.7	10.44
0.5	8.8	3.54	10	4.74	12.6	7.34	14.6	9.34
1	8.1	2.84	9.3	4.04	11.8	6.54	13.8	8.54
2	7.4	2.14	8.6	3.34	10.9	5.64	12.9	7.64
5	6.5	1.24	7.7	2.44	9.8	4.54	11.8	6.54
10	5.8	0.54	7	1.74	9	3.74	10.9	5.64
20	5	-	6.2	0.94	8	2.74	9.9	4.64
25	4.7	-	5.9	0.64	7.7	2.44	9.6	4.34
30	4.5	-	5.7	0.44	7.4	2.14	9.3	4.04
50	3.7	-	4.8	-	6.4	1.14	8.3	3.04
100	2.1	-	3.3	-	4.6	-	6.4	1.14

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	3	2	2	2	0	11	46

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	10	46	458	7/36
2030	30		1375	6/36
2050	50		2292	6/24
2070	100		4583	4/24

WOODS HOLE GROUP
A CLS COMPANY

Iselin

Asset Type: Buildings

Critical Elevation (CE): 6.08 FT. NAVD88

Threshold Description:

North Alvin high bay 130D Door - systems at grade

Room 138 (prior survey)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.62	11.8	5.72	14.5	8.42	16.6	10.52
0.2	10	3.92	11.1	5.02	13.7	7.62	15.7	9.62
0.5	8.8	2.72	10	3.92	12.6	6.52	14.6	8.52
1	8.1	2.02	9.3	3.22	11.8	5.72	13.8	7.72
2	7.4	1.32	8.6	2.52	10.9	4.82	12.9	6.82
5	6.5	0.42	7.7	1.62	9.8	3.72	11.8	5.72
10	5.8	-	7	0.92	9	2.92	10.9	4.82
20	5	-	6.2	0.12	8	1.92	9.9	3.82
25	4.7	-	5.9	-	7.7	1.62	9.6	3.52
30	4.5	-	5.7	-	7.4	1.32	9.3	3.22
50	3.7	-	4.8	-	6.4	0.32	8.3	2.22
100	2.1	-	3.3	-	4.6	-	6.4	0.32

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	4	3	3	4	2	20	83

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	83	417	8/36
2030	20		1667	4/36
2050	50		4167	-
2070	100		8333	-

WOODS HOLE GROUP

A CLS COMPANY

Iselin Dock

Asset Type: Coastal Infrastructure
Critical Elevation (CE): 6.50 FT. NAVD88
Threshold Description:
Representative of deck at lower operation area (from M&N)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.2	11.8	5.3	14.5	8	16.6	10.1
0.2	10	3.5	11.1	4.6	13.7	7.2	15.7	9.2
0.5	8.8	2.3	10	3.5	12.6	6.1	14.6	8.1
1	8.1	1.6	9.3	2.8	11.8	5.3	13.8	7.3
2	7.4	0.9	8.6	2.1	10.9	4.4	12.9	6.4
5	6.5	0	7.7	1.2	9.8	3.3	11.8	5.3
10	5.8	-	7	0.5	9	2.5	10.9	4.4
20	5	-	6.2	-	8	1.5	9.9	3.4
25	4.7	-	5.9	-	7.7	1.2	9.6	3.1
30	4.5	-	5.7	-	7.4	0.9	9.3	2.8
50	3.7	-	4.8	-	6.4	-	8.3	1.8
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	4	2	2	3	4	3	18	75

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	75	375	10/36
2030	10		750	12/36
2050	30		2250	-
2070	50		3750	-

WOODS HOLE GROUP
A CLS COMPANY

School Street Parking

Asset Type: Parking Lots and Parks

Critical Elevation (CE): 5.09 FT. NAVD88

Threshold Description:

Average elevation in footprint (LiDAR)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	5.5	11.7	6.6	14.3	9.2	16.6	11.5
0.2	9.8	4.7	11.0	5.9	13.5	8.4	15.7	10.6
0.5	8.9	3.8	10.0	4.9	12.5	7.4	14.6	9.5
1	8.2	3.1	9.3	4.2	11.6	6.5	13.8	8.7
2	7.5	2.4	8.6	3.5	10.8	5.7	12.9	7.8
5	6.5	1.4	7.7	2.6	9.7	4.6	11.8	6.7
10	5.8	0.7	7.0	1.9	8.9	3.8	10.9	5.8
20	5.0	-	6.2	1.1	7.9	2.8	9.9	4.8
25	4.7	-	5.9	0.8	7.6	2.5	9.6	4.5
30	4.5	-	5.7	0.6	7.3	2.2	9.3	4.2
50	3.7	-	4.8	-	6.3	1.2	8.3	3.2
100	2.0	-	3.1	-	4.2	-	6.0	0.9

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	3	1	0	2	1	0	7	29

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	10	29	292	11/36
2030	30		875	10/36
2050	50		1459	9/24
2070	100		2917	7/24

WOODS HOLE GROUP
A CLS COMPANY

Smith

Asset Type: Buildings
Critical Elevation (CE): 6.83 FT. NAVD88
Threshold Description:
Lab 115 Door - systems at grade Room 108 (prior survey)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	3.87	11.8	4.97	14.5	7.67	16.6	9.77
0.2	10	3.17	11.1	4.27	13.7	6.87	15.7	8.87
0.5	8.8	1.97	10	3.17	12.6	5.77	14.6	7.77
1	8.1	1.27	9.3	2.47	11.8	4.97	13.8	6.97
2	7.4	0.57	8.6	1.77	10.9	4.07	12.9	6.07
5	6.5	-	7.7	0.87	9.8	2.97	11.8	4.97
10	5.8	-	7	0.17	9	2.17	10.9	4.07
20	5	-	6.2	-	8	1.17	9.9	3.07
25	4.7	-	5.9	-	7.7	0.87	9.6	2.77
30	4.5	-	5.7	-	7.4	0.57	9.3	2.47
50	3.7	-	4.8	-	6.4	-	8.3	1.47
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	4	4	4	4	4	24	100

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	2	100	200	13/36
2030	10		1000	8/36
2050	30		3000	2/24
2070	50		5000	1/24

WOODS HOLE GROUP
A CLS COMPANY

Bigelow

Asset Type: Buildings
Critical Elevation (CE): 6.58 FT. NAVD88
Threshold Description:
W06 Door - systems below grade G12/G1 (prior survey)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.12	11.8	5.22	14.5	7.92	16.6	10.02
0.2	10	3.42	11.1	4.52	13.7	7.12	15.7	9.12
0.5	8.8	2.22	10	3.42	12.6	6.02	14.6	8.02
1	8.1	1.52	9.3	2.72	11.8	5.22	13.8	7.22
2	7.4	0.82	8.6	2.02	10.9	4.32	12.9	6.32
5	6.5	-	7.7	1.12	9.8	3.22	11.8	5.22
10	5.8	-	7	0.42	9	2.42	10.9	4.32
20	5	-	6.2	-	8	1.42	9.9	3.32
25	4.7	-	5.9	-	7.7	1.12	9.6	3.02
30	4.5	-	5.7	-	7.4	0.82	9.3	2.72
50	3.7	-	4.8	-	6.4	-	8.3	1.72
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	4	4	4	4	2	22	92

