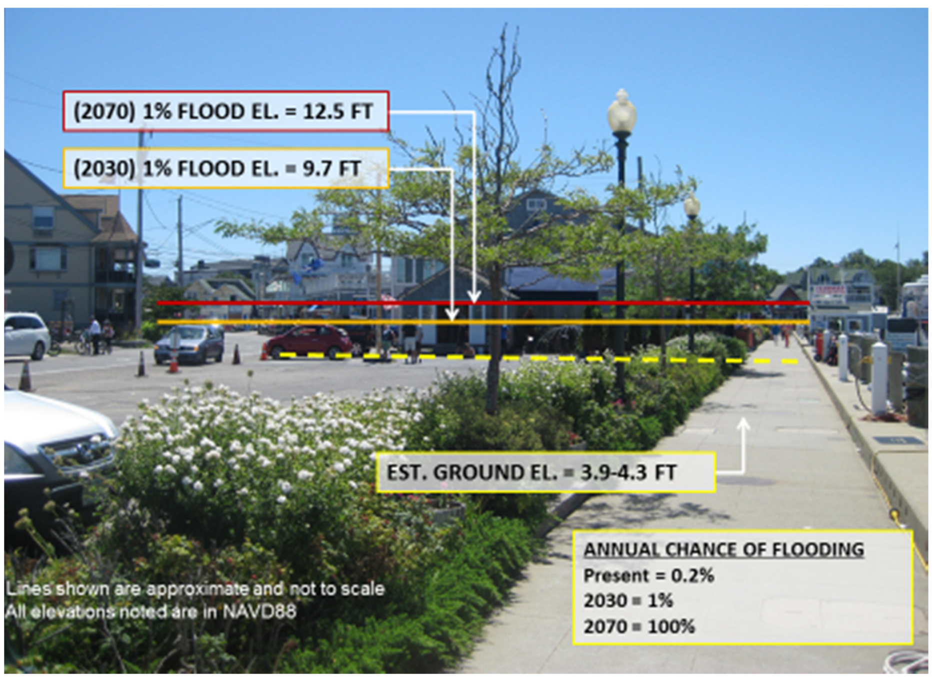
Coastal Vulnerability Assessment and Adaptation Plan

Town Oak Bluffs, MA

July, 2016



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EXECUTIVE SUMMARY

Given its exposure to the ocean, the Town of Oak Bluffs appropriated funds from the Town's Community Preservation Act fund to study the Town's vulnerability to future sea level rise and storm surge from extreme storm events, and to identify potential adaptation strategies to deal with the identified vulnerabilities. The firm of Kleinfelder from Cambridge, MA was retained to perform the study, in association with the Woods Hole Group from Falmouth, MA.

This project has four primary goals:

1. Identify areas of the town that are vulnerable to the combined effects of sea level rise and storm surge from extreme storm events.
2. Assess the vulnerability of municipally-owned public infrastructure and natural resources.
3. Identify adaptation strategies that will help to mitigate the long-term effects of sea level rise and storm surge.
4. Educate the public, city officials and state legislators about those potential impacts.

The water surface modeling for this study was based on the Boston Harbor – Flood Risk Model (BH-FRM), which utilized a complex hydrodynamic model generated using the ADvanced CIRCulation (ADCIRC) software to predict storm surge flooding and the Simulated WAves Nearshore (SWAN) software, a wave generation and transformation model. The model explicitly and quantitatively incorporates climate change influences on sea level rise, tides, waves, storm track, and storm intensity for the present 2030 and 2070 time horizons. This probability-based modeling approach provides the Town with useful data for assessing its infrastructure's flood risks and making decisions on adaptation priorities to mitigate future flooding damage.

The results of BH-FRM simulations for 2030 and 2070 were used to generate Percent Probability of Flooding maps and Depth of Flooding maps throughout the Town of Oak Bluffs. Enlarged Depth of Flooding maps for a 1% Probability of Exceedance were developed for areas of the town found to be most susceptible to flooding. All maps generated for this project are included in Appendix A. In addition, GIS layers for all maps were submitted to the Town.

A risk-based vulnerability assessment was performed on municipally-owned infrastructure subject to flooding to help prioritize flooding issues. Municipally-owned infrastructure includes sewer pump stations, roads, bridges, wharves, seawalls, and other critical facilities such as schools, police stations, fire stations, etc. owned and operated by the Town of Oak Bluffs. Critical infrastructure was selected based on the inundation modeling results, using infrastructure information obtained from the Oak Bluffs Hazard Mitigation Plan and information provided by Town Departments. Some key infrastructure that is not municipally owned (e.g. federal, state or privately owned) that is subject to flooding is shown on the maps, but vulnerability assessments were not performed on these assets. In some limited cases, state-owned roadways (e.g., Beach Rd, Seaview Ave), which are critical transportation links in Oak Bluffs, are included in the discussion of adaptation options.

The four areas in Oak Bluffs, which were found to be most vulnerable to flooding from future sea level rise and storm surge, are:

- Oak Bluffs Harbor
- Crystal Lake and Hospital area
- Farm Pond area
- Sengekontacket Pond and Sylvia State Beach area

A number of strategies were identified to help adapt to future project flooding levels. These strategies included:

- Permanent and temporary flood barriers.
- Dune enhancement and beach nourishment projects.
- Raising low sections of roadway.
- Raising vulnerable infrastructure.
- Construction of a hurricane barrier to close off Oak Bluffs Harbor.
- Changes to town regulations and policies to help steer the course of future development in flood-prone areas.
- Develop a formal coastal flood operations plan.
- Join the National Flood Insurance Program Community Rating System to help lower flood insurance premiums for residents and businesses.
- Thin layer deposition projects to maintain and enhance salt marsh vulnerable to the long-term effects of sea level rise.
- Acquire land adjacent to vulnerable coastal resource areas to accommodate changing conditions of natural resource areas.
- Investigate the possibility of implementing a rolling easement program in which the Town purchases an easement from a property owner today in exchange for a promise to surrender the property to the Town once it is substantially damaged by a flood event. This would be part of a policy of retreat from areas most vulnerable to flooding.

A number of recommendations for further action are presented.

INTRODUCTION

The Town of Oak Bluffs is highly vulnerable to sea level rise being a coastal community located on Martha's Vineyard, Massachusetts. With its northeast exposure, Oak Bluffs is particularly susceptible to nor'easter storms. Floods caused by hurricanes, nor'easters, severe rainstorms and thunderstorms have been identified by local officials to be the most serious natural hazard for Oak Bluffs.

Given its exposure to the ocean, the Town of Oak Bluffs appropriated funds from the Town's Community Preservation Act fund to study the Town's vulnerability to future sea level rise and storm surge from extreme storm events, and to identify potential adaptation strategies to deal with the identified vulnerabilities.

This project has four primary goals:

1. Identify areas of the town that are vulnerable to the combined effects of sea level rise and storm surge from extreme storm events.
2. Assess the vulnerability of municipally-owned public infrastructure and natural resources.
3. Identify adaptation strategies that will help to mitigate the long-term effects of sea level rise and storm surge.
4. Educate the public, city officials and state legislators about those potential impacts.

It is important to note that this vulnerability assessment and adaptation planning study is in no way connected with flood risk studies and mapping efforts periodically conducted by the Federal Emergency Management Agency (FEMA) to produce Flood Insurance Rate Maps (FIRM) for Oak Bluffs. The inundation maps prepared as part of this study were developed for the purpose of long-term planning using very different scenarios and data sets than were used by FEMA to prepare FIRMs for the Town of Oak Bluffs. Data from this report, therefore, should not be used in any way as a substitute for FIRMs to determine flood insurance premiums or for engineering input in the design and permitting associated with siting or flood proofing of structures. Design and permitting associated with siting or flood proofing of structures must rely on the legally-binding FIRMs.

Project Team

The Town of Oak Bluffs selected the team of Kleinfelder and Woods Hole Group through a Request for Proposal process. Kleinfelder, located in Cambridge, MA, was the prime consultant responsible for client liaison, vulnerability assessment, adaptation planning, and public process. Woods Hole Group, located in Falmouth, MA, was responsible for inundation modeling and natural resource impacts. The team's primary members included:

- Andre Martecchini, PE – Kleinfelder - Project Manager, Public Process
- Nasser Brahim – Kleinfelder - Project Scientist, Vulnerability Assessment, Adaptation Planning
- Kirk Bosma, PE – Woods Hole Group – Inundation and Natural Resources Modeling

Kleinfelder worked closely with the Town's Steering Committee, which included the following members:

- Elizabeth Durkee, Conservation Administrator (Project Manager)
- Penny Hinkle, Conservation Commission and East Chop Beach Club

- Amy Billings, Parks and Recreation
- Joan Hughes, Conservation Commission
- David Grunden, Shellfish Constable

Public Outreach

As noted above, one of the primary goals of the project was to raise public awareness of both the escalating flood risks posed by sea level rise and storm surge, and the potential strategies available to adapt to those changes over time. Four Steering Committee meetings were held to review interim findings and to obtain feedback from committee members. Members of the public often attended these open meetings. A presentation was made to the Oak Bluffs Selectman on November 18, 2014, which provided an overview to the public of the project's goals and methodologies. Another public presentation was held on September 10, 2015, which provided an in-depth review of the project's findings. This public meeting, held at the Public Library, was very well attended and was televised on local cable television. Additional public meetings will be conducted in the future to present the findings of this final report.

Acknowledgements

We wish to acknowledge the contribution of the Massachusetts Department of Transportation under the direction of Steven Miller, Project Manager, and the Federal Highway Administration related to the modeling associated with the Boston Harbor – Flood Risk Model (BH-FRM). Modeling data from this model was utilized in the preparation of this study.

INUNDATION MODELING

Sea Level Rise and Storm Surge Model

The hydrodynamic modeling utilized for this study is based on mathematical representations of the processes that affect coastal water levels including tides, waves, winds, storm surge, sea level rise, wave set-up, etc. at a fine enough resolution to identify site-specific locations that may require adaptation alternatives. The water surface was modelled using the ADvanced CIRCulation (ADCIRC) software to predict storm surge flooding and the Simulated WAves Nearshore (SWAN) software, a wave generation and transformation model.

Water surface modeling was performed by the Woods Hole Group as part of the Boston Harbor – Flood Risk Model (BH-FRM), which was developed for the Massachusetts Department of Transportation (MassDOT) and the Federal Highway Administration (FHWA) to assess potential flooding vulnerabilities in the Central Artery tunnel system and other transportation infrastructure. Since the BH-FRM model domain covers the entire coastline of Massachusetts, including the Town of Oak Bluffs, this model was ideally suited to assess the vulnerability and risk of coastal flooding to Oak Bluffs' infrastructure and natural resources. Using this existing model was beneficial to the Oak Bluffs since much of the upfront work in developing the model was already conducted as part of the MassDOT/FHWA project.

The ADCIRC model is tightly coupled with SWAN, dynamically exchanging physical processes information during each time step, to provide an accurate representation of water surface elevations, winds, waves, and flooding along the Oak Bluffs coast and shoreline. The spatial resolution of the model is 10 meters or less, sometimes as low as 1 meter to capture important changes in topography and physical processes related to storm dynamics. This high-resolution model offers more accuracy than other storm surge models, such as SLOSH. This modeling approach is also far superior compared to a more rudimentary "bathtub" approach, since the latter does not account for critical physical processes that occur during a storm event, including waves and winds, nor can it determine the volumetric flux of water that may be able to access certain areas.

The model explicitly and quantitatively incorporates climate change influences on sea level rise, tides, waves, storm track, and storm intensity for the present (2013), 2030, and 2070 time horizons. With modeling results for multiple time horizons, decision makers can more easily identify areas of existing vulnerability in Oak Bluffs requiring immediate action, as well as areas that benefit from present planning for future action.

For each sea level rise scenario, BH-FRM uses a fully-optimized Monte Carlo approach, simulating a statistically-robust sample of storms, including tropical (hurricanes) and extra-tropical (nor'easters), based on the region's existing and evolving climatology. Results of the Monte Carlo simulations are used to generate Cumulative probability Distribution Functions (CDFs) of the storm surge water levels at a high degree of spatial precision. In particular, an accurate and precise assessment of the exceedance probability of combined SLR and storm surge is provided for each node in the model. The resulting flood risk maps and probability curves can be interpreted using geographic information systems (GIS) to identify the estimated annual probability, or likelihood, that any node within the model will experience flooding, and if so, up to what elevation.

This probability-based modeling approach provides the Town with useful data for assessing its infrastructure's flood risks and making decisions on adaptation priorities to mitigate future flooding damage. It also can be used to help inform conversations with local, state and federal officials about whether engineering design criteria should be strengthened to adapt to this changing regime, and if so, to what level. In some cases, current FEMA FIRM flood levels exceed modeling results, and still need to be incorporated into future design criteria.

Some of the unique aspects of the BH-FRM model include the following:

- An extensive understanding of the physical system as a whole.
- Inclusion of significant physical processes affecting water levels (e.g., tides, waves, winds, storm surge, sea level rise, wave set-up, etc.).
- Full consideration of the interaction between physical processes.
- Characterization of forcing functions that correspond with real world observations.
- Resolution that will be able to resolve physical and energetic processes, while also being able to identify site-specific locations that may require adaptation alternatives.

Storm Events and Storm Climatology

Figure 1 - Storms input into ADCIRC/SWAN model

The types of storms included in the Monte Carlo simulations included both tropical storms (hurricanes) and extra-tropical storm (nor'easters). The storm climatology parameters that are included in the BH-FRM model include wind directions and speeds, radius of maximum winds, pressure fields, and forward track of the storms in the Boston and Massachusetts region. While hurricanes are typically shorter duration events that often last over only one tidal cycle, nor'easters are longer duration events that typically last over multiple tidal cycles spanning multiple days. So the probability of a nor'easter occurring or lasting through a high tide is more likely than a hurricane. Also, the diameter of a nor'easter (also commonly called the "fetch") can typically be 3-4 times that of hurricanes, and therefore they can impact much larger areas of inland as well. The inclusion of nor'easters is one of the unique aspects of the BH-FRM model that is not available in other storm surge models, such as SLOSH. Figure 1 shows a representation of storms included in the model. The probability of flooding due to both hurricanes and nor'easters was estimated by developing composite probability distributions for flooding. Under current (circa 2013) and near-term future (2030) climate conditions, the probability of flooding due to nor'easters dominates because the annual average frequency of nor'easters (~2.3) is much higher than that of hurricanes (~0.34).

The storm climatology for the hundreds of different types of storms are all factored in the Monte Carlo simulations of these storm events. The storm climatology is based on present climate for planning horizons until 2050. For storm simulations beyond 2050, 21st century climatology is used to simulate the storms. The latter half of 21st century climatology projections factored into the BH-FRM model are based on climatology projections by the notable MIT professor Dr. Kerry Emmanuel.

Selection of Sea Level Rise Scenarios

Sea level has risen and fallen over geologic time with the formation of large glaciers during ice ages, and the melting of glaciers and polar ice during intervening warm periods. Since the last ice age 10,000 years ago, sea level has continued to rise, with the rate of relative sea level rise in recent centuries of roughly 10 inches per century. Recent research published in the Proceedings of the National Academy of Sciences indicates that the pace of sea level change in the 20th century has been faster than any century in the previous 2,700 years (Kopp et al., 2016).

National Oceanographic and Atmospheric Administration (NOAA) tide gauge measurements since the 1930s at Tide Gauge No. 8447930 in nearby Woods Hole, MA, shown in Figure 2, indicate that the sea level has been rising at an approximate rate of 0.11 inches (2.83 mm) per year. Over this period, sea level in Woods Hole has risen approximately 9 inches. This rate of sea level rise is expected to increase due to global warming caused by greenhouse gas emissions causing a volumetric expansion of the oceans coupled with glacial ice melt.

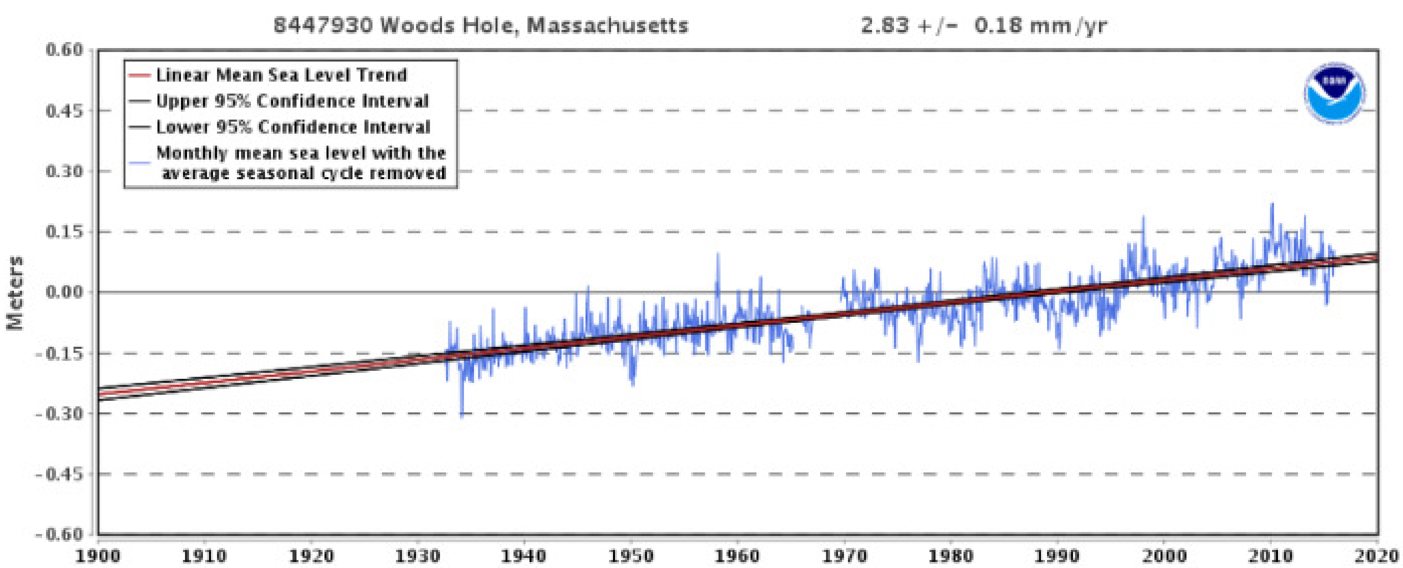

Figure 2 – Mean sea level trend at Woods Hole Tide Gauge (# 8447930)
Source: NOAA

Sea level rise (SLR) scenarios recommended by Parris et al. (2012) for the U.S. National Climate Assessment (Global Sea Level Rise Scenarios for the United States National Climate Assessment, NOAA Technical Report OAR CPO-1, December 12, 2012) were utilized in this study to predict future sea level rise (Figure 3). These scenarios are the same scenarios recommended by Massachusetts CZM for assessing sea level rise, as well as those being used by the Massachusetts Department of Transportation and other state agencies and communities for vulnerability assessments.