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	2	92	183	14/36
2030	10		917	9/36
2050	30		2750	3/24
2070	50		4584	3/24

Redfield

Asset Type: Buildings
Critical Elevation (CE): 7.28 FT. NAVD88
Threshold Description:
West Loading Door W06 - systems below grade
Room 143 (surveyed)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	3.3	11.7	4.4	14.3	7.1	16.6	9.3
0.2	9.8	2.5	11.0	3.7	13.5	6.2	15.7	8.4
0.5	8.9	1.6	10.0	2.7	12.5	5.2	14.6	7.3
1	8.2	0.9	9.3	2.0	11.6	4.4	13.8	6.5
2	7.5	0.2	8.6	1.3	10.8	3.5	12.9	5.6
5	6.5	-	7.7	0.4	9.7	2.4	11.8	4.5
10	5.8	-	7.0	-	8.9	1.6	10.9	3.6
20	5.0	-	6.2	-	7.9	0.6	9.9	2.6
25	4.7	-	5.9	-	7.6	0.3	9.6	2.3
30	4.5	-	5.7	-	7.3	0.0	9.3	2.0
50	3.7	-	4.8	-	6.3	-	8.3	1.0
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	4	3	3	4	2	20	83

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	2	83	167	15/36
2030	5		417	16/36
2050	30		2500	5/24
2070	50		4167	5/24

Dyers Parking

Asset Type: Parking Lots and Parks
Critical Elevation (CE): 5.91 FT. NAVD88
Threshold Description:
Average elevation in footprint (LiDAR)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.79	11.8	5.89	14.5	8.59	16.6	10.69
0.2	10	4.09	11.1	5.19	13.7	7.79	15.7	9.79
0.5	8.8	2.89	10	4.09	12.6	6.69	14.6	8.69
1	8.1	2.19	9.3	3.39	11.8	5.89	13.8	7.89
2	7.4	1.49	8.6	2.69	10.9	4.99	12.9	6.99
5	6.5	0.59	7.7	1.79	9.8	3.89	11.8	5.89
10	5.8	-	7	1.09	9	3.09	10.9	4.99
20	5	-	6.2	0.29	8	2.09	9.9	3.99
25	4.7	-	5.9	-	7.7	1.79	9.6	3.69
30	4.5	-	5.7	-	7.4	1.49	9.3	3.39
50	3.7	-	4.8	-	6.4	0.49	8.3	2.39
100	2.1	-	3.3	-	4.6	-	6.4	0.49

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	3	1	0	2	1	0	7	29

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	29	146	16/36
2030	20		583	13/36
2050	50		1459	10/24
2070	100		2917	8/24

WOODS HOLE GROUP
A CLS COMPANY

Iselin Sewer Pump Shed

Asset Type: Buildings

Critical Elevation (CE): 6.79 FT. NAVD88

Threshold Description:

Pump chamber metal hatch (prior survey)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	3.91	11.8	5.01	14.5	7.71	16.6	9.81
0.2	10	3.21	11.1	4.31	13.7	6.91	15.7	8.91
0.5	8.8	2.01	10	3.21	12.6	5.81	14.6	7.81
1	8.1	1.31	9.3	2.51	11.8	5.01	13.8	7.01
2	7.4	0.61	8.6	1.81	10.9	4.11	12.9	6.11
5	6.5	-	7.7	0.91	9.8	3.01	11.8	5.01
10	5.8	-	7	0.21	9	2.21	10.9	4.11
20	5	-	6.2	-	8	1.21	9.9	3.11
25	4.7	-	5.9	-	7.7	0.91	9.6	2.81
30	4.5	-	5.7	-	7.4	0.61	9.3	2.51
50	3.7	-	4.8	-	6.4	-	8.3	1.51
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	3	1	3	3	0	12	50

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	2	50	100	20/36
2030	10		500	14/36
2050	30		1500	-
2070	50		2500	-

WOODS HOLE GROUP
A CLS COMPANY

38 Water Street

Asset Type: Buildings

Critical Elevation (CE): 8.60 FT. NAVD88

Threshold Description:

Rear bulkhead threshold (surveyed)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	2.1	11.8	3.2	14.5	5.9	16.6	8
0.2	10	1.4	11.1	2.5	13.7	5.1	15.7	7.1
0.5	8.8	0.2	10	1.4	12.6	4	14.6	6
1	8.1	-	9.3	0.7	11.8	3.2	13.8	5.2
2	7.4	-	8.6	0	10.9	2.3	12.9	4.3
5	6.5	-	7.7	-	9.8	1.2	11.8	3.2
10	5.8	-	7	-	9	0.4	10.9	2.3
20	5	-	6.2	-	8	-	9.9	1.3
25	4.7	-	5.9	-	7.7	-	9.6	1
30	4.5	-	5.7	-	7.4	-	9.3	0.7
50	3.7	-	4.8	-	6.4	-	8.3	-
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	4	2	2	2	0	12	50

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.5	50	25	24/36
2030	2		100	23/36
2050	10		500	11/24
2070	30		1500	11/24

WOODS HOLE GROUP

A CLS COMPANY

Iselin Transformers 1/2/3

Asset Type: Infrastructure

Critical Elevation (CE): 10.31 FT. NAVD88

Threshold Description:

Pad (surveyed) 1&3=10.31 / 2=10.68

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	0.39	11.8	1.49	14.5	4.19	16.6	6.29
0.2	10	-	11.1	0.79	13.7	3.39	15.7	5.39
0.5	8.8	-	10	-	12.6	2.29	14.6	4.29
1	8.1	-	9.3	-	11.8	1.49	13.8	3.49
2	7.4	-	8.6	-	10.9	0.59	12.9	2.59
5	6.5	-	7.7	-	9.8	-	11.8	1.49
10	5.8	-	7	-	9	-	10.9	0.59
20	5	-	6.2	-	8	-	9.9	-
25	4.7	-	5.9	-	7.7	-	9.6	-
30	4.5	-	5.7	-	7.4	-	9.3	-
50	3.7	-	4.8	-	6.4	-	8.3	-
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	4	2	4	4	0	18	75

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.1	75	8	25/36
2030	0.2		15	26/36
2050	2		150	-
2070	10		750	-

WOODS HOLE GROUP

A CLS COMPANY

Dyers Dock Electrical Shed

Asset Type: Buildings

Critical Elevation (CE): 8.90 FT. NAVD88

Threshold Description:

Grade + 3ft to systems (prior survey)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	1.8	11.8	2.9	14.5	5.6	16.6	7.7
0.2	10	1.1	11.1	2.2	13.7	4.8	15.7	6.8
0.5	8.8	-	10	1.1	12.6	3.7	14.6	5.7
1	8.1	-	9.3	0.4	11.8	2.9	13.8	4.9
2	7.4	-	8.6	-	10.9	2	12.9	4
5	6.5	-	7.7	-	9.8	0.9	11.8	2.9
10	5.8	-	7	-	9	0.1	10.9	2
20	5	-	6.2	-	8	-	9.9	1
25	4.7	-	5.9	-	7.7	-	9.6	0.7
30	4.5	-	5.7	-	7.4	-	9.3	0.4
50	3.7	-	4.8	-	6.4	-	8.3	-
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	0	2	0	1	1	1	5	21

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.2	21	4	27/36
2030	1		21	25/36
2050	10		208	17/24
2070	30		625	14/24

WOODS HOLE GROUP
A CLS COMPANY

E-2 MBL Asset Risk Profiles

MRC Dock

Asset Type: Coastal Infrastructure

Critical Elevation (CE): 2.46 FT. NAVD88

Threshold Description:

Top of ramp (adjacent parking lot elevation)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	8.1	11.7	9.2	14.3	11.9	16.6	14.1
0.2	9.8	7.3	11.0	8.5	13.5	11.1	15.7	13.2
0.5	8.9	6.4	10.0	7.5	12.5	10.0	14.6	12.1
1	8.2	5.7	9.3	6.8	11.6	9.2	13.8	11.3
2	7.5	5.0	8.6	6.1	10.8	8.4	12.9	10.4
5	6.5	4.0	7.7	5.2	9.7	7.3	11.8	9.3
10	5.8	3.3	7.0	4.5	8.9	6.4	10.9	8.4
20	5.0	2.5	6.2	3.7	7.9	5.5	9.9	7.4
25	4.7	2.2	5.9	3.4	7.6	5.1	9.6	7.1
30	4.5	2.0	5.7	3.2	7.3	4.9	9.3	6.8
50	3.7	1.3	4.8	2.3	6.3	3.9	8.3	5.8
100	2.1	-	3.3	0.8	4.6	2.1	6.4	3.9

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	4	3	3	3	2	19	79

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	50	79	3959	1/54
2030	100		7917	1/54
2050	100		7917	1/54
2070	100		7917	4/54

WOODS HOLE GROUP

A CLS COMPANY

Lillie Laboratory

Asset Type: Buildings

Critical Elevation (CE): 5.17 FT. NAVD88

Threshold Description:

Loading dock slab entry from 2017 ELV CERT

Additional CEs:

Lillie Fuel Tank (5.30 FT. NAVD88), Lillie/MRC Junction Box (9.33 FT. NAVD88), Lillie Transformer (9.89 FT. NAVD88), Lillie/MRC Meter Box (11.37 FT. NAVD88)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	5.4	11.7	6.5	14.3	9.2	16.6	11.4
0.2	9.8	4.6	11.0	5.8	13.5	8.4	15.7	10.5
0.5	8.9	3.7	10.0	4.8	12.5	7.3	14.6	9.4
1	8.2	3.0	9.3	4.1	11.6	6.5	13.8	8.6
2	7.5	2.3	8.6	3.4	10.8	5.7	12.9	7.7
5	6.5	1.3	7.7	2.5	9.7	4.5	11.8	6.6
10	5.8	0.6	7.0	1.8	8.9	3.7	10.9	5.7
20	5.0	-	6.2	1.0	7.9	2.8	9.9	4.7
25	4.7	-	5.9	0.7	7.6	2.4	9.6	4.4
30	4.5	-	5.7	0.5	7.3	2.1	9.3	4.1
50	3.7	-	4.8	-	6.3	1.2	8.3	3.1
100	2.1	-	3.3	-	4.6	-	6.4	1.2

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	4	4	4	4	3	23	96

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	10	96	958	6/54
2030	30		2875	3/54
2050	50		4792	2/54
2070	100		9583	1/54

Ebert Hall

Asset Type: Buildings

Critical Elevation (CE): 5.33 FT. NAVD88

Threshold Description:

Grade from LiDAR at north sidewalk
(path to basement doors)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	5.2	11.7	6.4	14.3	9.0	16.6	11.3
0.2	9.8	4.5	11.0	5.7	13.5	8.2	15.7	10.4
0.5	8.9	3.6	10.0	4.7	12.5	7.1	14.6	9.3
1	8.2	2.9	9.3	4.0	11.6	6.3	13.8	8.5
2	7.5	2.2	8.6	3.3	10.8	5.5	12.9	7.6
5	6.5	1.2	7.7	2.4	9.7	4.4	11.8	6.5
10	5.8	0.5	7.0	1.7	8.9	3.5	10.9	5.6
20	5.0	-	6.2	0.9	7.9	2.6	9.9	4.6
25	4.7	-	5.9	0.6	7.6	2.3	9.6	4.3
30	4.5	-	5.7	0.4	7.3	2.0	9.3	4.0
50	3.7	-	4.8	-	6.3	1.0	8.3	3.0
100	2.1	-	3.3	-	4.6	-	6.4	1.1

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	3	3	2	1	3	3	15	63

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	10	63	625	7/54
2030	30		1875	7/54
2050	50		3125	6/54
2070	100		6250	6/54

Marine Resources Center

Asset Type: Buildings

Critical Elevation (CE): 6.24 FT. NAVD88

Threshold Description:

TBF from 2017 ELV CERT

Additional CEs:

MRC Fuel Tank (4.80 FT. NAVD88), MRC Transformer (8.71 FT. NAVD88), Lillie/MRC Junction Box (9.33 FT. NAVD88), Lillie/MRC Meter Box (11.37 FT. NAVD88)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	4.3	11.7	5.5	14.3	8.1	16.6	10.4
0.2	9.8	3.6	11.0	4.8	13.5	7.3	15.7	9.5
0.5	8.9	2.7	10.0	3.8	12.5	6.2	14.6	8.4
1	8.2	2.0	9.3	3.1	11.6	5.4	13.8	7.6
2	7.5	1.3	8.6	2.4	10.8	4.6	12.9	6.7
5	6.5	0.3	7.7	1.5	9.7	3.5	11.8	5.6
10	5.8	-	7.0	0.8	8.9	2.6	10.9	4.7
20	5.0	-	6.2	0.0	7.9	1.7	9.9	3.7
25	4.7	-	5.9	-	7.6	1.4	9.6	3.4
30	4.5	-	5.7	-	7.3	1.1	9.3	3.1
50	3.7	-	4.8	-	6.3	0.1	8.3	2.1
100	2.1	-	3.3	-	4.6	-	6.4	0.2

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	2	2	4	4	4	20	83

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	83	417	8/54
2030	10		833	11/54
2050	50		4167	3/54
2070	100		8333	2/54

Swope Building

Asset Type: Buildings

Critical Elevation (CE): 7.60 FT. NAVD88

Threshold Description:

Loading dock and FFE from 2017 ELV CERT

Additional CEs:

Swope Generator (8.30 FT. NAVD88)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	12.7	5.1	13.9	6.3	16.2	8.6	18.6	11.0
0.2	11.9	4.3	13.1	5.5	15.3	7.7	17.6	10.0
0.5	10.8	3.2	12.0	4.4	14.0	6.4	16.3	8.7
1	9.9	2.3	11.1	3.5	13.0	5.4	15.3	7.7
2	9.1	1.5	10.3	2.7	12.1	4.5	14.2	6.6
5	8.0	0.4	9.1	1.5	10.8	3.2	12.9	5.3
10	7.1	-	8.2	0.6	9.7	2.1	11.8	4.2
20	6.1	-	7.2	-	8.6	1.0	10.6	3.0
25	5.7	-	6.8	-	8.2	0.6	10.2	2.6
30	5.4	-	6.5	-	7.9	0.3	9.9	2.3
50	4.3	-	5.5	-	6.8	-	8.6	1.0
100			5.3	-	6.5	-	8.3	0.7

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	3	4	3	2	4	4	20	83

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	83	417	9/54
2030	10		833	12/54
2050	30		2500	8/54
2070	100		8333	3/54

WOODS HOLE GROUP
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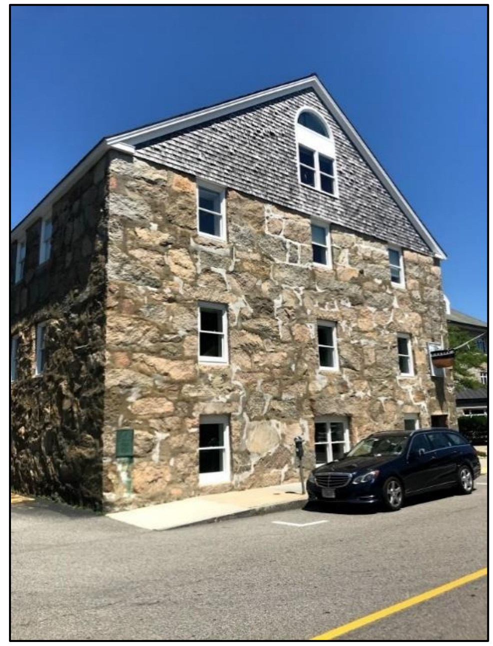

Candle House

Asset Type: Buildings

Critical Elevation (CE): 6.22 FT. NAVD88

Threshold Description:

TBF from 2017 ELV CERT

Probability of Exceedance Summary Table

Probability	Present Flood Elevation	Present Depth Over CE	2030 Flood Elevation	2030 Depth Over CE	2050 Flood Elevation	2050 Depth Over CE	2070 Flood Elevation	2070 Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	4.4	11.7	5.5	14.3	8.1	16.6	10.4
0.2	9.8	3.6	11.0	4.8	13.5	7.3	15.7	9.5
0.5	8.9	2.7	10.0	3.8	12.5	6.2	14.6	8.4
1	8.2	2.0	9.3	3.1	11.6	5.4	13.8	7.6
2	7.5	1.3	8.6	2.4	10.8	4.6	12.9	6.7
5	6.5	0.3	7.7	1.5	9.7	3.5	11.8	5.6
10	5.8	-	7.0	0.8	8.9	2.6	10.9	4.7
20	5.0	-	6.2	0.0	7.9	1.7	9.9	3.7
25	4.7	-	5.9	-	7.6	1.4	9.6	3.4
30	4.5	-	5.7	-	7.3	1.1	9.3	3.1
50	3.7	-	4.8	-	6.3	0.1	8.3	2.1
100	2.1	-	3.3	-	4.6	-	6.4	0.2

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	2	2	1	2	2	11	46

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	46	229	13/54
2030	10		458	14/54
2050	50		2292	9/54
2070	100		4583	8/54

Collection Support Facility

Asset Type: Buildings

Critical Elevation (CE): 6.29 FT. NAVD88

Threshold Description:

Slab (alt 10.8 generator fuel pump) from 2017 ELV CERT

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	4.3	11.7	5.4	14.3	8.0	16.6	10.3
0.2	9.8	3.5	11.0	4.7	13.5	7.2	15.7	9.4
0.5	8.9	2.6	10.0	3.7	12.5	6.2	14.6	8.3
1	8.2	1.9	9.3	3.0	11.6	5.3	13.8	7.5
2	7.5	1.2	8.6	2.3	10.8	4.5	12.9	6.6
5	6.5	0.2	7.7	1.4	9.7	3.4	11.8	5.5
10	5.8	-	7.0	0.7	8.9	2.6	10.9	4.6
20	5.0	-	6.2	-	7.9	1.6	9.9	3.6
25	4.7	-	5.9	-	7.6	1.3	9.6	3.3
30	4.5	-	5.7	-	7.3	1.0	9.3	3.0
50	3.7	-	4.8	-	6.3	0.0	8.3	2.0
100	2.1	-	3.3	-	4.6	-	6.4	0.1

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	2	2	2	1	2	1	10	42

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	42	208	14/54
2030	10		417	15/54
2050	50		2084	11/54
2070	100		4167	10/54

Carpentry Shop

Asset Type: Buildings

Critical Elevation (CE): 7.62 FT. NAVD88

Threshold Description:

Top of bottom floor (basement entry)

8.5 NGVD29 2001 ELV CERT

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	12.7	5.1	13.9	6.3	16.2	8.6	18.6	11.0
0.2	11.9	4.2	13.1	5.5	15.3	7.6	17.6	10.0
0.5	10.8	3.1	12.0	4.3	14.0	6.4	16.3	8.7
1	9.9	2.3	11.1	3.5	13.0	5.4	15.3	7.7
2	9.1	1.5	10.3	2.6	12.1	4.4	14.2	6.6
5	8.0	0.4	9.1	1.5	10.8	3.1	12.9	5.3
10	7.1	-	8.2	0.6	9.7	2.1	11.8	4.2
20	6.1	-	7.2	-	8.6	1.0	10.6	3.0
25	5.7	-	6.8	-	8.2	0.6	10.2	2.6
30	5.4	-	6.5	-	7.9	0.3	9.9	2.2
50	4.3	-	5.5	-	6.8	-	8.6	1.0
100			5.3	-	6.5	-	8.3	0.7

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	2	1	2	0	1	0	6	25

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	25	125	15/54
2030	10		250	16/54
2050	30		750	18/54
2070	100		2500	18/54

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Broderick House

Asset Type: Buildings

Critical Elevation (CE): 9.70 FT. NAVD88

Threshold Description:

Lower entry (Albatross St.) threshold from 2017 ELV CERT

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	12.7	3.0	13.9	4.2	16.2	6.5	18.6	8.9
0.2	11.9	2.2	13.1	3.4	15.3	5.6	17.6	7.9
0.5	10.8	1.1	12.0	2.3	14.0	4.3	16.3	6.6
1	9.9	0.2	11.1	1.4	13.0	3.3	15.3	5.6
2	9.1	-	10.3	0.6	12.1	2.4	14.2	4.5
5	8.0	-	9.1	-	10.8	1.1	12.9	3.2
10	7.1	-	8.2	-	9.7	0.0	11.8	2.1
20	6.1	-	7.2	-	8.6	-	10.6	0.9
25	5.7	-	6.8	-	8.2	-	10.2	0.5
30	5.4	-	6.5	-	7.9	-	9.9	0.2
50	4.3	-	5.5	-	6.8	-	8.6	-
100			5.3	-	6.5	-	8.3	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	3	2	1	1	1	10	42

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	1	42	42	21/54
2030	2		83	23/54
2050	10		417	24/54
2070	30		1250	23/54

Pump House

Asset Type: Buildings

Critical Elevation (CE): 8.28 FT. NAVD88

Threshold Description:

Front entry from 2017 ELV CERT

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	2.42	11.8	3.52	14.5	6.22	16.6	8.32
0.2	10	1.72	11.1	2.82	13.7	5.42	15.7	7.42
0.5	8.8	0.52	10	1.72	12.6	4.32	14.6	6.32
1	8.1	-	9.3	1.02	11.8	3.52	13.8	5.52
2	7.4	-	8.6	0.32	10.9	2.62	12.9	4.62
5	6.5	-	7.7	-	9.8	1.52	11.8	3.52
10	5.8	-	7	-	9	0.72	10.9	2.62
20	5	-	6.2	-	8	-	9.9	1.62
25	4.7	-	5.9	-	7.7	-	9.6	1.32
30	4.5	-	5.7	-	7.4	-	9.3	1.02
50	3.7	-	4.8	-	6.4	-	8.3	0.02
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	3	3	2	3	3	3	17	71

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.5	71	35	23/54
2030	2		142	20/54
2050	10		708	20/54
2070	50		3542	12/54

Loeb Laboratory

Asset Type: Buildings

Critical Elevation (CE): 9.61 FT. NAVD88

Threshold Description:

Sidewalk grade from LiDAR at front entry
(path to basement windows)

Additional CEs:

Junction Box (9.75 FT. NAVD88), Meter Box (9.91 FT. NAVD88),
Transformer Feeds (10.70 FT. NAVD88), Loeb Generator Building (15.08 FT. NAVD88)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.6	1.0	11.7	2.1	14.3	4.7	16.6	7.0
0.2	9.8	0.2	11.0	1.4	13.5	3.9	15.7	6.1
0.5	8.9	-	10.0	0.4	12.5	2.8	14.6	5.0
1	8.2	-	9.3	-	11.6	2.0	13.8	4.2
2	7.5	-	8.6	-	10.8	1.2	12.9	3.3
5	6.5	-	7.7	-	9.7	0.1	11.8	2.2
10	5.8	-	7.0	-	8.9	-	10.9	1.3
20	5.0	-	6.2	-	7.9	-	9.9	0.3
25	4.7	-	5.9	-	7.6	-	9.6	-
30	4.5	-	5.7	-	7.3	-	9.3	-
50	3.7	-	4.8	-	6.3	-	8.3	-
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	4	4	3	4	4	23	96

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.2	96	19	28/54
2030	0.5		48	27/54
2050	5		479	23/54
2070	20		1917	20/54

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Environmental Services Laboratory

Asset Type: Buildings

Critical Elevation (CE): 9.98 FT. NAVD88

Threshold Description:

First floor elevation from 2017 ELV CERT

Additional CEs:

Rowe/Homestead/ESL/Loeb Junction Box (9.75 FT. NAVD88), Rowe/Homestead/ESL/Loeb Meter Box (9.91 FT. NAVD88), Rowe/Homestead/ESL/Loeb Transformer Feeds (10.70 FT. NAVD88)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	1.0	11.9	2.2	14.1	4.4	16.4	6.7
0.2	10.0	0.3	11.2	1.5	13.3	3.6	15.5	5.8
0.5	9.1	-	10.3	0.6	12.3	2.6	14.4	4.7
1	8.5	-	9.7	0.0	11.5	1.8	13.5	3.8
2	7.6	-	8.6	-	10.7	1.0	12.7	3.0
5			7.6	-	9.6	-	11.6	1.9
10					8.9	-	10.7	1.0
20					7.8	-	9.7	-
25							9.4	-
30							9.1	-
50							8.3	-
100							6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	3	3	3	4	3	1	17	71

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.2	71	14	29/54
2030	0.5		35	32/54
2050	2		142	31/54
2070	10		708	31/54

Rowe Laboratory

Asset Type: Buildings

Critical Elevation (CE): 10.79 FT. NAVD88

Threshold Description:

First floor elevation from 2017 ELV CERT

Additional CEs:

Rowe Auditorium (7.87 FT. NAVD88), Junction Box (9.75 FT. NAVD88), Meter Box (9.91 FT. NAVD88), Transformer Feeds (10.70 FT. NAVD88), Rowe Chiller Building (10.03 FT. NAVD88), Rowe Generator Building (10.79 FT. NAVD88), Rowe Fuel Tank (15.65 FT. NAVD88)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	-	11.9	1.1	14.1	3.3	16.4	5.6
0.2	10.0	-	11.2	0.4	13.3	2.5	15.5	4.7
0.5	9.1	-	10.3	-	12.3	1.5	14.4	3.6
1	8.5	-	9.7	-	11.5	0.7	13.5	2.7
2	7.6	-	8.6	-	10.7	-	12.7	1.9
5			7.6	-	9.6	-	11.6	0.8
10					8.9	-	10.7	-
20					7.8	-	9.7	-
25							9.4	-
30							9.1	-
50							8.3	-
100							6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	4	3	3	4	3	2	19	79

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0	79	0	42/54
2030	0.2		16	40/54
2050	1		79	38/54
2070	5		396	38/54

Starr Laboratory

Asset Type: Buildings
Critical Elevation (CE): 10.85 FT. NAVD88
Threshold Description:
TBF slab from 2017 ELV CERT
Additional CEs:
Starr Electrical Switch Box (9.16 FT. NAVD88), Starr Transformer (12.39 FT. NAVD88)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	-	11.9	1.1	14.1	3.3	16.4	5.6
0.2	10.0	-	11.2	0.4	13.3	2.5	15.5	4.7
0.5	9.1	-	10.3	-	12.3	1.5	14.4	3.6
1	8.5	-	9.7	-	11.5	0.7	13.5	2.7
2	7.6	-	8.6	-	10.7	-	12.7	1.9
5			7.6	-	9.6	-	11.6	0.8
10					8.9	-	10.7	-
20					7.8	-	9.7	-
25							9.4	-
30							9.1	-
50							8.3	-
100							6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	3	3	3	3	3	3	18	75

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0	75	0	44/54
2030	0.2		15	41/54
2050	1		75	41/54
2070	5		375	41/54

Homestead

Asset Type: Buildings

Critical Elevation (CE): 11.47 FT. NAVD88

Threshold Description:

Grade from LiDAR at W side brick courtyard + 20"" to FFE

Additional CEs:

Rowe/Homestead/ESL/Loeb Junction Box (9.75 FT. NAVD88), Rowe/Homestead/ESL/Loeb Meter Box (9.91 FT. NAVD88), Rowe/Homestead/ESL/Loeb Transformer Feeds (10.70 FT. NAVD88)

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	-	11.9	0.4	14.1	2.6	16.4	4.9
0.2	10.0	-	11.2	-	13.3	1.8	15.5	4.0
0.5	9.1	-	10.3	-	12.3	0.8	14.4	2.9
1	8.5	-	9.7	-	11.5	0.0	13.5	2.0
2	7.6	-	8.6	-	10.7	-	12.7	1.2
5			7.6	-	9.6	-	11.6	0.1
10					8.9	-	10.7	-
20					7.8	-	9.7	-
25							9.4	-
30							9.1	-
50							8.3	-
100							6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	2	2	0	1	2	9	38

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0	38	0	45/54
2030	0.1		4	47/54
2050	1		38	46/54
2070	5		188	46/54

E-3 NOAA Asset Risk Profiles

Gear Shed

Asset Type: Buildings
Critical Elevation (CE): 5.09 FT. NAVD88
Threshold Description:
Grade at bay door (LiDAR)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	5.61	11.8	6.71	14.5	9.41	16.6	11.51
0.2	10	4.91	11.1	6.01	13.7	8.61	15.7	10.61
0.5	8.8	3.71	10	4.91	12.6	7.51	14.6	9.51
1	8.1	3.01	9.3	4.21	11.8	6.71	13.8	8.71
2	7.4	2.31	8.6	3.51	10.9	5.81	12.9	7.81
5	6.5	1.41	7.7	2.61	9.8	4.71	11.8	6.71
10	5.8	0.71	7	1.91	9	3.91	10.9	5.81
20	5	-	6.2	1.11	8	2.91	9.9	4.81
25	4.7	-	5.9	0.81	7.7	2.61	9.6	4.51
30	4.5	-	5.7	0.61	7.4	2.31	9.3	4.21
50	3.7	-	4.8	-	6.4	1.31	8.3	3.21
100	2.1	-	3.3	-	4.6	-	6.4	1.31

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	4	4	3	3	1	17	71

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	10	71	708	3/27
2030	30		2125	2/27
2050	50		3542	3/27
2070	100		7083	2/27

Maintenance Garage

Asset Type: Buildings
Critical Elevation (CE): 6.40 FT. NAVD88
Threshold Description:
Grade at bay door (LiDAR)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.3	11.8	5.4	14.5	8.1	16.6	10.2
0.2	10	3.6	11.1	4.7	13.7	7.3	15.7	9.3
0.5	8.8	2.4	10	3.6	12.6	6.2	14.6	8.2
1	8.1	1.7	9.3	2.9	11.8	5.4	13.8	7.4
2	7.4	1	8.6	2.2	10.9	4.5	12.9	6.5
5	6.5	0.1	7.7	1.3	9.8	3.4	11.8	5.4
10	5.8	-	7	0.6	9	2.6	10.9	4.5
20	5	-	6.2	-	8	1.6	9.9	3.5
25	4.7	-	5.9	-	7.7	1.3	9.6	3.2
30	4.5	-	5.7	-	7.4	1	9.3	2.9
50	3.7	-	4.8	-	6.4	0	8.3	1.9
100	2.1	-	3.3	-	4.6	-	6.4	0

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	3	4	4	3	3	1	18	75

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	75	375	6/27
2030	10		750	6/27
2050	50		3750	2/27
2070	100		7500	1/27

Aquarium Building

Asset Type: Buildings

Critical Elevation (CE): 6.26 FT. NAVD88

Threshold Description:

Gear Shed Slab + 14"" to basement vent shaft
(alt = Gear Shed Slab +62"" FF)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.44	11.8	5.54	14.5	8.24	16.6	10.34
0.2	10	3.74	11.1	4.84	13.7	7.44	15.7	9.44
0.5	8.8	2.54	10	3.74	12.6	6.34	14.6	8.34
1	8.1	1.84	9.3	3.04	11.8	5.54	13.8	7.54
2	7.4	1.14	8.6	2.34	10.9	4.64	12.9	6.64
5	6.5	0.24	7.7	1.44	9.8	3.54	11.8	5.54
10	5.8	-	7	0.74	9	2.74	10.9	4.64
20	5	-	6.2	-	8	1.74	9.9	3.64
25	4.7	-	5.9	-	7.7	1.44	9.6	3.34
30	4.5	-	5.7	-	7.4	1.14	9.3	3.04
50	3.7	-	4.8	-	6.4	0.14	8.3	2.04
100	2.1	-	3.3	-	4.6	-	6.4	0.14

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	4	4	1	2	3	16	67

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	67	333	7/27
2030	10		667	7/27
2050	50		3334	4/27
2070	100		6667	3/27

Small Vessel Berthing (160ft)

Asset Type: Coastal Infrastructure
Critical Elevation (CE): 6.43 FT. NAVD88
Threshold Description:
Grade at parking lot (LiDAR) + 24""

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.27	11.8	5.37	14.5	8.07	16.6	10.17
0.2	10	3.57	11.1	4.67	13.7	7.27	15.7	9.27
0.5	8.8	2.37	10	3.57	12.6	6.17	14.6	8.17
1	8.1	1.67	9.3	2.87	11.8	5.37	13.8	7.37
2	7.4	0.97	8.6	2.17	10.9	4.47	12.9	6.47
5	6.5	0.07	7.7	1.27	9.8	3.37	11.8	5.37
10	5.8	-	7	0.57	9	2.57	10.9	4.47
20	5	-	6.2	-	8	1.57	9.9	3.47
25	4.7	-	5.9	-	7.7	1.27	9.6	3.17
30	4.5	-	5.7	-	7.4	0.97	9.3	2.87
50	3.7	-	4.8	-	6.4	-	8.3	1.87
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	4	2	2	1	1	12	50

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	50	250	8/27
2030	10		500	9/27
2050	30		1500	8/27
2070	50		2500	11/27

Large Vessel Berthing (200ft)

Asset Type: Coastal Infrastructure
Critical Elevation (CE): 6.43 FT. NAVD88
Threshold Description:
Grade at parking lot (LiDAR) + 24"”

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.27	11.8	5.37	14.5	8.07	16.6	10.17
0.2	10	3.57	11.1	4.67	13.7	7.27	15.7	9.27
0.5	8.8	2.37	10	3.57	12.6	6.17	14.6	8.17
1	8.1	1.67	9.3	2.87	11.8	5.37	13.8	7.37
2	7.4	0.97	8.6	2.17	10.9	4.47	12.9	6.47
5	6.5	0.07	7.7	1.27	9.8	3.37	11.8	5.37
10	5.8	-	7	0.57	9	2.57	10.9	4.47
20	5	-	6.2	-	8	1.57	9.9	3.47
25	4.7	-	5.9	-	7.7	1.27	9.6	3.17
30	4.5	-	5.7	-	7.4	0.97	9.3	2.87
50	3.7	-	4.8	-	6.4	-	8.3	1.87
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	4	2	2	1	1	12	50