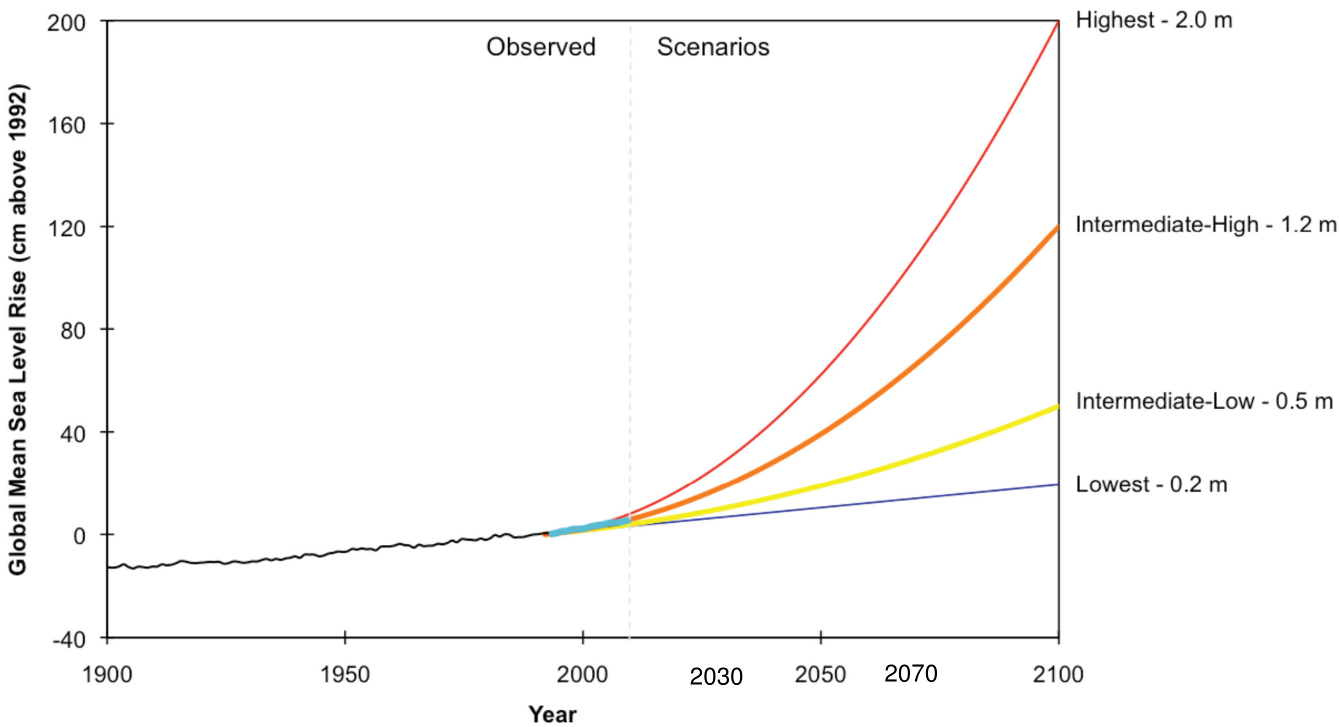

Figure 3 - Global mean sea level rise scenarios (Not including local subsidence)

In addition to global SLR, local mean sea level changes are also factored in. Local mean sea level changes were estimated by considering local tide gage records in combination with models or actual measurements of the Earth's local tectonic movements. The NOAA tide gauge at Boston Harbor (station ID 8443970), shown in Figure 4, has recorded an increase in relative mean sea level of 2.63 mm (+/- 0.18 mm) annually based on monthly mean sea level data from 1921 to 2006. Over that same time period, the global rate of sea level rise was about 1.7 mm annually. This difference implies that there is about 1 mm (0.04 in./yr) per year local land subsidence in the relative sea level record for the Boston area (MA Adaptation report 2011). The ADCIRC/SWAN model incorporates this local subsidence into the BH-FRM model. As the tidal data from the nearby Woods Hole tide gauge is comparable to that of Boston, no additional compensation for local subsidence has been included for this study.

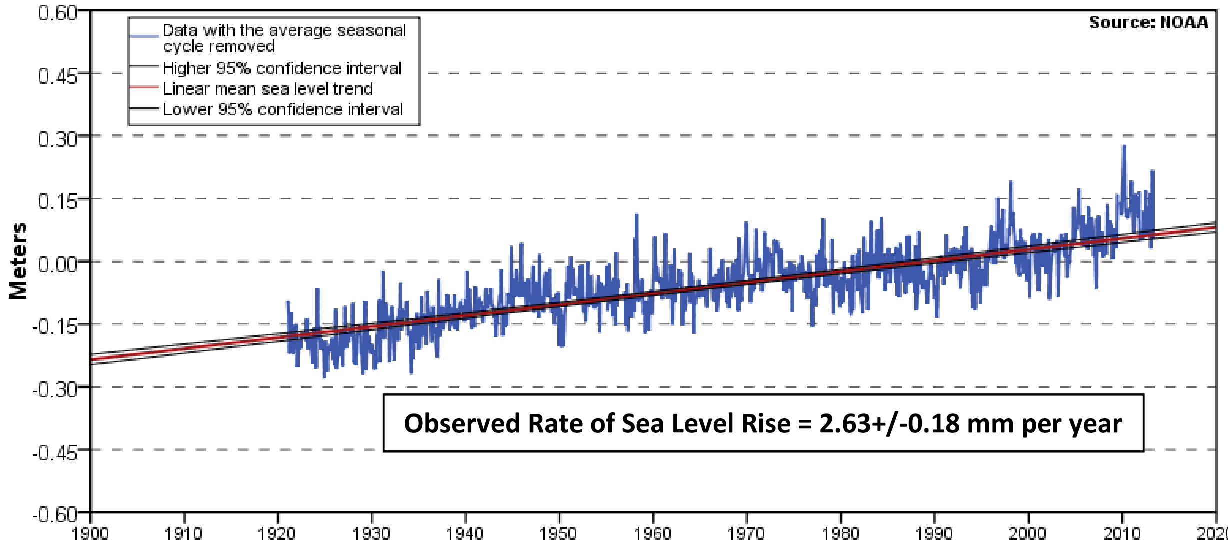

Figure 4 - Mean sea level trend at Boston Tide Gauge (#8443970)

Figure 5 below presents the total relative SLR values (global SLR and local land subsidence rate of 0.04 in./yr) for years 2020 through 2100 in 10 year increments for Oak Bluffs, considering a start year of 2013 (since 2013 was used as the start year for the SLR calculations in the BH-FRM model). Calculations were also performed using 2016 as the start year, considering 2016 will be the completion year of this project, and it was found that the difference in SLR projections between using 2013 and 2016 as the start years is less than one-tenth of a foot. Hence it was agreed to use the same SLR values that have been used in the BH-FRM model. Figure 5 presents the SLR projections for Oak Bluffs using the NOAA “Highest”, “Intermediate-High” and “Intermediate-Low” scenarios for the purposes of comparison.

While selection of the “Highest” scenario may be interpreted as conservative, this selection also allows for representing a range of scenarios that allows decision makers to consider multiple future conditions and to develop multiple response options.

The SLR scenarios that were utilized in this Oak Bluffs vulnerability assessment are:

- Existing conditions for the current time period (considered to be 2013).
- The value for the “Highest” scenario, including local subsidence, at 2030 (0.66 ft of SLR), which is also close to the “Intermediate-High” value at that same time period, and approximately the “Intermediate-Low” value for 2050.
- The value for the “Highest” scenario, including local subsidence, at 2070 (3.39 ft of SLR), which is also approximately the “Intermediate-High” scenario value for 2090.

Scenarios	2020	2030	2040	2050	2060	2070	2080	2090	2100
Global SLR (from 2013-year of interest) "Highest" (feet)	0.21	0.61	1.10	1.70	2.40	3.21	4.11	5.12	6.23
Global SLR (from 2013-year of interest) "Intermediate-High" (feet)	0.14	0.38	0.68	1.04	1.46	1.93	2.46	3.05	3.69
Global SLR (from 2013-year of interest) "Intermediate-Low" (feet)	0.07	0.18	0.32	0.47	0.63	0.82	1.02	1.24	1.48
Land subsidence (feet) @ 0.04 in./yr	0.02	0.06	0.09	0.12	0.15	0.19	0.22	0.25	0.29
Total Relative SLR - "Highest" (feet)	0.24	0.66	1.19	1.82	2.56	**3.39**	4.33	5.37	6.52
Total Relative SLR – "Intermediate-High" (feet)	0.16	0.44	0.77	1.16	1.61	2.12	2.68	3.30	3.98
Total Relative SLR – "Intermediate-Low" (feet)	0.09	0.24	0.40	0.59	0.79	1.01	1.24	1.50	1.77

Figure 5 – Sea level rise estimates for Oak Bluffs using the 2012 NOAA NCA SLR scenarios

Planning Horizons

2030 and 2070 were selected as appropriate planning horizons for Oak Bluffs' vulnerability analysis to provide an estimate of near-term and long-term vulnerabilities. As discussed above, risk-based scenarios are used to assess potential vulnerabilities in the Town of Oak Bluffs.

The BH-FRM model was developed for the years 2030, 2070, and 2100. Upon the recommendation of the project team, the Steering Committee agreed that the study include only two future planning horizons, 2030 and 2070, as well as the present. The 2030 and 2070 future planning horizons, with their corresponding sea level rise projections, were chosen for the following reasons:

- The BH-FRM model developed for the greater Boston area includes the coastline of Oak Bluffs. The Town benefits from using best-available model results at a lower cost than it would take to run any other modeling scenario. In addition, the model's performance and accuracy has already been peer-reviewed by MassDOT's scientific advisory team.

- 2030 (15 years from 2015) planning horizon for near-term inundation modeling are consistent with planning horizons used in the majority of studies in Eastern Massachusetts, therefore allowing for easy comparisons.

- 2070 (55 years from 2015) was recommended as a more useful long-term planning horizon for the following reasons:
  (a) The level of uncertainty associated with sea rise projections for the end-of-century (2100 and beyond) are quite high.
  (b) The expected service life of most infrastructure to be evaluated for risk is much less than 100 years, and 2070 is closer to the expected life of typical infrastructure.
  (c) The 2070 timeframe is more consistent with other regional climate change vulnerability studies.

Modeling the Effects of Coastal Storms and Climate Change

The first step in building the BH-FRM ADCIRC/SWAN model was construction of the modeling grid. The grid is a digital representation of the domain geometry that provides the spatial discretization on which the model equations are solved. The grid was developed at three resolutions:

1) A regional-scale mesh, which is a previously validated model mesh used in numerous Federal Emergency Management Agency (FEMA) studies, National Oceanic and Atmospheric Administration (NOAA) operational models, and most recently the United States Army Corps of Engineers North Atlantic Coast Comprehensive Study (NACCS);
2) A local-scale mesh providing an intermediate level of mesh resolution to transition from the regional-scale mesh to the highly resolved mesh along the Massachusetts coastline; and
3) A site-specific mesh of sufficient resolution to ensure that all critical topographic and bathymetric features that influence flow dynamics along the near shore are captured. The site-specific mesh includes areas of open water, along with the entire coast and shoreline subject to present and future flooding. A screenshot of the model mesh for Oak Bluffs is shown in Figure 6.

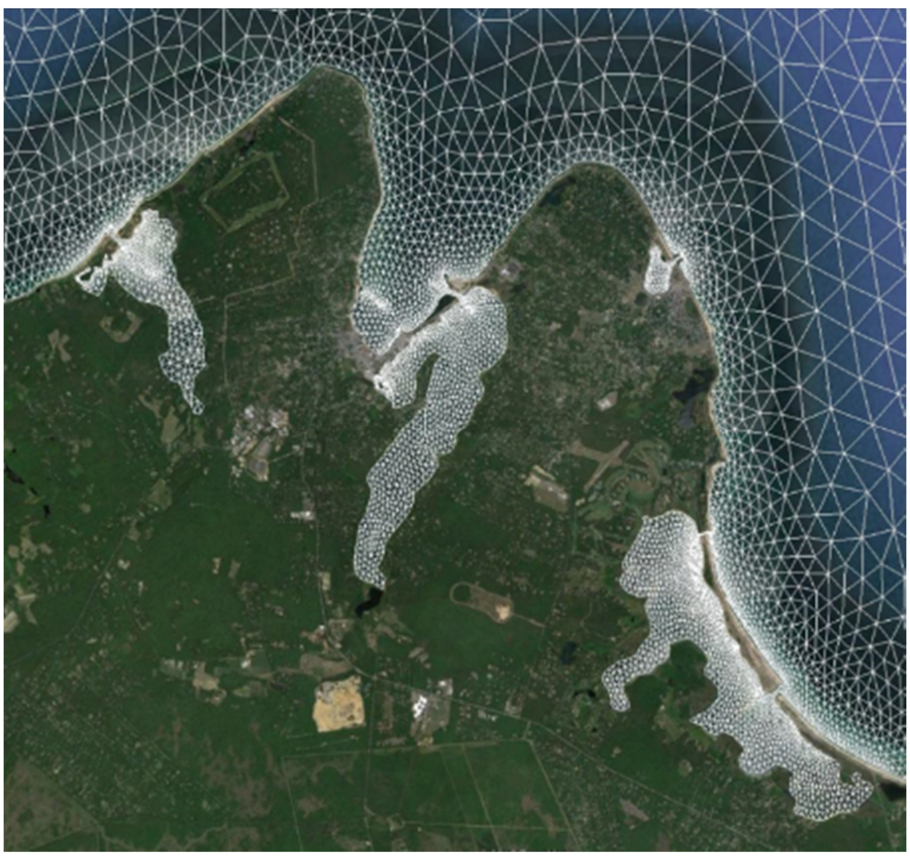

Figure 6 - Model mesh for BH-FRM ADCIRC/SWAN model

The ADCIRC model in the area of Oak Bluffs includes Lagoon Pond, Oak Bluffs Harbor and Sengekontacket Pond, but it does not include upland topography. The boundary of the model is at the approximate edge of shoreline. As an example, Figure 7 shows a close-up view of the model limits at Crystal Lake and East Chop Drive. To determine flooding impacts landward of the model's boundary, the water surface generated by the model is propagated towards the shore as a plane until it meets the ground elevation as represented by the LiDAR topographic map (Figure 8). Although the propagated surface is approximate, it gives a relatively accurate representation of the effects of flooding suitable for planning purposes. A representative number of model nodes are propagated, so at any given location along the model boundary there may be slight elevation discrepancies between the model surface and the propagated surface as shown in Figure 9. The inundation results in this example area are shown in Figure 8.

MassDOT is planning to extend the upland modeling of the BH-FRM model to include the upland areas throughout all coastal areas of the Massachusetts, including Oak Bluffs, up to approximately the 30 foot contour (NAVD88). Results from the extended model, which may be available in about two years, could be used to refine the vulnerability analysis.

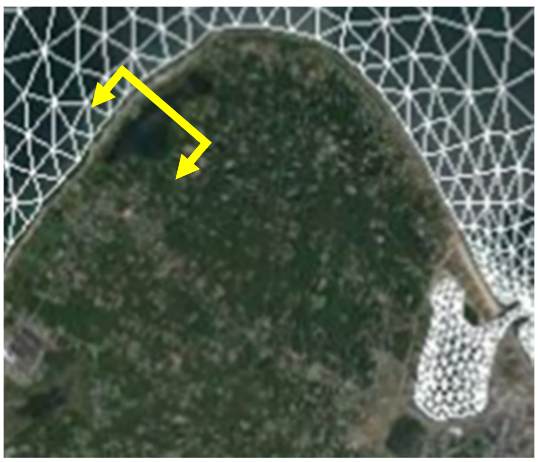

Figure 7 – Model limits at Crystal Lake

Figure 8 – Inundation results based on propagated water surface at Crystal Lake

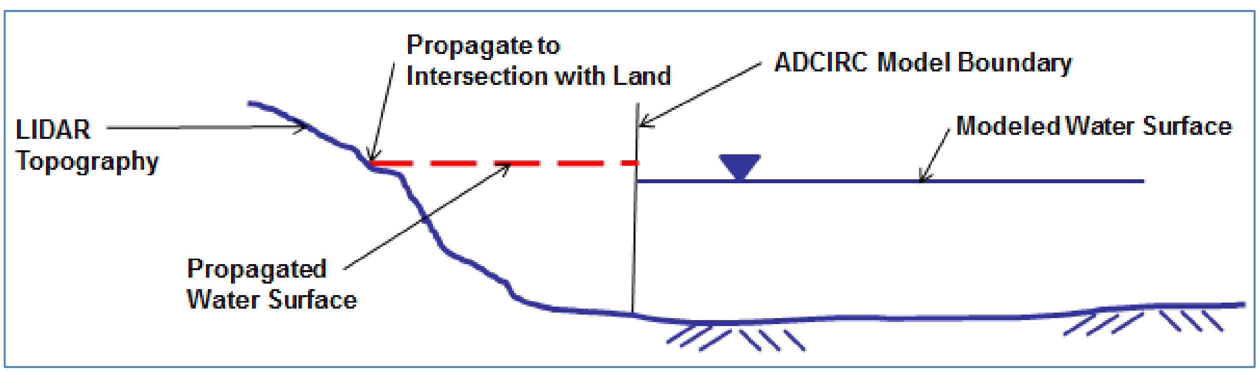

Figure 9 – Propagation of water surface landward of model limits

Model Calibration and Validation

The BH-FRM model was calibrated and validated at three levels. First, the BH-FRM model was calibrated to average tidal conditions over the entire model domain, from the Caribbean Islands to Canada to ensure the model was capable of reproducing water levels and coastal hydrodynamics. The magnitude of the bias is equal or less than 0.02 feet at all locations meaning that the calibration simulation reproduced average water levels within 0.25 inch at all locations. Second, the model was calibrated to both water surface elevation time series data (measured at NOAA gages) and observed high water marks from the Blizzard of 1978, which had significant impact in the Oak Bluffs area. The water surface elevation time series comparison had a bias of less than a 0.25 inch, RMSE (Root-Mean-Square Error) of 3 inches, and a percent error of 2.5%. The model had an 8% relative error to the observed high water mark data, which is quite reasonable considering the uncertainty associated with the high water mark observations. Greater error is expected when comparing model results to observed high water marks due to the uncertainty associated with the high water marks themselves, which are subject to human interpretation and judgment errors (e.g., wet mark on the side a building). Finally, the model was validated to the No Name Storm of 1991 (the "Perfect Storm"), to observed water surface elevation time series with bias of ¼ inch and RMSE of ¾ of an inch. This storm also had significant impacts in the Oak Bluffs area, hence it was an appropriate storm for validation in this area as well.

In order to select appropriate historical storm events for model calibration and validation, a number of key factors were considered, including:

- The historic storm must be considered a significant storm for the Boston area (a historic storm of record) that was of large enough magnitude to produce substantial upland flooding.
- The historic storm must have adequate meteorological conditions to be able to generate pressure and wind fields for ADCIRC input. This required the use of global reanalysis data, which was generally available for historic storm events post-1957.
- The historic storm must have sufficient observations and/or measurements of flooding within the northeast and Boston area. This could consist of high water marks data, tide station observations, wave observations, and other data measures.

Complete details on the calibration and validation of the model can be found in the MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery (2015), which is available from MassDOT. In addition, the model was reviewed by a technical advisory committee made up of experts from the USGS, EPA, NOAA, USACE, and Woods Hole Oceanographic Institute.

Inundation Maps

The results of BH-FRM simulations for 2030 and 2070 were used to generate maps of potential flooding and associated water depths throughout the Town of Oak Bluffs. Two different types of maps were produced:

- Percent Probability of Flooding Maps - These maps can be used to identify locations, structures, assets, etc. that lie within different flood probability levels. For example, a building that lies within the 2% flood exceedance probability zone would have a 2% chance of flooding occurring in that study year. Stakeholders can then determine if that level of risk is acceptable, or if some action may be required to improve resiliency, engineer an adaption, consider relocation, or implement an operational plan.

- Depth of Flooding Maps – These maps show the estimated difference between the projected water surface elevation for a given percent probability of flooding during the study year and existing ground elevations derived from the 2011 Northeast LiDAR survey. The datum for depth calculations is NAVD88. For this study, two sets of Depth of Flooding Maps were produced:

  - Depths at 1% Probability of Exceedance which has approximately a 100 year recurrence interval.
  - Depths at 0.2% Probability of Exceedance which has approximately a 500 year recurrence interval.

In addition, enlarged Depth of Flooding maps for the 1% Probability of Exceedance scenario were developed for the Oak Bluffs Harbor, Crystal Lake and Hospital, Farm Pond and Sengekontacket Pond areas to better visualize the potential flooding impacts in these areas.

The following inundation maps are included in Appendix A:

- A-1: 2030 – Percent Probability of Inundation Map
- A-2: 2030 - Depth of Flooding at 1% Annual Probability (≈100 year recurrence)
- A-3: 2030 - Depth of Flooding at 0.2% Annual Probability (≈500 year recurrence)
- A-4: 2070 – Percent Probability of Inundation Map
- A-5: 2070 - Depth of Flooding at 1% Annual Probability (≈100 year recurrence)
- A-6: 2070 - Depth of Flooding at 0.2% Annual Probability (≈500 year recurrence)
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- A-11: 2030 – Farm Pond - Depth of Flooding at 1% Annual Probability
- A-12: 2070 – Farm Pond - Depth of Flooding at 1% Annual Probability
- A-13: 2030 – Sengekontacket Pond - Depth of Flooding at 1% Annual Probability
- A-14: 2070 – Sengekontacket Pond - Depth of Flooding at 1% Annual Probability

NATURAL RESOURCES

Modeling

Impacts to natural resources including beaches, coves and salt marsh, were assessed on a qualitative basis. Woods Hole Group is currently working for the Massachusetts Office of Coastal Zone Management (CZM) to model the effects of sea level rise on coastal wetlands and natural resources statewide. The software Sea Level Rise Affecting Marshes Model (SLAMM) was used to assess the impacts to natural resources for that project. The SLAMM results were also linked to results from the Marsh Equilibrium Model (MEM). Final model simulations are currently being run for both sub-site and state-wide simulation for three out-year scenarios and three projected sea level rise curves. The results of this statewide project were incorporated into this study.

Elevation Information

High resolution elevation data may be the most important Sea Level Affecting Marsh Migration (SLAMM) model data requirement, since the elevation data demarcate not only where salt water penetration is expected, but also the frequency of inundation 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 inundation.

For the Oak Bluffs area, the 2013-14 USGS LiDAR flight was used. In order 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 feet (NAVD88) were clipped from the input files.

Wetland Classification Information

The 2011 wetland layer developed by the National Wetlands Inventory (NWI) is used as the baseline source for the wetlands input file for marsh migration modeling.

Utilizing the NWI data had two key benefits over the 1990s MassDEP wetland layer. First, the NWI data not only provided a more recent dataset, but also matches that of the LiDAR datasets. Although different input years were used, most of the LiDAR data used was collected in or around 2011.

The second benefit to utilizing the NWI data is that it streamlined the conversion between source wetland categories and SLAMM model wetland codes. The documentation provided with the SLAMM software contains a key to convert each NWI classification to the wetland classification system used by SLAMM. A summary of this conversion key is present in Table B1 included in Appendix B.

Sea Level Rise Projections

The Sea Level Rise (SLR) projections used in the marsh migration modeling are consistent with those used in the BH-FRM modeling to produce the inundation risk maps.

Additional Data Input

Additional model input includes, but is not limited to, accretion rates (marsh, beach, etc.), erosion rates, tidal range and attenuation, freshwater parameters, dikes and dams, and impervious surfaces.

There is a limited amount of accretion rate data throughout the state (only select areas have measured accretion data), so the model is 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.

The Oak Bluffs region has some regional data that is applicable and will have both run types eventually available. The results provided in this report are for the historical SLR rate only. While it is likely that increased sediment may be brought into the region due to storms, these ephemeral increases are not nearly enough to keep up with SLR. Therefore, the influence of any accretion unaccounted for by the current methodology would likely be small.

SLAMM was intentionally run first without protected areas (e.g., impervious surfaces not subject to change) to see how the marshes and other natural resources would migrate, and if they had room to migrate. As such, the ecological modeling assumes that the existing infrastructure may not remain in place. The mapping results therefore do not reflect certain realities. For example, areas of the Harbor downtown area are shown to convert to ocean beach – an obviously unlikely scenario. However, as part of the ongoing Statewide project (not included as part of this study) an additional post-processing step will be applied to overlay the impervious layer and indicate areas that are not expected to change in heavily developed areas.

For complete details of the natural resources mapping process, see the Statewide Modeling: the Effects of Sea Level Rise on Coastal Wetlands for Massachusetts Coastal Zone Management. (ENV 14 CZM 08 in publication, 2015).

Impacts to Natural Resources

Figures B1 through B3 in Appendix B show the wetland classification areas for 2011, 2030, and 2070 respectively based on the marsh migration modeling. Figure B1 presents the current conditions, as defined by the NWI (with the exception of non-tidal upland swamp). Figure B2 shows the change in wetland classification locations projected to 2030, impacted by SLR. Similarly, Figure B3 shows the change in wetland classification locations projected to 2070 impacted by SLR. Both the results shown in Figures B2 and B3 for 2030 and 2070, respectively, are based on the marsh migration SLAMM modeling.

Primary Areas Where Natural Resources are Evolving in Response to SLR and Potential Adaptation Strategies

Sunset Lake Region

In 2013 and 2030, the regions surrounding Sunset Lake (primarily to the southwest of the lake) are tidal fresh marsh areas; however, by 2070 those regions have expanded drastically into tidal flats with salt marsh regions and fringe areas of transitional marsh and scrub-shrub. This indicates the advancing tide levels propagate past Oak Bluffs Harbor and Sunset Lake and regularly inundate low-lying areas southwest of the current Sunset Lake region.

Potential adaptations in this area include:

- Protection of Oak Bluffs Harbor via infrastructure or other engineering methods and providing for controlled tidal exchange into the Sunset Lake area to create a marsh restoration project. This adaptation would protect the Harbor region and industry and allow marsh restoration in the low lying areas landward of Sunset Lake. However, this would also potentially result in the loss of upland areas and properties surrounding the Sunset Lake area. This adaptation approach could be implemented presently to allow for enhanced tidal exchange into Sunset Lake, as well as to allow for initial marsh transition and development.

- Protection of Oak Bluffs Harbor via infrastructure or other engineering methods, and closure of tidal exchange between the harbor and Sunset Lake. This solution would transition Sunset Lake to a freshwater system and limit formation of salt marsh areas, but would also maintain all current upland areas. This strategy, however, is not practical because Sunset Lake is a major surface drainage collection system that needs to drain into the harbor. Closing off the connection between the harbor and Sunset Lake would require other methods such as pumping to remove collected drainage water. This is not practical, and therefore is not considered further.

Oak Bluffs Harbor

The Oak Bluffs Harbor area indicates expansion of both open water and estuarine beach regions around the perimeter of the harbor. While the areas in the natural resources model are shown to expand, in reality the built infrastructure in this area would not result in conversion of these areas, but rather direct flooding. It is likely that these areas would be protected through adaptation measures in the future.

Brush Pond

The Brush Pond area is currently surrounded by salt marsh resources. In 2030, the salt marsh areas start to degrade since the accretion cannot keep up with the rising sea levels and former marsh areas begin to convert to tidal flats. By 2070, a vast majority of the marsh is lost to open water areas, including expansion of open water into former upland areas. Due to the relatively steep increases in the surrounding elevation, there is no migration (retreat) of marsh area upland. Therefore, there is essentially a complete loss of the existing healthy marsh in this system.

A recommended potential adaptation for this area may consist of thin layer deposition projects to maintain and enhance the salt marsh in the face of the changing climate and increasing rate of sea level rise. This adaptation would involve the placement of clean, compatible sediment in thin layers on the existing salt marsh to assist the elevations in keeping up with the rising tidal levels.

Farm Pond

By 2030, there are changes occurring along the barrier beach, inlet, and entrance areas of the Farm Pond system as it is likely that this barrier becomes regularly overtopped during higher waters and coastal storms. By 2070, there is loss of the Pond perimeter salt marsh areas in the south as they convert to open water, but other areas (west and north) also transition from tidal swamp to a mix of salt marsh, tidal flats, and transitional marsh. For the southern marsh regions there is no room for migration (due to steep elevation increases), while the areas to the west and north have the ability to migrate into open non-developed land areas.

The recommended potential adaptations, as related to natural resources in the Farm Pond region, consist of a mix of options, including restoration of the Farm Pond system (on-going and perhaps enhanced to account for climate change) to allow for increased tidal exchange (which may need to be controlled in the future), roadway and barrier beach protection or elevation, thin layer deposition considerations for the southern marsh areas, and allowing natural evolution coupled with monitoring of fringing properties in the west and northern marsh areas. The areas to the west and north should be able to migrate naturally landward into undeveloped open space and result in an expansion of marsh area, transitioning from tidal swamp.

Hamlin Pond and Harthaven

These two areas show minimal spatial expansion of natural resource areas, as some tidal swamp regions transition to salt marsh by 2070, especially to the west of Harthaven. Harthaven and Hamlin Pond eventually become connected via a salt marsh area that develops between the two embayments.

No adaptations are required for this area in terms of natural resources and the expected sea level rise will expand some small salt marsh areas for beneficial ecological gains.

East Chop Road, Beach Road, and Crystal Lake

At Crystal Lake a permanent connection is expected to develop by 2070 between Vineyard Sound and Crystal Lake. The fronting shoreline and beach will erode, expanding the sandy shoreline and eventually jeopardizing East Chop Drive. Low-lying areas inland of the roadway will transition into coastal salt ponds also connected to Vineyard Sound.

Depending on the desired goals related to Crystal Lake and the adjacent roadways, there are a number of potential adaptation options available for this area:

- If there is a desire to keep Crystal Lake a freshwater system, and protect the local roadway and infrastructure, then a large-scale beach restoration project should be considered consisting of possible components such as dune restoration, beach nourishment, and floodproofing of local infrastructure and elevation of homes (for storm events). The goal of such a dune and beach restoration project would be to minimize the intrusion of rising tides into Crystal Lake while also protecting against an inlet breach into the lake.

- If there is a desire to transition Crystal Lake into a salt water estuarine system, adaptation options should be developed to work with the expected natural evolution and allow for transition and expansion of the water body in concert with protection of the local infrastructure. In this case, a preemptive inlet construction or connection to Crystal Lake could be considered (to control where the connection would occur) coupled with additional infrastructure protection elements such as beach nourishment, floodproofing, elevation, etc.

Sengekontacket Pond and Sylvia State Beach

In the Oak Bluffs portion of Sengekontacket Pond, there is loss of fringe salt marsh areas to open water and tidal flats. While there is some migration of these resources into surrounding tidal swamp areas, it is limited and there appears to be little space for migration due to steep elevation increases in the upland areas. These resource losses occur around the entire perimeter of the Pond, but are most focused along the western shoreline.

The barrier beach region experiences a loss of all dune resources and becomes solely a barrier beach migrating landward due to the more frequent overtopping expected in the future, putting Beach Road under constant risk. There is adequate space to allow the barrier beach to migrate westward (landward) into Sengekontacket Pond as necessary.

For this region, since there appears to be limited ability for the marsh areas to migrate due to steep elevation grades around the pond perimeter, site specific marsh enhancement projects would be required to assist in the enhancement, protection, and growth of the perimeter salt marsh areas. The barrier beach area could be enhanced through a dune and beach restoration project to mitigate erosion, overtopping, and provide more protection for the roadway and bikeway infrastructure.

The protective aspects of theses marsh and natural resource systems could also be reduced substantially by 2070, as storm surges will likely more readily propagate through various degraded areas and impact upland infrastructure.

INFRASTRUCTURE VULNERABILITY ASSESSMENT

Scope of Infrastructure Vulnerability Assessment

A vulnerability assessment was performed on municipally-owned infrastructure subject to flooding. Municipally-owned infrastructure includes sewer pump stations, roads, bridges, wharves, seawalls, and other critical facilities such as schools, police stations, fire stations, etc. owned and operated by the Town of Oak Bluffs. Critical infrastructure was selected based on the inundation modeling results, using infrastructure information obtained from the Oak Bluffs Hazard Mitigation Plan and information provided by Town Departments. Some key infrastructure that is not municipally owned (e.g. federal, state or privately owned) that is subject to flooding is shown on the maps, but vulnerability assessments were not performed on these assets. In some limited cases, state-owned roadways (e.g., Beach Rd, Seaview Ave), which are critical transportation links in Oak Bluffs, are included in the discussion of adaptation options.

Survey data for public coastal stabilization structures, including sea walls, revetments and groins, were obtained from the LiDAR and from Massachusetts office of Coastal Zone Management (CZM) as part of a report titled *Mapping and Analysis of Privately Owned Coastal Structures Along the Massachusetts Shoreline* (March, 2013). Where ownership information was not available, the Town identified municipally-owned structures.

A risk-based vulnerability assessment was performed for each of the municipally-owned assets impacted by flooding. These are built assets and do not include natural resources. The impacts of flooding were assessed for each asset deemed to be susceptible to flooding during any one of the time periods being investigated. The following is a description of the vulnerability assessment methodology for infrastructure.

Using Risk to Understand the Vulnerability of Infrastructure Susceptible to Flooding

Risk is defined here as the probability of an asset failing times the consequence of that asset failing. Put into mathematical terms:

$$\text{Risk (R)} = \text{Probability of Flooding (P) x Consequence of Failure (C)}$$

or

$$\text{R} = \text{P x C}$$

Each node in the mesh for the ADCIRC model has a unique Probability of Exceedance curve associated with it, which gives the probabilities of exceeding various water elevations at that node.

Using risk to assess the vulnerability of infrastructure allows one to take into account both how likely a damaging flood event is, and also, what the consequence of that damaging flood is to the community. Relative risk rankings are an excellent way for helping to prioritize scarce capital funds.

Risk Assessment - A Five Step Process

The risk assessment process, described below, was implemented using the following five basic steps:

1. Determine Critical Assets Subject to Flooding
2. Determine Critical Elevations
3. Obtain Probability of Exceedance Data
4. Determine Consequence of Failure Score
5. Calculate Risk Scores and Rankings

1. Determine Critical Assets Subject to Flooding

All identified municipally-owned infrastructure were located as an overlay in the GIS project map. The Percent Probability of Flooding map for 2070 was then used to screen out assets that showed no probability of flooding in 2070. Assets that showed no probability of flooding were excluded from further analysis.

The following municipally-owned infrastructure assets have been identified in Tables 1 (Facilities/Buildings), 2 (Roadways) and 3 (Coastal Stabilization Structures) as being vulnerable to flooding at the indicated time between the present time and 2070:

Table 1 - Facilities/Buildings Vulnerable to Flooding

Time Horizon	Facility Name	Location
Present	Electrical Panel	1 East Chop Drive
	Island Queen Ferry Dock	Circuit Ave Extension at Seaview Ave.
	Oak Bluffs Harbor Master	10 Circuit Ave Extension
	Sewer Pump Station	13 School St.
	Sewer Substation	14 Siloam Ave.
	SSA Ferry Terminal	1 Seaview Ave.
2030	Oak Bluffs Police Department	2 Oak Bluffs Ave.
2070	Lagoon Pond Well	Barnes Road at Head of Pond Rd

Table 2 – Roadways Vulnerable to Flooding

Time Horizon	Roadway Name	Location
Present	Acushnet Avenue	South Circuit Avenue to Dead End
	Barnes Road	County Road to Edgartown Vineyard Haven Road
	Beach Road	Tisbury Town Line to Eastville Avenue
	Bridge Street	Park Street to Marginal Street
	Butler Avenue	Victorian Park to Hope Avenue
	Calves Pasture Lane	Hidden Cove Road to Dead End
	Canonicus Avenue	Seaview Avenue to Nauchon Avenue
	Central Avenue	Lake Avenue to Montgomery Avenue
	Circuit Avenue	Dukes County Avenue to Lake Avenue

Time Horizon	Roadway Name	Location
Present	Circuit Avenue Extension	Oak Bluffs Avenue to Seaview Avenue Extension
	Clinton Avenue	Dukes County Avenue to Jordan Crossing
	Commonwealth Avenue	Siloam Avenue to Montgomery Avenue
	County Road	Eastville Avenue to Edgartown Vineyard Haven Road
	Crystal Lake Road	New York Avenue to Eddy Avenue
	Debettencourt Place	Spindles Path to Dead End
	East Chop Drive	New York Avenue to Temahigan Avenue
	Eastville Avenue	Dead End to Towanticut Street
	Eddy Avenue	Crystal Lake Road to Park Street
	Farm Pond Road	Edgartown - Oak Bluffs Road to Martha's Park Road
	Franklin Street Extension	Vineyard Avenue to Garvin Street
	Frazier Circle	First Avenue to Dead End
	Garvin Street	Second Avenue to Dukes County Avenue
	Goodwin Road	Naumkeag Avenue to Katama Avenue
	Greenleaf Avenue	Rowland Avenue to Dukes County Avenue
	Gull Landing	Lagoon Road to Dead End
	Harthaven Road	Martha's Park Road to Tradewinds Road
	Heather Lane	Dead End to Dead End
	Huntington Avenue	Dead End to James Street
	James Street	Greenleaf Avenue to Huntington Avenue
	Jordan Crossing	Siloam Avenue to Cul-De-Sac
	Katama Avenue	Tuckernuck Avenue to South Circuit Avenue
	Kennebec Avenue	Samoset Avenue to Oak Bluffs Avenue
	Lake Avenue	New York Avenue to Seaview Avenue
	Marginal Street	Dead End to East Chop Drive
	Montgomery Avenue	Trinity Park to Commonwealth Avenue
	Nantucket Avenue	Nauchon Avenue to Seaview Avenue
	Naumkeag Avenue	Ocean Avenue to Canonicus Avenue
	New York Avenue	Temahigan Avenue to East Chop Drive
	Newton Avenue	Lagoon Road to Linden Avenue
	Pall Mall	Park Street to Winemack Street
	Pasque Avenue	Circuit Avenue Extension to Seaview Avenue Extension
	Pawtucket Avenue	Trinity Park to Dukes County Avenue
	Rock Avenue	Central Avenue to Commonwealth Avenue
	Roque Avenue	Faith Avenue to Dorothy West Avenue
	Saco Avenue	Circuit Avenue Extension to Seaview Avenue Extension
	Sengekontacket Road	County Road to Dead End
	Siloam Avenue	Jordan Crossing to Dukes County Avenue
	South Circuit Avenue	Circuit Avenue to Naumkeag Avenue
	Tuckernuck Avenue	Seaview Avenue to Circuit Avenue
	Vineyard Avenue	Dukes County Avenue to County Road
	Wapello Street	Eastville Avenue to Dead End