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	50	250	9/27
2030	10		500	10/27
2050	30		1500	9/27
2070	50		2500	12/27

50A Service – Small Vessel Bulkhead

Asset Type: Infrastructure

Critical Elevation (CE): 5.99 FT. NAVD88

Threshold Description:

Grade at parking lot (LiDAR) + 18"" to box

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	4.71	11.8	5.81	14.5	8.51	16.6	10.61
0.2	10	4.01	11.1	5.11	13.7	7.71	15.7	9.71
0.5	8.8	2.81	10	4.01	12.6	6.61	14.6	8.61
1	8.1	2.11	9.3	3.31	11.8	5.81	13.8	7.81
2	7.4	1.41	8.6	2.61	10.9	4.91	12.9	6.91
5	6.5	0.51	7.7	1.71	9.8	3.81	11.8	5.81
10	5.8	-	7	1.01	9	3.01	10.9	4.91
20	5	-	6.2	0.21	8	2.01	9.9	3.91
25	4.7	-	5.9	-	7.7	1.71	9.6	3.61
30	4.5	-	5.7	-	7.4	1.41	9.3	3.31
50	3.7	-	4.8	-	6.4	0.41	8.3	2.31
100	2.1	-	3.3	-	4.6	-	6.4	0.41

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	1	4	1	0	1	0	7	29

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	5	29	146	10/27
2030	20		583	8/27
2050	50		1459	10/27
2070	100		2917	6/27

300A Service – Large Vessel Bulkhead

Asset Type: Infrastructure

Critical Elevation (CE): 6.91 FT. NAVD88

Threshold Description:

Grade at parking lot (LiDAR) + 29""

Applies to both service units (North and South)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	3.79	11.8	4.89	14.5	7.59	16.6	9.69
0.2	10	3.09	11.1	4.19	13.7	6.79	15.7	8.79
0.5	8.8	1.89	10	3.09	12.6	5.69	14.6	7.69
1	8.1	1.19	9.3	2.39	11.8	4.89	13.8	6.89
2	7.4	0.49	8.6	1.69	10.9	3.99	12.9	5.99
5	6.5	-	7.7	0.79	9.8	2.89	11.8	4.89
10	5.8	-	7	0.09	9	2.09	10.9	3.99
20	5	-	6.2	-	8	1.09	9.9	2.99
25	4.7	-	5.9	-	7.7	0.79	9.6	2.69
30	4.5	-	5.7	-	7.4	0.49	9.3	2.39
50	3.7	-	4.8	-	6.4	-	8.3	1.39
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	1	4	1	0	1	0	7	29

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	2	29	58	12/27
2030	10		292	12/27
2050	30		875	13/27
2070	50		1459	16/27

Seawater Pump House

Asset Type: Infrastructure

Critical Elevation (CE): 7.71 FT. NAVD88

Threshold Description:

Grade at parking lot SE corner (LiDAR)
+ 15"" to pump plinth

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	2.99	11.8	4.09	14.5	6.79	16.6	8.89
0.2	10	2.29	11.1	3.39	13.7	5.99	15.7	7.99
0.5	8.8	1.09	10	2.29	12.6	4.89	14.6	6.89
1	8.1	0.39	9.3	1.59	11.8	4.09	13.8	6.09
2	7.4	-	8.6	0.89	10.9	3.19	12.9	5.19
5	6.5	-	7.7	-	9.8	2.09	11.8	4.09
10	5.8	-	7	-	9	1.29	10.9	3.19
20	5	-	6.2	-	8	0.29	9.9	2.19
25	4.7	-	5.9	-	7.7	-	9.6	1.89
30	4.5	-	5.7	-	7.4	-	9.3	1.59
50	3.7	-	4.8	-	6.4	-	8.3	0.59
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	4	1	1	3	3	14	58

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	1	58	58	13/27
2030	2		117	14/27
2050	20		1167	11/27
2070	50		2917	7/27

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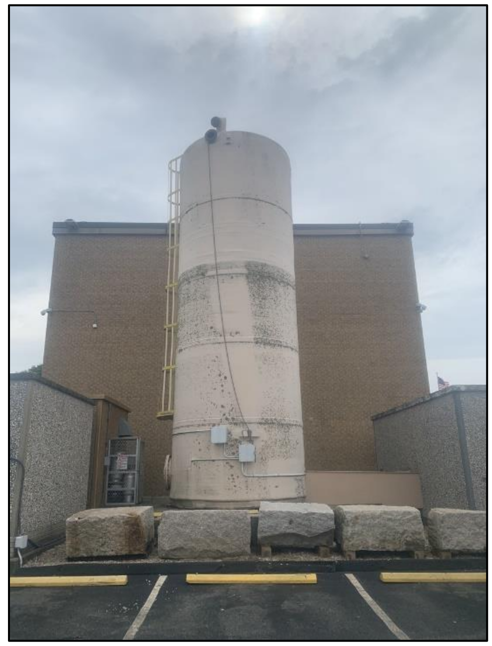

Make Up Seawater Tower

Asset Type: Infrastructure

Critical Elevation (CE): 7.71 FT. NAVD88

Threshold Description:

Same as Seawater Pump House (linked infrastructure)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	2.99	11.8	4.09	14.5	6.79	16.6	8.89
0.2	10	2.29	11.1	3.39	13.7	5.99	15.7	7.99
0.5	8.8	1.09	10	2.29	12.6	4.89	14.6	6.89
1	8.1	0.39	9.3	1.59	11.8	4.09	13.8	6.09
2	7.4	-	8.6	0.89	10.9	3.19	12.9	5.19
5	6.5	-	7.7	-	9.8	2.09	11.8	4.09
10	5.8	-	7	-	9	1.29	10.9	3.19
20	5	-	6.2	-	8	0.29	9.9	2.19
25	4.7	-	5.9	-	7.7	-	9.6	1.89
30	4.5	-	5.7	-	7.4	-	9.3	1.59
50	3.7	-	4.8	-	6.4	-	8.3	0.59
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	0	1	2	1	1	3	8	33

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	1	33	33	15/27
2030	2		67	19/27
2050	20		667	14/27
2070	50		1667	14/27

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Aquarium Complex Transformer

Asset Type: Infrastructure

Critical Elevation (CE): 8.23 FT. NAVD88

Threshold Description:

Grade at parking lot (LiDAR) + 24"" to box

Probability of Exceedance Summary Table

Probability	Present Flood Elevation	Present Depth Over CE	2030 Flood Elevation	2030 Depth Over CE	2050 Flood Elevation	2050 Depth Over CE	2070 Flood Elevation	2070 Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	2.47	11.8	3.57	14.5	6.27	16.6	8.37
0.2	10	1.77	11.1	2.87	13.7	5.47	15.7	7.47
0.5	8.8	0.57	10	1.77	12.6	4.37	14.6	6.37
1	8.1	-	9.3	1.07	11.8	3.57	13.8	5.57
2	7.4	-	8.6	0.37	10.9	2.67	12.9	4.67
5	6.5	-	7.7	-	9.8	1.57	11.8	3.57
10	5.8	-	7	-	9	0.77	10.9	2.67
20	5	-	6.2	-	8	-	9.9	1.67
25	4.7	-	5.9	-	7.7	-	9.6	1.37
30	4.5	-	5.7	-	7.4	-	9.3	1.07
50	3.7	-	4.8	-	6.4	-	8.3	0.07
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	2	3	2	2	2	2	13	54

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.5	54	27	16/27
2030	2		108	15/27
2050	10		542	15/27
2070	50		2708	9/27

UST

Asset Type: Infrastructure

Critical Elevation (CE): 8.34 FT. NAVD88

Threshold Description:

Grade (LiDAR)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	2.36	11.8	3.46	14.5	6.16	16.6	8.26
0.2	10	1.66	11.1	2.76	13.7	5.36	15.7	7.36
0.5	8.8	0.46	10	1.66	12.6	4.26	14.6	6.26
1	8.1	-	9.3	0.96	11.8	3.46	13.8	5.46
2	7.4	-	8.6	0.26	10.9	2.56	12.9	4.56
5	6.5	-	7.7	-	9.8	1.46	11.8	3.46
10	5.8	-	7	-	9	0.66	10.9	2.56
20	5	-	6.2	-	8	-	9.9	1.56
25	4.7	-	5.9	-	7.7	-	9.6	1.26
30	4.5	-	5.7	-	7.4	-	9.3	0.96
50	3.7	-	4.8	-	6.4	-	8.3	-
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	3	1	0	3	1	3	11	46

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.5	46	23	17/27
2030	2		92	16/27
2050	10		458	17/27
2070	30		1375	17/27

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Main Office

Asset Type: Buildings

Critical Elevation (CE): 9.13 FT. NAVD88

Threshold Description:

Grade at front door driveway (LiDAR)

+ 17"" FFE (alt = load dock grade +20"")

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	1.57	11.8	2.67	14.5	5.37	16.6	7.47
0.2	10	0.87	11.1	1.97	13.7	4.57	15.7	6.57
0.5	8.8	-	10	0.87	12.6	3.47	14.6	5.47
1	8.1	-	9.3	0.17	11.8	2.67	13.8	4.67
2	7.4	-	8.6	-	10.9	1.77	12.9	3.77
5	6.5	-	7.7	-	9.8	0.67	11.8	2.67
10	5.8	-	7	-	9	-	10.9	1.77
20	5	-	6.2	-	8	-	9.9	0.77
25	4.7	-	5.9	-	7.7	-	9.6	0.47
30	4.5	-	5.7	-	7.4	-	9.3	0.17
50	3.7	-	4.8	-	6.4	-	8.3	-
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	3	4	4	4	4	3	22	92

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0.2	92	18	18/27
2030	1		92	17/27
2050	5		458	18/27
2070	30		2750	8/27

Main Office A/C Units

Asset Type: Infrastructure

Critical Elevation (CE): 6.96 FT. NAVD88

Threshold Description:

Grade (LiDAR)

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	3.74	11.8	4.84	14.5	7.54	16.6	9.64
0.2	10	3.04	11.1	4.14	13.7	6.74	15.7	8.74
0.5	8.8	1.84	10	3.04	12.6	5.64	14.6	7.64
1	8.1	1.14	9.3	2.34	11.8	4.84	13.8	6.84
2	7.4	0.44	8.6	1.64	10.9	3.94	12.9	5.94
5	6.5	-	7.7	0.74	9.8	2.84	11.8	4.84
10	5.8	-	7	0.04	9	2.04	10.9	3.94
20	5	-	6.2	-	8	1.04	9.9	2.94
25	4.7	-	5.9	-	7.7	0.74	9.6	2.64
30	4.5	-	5.7	-	7.4	0.44	9.3	2.34
50	3.7	-	4.8	-	6.4	-	8.3	1.34
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach		
Scores	0	1	1	0	0	0	2	8

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	2	8	17	19/27
2030	10		83	18/27
2050	30		250	19/27
2070	50		417	21/27

Engine Generator

Asset Type: Infrastructure

Critical Elevation (CE): 10.90 FT. NAVD88

Threshold Description:

Grade at parking lot (LiDAR) + 56""

Probability of Exceedance Summary Table

Probability	Present		2030		2050		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	-	11.8	0.9	14.5	3.6	16.6	5.7
0.2	10	-	11.1	0.2	13.7	2.8	15.7	4.8
0.5	8.8	-	10	-	12.6	1.7	14.6	3.7
1	8.1	-	9.3	-	11.8	0.9	13.8	2.9
2	7.4	-	8.6	-	10.9	0	12.9	2
5	6.5	-	7.7	-	9.8	-	11.8	0.9
10	5.8	-	7	-	9	-	10.9	0
20	5	-	6.2	-	8	-	9.9	-
25	4.7	-	5.9	-	7.7	-	9.6	-
30	4.5	-	5.7	-	7.4	-	9.3	-
50	3.7	-	4.8	-	6.4	-	8.3	-
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	3	4	2	3	3	3	18	75

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0	75	0	22/27
2030	0.2		15	21/27
2050	2		150	20/27
2070	10		750	20/27

Hazmat Storage Sheds

Asset Type: Infrastructure

Critical Elevation (CE): 11.67 FT. NAVD88

Threshold Description:

Grade at parking lot N side (LiDAR) + 77"" to fan vent

Probability of Exceedance Summary Table

	Present		2030		2050		2070	
Probability	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
%	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.7	-	11.8	0.13	14.5	2.83	16.6	4.93
0.2	10	-	11.1	-	13.7	2.03	15.7	4.03
0.5	8.8	-	10	-	12.6	0.93	14.6	2.93
1	8.1	-	9.3	-	11.8	0.13	13.8	2.13
2	7.4	-	8.6	-	10.9	-	12.9	1.23
5	6.5	-	7.7	-	9.8	-	11.8	0.13
10	5.8	-	7	-	9	-	10.9	-
20	5	-	6.2	-	8	-	9.9	-
25	4.7	-	5.9	-	7.7	-	9.6	-
30	4.5	-	5.7	-	7.4	-	9.3	-
50	3.7	-	4.8	-	6.4	-	8.3	-
100	2.1	-	3.3	-	4.6	-	6.4	-

Consequence of Exceedance

	Direct Impacts			Mission Impairment				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Research & Applied Science	Operations & Economic Activity	Education & Outreach	Sum	Consequence Score
Scores	1	2	1	0	1	0	5	21

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	0	21	0	25/27
2030	0.1		2	24/27
2050	1		21	24/27
2070	5		104	24/27