Time Horizon	Roadway Name	Location
	West Clinton Avenue	Dukes County Avenue to Clinton Avenue
2030	Dukes County Avenue	Circuit Avenue to Lake Avenue
	Hidden Cove Road	To Calves Pasture Lane
	Hospital Road	Beach Road to Dead End
	Lady Slipper Way	Sengekontacket Road to Dead End
	North Bluff Lane	Circuit Avenue Extension to Seaview Avenue Extension
	Oak Bluffs Avenue	Lake Avenue to Seaview Avenue
	Ocean Avenue	Seaview Avenue to Seaview Avenue
	Rural Circle	Circuit Avenue to Cul-De-Sac
	School Street	Pacific Avenue to Dukes County Avenue
	Sea View Avenue	Oak Bluffs Avenue to Beach Road
	Victorian Park	Clinton Avenue to Rural Circle
	Waterfront Trail	Old Harbor Lane to Dead End
	Windemere Road	Hospital Road to Dead End
2070	Brush Pond Road	Shirley Avenue to Dead End
	Chapman Avenue	New York Avenue to Wayland Avenue
	Rustic Avenue	Central Avenue to Hebron Avenue
	Tamarack Lane	Farm Neck Way to Cul-De-Sac

Table 3 – Coastal Stabilization Structures Vulnerable to Flooding and Overtopping (All coastal stabilization structures vulnerable to flooding in present)

Time Horizon	Structure Type	Structure Number	Location
Present	Revetment	221-006-000-034-001	East Chop Drive at Hospital Road
	Revetment	221-001-000-003-001	330 East Chop Drive
	Bulkhead/Seawall	221-005-000-001-002	East Chop Drive at Hospital Road
	Bulkhead/Seawall	221-008-000-293-001	Circuit Ave Ext. to Sea View Ave Ext.
	Revetment	221-005-000-003-003	East Chop Drive at Hospital Road
	Revetment	221-001-000-013-001	East Chop Drive at Marginal St.
	Bulkhead/Seawall	221-009-000-058-003	Sea View Ave Extension
	Revetment	221-018-000-032-001	Beach Road at Farm Pond
	Bulkhead/Seawall	221-003-000-028-001	East Chop Dr. at East Chop Beach Club
	Bulkhead/Seawall	221-009-000-001-001	Beach Road at Farm Pond
	Bulkhead/Seawall	221-009-000-058-001	Sea View Ave. Ext. at Ferry Terminal
	Bulkhead/Seawall	221-009-000-001-002	Beach Road at Waban Park
	Revetment	221-009-000-001-009	Sea View Avenue at Ferry Terminal
	Bulkhead/Seawall	221-009-000-058-004	Sea View Avenue Extension

2. Determine Critical Elevations

Critical elevations (NAVD88 datum) for each asset, that might be subject to flooding at some point, were then determined. Critical elevations are defined as that elevation at which flood water will cause the asset to cease to function as intended. For example, the critical elevation may be the first floor of a building. In another case, the critical elevation could be a basement window sill elevation, above which water can enter the basement and damage critical mechanical equipment located in the basement. 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.

For buildings, pump stations and similar facilities, critical elevations are determined in several ways:

- Information provided by Town staff,
- Estimated from on-site observations (no surveys were performed for this project),
- Estimated from LiDAR survey and aerial photography.

Critical elevations for roads and bridges were determined using LiDAR survey data. The low points of a roadway section subject to flooding were used as the critical elevation. Critical elevations for bridges were set as the lowest approach road elevations at the ends of the bridge.

Critical elevations for coastal stabilization structures were determined using LiDAR data or survey elevations included in the Department of Conservation and Recreation's (DCR) "*Massachusetts Coastal Infrastructure Inventory and Assessment Project for Cape Cod and the Islands*" (July, 2009).

3. <u>Obtain Probability of Exceedance Data</u>

Probability of Exceedance data for the present, 2030 and 2070 time horizons for each critical infrastructure asset were obtained directly from the BH-FRM model. Data were obtained from the closest mesh node to the asset.

A representative example of Probability of Exceedance data from the School Street Sewer Pump Station is shown in Figure 10. For this facility, the critical elevation is 3.07 feet NAVD88. This data shows some of the following information:

- For the present year time frame, there is a 30% probability that flood water will exceed the critical elevation.
- In the 2030 time frame, there is a 50% probability that water will exceed the critical elevation, and at a 1% probability (100 year recurrence interval) the water level would be approximately 5.60 feet above the critical elevation.
- In the 2070 time frame, the probability of exceeding the critical elevation increases to 100% while the depth of water above the critical elevation at a 1% probability (100 year recurrence interval) increases to about 9.40 feet.

	Present		2030		2070	
% Probability	Flood Elevation	Depth Above Critical Elev.	Flood Elevation	Depth Above Critical Elev.	Flood Elevation	Depth Above Critical Elev.
0.1	10.5	7.4	11.5	8.4	14.1	11.0
0.2	9.9	6.8	10.9	7.8	13.7	10.6
0.5	9.1	6.0	10.1	7.0	12.9	9.8
1	8.7	5.6	9.7	6.6	12.5	9.4
2	8.3	5.3	9.3	6.2	12	8.9
5	7.1	4.0	8.1	5.0	10.7	7.6
10	5.4	2.3	6.4	3.3	9.7	6.6
20	4.8	1.7	5.8	2.7	8.4	5.3
25	4.5	1.4	5.5	2.4	8	4.9
30	4.2	1.1	5.2	2.1	7.7	4.6
50	dry	dry	4.3	1.2	6.8	3.7
100	dry	dry	dry	dry	5.9	2.8

Figure 10– Probability of Exceedance Data for School Street Sewer Pump Station

4. Determine Consequence of Failure Score

The Consequence of Failure for each infrastructure asset subject to flooding was rated for six different potential impacts in accordance with the guide shown in Figure 11. Each impact is rated separately and then a composite consequence of failure score is determined by summing the scores and normalizing to 100 using the following equation:

$$\textbf{Composite Consequence of Failure Score} = \frac{\sum \textbf{all six ratings}}{\textbf{30}} \textbf{x 100}$$

Figure 12 shows a representative example of the Consequence of Failure rating for the School Street Sewer Pump Station with a total rating of 47 out of a possible 100. The higher the rating, the higher the consequence of failure of the asset.

Rating	Area of Service Loss	Duration of Service Loss	Cost of Damage	Impact on Public Safety & Emergency Services	Impact on Important Economic Activities	Impact on Public Health & Environment
5	Whole town/city	> 30 days	> $10m	Very high	Very high	Very high
4	Multiple neighborhoods	14 - 30 days	$1m - $10m	High	High	High
3	Neighborhood	7 - 14 days	$100k - $1m	Moderate	Moderate	Moderate
2	Locality	1 - 7 days	$10k - $100k	Low	Low	Low
1	Property	< 1 day	< $10k	None	None	None

Figure 11 – Consequence of Failure Rating Guide

	Area of Service Loss	Duration of Service Loss	Cost of Damage	Impacts to Public Safety Services	Impacts to Economic Activities	Impacts to Public Health/ Environment	Consequence Score (out of 100)
Rating	3	2	3	2	2	2	46.67

Figure 12 – Consequence of Failure Scoring Example for the School Street Sewer Pump Station

5. Calculate Risk Scores and Rankings

The risk score for an infrastructure asset subject to flooding for a given time horizon was calculated 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 or 2070)

This risk score can be used to rank an asset's vulnerability to flooding for a given time horizon. A composite ranking can also be developed taking into account the rankings from all time horizons using the following equation:

$$R_{comp} = (R_{present} \times W_{present}) + (R_{2030} \times W_{2030}) + (R_{2070} \times W_{2070})$$

Where:

R_{comp} = Composite risk score for all time horizons
$R_{Present}$ = Risk score for present day time horizon
R_{2030} = Risk score for 2030 time horizon
R_{2070} = Risk score for 2070 time horizon
$W_{Present}$, W_{2030} W_{2070} = Weighting factors for each respective time horizon

A weighting factor is used to give more emphasis to assets vulnerable to flooding in the nearer time horizons. For example, a facility which is susceptible to flooding today and more flooding in the future, should probably get more priority than a facility that is only vulnerable to flooding starting in 2070. The weighting factors can be adjusted, but for the purposes of this study, the Steering Committee decided to use the following weighting:

- $W_{Present}$ = 50% (or 0.50)
- W_{2030} = 30% (or 0.30)
- W_{2070} = 20% (or 0.20)

100%

An Excel spreadsheet was developed which incorporated the Probability of Exceedance data, Consequence of Failure scores and the Risk formulas to automate the ranking process. An example of the Risk Scoring for the School Street Pump Station is shown in Figure 13.

	% Probability of Exceedance	Consequence Score (out of 100)	Risk Score	Weight	Composite Risk Score
Present	30	46.67	1400	0.5	2333
2030	50	46.67	2333	0.3	
2070	100	46.67	4667	0.2	

Figure 13 - Risk Scoring Example Matrix for the School Street Pump Station

Note that the Consequence of Failure score remains constant for an asset over the life of the asset, and that only the Probabilities of Flooding change over time. The only instance where the Consequence of Failure score would change is if some known changes can be anticipated in the future, such as construction of a redundant facility, which would make failure of the asset in question less consequential. For the purposes of this study, we have not anticipated any future changes that would change the Consequence of Failure scores.

Vulnerability Assessment Results

Risk scores can be used to rank an asset's vulnerability to flooding for a given time horizon. Table 4 presents the top 20 vulnerable assets ranked using four different rankings:

- Ranked by present
- Ranked by 2030
- Ranked by 2070
- Ranked by composite risk score

Table 4 – Top 20 Vulnerable Municipal Assets Ranked by Present, 2030, 2070, and Composite Risk Score

Present		2030		2070		Composite	
Facility	Score	Facility	Score	Facility	Score	Facility	Score
Central Avenue (Lake Avenue to Montgomery Avenue)	3667	Bulkhead/Seawall - 221-008-000-293-001 (Circuit Ave Ext to Sea View Ave Ext)	6333	Bulkhead/Seawall - 221-008-000-293-001 (Circuit Ave Ext to Sea View Ave Ext)	6333	Bulkhead/Seawall - 221-008-000-293-001 (Circuit Ave Ext to Sea View Ave Ext)	4750
Bulkhead/Seawall - 221-008-000-293-001 (Circuit Ave Ext to Sea View Ave Ext)	3167	East Chop Drive (New York Avenue to Temahigan Avenue)	5000	Eastville Avenue (Dead End to Towanticut Street)	5667	East Chop Drive (New York Avenue to Temahigan Avenue)	3750
Revetment - 221-006-000-034-001 (East Chop Dr at Hospital Rd)	3000	Central Avenue (Lake Avenue to Montgomery Avenue)	3667	Bulkhead/Seawall - 221-009-000-058-003 (Sea View Ave Ext)	5667	Central Avenue (Lake Avenue to Montgomery Avenue)	3667
Revetment - 221-001-000-003-001 (330 East Chop Dr)	2667	Canonicus Avenue (Seaview Avenue to Nauchon Avenue)	3333	County Road (Eastville Avenue to Edgartown Vineyard Haven Road)	5667	Revetment - 221-006-000-034-001 (East Chop Dr at Hospital Rd)	3000
Bulkhead/Seawall - 221-005-000-001-002 (East Chop Dr at Hospital Rd)	2667	Nantucket Avenue (Nauchon Avenue to Seaview Avenue)	3333	Oak Bluffs Avenue (Lake Avenue to Seaview Avenue)	5667	Eastville Avenue (Dead End to Towanticut Street)	2833
East Chop Drive (New York Avenue to Temahigan Avenue)	2500	Revetment - 221-006-000-034-001 (East Chop Dr at Hospital Rd)	3000	Circuit Avenue Extension (Oak Bluffs Avenue to Seaview Avenue Extension)	5333	Revetment - 221-001-000-003-001 (330 East Chop Dr)	2667
Sewer Substation (14 Siloam Ave)	2167	Eastville Avenue (Dead End to Towanticut Street)	2833	Bulkhead/Seawall - 221-009-000-001-001 (Beach Rd at Farm Pond)	5333	Bulkhead/Seawall - 221-005-000-001-002 (East Chop Dr at Hospital Rd)	2667
Eastville Avenue (Dead End to Towanticut Street)	1700	Revetment - 221-001-000-003-001 (330 East Chop Dr)	2667	East Chop Drive (New York Avenue to Temahigan Avenue)	5000	Sewer Substation (14 Siloam Ave)	2600
Canonicus Avenue (Seaview Avenue to Nauchon Avenue)	1667	Bulkhead/Seawall - 221-005-000-001-002 (East Chop Dr at Hospital Rd)	2667	Revetment - 221-018-000-032-001 (Beach Rd at Farm Pond)	5000	Canonicus Avenue (Seaview Avenue to Nauchon Avenue)	2500
Nantucket Avenue (Nauchon Avenue to Seaview Avenue)	1667	Revetment - 221-005-000-003-003 (East Chop Dr at Hospital Rd)	2667	Island Queen Ferry Dock (Circuit Ave Ext at Seaview Ave)	4667	Nantucket Avenue (Nauchon Avenue to Seaview Avenue)	2500
Island Queen Ferry Dock (Circuit Ave Ext at Seaview Ave)	1400	Revetment - 221-001-000-013-001 (East Chop Dr at Marginal St)	2667	Sewer Pump Station (13 School St)	4667	Island Queen Ferry Dock (Circuit Ave Ext at Seaview Ave)	2333
Sewer Pump Station (13 School St)	1400	Island Queen Ferry Dock (Circuit Ave Ext at Seaview Ave)	2333	Oak Bluffs Harbor Master (10 Circuit Ave Ext)	4667	Sewer Pump Station (13 School St)	2333

Present		2030		2070		Composite	
Facility	**Score**	**Facility**	**Score**	**Facility**	**Score**	**Facility**	**Score**
Revetment - 221-005-000-003-003 (East Chop Dr at Hospital Rd)	1333	Sewer Pump Station (13 School St)	2333	Sewer Substation (14 Siloam Ave)	4333	Revetment - 221-005-000-003-003 (East Chop Dr at Hospital Rd)	2000
Commonwealth Avenue (Siloam Avenue to Montgomery Avenue)	1200	Sewer Substation (14 Siloam Ave)	2167	Hospital Road (Beach Road to Dead End)	4333	Commonwealth Avenue (Siloam Avenue to Montgomery Avenue)	2000
New York Avenue (Temahigan Avenue to East Chop Drive)	1000	Hospital Road (Beach Road To Dead End)	2167	Commonwealth Avenue (Siloam Avenue to Montgomery Avenue)	4000	Bulkhead/Seawall - 221-009-000-058-003 (Sea View Ave Ext)	1927
Electrical Panel (1 East Chop Dr)	1000	Commonwealth Avenue (Siloam Avenue to Montgomery Avenue)	2000	New York Avenue (Temahigan Avenue to East Chop Drive)	4000	County Road (Eastville Avenue to Edgartown Vineyard Haven Road)	1927
Montgomery Avenue (Trinity Park to Commonwealth Avenue)	1000	New York Avenue (Temahigan Avenue to East Chop Drive)	2000	Central Avenue (Lake Avenue to Montgomery Avenue)	3667	New York Avenue (Temahigan Avenue to East Chop Drive)	1900
Siloam Avenue (Jordan Crossing to Dukes County Avenue)	1000	Bulkhead/Seawall - 221-009-000-058-003 (Sea View Ave Ext)	1700	Sengekontacket Road (County Road to Dead End)	3667	Oak Bluffs Harbor Master (10 Circuit Ave Ext)	1820
Oak Bluffs Harbor Master (10 Circuit Ave Ext)	933	County Road (Eastville Avenue to Edgartown Vineyard Haven Road)	1700	North Bluff Lane (Circuit Avenue Extension to Seaview Avenue Extension)	3667	Revetment - 221-001-000-013-001 (East Chop Dr at Marginal St)	1733
Frazier Circle (First Avenue to Dead End)	900	Oak Bluffs Avenue (Lake Avenue to Seaview Avenue)	1700	Saco Avenue (Circuit Avenue Extension to Seaview Avenue Extension)	3667	Circuit Avenue Extension (Oak Bluffs Avenue to Seaview Avenue Extension)	1733

MODELING LIMITATIONS

General

The science of climate change and translating climate risks into design criteria are new and evolving practices, involving many uncertainties. Therefore, the projections made in this report only reflect the professional judgment of the Project Team applying a standard of care consistent with the practice of other professionals undertaking similar work. For these reasons, the recommendations and projections made within this report provide guidelines for investment decisions based on the knowledge to date. The flood level predictions made 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.

The scope of this contract did not include a full review of building and facility drawings, material testing, survey or structural analysis of the building's ability to withstand the projected hydrostatic forces due to flooding. 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.

Flood Maps

The flood maps included in this report illustrate predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. The BH-FRM model, from which these maps were developed, did not model the upland topography beyond the edge of coastline in the Town of Oak Bluffs. As such, predicted water elevations, which were propagated landward of the model boundary using engineering judgment, do not include the true effects of land topography and friction and other factors which can affect calculated water surface elevations landward of the model boundary. The water surface elevations presented in this document, are a reasonable prediction of possible future conditions, given these limitations.

The authors of this study understand that the Massachusetts Department of Transportation is planning to further refine the upland topography contained in the BH-FRM model to include all coastal communities in Massachusetts, including the town of Oak Bluffs, within the next few years. The readers of this study should understand that the water surface elevations generated by the refined model may be different than those presented in this study, and that the conclusions of this study may need to be revisited and updated once the new data is available.

These flood maps expressly do not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation-driven overland flooding. Therefore, the extent and magnitude of flooding depicted on these flood maps strictly represent coastal flooding from sea level rise and storm surge. These flood maps shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on these flood maps are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

ADAPTATION STRATEGIES

General

Types of Adaptation Strategies

There are generally three types of adaptation strategies that can be implemented, individually or in combination, to adapt to long-term risks of flooding from sea level rise and storm surge:

- Protection
- Accommodation
- Retreat

Protection

Protection strategies try to prevent unsafe conditions and physical damage from occurring by creating a barrier between flood water and vulnerable areas, infrastructure, and buildings. To be truly effective over the long-term, existing protective structures may need to be raised incrementally, in response to sea level rise, and strengthened to withstand the forces of increasingly powerful storms. New structures may also be needed to protect areas that have not historically flooded.

Sea walls, dikes, bulkheads, levees, revetments, flood gates, temporary flood protection barriers, dry floodproofing, and hurricane barriers are all examples of protection strategies that aim to prevent flood water from reaching sensitive areas.

Accommodation

Accommodation strategies accept that vulnerable areas, infrastructure, and buildings will flood, but aim to minimize and control physical damage and unsafe conditions. Accommodation strategies may include physical, operational, or regulatory measures.

Figure 14 – Examples of Accommodation Strategies

<table>
<tr><th>Type of Measure</th><th colspan="3">Examples</th></tr>
<tr><td>Physical</td><td>Construct an artificial floodway to convey flood water away from roadways and homes to a natural area or flood-tolerant green space that can store the water with limited damage.</td><td>Construct sacrificial dunes and structures that are designed to absorb the impact of large storms to prevent major damage to infrastructure behind them, with the understanding that they will need repair or replacement if destroyed.</td><td>Implement wet floodproofing measures such as raising occupied spaces and utilities above flood elevations, building with flood damage resistant materials, or using flood-resilient structural design.</td></tr>
<tr><td>Operational</td><td colspan="3">Improve flood evacuation and emergency planning by updating scenarios and plans, training first responders, or providing education and resources to residents and businesses in high flood risk areas.</td></tr>
<tr><td>Regulatory</td><td colspan="3">Strengthen building codes and zoning to require or encourage projects in high flood risk areas to implement increased setbacks, physical protection or accommodation measures, onsite flood storage, or protection or enhancement of existing natural systems (e.g., dunes, wetlands).</td></tr>
</table>

Retreat

Retreat strategies recognize the fact that in some areas it may be too costly, technically not feasible, or politically unrealistic to prevent damage from rising sea levels and storm surge, and that the best strategy is to remove vulnerable infrastructure, buildings, or populations from high risk flood zones. These areas can then be transformed back to more natural states to provide protective, recreational, or other functions that are compatible with occasional or regular flooding. Retreat strategies require significant planning to relocate infrastructure and buildings or resettle populations in areas outside of high risk flood zones.

Examples of retreat strategies include property buyouts, relocation of roads and infrastructure, implementation of new zoning or other regulations that limit new construction, reconstruction, or expansion of structures in high risk flood areas, and policies and programs that steer development towards areas that are safe from flood risks.

Recommended Base Flood Elevations

Prior to developing adaptation strategies, it is important to select a base flood elevation that will be the level to which an infrastructure asset is adapted to.

For the purposes of this study, base flood elevations do not include additional height for wave run-up or overtopping, nor do they include "freeboard" - height often added above the expected flood level for additional safety. The *design flood elevation* should include these factors and will vary from site-to-site, reflecting local conditions, criticality of the facility in question, and the owner's tolerance for risk. In addition, designs of any adaption measures must also take into account any code-required minimum base-elevations such as shown on FEMA Flood Insurance Rate Maps. The base flood elevations discussed in this report do not in any way supersede the minimum base flood elevations legally established by the Massachusetts State Building Code or other applicable codes for the design of buildings and infrastructure. The base flood elevations used in this report are presented for the purpose of establishing a reference elevation by which to evaluate various strategies to address flooding impacts from sea level rise and storm surge.

During the preliminary design stage of a project, additional investigations, such as wave run-up and overtopping analyses and code reviews, should be completed where applicable (e.g., seawalls and dunes) to determine actual design flood elevations.

Figure 15 below shows representative coastal base flood elevations for Oak Bluffs at different probabilities of exceedance in the 2030 and 2070 time horizons. For the purposes of this study, we have based recommended adaptation options on a base flood elevation equivalent to the 1% probability of exceedance flood levels in 2030 and 2070 (approximate 100 year recurrence interval). This sets a reasonably conservative base flood elevation on which to base minimum standards for critical assets and large floodplains.

	2030	2070
% Probability	Flood Elevation	Flood Elevation
0.1	11.5	14.1
0.2	10.9	13.7
0.5	10.1	12.9
1	9.7	12.5
2	9.3	12
5	8.1	10.7
10	6.4	9.7
20	5.8	8.4
25	5.5	8
30	5.2	7.7
50	4.3	6.8
100	dry	5.9

Recommended Base Flood Elevations

Figure 15 – Water Levels at Different Probabilities of Exceedance for Present, 2030 and 2070

Selecting a more conservative base flood elevation, such as the 0.2% probability elevation (500-year recurrence interval), may be prudent if the criticality of the area or asset to be protected is very high, but it has some impacts on the feasibility and cost of adaptation strategies to modify what exists today in vulnerable areas. If, for example, the Town proposed to raise an existing seawall, the cost of construction would be higher if it raised it to the 0.2% flood elevation than to the 1% flood elevation. It might also present design challenges, depending on the site.

In both 2030 and 2070, the differences between the 1% and 0.2% flood elevations are 1.2 feet

Adaptation at Different Scales

Regional

Regional adaptation strategies aim to reduce flood risks across a geographical area that may contain multiple critical town-owned assets as well as privately-owned assets including buildings, roadways, and other infrastructure. All of the large areas at risk of coastal flooding in Oak Bluffs are at risk because of direct ocean exposure or “flood pathways”, which are low-lying strips of land that permit coastal flood waters to flow further inland into other low-lying areas where there is existing development (areas that are usually dry). Solutions to close these flood pathways, or otherwise address them, are referred to in this report as regional strategies.

Regional strategies can be costly to implement. However, the benefits of regional strategies are that they are generally cost-effective and provide significant reduction in flood risk for a large number of beneficiaries through a single project. Implementation of regional strategies to address flood risks in the 2070 time horizon, when certain areas (e.g., Oak Bluffs Harbor) will have more significant risks, may face higher technical, political, and financial challenges.

Asset Level

For specific critical infrastructure assets and buildings, it may be necessary or preferable to implement strategies at the asset level to adapt to flooding. Asset level strategies are particularly needed for assets located in high flood risk areas for which regional strategies have been rejected for technical, political, or financial reasons. It is also necessary for assets that are outside of the scope of regional flood protection strategies. Asset level adaptation is also preferable for very critical assets that cannot afford to wait until regional solutions are implemented.

Regional Adaptation Strategies for High Risk Areas and Assets

This section of the report describes the possible adaptation strategies for areas and critical Town-owned assets at a high risk of coastal flooding. For each high risk area, the critical municipal assets within it are listed, the potential pathways and sources of coastal flooding are described, and the regional and asset level adaptation options are recommended with additional guidance for decision makers and designers. Order-of-magnitude cost estimates, in 2016 dollars, are provided, where possible for long-term planning purposes. These costs in no way are meant to represent actual estimates of total project costs as no surveying, subsurface exploration, engineering design, permitting and escalation of costs was performed as part of this project, all of which are necessary to establish true project costs required to design and construct a project.

The following flood-affected areas of Oak Bluffs, which include critical municipal assets, are included:

- Oak Bluffs Harbor Area
- Crystal Lake and Hospital Area
- Farm Pond and Beach Road Area
- Sengekontacket Pond and Joseph Sylvia State Beach Area

Oak Bluffs Harbor Area

Description of the Area Vulnerable to Flooding

The Oak Bluffs Harbor area is the town's commercial, transportation and government center. It is also the town's center for tourism, which is vital to Oak Bluff's economic vitality.

The area subject to flooding in 2070 from a 1% probability storm is shown in Figure 16. It is roughly bounded by Vineyard Sound along the north, Sunset Pond and contiguous wetlands to the south, East Chop Drive to the west and Circuit Avenue Extension to the east. The northern limits of the area include Jetty Beach to the north of the harbor entrance.

Figure 16 – Oak Bluffs Harbor Area Subject to Flooding in 2070 (1% Probability)

Sources of Flooding

The Oak Bluffs Harbor area is subject to flooding from storm surge through the harbor opening and from overtopping of the Jetty Beach dune (see the red arrow in Figure 16). As described above, the model does not include the effects of wave run-up and overtopping, so the predicted inundation depths shown immediately along the north shore (Jetty Beach and North Bluff) will be significantly higher than indicated due to the direct exposure to waves from Nor'easter storms. However, the overall extent of flooding will not be significantly different in areas away from the seawalls, beach and harbor entrance.

The elevation of the existing bulkhead around the harbor varies, but is in the range of elevation 4.5 feet to 5.0 feet NAVD88. Mean Higher High Water (MHHW) today is at approximately elevation 1.06 NAVD88. With a predicted increase in sea level of 0.66 feet by 2030, MHHW would increase to approximately elevation 1.72 feet NAVD88, still well below the top of bulkhead. However in 2070, with an expected sea level rise of 3.39 feet, MHHW would increase to approximately elevation 4.45 feet NAVD88, which is basically at the top of the bulkhead. This means that there would be many times during the year that water would be expected to overtop the bulkhead from normal astronomical high tides and minor storms.

The level of Sunset Lake is normally controlled by a culvert between the lake and the harbor. The culvert restriction attenuates the water level in the lake versus the level in the harbor. Once the water level in the harbor exceeds the bulkhead elevation and crosses Lake Avenue, the lake water level will equal the harbor elevation.

Critical Assets at Risk

There are numerous municipally-owned assets within this area, including:

Sewer Pump Station at School Street and Dukes County Avenue	Siloam Avenue Sewer Pump Station at Sunset Lake
Electrical Panel, Sewer Pump Station and public restrooms adjacent to "Our Market"	Hy-Line Ferry Dock
Island Queen Ferry Dock	Oak Bluffs Police Department
Oak Bluffs Harbor Master Building	Jetty Beach

Some of the important streets vulnerable to flooding in this area, include:

Lake Avenue	Circuit Avenue Extension
East Chop Drive	Dukes County Avenue
Siloam Avenue	School Street
Garvin Street	Clinton Street
Old Mill Road	Community Avenue
Oak Bluffs Avenue	Commonwealth Avenue

Although not a municipally-owned asset, the Steamship Authority Building on Seaview Avenue, is also vulnerable to flooding.

The Oak Bluffs Harbor area also includes numerous commercial enterprises, including restaurants, hotels and shops, as well as numerous private residences.

Figure 17 illustrates approximate flood levels in 2030 and 2070 for a 1% probability event adjacent to the Circuit Road Extension along the harbor bulkhead. Figure 18 illustrates approximate flood levels in 2030 and 2070 for a 1% probability event at the Harbormaster building at the Circuit Road Extension.

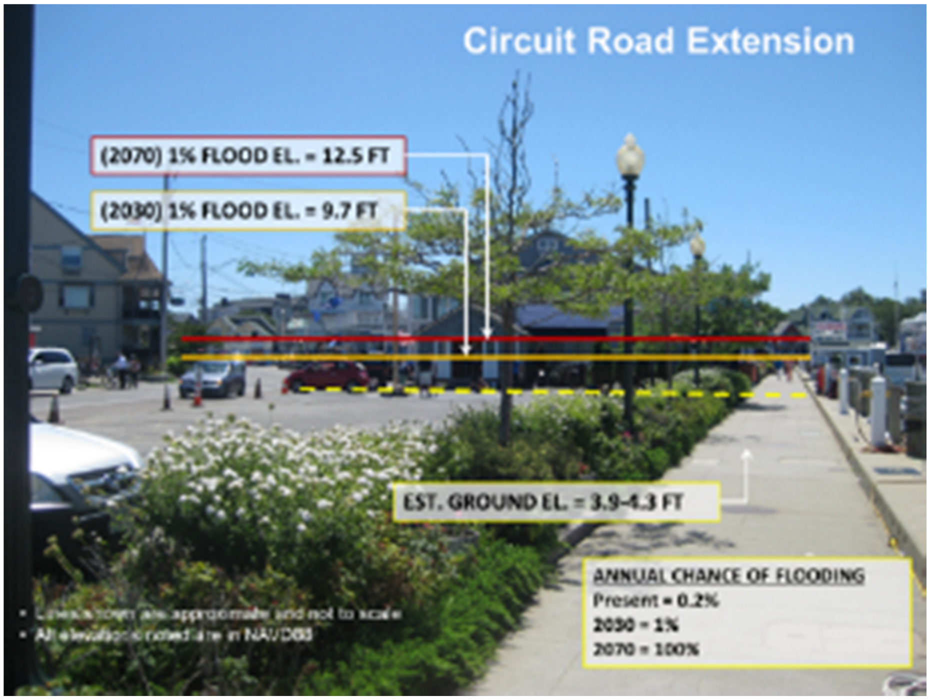


Figure 17 – Flooding at Circuit Rd. Extension

Figure 18 – Flooding at Harbormaster Building

Figure 19 illustrates flooding for the same time scenarios at the Steamship Authority building and dock along Seaview Avenue. The docking facilities themselves are significantly lower in elevation than the roadway, and are therefore very susceptible to flooding. Because the model does not include the effects of wave run-up and overtopping, the predicted inundation depths shown immediately along the revetment will be significantly higher than indicated due to the direct exposure to waves from Nor'easter storms.

Figure 19 – Flooding at Steamship Authority Dock

Regional Adaptation Strategies

The Oak Bluffs Harbor area is vulnerable to flooding, especially in 2070, with flooding being caused by storm surge from a Nor'easter storm coming through the harbor entrance channel and overtopping of the Jetty Beach dune and the North Bluff sea wall.

There are numerous municipally owned assets vulnerable to flooding in addition to numerous commercial and residential properties. It is very difficult to protect individual assets, especially commercial and residential properties due to diverse ownership and the tight spacing of buildings.

Therefore, a regional approach to long-term flood protection may be the most cost effective solution to protect property and allow for quick recovery after an extreme storm. A regional approach would be a solution that stops storm surge from entering the area surrounding the harbor.

Two possible strategies are presented:

- Option A – Raise Perimeter Bulkhead
    - A1 – Permanent Barrier
    - A2 – Active or Passive Movable Barrier
- Option B – Hurricane Barrier to Close Harbor Entrance Channel

Option A – Raise Perimeter Bulkhead

This option involves raising the bulkhead around the harbor and the Jetty Beach Dune to prevent storm surge from overtopping the bulkhead. This solution would allow storm surge to enter the harbor, but be contained within a higher bulkhead to prevent flooding beyond the bulkhead. Figure 20 illustrates a plan view of the concept.

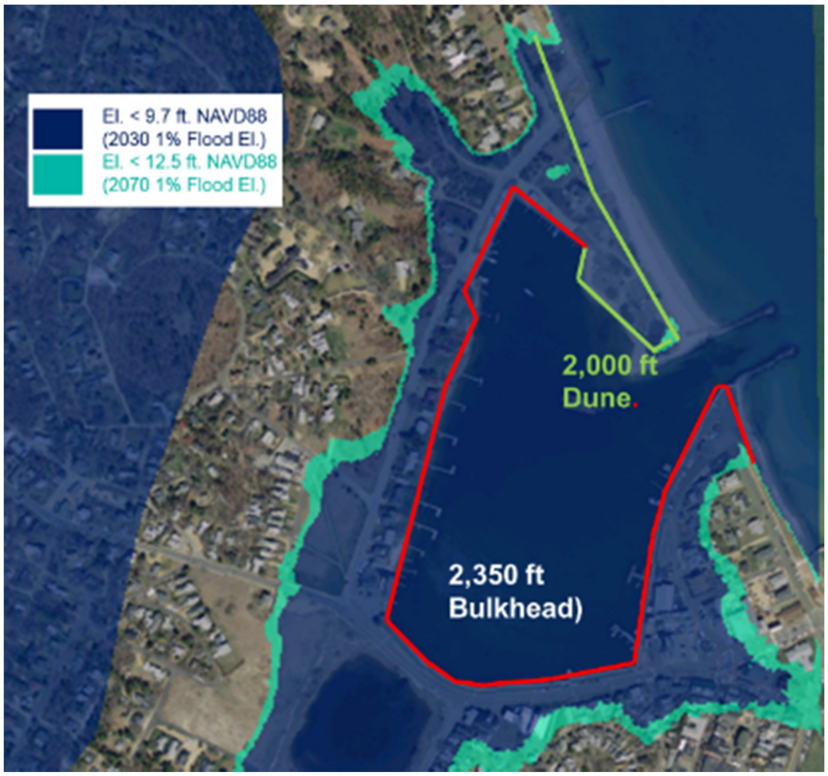


Figure 20 – Option A – Plan of Raised Perimeter Bulkhead and Dune

There are two main components to this Option. First is to raise the dune on Jetty beach (green line in Figure 20) and behind the East Chop Beach Club to prevent overtopping of the dune which would allow flood water behind the bulkhead. This study's recommended base flood elevation of 12.5 feet NAVD88 in 2070 is above the current FEMA VE base flood elevation of 12.0 feet NAVD 88. The existing dune elevation varies in elevation, but is estimated to be approximately 7.0 – 8.0 feet NAVD88. Ideally raising the dune should be done in conjunction with a beach nourishment project, which will help reduce wave energy and protect the dune from erosion. A more detailed coastal processes study will need to be performed to gain a better understanding of the dynamic forces affecting the dune/beach system, to ensure that a raised dune will be able to withstand the high wave forces in this area. The dune should be considered as a "sacrificial" dune with the understanding that a major storm could significantly erode the dune, but it would last for the storm and would need to be repaired and maintained periodically to ensure continued protection.

The other key component of Option A is the raised bulkhead around the harbor. A large portion of the bulkhead is privately owned, especially on the west side of the harbor. This could make it more difficult to construct the full perimeter. But without, the full perimeter, the solution cannot work.

This study's recommended base flood elevation of 12.5 feet NAVD88 in 2070 is above the current FEMA AE zone base flood elevation of 8.0 feet NAVD88 in the immediate harbor area. Assuming the existing top of bulkhead elevation is approximately 5.0 feet NAVD88, the bulkhead would have to be raised approximately 7.5 feet to achieve a design elevation of 12.5 feet NAVD88. Alternatively, the barrier could be designed to the 2030 1% probability elevation of 9.7 feet, which would result in a 10% chance of it being overtopped in 2070, based on the probabilities shown in Figure 15. Given the significantly higher costs to raise the bulkhead 7.5 feet instead of 4.7 feet and the more complicated construction issues, we recommend raising the bulkhead to elevation 9.7 feet NAVD88.

There are two ways to construct the raised perimeter bulkhead. One is with a permanent barrier (Option A1) and the other is with an active or passive barrier that is stored in the sidewalk when not needed, and then is raised before an impending storm (Option A2).

Option A1 will require changes to the existing boat docking system. The typical existing docking configuration is "stern-in" as shown in Figure 21. If a permanent barrier is erected on top of the bulkhead, it will not be possible for boaters to disembark as they do now over the bulkhead. Therefore the docking system will need to be revised, possibly to a scheme as shown in Figure 22. Boaters would disembark on a floating dock and then use a ramp to get from the floating dock to the street level.

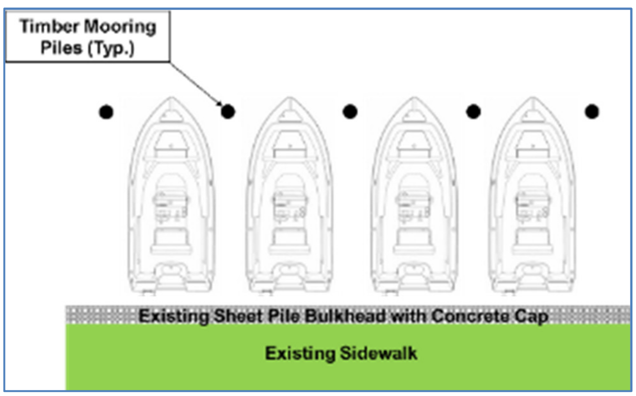


Figure 21 – Typical existing docking configuration

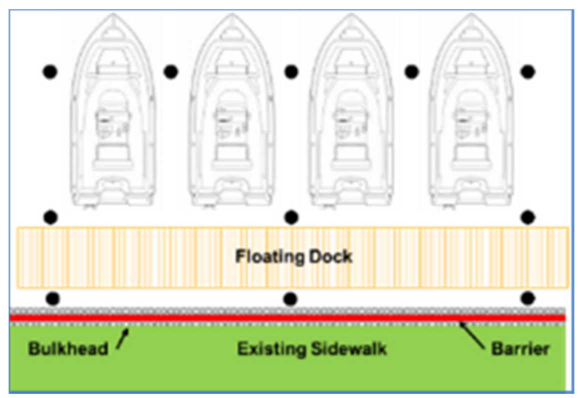


Figure 22 – Option A1 – Revised docking

It is very important for the tourist business to maintain the views of the harbor from the roadways, sidewalks and adjacent commercial establishments. Therefore, any permanent raised barrier should be constructed of aquarium glass so that people can look through the barrier. Figures 23 and 24 show conceptually how a permanent glass barrier system would function under normal conditions and during a storm.

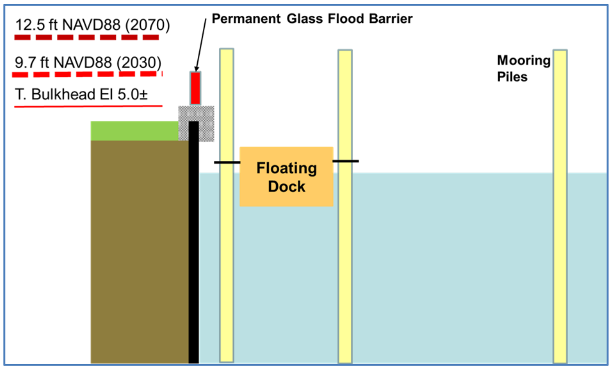


Figure 23 – Option A1 – Glass barrier normal

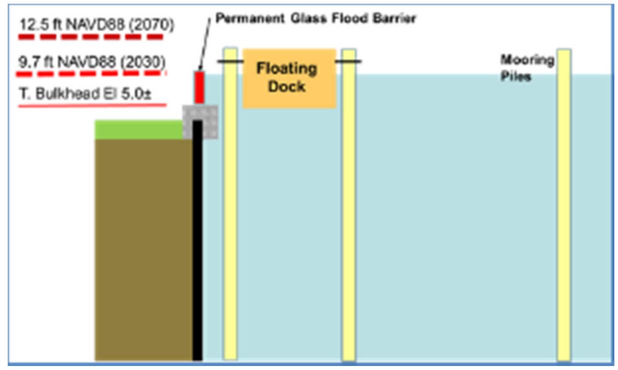


Figure 24 – Option A1 – Glass barrier during storm

Figure 25 shows some example photos of glass flood barriers. Sitting walls, benches and other amenities can be incorporated into the barrier system to make the area an inviting place for pedestrians. An added feature is that glass barriers can act as welcome wind breaks on windy days.

Figure 25 – Example photos of permanent glass flood barriers

Figure 26 is an illustration of the approximate scale of a permanent glass barrier along the harbor sidewalk.

Figure 26 – Approximate scale of a permanent glass flood barrier at elevation 9.7 feet NAVD88

Option A2 does not have a permanent flood barrier mounted on top of the barrier, therefore the existing docking system does not have to be changed. However, consideration should be given to the condition when water gets so high during a storm that docks exceed their mooring lengths or float over pilings and become loose.

In Option 2A, the flood barrier is stored horizontally in the sidewalk when it is not needed, and then is raised into position, either manually (active) or automatically (passive). Option 2A is illustrated in Figures 27 and 28.

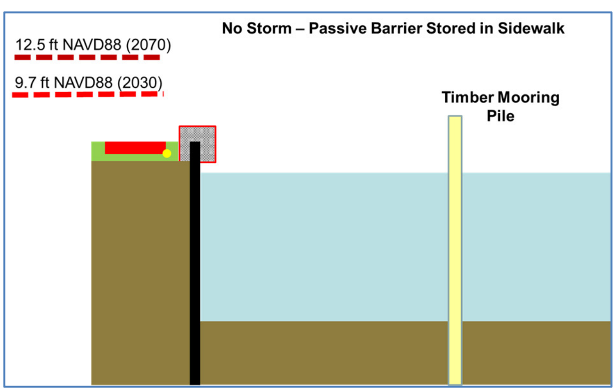


Figure 27 – Option A2 – Passive barrier stored

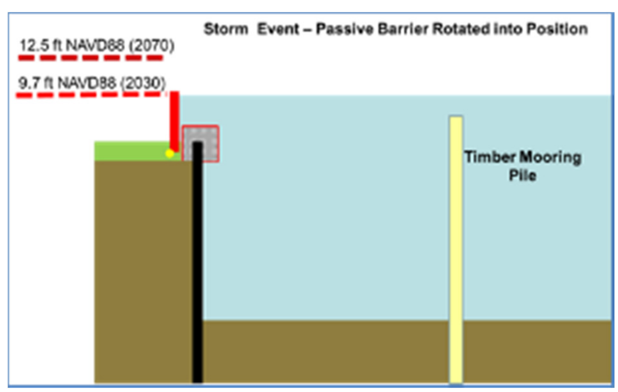


Figure 28 – Option A2 – Passive barrier deployed

Some examples of passive flood barriers are shown in Figures 29, 30 and 31.

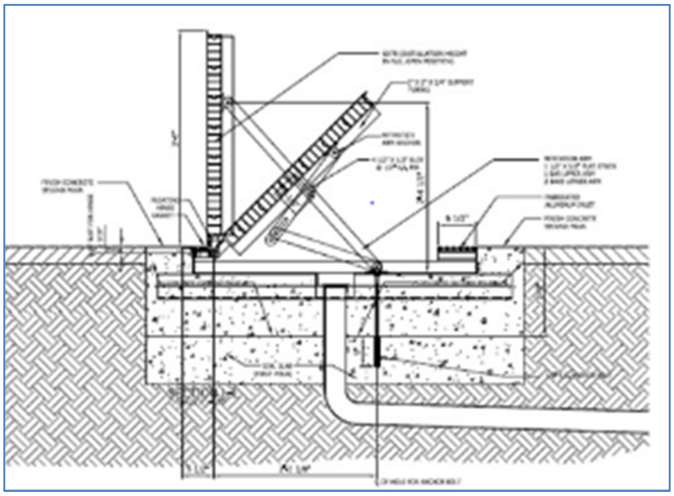


Figure 29 – Option A2 – Typical passive barrier

Figure 30 – Option A2 – Lourdes Hospital, Binghamton, NY

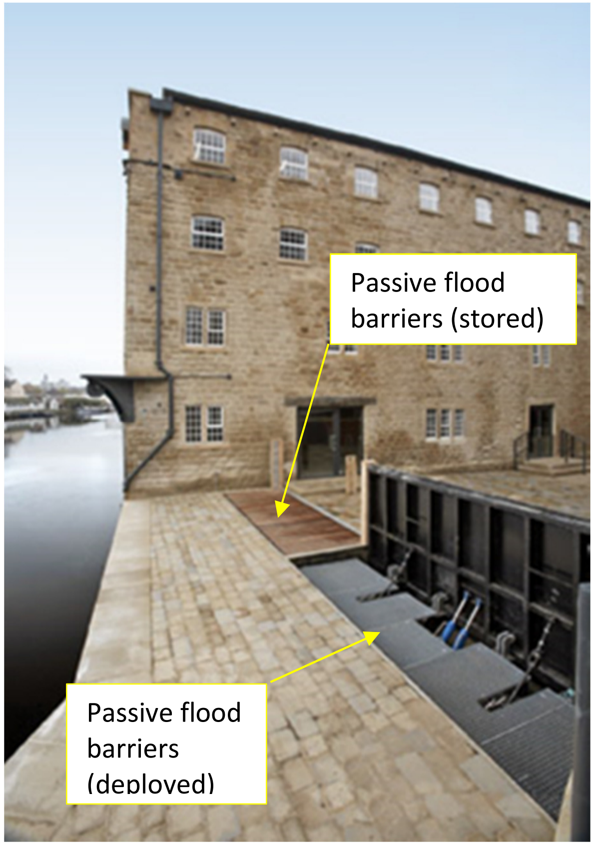


Figure 31 – Option A2 –Passive barrier

Option B – Hurricane Barrier to Close Harbor Entrance Channel

This option seals off the harbor area with hurricane barrier system, which prevents storm surges from entering the harbor, thereby keeping the downtown area free of water. This option is conceptually illustrated in Figures 32 and 33.

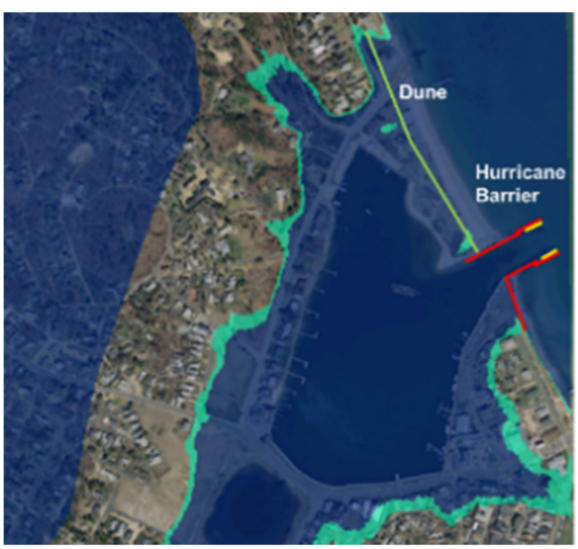


Figure 32 – Option B –Hurricane barrier – Open

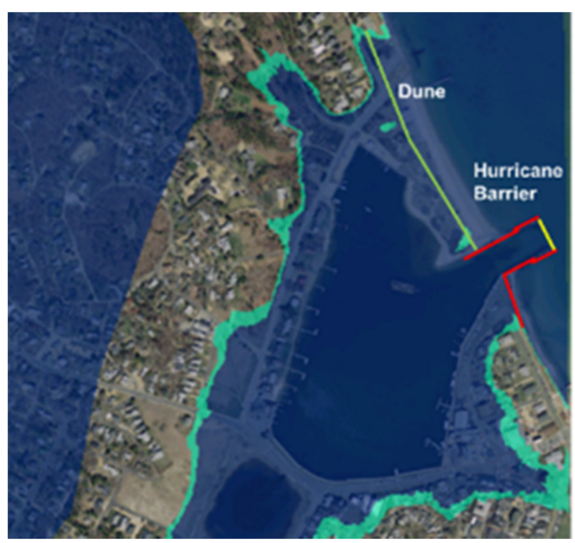


Figure 33 – Option B – Hurricane barrier - closed

Like Option A, there are two main components to this Option. First is to raise the dune on Jetty beach (green lines in Figures 32 and 33) and behind the East Chop Beach Club to prevent overtopping of the dune which would allow flood water into the harbor. This study's recommended base flood elevation of 12.5 feet NAVD88 in 2070 is above the current FEMA VE base flood elevation of 12.0 feet NAVD88. The existing dune elevation varies between elevation 7.0 and 8.0 feet NAVD88. As in Option A, raising the dune should be done in conjunction with a beach nourishment project, which will help reduce wave energy and protect the dune from erosion.

The other key component of Option B is to construct a hurricane barrier at the harbor entrance channel with flood doors that can be closed before an impending storm. The existing stone breakwater jetties on either side of the harbor entrance channel would be replaced with concrete walls with large flood doors attached to each wall. The doors could be swing-type doors or a barrier that lies horizontal on the sea floor in the open position, and then rotates vertical when deployed, similar to the hurricane barrier in Stamford, CT.

The existing FEMA VE zone base flood elevation on the south side of the channel along the North Bluff sea wall is 21.0 feet NAVD88. This is significantly higher than the 2070 1% probability elevation of 12.5 feet NAVD88. This VE zone elevation appears to be very conservative, given that the VE zone elevation on the other side of the harbor entrance channel is only 12.0 feet NAVD88. Because the BH-FRM model used in this study does not include the effects of wave-run-up and overtopping, the design elevation will likely need to be between elevations 12.5 and 21.0 feet NAVD88. For purposes of this study, we recommend using the VE zone based flood elevation of 21.0 feet NAVD88 as the design height of the hurricane barrier. The dune can be set at a lower elevation, say elevation 18 feet NAVD88, because the effects of wave run-up and overtopping can be reduced with a well-designed beach and dune system.

There are many unknowns at this point to determine the feasibility of constructing such a hurricane barrier. A coastal processes study would have to be performed to understand how such a large structure would affect the hydrodynamics of area, sediment transport in the area, and erosion potential of surrounding beaches and shorelines. In addition, bathymetric surveys and subsurface investigations would need to be performed to understand the structural and geotechnical constraints that would affect the cost and feasibility of the project. It would also be extremely difficult to permit such a hurricane barrier.

The cities of New Bedford, MA, Providence, RI and Stamford CT all have larger hurricane barriers that have successfully protected their infrastructure from storm surge damage.

Crystal Lake and Hospital Area

Description of the Area Vulnerable to Flooding

The Crystal Lake and Hospital area is primarily a residential area, but the Martha's Vineyard's Hospital, the island's only hospital, is located at the cross-roads of several roads located within the area.

The area subject to flooding in 2070 from a 1% probability storm is shown in Figure 34. It is roughly bounded by Vineyard Sound, Beach Road and East Chop Drive along the west, Lagoon Pond to the south, Eastville Avenue to the north and County Road to the east.

Figure 34 – Crystal Lake and Hospital Area Subject to Flooding in 2070 (1% Probability)

Sources of Flooding

The Crystal Lake and Hospital area is subject to flooding from storm surge from Vineyard Sound to the west as shown by the red arrows in Figure 34. Beach Road and East Chop Drive are flooded from Vineyard Sound overtopping the beach. Eastville Avenue and County Road are flooded from Lagoon Pond to the south. Water enters Lagoon Pond either by overtopping of Beach Road or through the Lagoon Pond entrance channel under the Beach Road Bridge.

Critical Assets at Risk

The municipally-owned assets in this area are primarily streets, which include:

Beach Road	Eastville Avenue
County Road	East Chop Drive
Hospital Road	Wapello Street
Crystal Lake Road	Pall Mall Street
Bridge Street	Windemere Road

Figure 35 – Low lying area of East Chop Drive vulnerable to flooding

The buildings of the Martha's Vineyard Hospital, which is not municipally-owned, appear to be just outside the 2070 1% probability flood zone, however some of the parking lots appear to be vulnerable to flooding in 2070.

Beach Road and County Road are the primary access routes to the Hospital from Vineyard Haven and points west. Both of these roads are vulnerable to flooding, which leaves Temahigan Avenue as the only possible access to the hospital during flood events. Because the maps shown do not include flooding from wave run-up or overtopping, the probability of Temahigan Avenue flooding may be slightly under-represented. Although emergency routes can be adjusted to use Temahigan Avenue in the event that it is not flooded, response times will be delayed.

Regional Adaptation Strategies

Due to extent of shoreline subject to storm surge flooding, and the fact that the majority of that shoreline along Beach Road and East Chop Drive is developed with residential structures, developing a regional solution to protect all the roads and private residences will be extremely difficult and very expensive.

Option A, shown in Figure 36, is to ring the hospital area with a series of dunes and nourished beaches. This would require about 4,060 feet of enhanced dune and beach nourishment along Vineyard Sound and the beach between Brush Pond and Lagoon Pond. A roadway closure barrier would need to be constructed on Beach Road to allow traffic to pass through the raised barrier during non-flood times. In addition, a culvert with a tide gate would need to be constructed to allow free flow of water between Brush Pond and Lagoon Pond. The road barrier and tide gate would have to be closed in advance of a major flood event.

Figure 36 – Option A - Dune Protection at Hospital

Figure 37 – Existing beach between Lagoon and Brush Ponds looking east

Due to the high cost and numerous potential environmental impacts of Option A, and the fact that only about 50 private residences would be protected, Option A is not recommended for further consideration.

A more cost effective solution to provide additional emergency access to the hospital would be to raise the low areas of Eastville Avenue and County Road to prevent flooding of these roads as shown in Figure 38. The maximum depth of water at the low point of Eastville Road during a 1% probability storm in 2070 is approximately 3.7 feet, while it is only 1.0 feet for County Road. Approximately 940 feet of Eastville Avenue would need to be raised. Because the amount of inundation on County Road is only 1.0 feet, it is probably not cost effective to raise the entire 1,610 feet length of County Road, but only the section intersecting with Eastville Road.

Due to the 2,560 feet of East Chop Drive vulnerable to flooding in the vicinity of Crystal Lake, and the need to raise it at least 2.7 feet to meet the 1% probability storm in 2070, it is not cost effective to raise the road because there are no other critical municipal assets to protect, only private residences. It is more cost effective for the approximately 20 home owners to raise their homes out of the flood zone. The FEMA flood map for East Chop Drive shows the area to be in a VE zone with a base flood elevation of 12.0 feet NAVD88. Most homes would have to be raised 3.0 – 5.0 feet to be above the VE zone elevation. A number of homes have already been raised.

Figure 38 – Option B – Raise Eastville Avenue and County Road

Farm Pond and Seaview Avenue Area

Description of the Area Vulnerable to Flooding

The Farm Pond and Seaview Avenue area is primarily a residential area, but Seaview Avenue is an important transportation link between Oak Bluffs and Edgartown as well as a major bicycle route for tourists.

The area subject to flooding in 2070 from a 1% probability storm is shown in Figure 39. It is roughly bounded by Vineyard Sound and Seaview Avenue to the east, Waban park to the north, Harthaven to the south and Farm Pond to the west.

Sources of Flooding

The Farm Pond and Seaview Avenue area is subject to flooding from storm surge over Seaview Avenue from Vineyard Sound to the east as shown by the large red arrow in Figure 40. Farm Pond is connected to Vineyard Sound by a culvert under Seaview Avenue denoted by the small red arrow in Figure 40. There is a large concrete sea wall that stops just north of the low point of Seaview Avenue (Figure 39), which is at an approximate elevation of 4.1 feet NAV88. Even today, this low area of Seaview Avenue is subject to extensive storm surge flooding.

Figure 39 – End of Existing Seawall at Seaview Ave. at Farm Pond

Figure 40 - Farm Pond and Seaview Avenue Area Subject to Flooding in 2070 (1% Probability)

Critical Assets at Risk

The municipally-owned assets in this area are primarily streets, which include:

Seaview Avenue	South Circuit Avenue
Katama Avenue	Vanessa Avenue
Canonicus Avenue	Nantucket Avenue
Naumkeag Avenue	Tuckernuck Avenue

Waban Park is also subject to flooding.

Adaptation Strategies

The primary asset to protect in this area is Seaview Avenue. There are three basic adaptation strategies to prevent flooding on Seaview Avenue:

- Option A – Extend existing sea wall to Harthaven
- Option B – Raise Seaview Avenue
- Option C – Construct a protective dune and beach east of Seaview Avenue

Option A – Extend Existing Sea Wall to Harthaven

Extending the existing concrete sea wall to the Harthaven area will offer a significant amount of protection to Seaview Avenue. The existing concrete sea wall is at approximately elevation 6.5 feet NAVD88, which is well below the design flood elevation of 12.5 feet NAVD88 in 2070. The FEMA VE zone base flood elevation for this area is 12.0 feet NAVD88. Therefore the wall, if it is extended, should be constructed to at least elevation 12.0 feet NAVD88. Because the road is currently at about elevation 4.1 feet NAVD88 at its low spot, having such a high wall would severely impact views from the road to Vineyard Sound.

The wall could be constructed in a phased approach as shown in Figures 41 through 43.

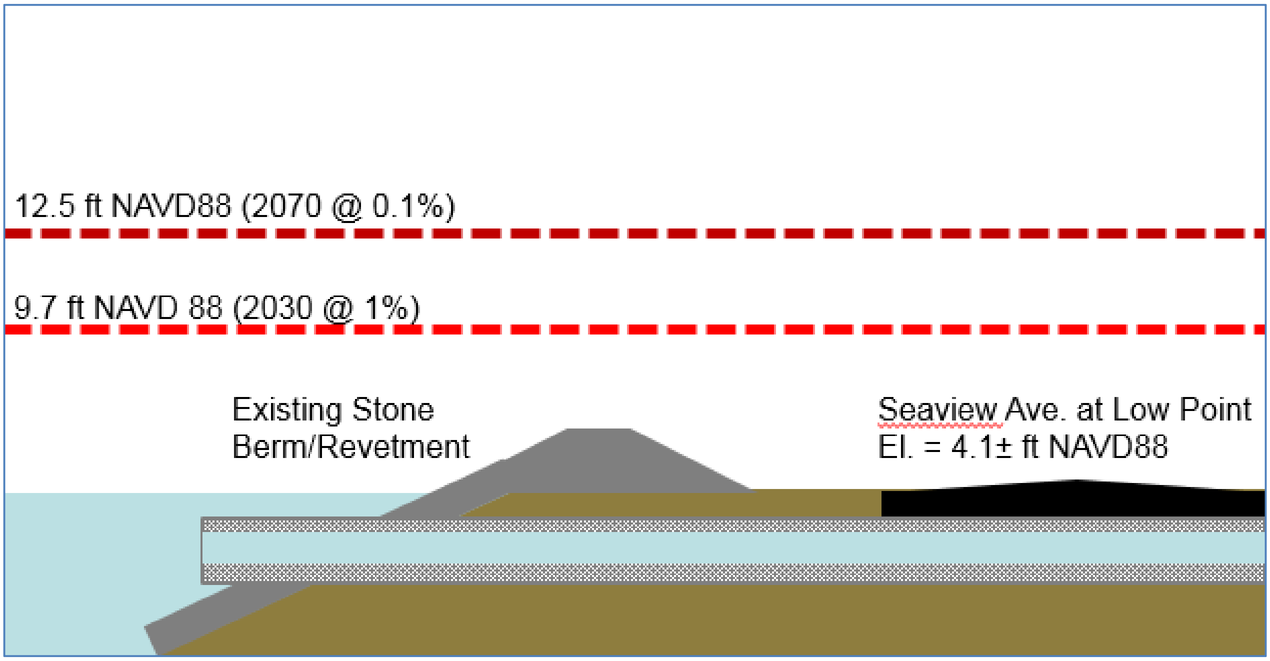


Figure 41 – Seaview Avenue at Farm Pond – Existing Conditions

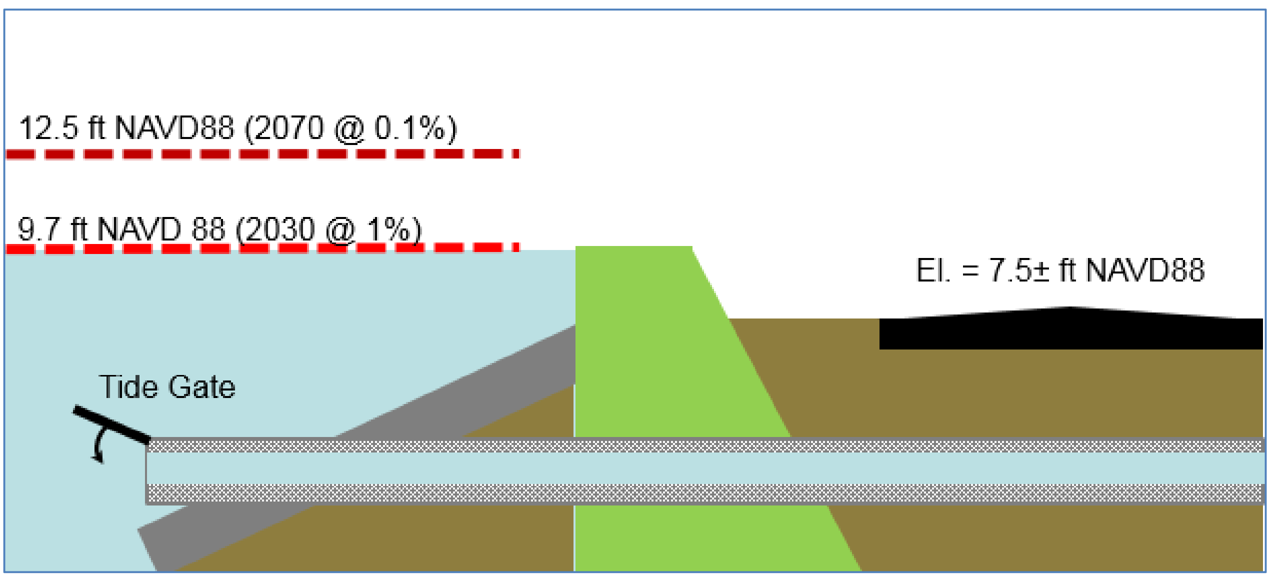


Figure 42 – Seaview Avenue at Farm Pond – Phase 1 Sea Wall Construction

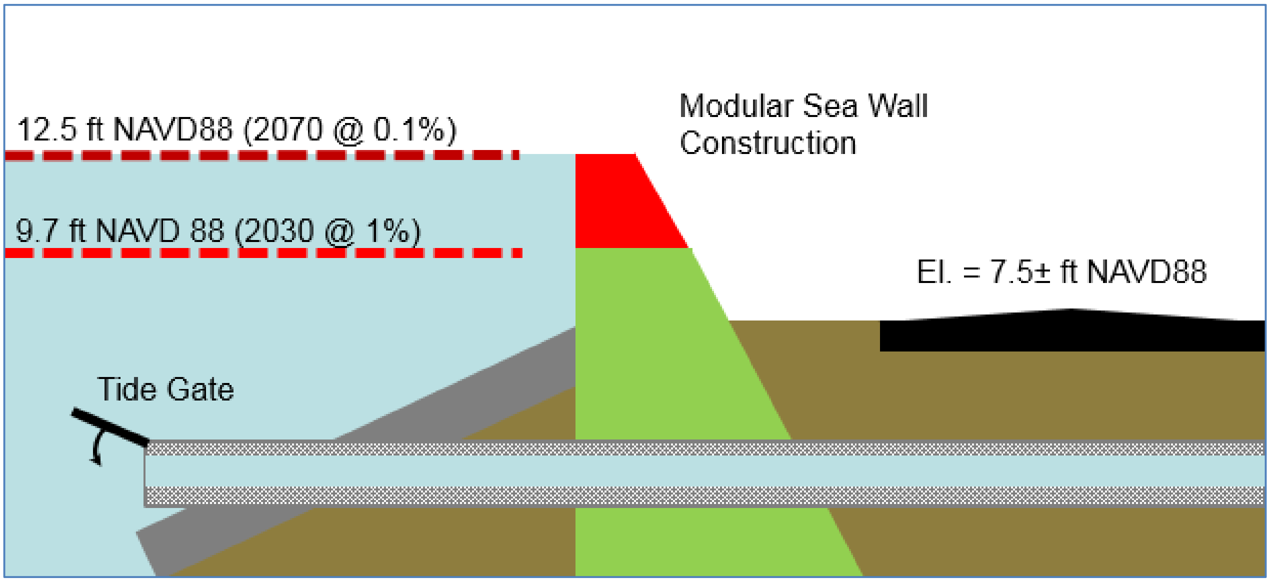


Figure 43 – Seaview Avenue at Farm Pond – Future Phase 2 Sea Wall Construction

The wall could be designed to elevation 12.5 feet NAVD88, but only constructed to the 2030 1% probability elevation of 9.7 feet NAVD88. The wall could be raised to the higher height in the future if warranted.

In Figure 42, the road is shown be raised approximately 3.4 feet behind the wall to minimize the visual impact of the wall. In addition, a tide gate (e.g. self-regulating) is recommended to be installed on the culvert connecting to Farm Pond to allow for enhanced flow during normal weather conditions while preventing sea water from entering and flooding the pond during a storm.

Option B – Raise Seaview Avenue

Raising Seaview Avenue alone, without a sea wall or dune protecting it, is not a recommended solution. Although technically it could be raised using sheet pile bulkheads on either side of the road to minimize the footprint of the raised road, it would be very costly and difficult to protect from wave action. As the road is owned by MassDOT, it is unlikely that they will pay for raising the road.

Option C - Construct a Protective Dune and Beach East of Seaview Avenue

Option C involves constructing a sacrificial dune and beach system on the east side of the road to the 2030 1% probability elevation of 9.7 feet NAVD88. If this is too high, then the minimum dune elevation should be the top of the existing concrete sea wall. Although not ideal, this lower elevation would provide a big improvement over existing conditions. Figure 44 shows an illustration of a dune/beach protection system.

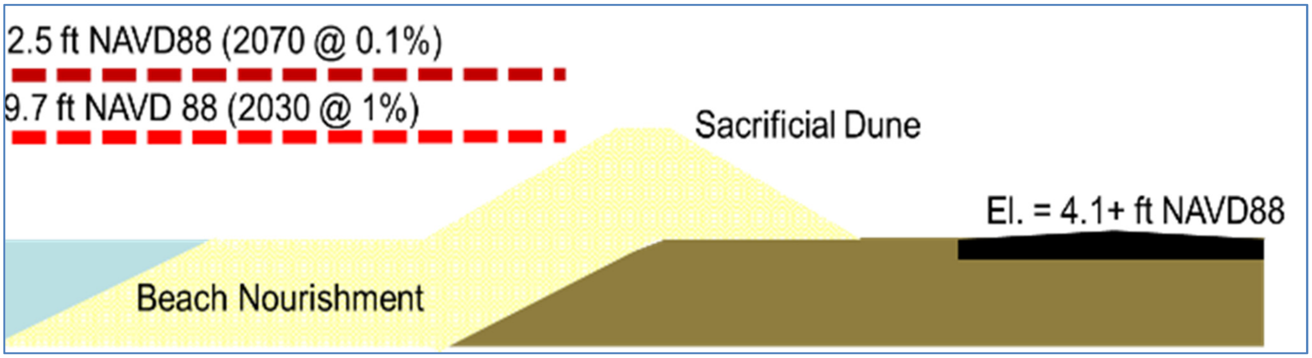


Figure 44 – Seaview Avenue at Farm Pond – Option C - Dune Protection

Sengekontacket Pond and Joseph Sylvia State Beach Area

Description of the Area Vulnerable to Flooding

The Sengekontacket Pond and Joseph Sylvia State Beach area is primarily a recreational area. The area is also designated on the FEMA maps as part of the Coastal Barrier Resource System. Both Beach Road, which runs along the beach, and the beach itself are state-owned and maintained. However, because of their importance to the island's transportation system and their recreational value, they were included in this study.

The area subject to flooding in 2070 from a 1% probability storm is shown in Figure 45. It is roughly bounded by Vineyard Sound to the east, Farm Neck Country Club to the north, the Town of Edgartown border to the south and Sengekontacket Pond to the west.

Figure 45 – Sengekontacket Pond and State Beach Area Subject to Flooding in 2070 (1% Probability)

Sources of Flooding

The Sengekontacket Pond and Joseph Sylvia State Beach area is subject to flooding from storm surge over the beach dune from Vineyard Sound to the east as shown by the large red arrow in Figure 45. Sengekontacket Pond is connected to Vineyard Sound by two large open channel waterways under two roadway bridges denoted by the small red arrows in Figure 45. These open channels cannot be closed in their existing design.

Critical Assets at Risk

The municipally-owned assets in this area are primarily streets, which include:

Beach Road	Sengekontacket Pond Road

Adaptation Strategies

As discussed in the section on natural resources, if no action is taken to maintain and manage the dunes and beach, the barrier beach in this area will likely experience a loss of all dune resources and become solely a barrier beach migrating landward due to the more frequent overtopping expected in the future, putting Beach Road under constant risk. There is adequate space to allow the barrier beach to migrate westward (landward) into Sengekontacket Pond as necessary.

The barrier beach area can be enhanced through a dune and beach restoration project to mitigate erosion, overtopping, and provide more protection for the roadway and bikeway infrastructure. However, because this a high energy shoreline, the barrier beach will continue to move and reshape itself. It may not be possible over the long-term to fully protect the beach in a financially sustainable way.

To better understand how to design the most cost effective and long-lasting dune and beach restoration project, we recommend performing a coastal processes study to understand the hydrodynamic forces and sediment transport systems that affect the beach system. A coastal processes study should include the following:

- Site specific data collection: Collect and measure information on currents, tides, waves, water salinity and temperature. Obtain grain size samples from the beach and analyze size and chemical composition and contamination to determine compatibility with borrow material. Evaluate regional geomorphic change for calculating potential sediment movement.
- Hydrodynamic modeling: Develop a hydrodynamic model of the ocean front and Sengekontacket Pond to determine overall coastal processes in the area and to assess existing conditions on the back side of the barrier beach. Run the model for normal tide conditions, storm conditions and potential sea level rise scenarios.
- Wave transformation modeling: Utilize a regional wave model to propagate waves over the irregular offshore bathymetry, and simulate a range of wave conditions to determine changing impacts on the shoreline.
- Sediment transport modeling: Develop a sediment transport model to identify existing movement of sediment alongshore and patterns of erosion and accretion.
- Conceptual restoration alternatives: Develop conceptual restoration alternatives and then test them against the various models to model their effectiveness.

As this is a barrier beach system, hard infrastructure such as sea walls, groins and jetties will not be permitted.

Another recommendation is to undertake a vegetation planting and sand fencing program for erosion control. The dunes should be planted with native, slat-tolerant, erosion-control vegetation with extensive root systems to help hold the sediments in place. Sand fencing should also be installed to help trap windblown sand to help maintain and build the volume of the dune.

Maintenance of the dune system is critical to its success as a coastal protection system. If none already exists, we strongly suggest developing a Beach Management Plan.

Asset Level Adaptation Strategies

There are a number of municipally-owned infrastructure assets that are vulnerable to flooding today and more so by 2030. Some of the regional adaption strategies discussed above may take many years to implement, if they can be implemented at all. Therefore some asset-level recommendations are presented that can be implemented in the near future at a reasonable cost.

The following assets are included:

- Sewer Pump Station at School Street: The town has recognized the vulnerability of this facility by installing the new emergency generator on a raised platform. However, there are still a number of electrical panels and equipment that could still be subject to damage from a flood. The approximate elevation of the ground level of the pump station is 3.07 feet NAVD88. The approximate location of the 2030 1% storm elevation of 9.7 feet NAVD88 is shown in Figure 46.

Figure 46 – School Street Pump Station

The building itself is a wooden enclosure, which cannot be effectively waterproofed, even with floodproof doors. We recommend that any sensitive electrical panels and equipment be raised and relocated as high as possible onto the adjacent generator platform.

If this is not possible, another option is to surround the building with a temporary flood barrier that can be deployed in advance of a major flood event. An example of such a barrier, is the AquaFence system that was recently adopted by the Massachusetts Port Authority to protect some critical assets from flooding. The barriers, shown in Figures 47 and 48 during test deployments at the Logan Airport State Police headquarters and at the Fish Pier gate house transformer, are lightweight and easy to deploy, and can be stored off-site in their own storage boxes. Although panels are available in heights up to 8 feet, we do not recommend using such high panels due to the potential for minor wave action. Instead we recommend using 4 or 5 foot high barriers. The lower height barriers will not quite provide the full protection desired, but the facility will be significantly more protected than it is now. In addition to the barriers, other pathways for water entry must be sealed such as underground conduits and drains. Approximately 240 feet of flood barrier could enclose the entire facility.

Figure 47 – Flood barrier deployed at Logan Airport

Figure 48 – Flood barrier at Fish Pier

- Sewer Substation at Siloam Avenue: The approximate elevation of the ground level of this pump station is 2.78 feet NAVD88, which is well below the 2030 1% probability elevation of 9.7 feet. As seen in Figures 49 and 50, the only component of the substation that appears to be vulnerable to flooding is the small building containing electrical equipment. We recommend that this small wooden enclosure building be replaced with a watertight enclosure that is designed to resist flooding.

Figure 49 – Sewer substation at Lake Avenue and Siloam Avenue

Figure 50 – Electrical equipment at sewer substation at Lake Avenue and Siloam Avenue

- Electrical Panels, Sewer Pump Station and Rest Rooms at "Our Market" at Oak Bluffs Harbor: The approximate elevation of the ground level of the pump station is 3.85 feet NAVD88. The approximate location of the 2030 1% storm elevation of 9.7 feet NAVD88 is shown in Figure 51. The pumping equipment, located in the adjacent parking lot, is designed to operate under water, but the electrical panels and transformers associated with the pumping equipment are subject to flood damage. The recommended approach to protect the electrical panels is to either raise them above the flood level or to enclose them in a waterproof enclosure designed to resist flooding.

Figure 51 – Sewer pump station electrical panels at "Our Market"

- Oak Bluffs Harbor Master Building: The Oak Bluffs Harbormaster building has an approximate floor elevation of 4.60 feet, which makes it vulnerable to flooding. It is not economically feasible to protect this building, which is a wood structure built on a pile-supported pier over the harbor. The services provided from this building can be provided remotely or in a temporary trailer should the building be damaged beyond repair. Therefore no adaptation recommendations are included for this building.

- Oak Bluffs Police Department: The Oak Bluffs Police Station is located on higher ground with an approximate critical elevation of 10.85. Based on the BH-FRM model results, the station does not see flood water presently. In 2030, the building is dry in a 1% probability storm, but could flood at a 0.2% probability (500 year) storm. In 2070 it is vulnerable to flooding at a 1% (100 year) probability storm. The current FEMA flood map shows the Police station in Zone X, which is defined as having a 0.2% annual chance of flooding (500 year) or areas with a 1% annual chance of flooding (100 year) with average depths of less than 1 foot. Therefore, using the 2070 1% probability storm elevation of 12.5 feet, NAVD88, the expected flooding is less than 2.0 feet. Even though the probability of flooding is relatively low, the building is located close to the sea wall and wave overtopping can be expected to reach the building.

  The building has a basement which has a stairwell at the rear of the building (Figure 53). There are also windows below the first floor with access into the basement. There are mechanical and electrical equipment located in the basement which would be damaged in a flood. In addition, there is an evidence storage room in the basement, which, if flooded, would result in lost evidence which is very important to the department' ability to prosecute criminals.

Figure 52 – Police Station – Front (Oak Bluffs Ave.)

Figure 53 – Rear of Police Station

Police operations are difficult to relocate if the building is flooded. Therefore, we recommend that measures be taken to flood proof the building as much as possible. As the basement walls are solid concrete, one option would be to install flood panels on all exterior doors and windows to prevent water from entering. Another option would be to install flood panels on the basement windows, and install an AquaFence flood barrier around the rear entrance area to seal off the stairwell. In addition, all underground electrical conduits that could convey water through the basement walls would need to be sealed under either option. Also shut-off valves or other similar device would need to be installed on any storm drain or sanitary pipes that could convey water back into the building.

Recommendations for Potential Changes to Policies/Regulations

Potential Changes to the Oak Bluffs Rules and Regulations for the Floodplain Overlay Zoning District (FPOD)

- Establish performance criteria for sea level rise, such as curves to be used, time frames relative to the expected life of the project, and acceptable methodologies.
- *Appendix 1 – Pre-Application Submission Requirements*: In Section 2, consider adding a new subsection "k", which would require the applicant to submit a discussion on expected sea level rise and what adaptation is being proposed to manage the effects of sea level rise.
- *Appendix 2 – Flood Plain Overlay District Special Permit Submission Criteria*: In Section 2, consider adding a new subsection "k", which would require the applicant to submit a discussion on expected sea level rise and what adaptation is being proposed to manage the effects of sea level rise.

Potential Changes to the Oak Bluffs Zoning By-Laws

- Consider amending By-Law to provide incentives to residential and commercial property owners to raise and protect structures:
  - Consider allowing higher maximum height restrictions in Sections 4.2.8, in the case of structures being elevated to improve flood protection.
  - Consider adopting a freeboard incentive for residential and commercial building elevation projects. Town of Hull adopted a $500 permit fee reduction for an additional 2 ft. of freeboard.
  - *Section 8.1.1 (Floodplain Overlay District Statement of Purpose)* – Consider adding a subsection "g" as follows:

    g) Protect public and private infrastructure from the combined effects of rising sea levels due to climate change and storm surge.
  - *Section 8.1.5 (Permitted Uses by Special Permit)* – Consider adding subsections "7", "8" and "9" to 8.1.5.1 as follows:

    7. Raising and altering roadways, sidewalks and parking lots to adapt to the effects of sea level rise and storm surge.
    8. Installing temporary and/or permanent flood protection barriers.
    9. Raising of residential and commercial structures to be above the design flood elevation.
- *Section 8.1.6.2.8*: Consider amending this subsection, which lists man-made alterations to sand dunes as a prohibited use within the V, VE and AO Zones of the FPOD. The language as written

prohibits constructing an artificial dune or other potential dune protection projects. Consider amending the language to read as follows:

> 8. Man-made alterations to sand dunes, with the exception of dune restoration and enhancement projects for the purpose of flood and erosion control to adapt to rising sea levels due to climate change and storm surge.

- *Section 8.1.12 (Definitions)*: Consider adding a definition for sea level rise and how it is to be determined.

- *Section XIII (Coastal Regulations)*: Consider adjusting references to 10 ft. above MSL to reflect latest baseline recommendations from this study. Adjustments would need to be made in subsections (floor level), 2 (septic systems) and 3 (water supplies). Alternatively, consider referencing instead FEMA flood maps because any new structure must comply with current FEMA base flood elevations.

- *Section XVIII (Districts of Critical Planning Concern Regulations)*: In Subsection A (Coastal District), there may be some overlap between this section and the FPOD. Recommend coordinating the two sections and perhaps just referring to the FPOD for applicable requirements so that there is one uniform set of standards.

- Section 10.4. (Site Plan Review): Consider the following amendments to this section:

    - Subsection 10.4.1 (Applicability) – Consider adding a subsection "4" as follows:

        4. Construction of permanent flood control or protection projects.

    - Subsection 10.4.5 (Contents of Plan) – Consider adding subsection "7" as follows:

        7. For projects located within the FPOD, provide a discussion on how the proposed project mitigates the combined effects of sea level rise and storm surge. Include information on how sea level rise is included in the project design, what temporary and permanent measures are used to control potential flooding, and any adverse effects these measures may have on adjacent properties.

- *Section 11.0 (Definitions)*: Consider adding a definition for sea level rise and how it is defined, calculated and at what time periods. For example, you may want to establish a standard that the "Highest" curve from the U.S. National Climate Assessment (Global Sea Level Rise Scenarios for the United States National Climate Assessment, NOAA Technical Report OAR CPO-1, December 12, 2012) shall be used as the basis for all sea level rise determinations. This will ensure consistency, and will prevent developers from developing projects using a lower standard.

- *Appendix B (Table of Dimensional Requirements)*: Consider adding provisions to allow for increases to maximum building height in all zones to allow for raising of structures above the design flood elevation.

Other Potential Changes to Policies

- Consider adding language in the Subdivision Rules and Regulations and other applicable regulations, to encourage preservation of land bordering salt marsh and other coastal resources to allow for natural growth and evolution of natural resources resulting from climate change and future sea level rise.

- Establish performance standards, wherever possible, regarding design of flood protection systems to adapt to sea level rise and storm surge.

Land/Resource Acquisition

- Consider acquiring land adjacent to coastal resource areas to accommodate changing conditions of natural resource areas such as salt marsh, especially those areas identified in this study as areas of potential resource change and/or migration. The natural resource information provided in this study can be used to identify priority areas for acquisition through easements, fee interest or purchase of development rights to accommodate project effects of sea level rise.

- Investigate the possibility of implementing a rolling easements program in which the Town can purchase an easement from a property owner today in exchange for a promise to surrender the property to the Town once it is substantially damaged by a flood event. This program would be part of a “retreat” policy to be implemented in areas subject to severe and repeated flooding. Rolling easements are a potential way to provide cash to a property owner today with the understanding that when the property is substantially damaged, it will not be rebuilt and will be turned over to the Town. Based on information provided in the latest Dukes County Hazard Mitigation Plan Update dated March 19, 2014, there have been 60 total properties in Oak Bluffs that have submitted flood insurance claims, of which nine (9) are classified as “repetitive loss” properties by the Community Rating System (CRS) of the National Flood Insurance Program. These nine properties, with a total of 23 claims among them, each having had at least two or more flood claims of $1,000 or more in any given 10-year period since 1978, might be ideal candidates for such a program as they have already experience repeated flood damage in the past. It is likely that these properties will experience more claims in the future unless they have been elevated or otherwise protected from flooding. Four of these properties have experienced five or more claims related to flooding.

Potential Policies for Public Projects

- Develop policies for public projects that incorporate the anticipated effects of climate change and sea level rise and promote more sustainable practices throughout the community.

  - Require that all Town-funded projects take into account predicted impacts of climate change and sea level rise.

  - Update the County’s Hazard Mitigation Plan in the context of this study and amend as appropriate. Include a documentation requirement/goal to build data on the impacts of coastal storms to inform implementation of future adaptation measures.

- Develop a regular (perhaps bi-annual) inventory/report of actions taken by the community to improve resilience to climate change and sea level rise.

Develop a Coastal Flood Operations Plan

- Consider developing a Coastal Flood Operations Plan to prepare for and minimize flood damage due to coastal flooding as a result of extreme weather events. The plan will help to institutionalize flood prevention actions that need to be performed before, during and after a major storm.
  - The plan should utilize actual maximum predicted water elevations for a storm and should clearly define what the sources of the data are and who makes the decision to implement the plan.
  - The plan should clearly define actions to be taken based on the maximum predicted water elevations, parties responsible to perform the actions and timelines required to implement the actions. Actions should include pre-storm mobilization, monitoring during the storm, and post-storm recovery.
  - The plan should identify training, storage, and maintenance needs for any specific equipment such as temporary flood barriers.
  - Each facility being protected should have facility-specific instructions located on-site for easy access during pre-storm mobilization.
  - The plan should be incorporated into the City's overall emergency response planning documents.

Join the National Flood Insurance Program Community Rating System

The National Flood Insurance Program's (NFIP) Community Rating System (CRS) recognizes and encourages community floodplain management activities that exceed the minimum NFIP standards. Depending upon the level of participation, flood insurance premium rates for policyholders in the community can be reduced up to 45%, depending on the credit level achieved by the community. Besides the benefit of reduced insurance rates, CRS floodplain management activities enhance public safety, reduce damages to property and public infrastructure, avoid or reduce economic disruption and losses, reduce human suffering, and protect the environment. Technical assistance on designing and implementing some activities is available at no charge. Participating in the CRS provides an incentive to maintaining and improving a community's floodplain management program over the years. Implementing some CRS activities can also help projects qualify for certain other Federal assistance programs.

To participate in the program, Oak Bluffs can choose to undertake some or all of the 19 public information and floodplain management activities, which fall under the following four broad categories:

- *Series 300 - Public Information Activities:*
  This series credits programs that advise people about flood hazards, flood insurance, and ways to reduce flood damage. The activities also provide data that insurance agents need for accurate flood insurance rating. It includes the possible following activities:

- 310 Elevation Certificates (*Required*)
- 320 Map Information Service
- 330 Outreach Projects
- 340 Hazard Disclosure
- 350 Flood Protection Information
- 360 Flood Protection Assistance
- 370 Flood Insurance Promotion

- *Series 400 - Mapping and Regulations*:
  This series credits programs that provide increased protection to new development. It includes the possible following activities:

  - 410 Floodplain Mapping
  - 420 Open Space Preservation
  - 430 Higher Regulatory Standards
  - 440 Flood Data Maintenance
  - 450 Stormwater Management

- *Series 500 - Flood Damage Reduction Activities*:
  This series credits programs that reduce the flood risk to existing development. It includes the possible following activities:

  - 510 Floodplain Management Planning (*required*)
  - 520 Acquisition and Relocation
  - 530 Flood Protection
  - 540 Drainage System Maintenance

- *Series 600 - Warning and Respons*e:
  This series credits flood warning, levee safety, and dam safety projects. It includes the possible following activities:

  - 610 Flood Warning and Response
  - 620 Levee Safety
  - 630 Dam Safety

More detailed descriptions of each of the above activities is described in the *CRS - A Local Official's Guide to Saving Lives, Preventing Property Damage and Reducing the Cost of Flood Insurance* published by FEMA's National Flood Insurance Program, which is available on-line at:

Many of the recommendations in this study, if implemented, will qualify toward the above CRS activities. To get credit for activities already performed, the Town will need to prepare an application documenting the efforts performed.

Install a Tide Gauge in Oak Bluffs Harbor

Consider installing an automated tide gauge in Oak Bluffs Harbor to monitor actual sea level rise locally. This information will be very valuable for longer-term planning as a database of tidal data is collected.

Develop a Dredge Management Plan

After major storms, the Town often has to expend a large amount of money to dredge channels that silt up. For example, after "Hurricane" Sandy, the Town spent approximately $300,000 to dredge the two entrance channels at Sengekontacket Pond, which had silted up, almost to the point where the pond was cut off from tidal flow. A coastal processes study should be conducted to understand the sediment transport processes at work, and what possible mitigation measures can be taken to limit detrimental sediment transport. The Town should also investigate the feasibility and costs (capital and operating) associated with purchasing dredging equipment that can be quickly utilized to address siltation issues after major storms, as well as scheduled maintenance dredging. Dredging equipment could be purchased as a regional purchase, perhaps in conjunction with other Towns on Martha's Vineyard. Doing a regional purchase will help defray the acquisition, maintenance and operating costs.

REOMMENDATIONS FOR FURTHER ACTION

The following recommendations for further action are a guide to help the Town of Oak Bluffs in its quest to make the Town more resilient to the effects of sea level rise and storm surge:

Short Term Recommendations

1. Establish a local study committee comprised of land-use boards, including the Planning Board, Conservation Commission, Zoning Board of Appeals and Board of Health to review existing Town land-use regulations, by-laws and policies with the goal of updating them to include language to address flooding due to future sea level rise and storm surge. Present the study committee's recommended changes to the applicable bodies which have the authority to implement the changes and help to get the changes implemented.

2. Establish a committee made up of representatives from the Police and Fire Departments, DPW, Emergency Management and Selectmen to formalize and develop a Flood Operations Plan for the Town. The Flood Operations plan should be coordinated with outside agencies such as the Steamship Authority, State Police, private ferry services, and utility and fuel companies.

3. Investigate joining the National Flood Insurance Program Community Rating System to help with flood adaption and to help lower flood insurance premiums for residents and businesses.

4. Install a tide gauge in Oak Bluffs Harbor to help monitor local sea level rise.

5. Raise the electrical panels at the School Street Pump Station.

6. Enclose the pump station electrical equipment at the Siloam Avenue Sewer Pump Station in a flood-resistant enclosure.

7. Enclose the electrical equipment at the "Our Market" Sewer Pump Station in a flood-resistant enclosure.

8. Investigate the possibility of implementing a rolling easement program or other incentive-based programs with the goal of removing residential and business properties from areas that are particularly vulnerable to flooding. This would be part of a "retreat" policy.

9. Apply for CZM grant funding or use Community Preservation Act funds to conduct a more detailed study of natural resources identified in this report as being vulnerable to the long term effects of sea level rise, with the goal of identifying specific projects that can be undertaken with approximate construction costs.

10. Apply for grant funds (CZM or Hazard Mitigation Grant are possible sources) to undertake a feasibility study to further refine adaptation strategies for the Oak Bluffs Harbor area.

11. Meet with MassDOT to discuss potential road improvements at Seaview Avenue with the aim of reducing the road's vulnerability to flooding by either raising the road, introducing sea walls, or introducing sacrificial dunes with beach nourishment.

12. Investigate the feasibility and costs of raising low sections of Eastville Avenue and County Road in the vicinity of the Hospital with the goal of improving emergency access to the Hospital during major storm events.

13. Develop a Dredge Management Plan, and investigate the feasibility of purchasing dredging equipment, possibly in conjunction with other communities on Martha's Vineyard or on Cape Cod.

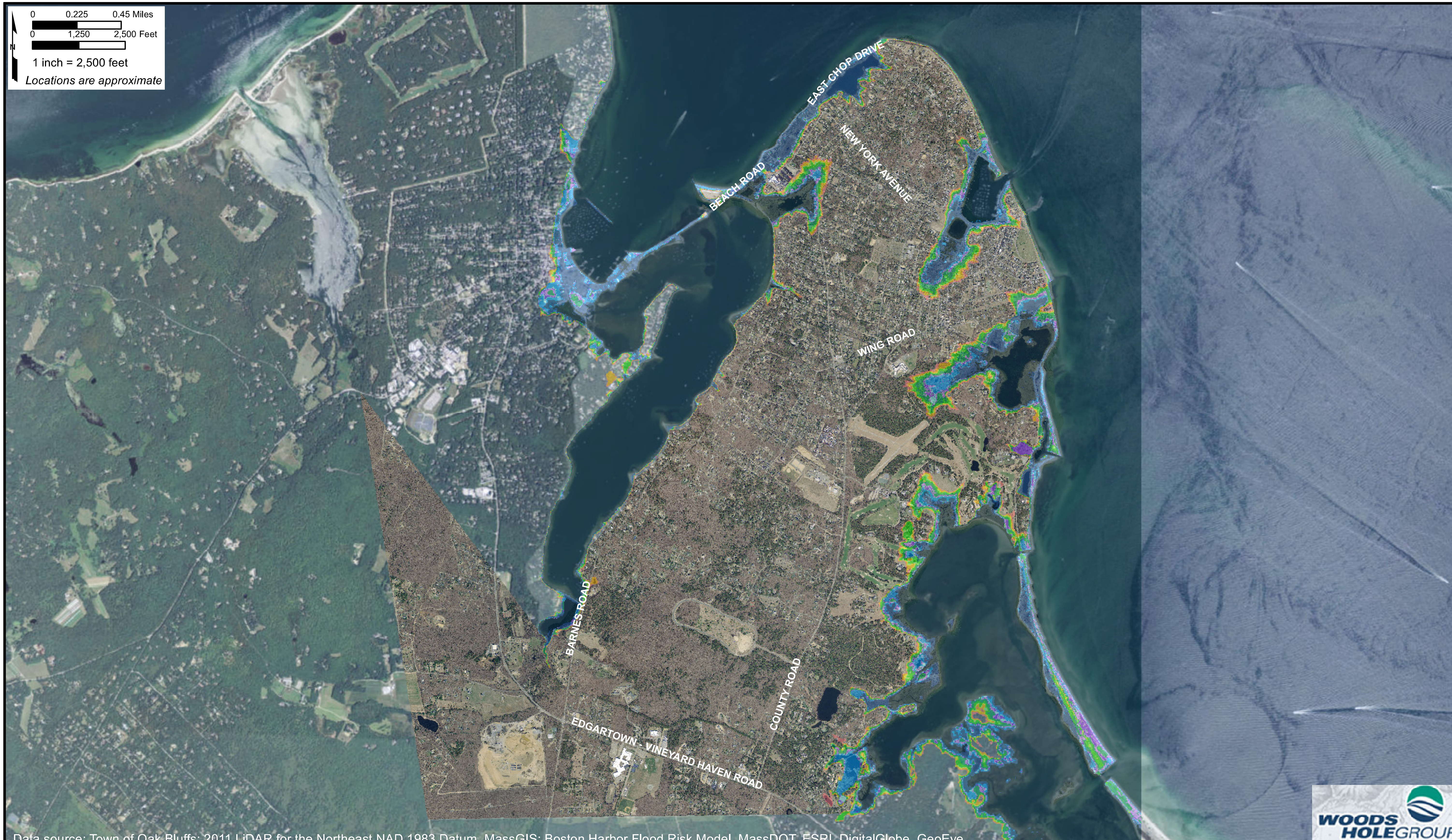
Long Term Recommendations

14. Implement flood proofing measures at the Police Department Building.

15. Review the conclusions in this report based on updated water surface modeling results, which will be released by MassDOT in several years.

16. Investigate the feasibility and costs of constructing a hurricane barrier system at the entrance of Oak Bluffs Harbor.

APPENDIX A – INNUNDATION MAPS



Legend

Percent Probability of Inundation

0.1%	2%	25%
0.2%	5%	30%
0.5%	10%	50%
1%	20%	100%

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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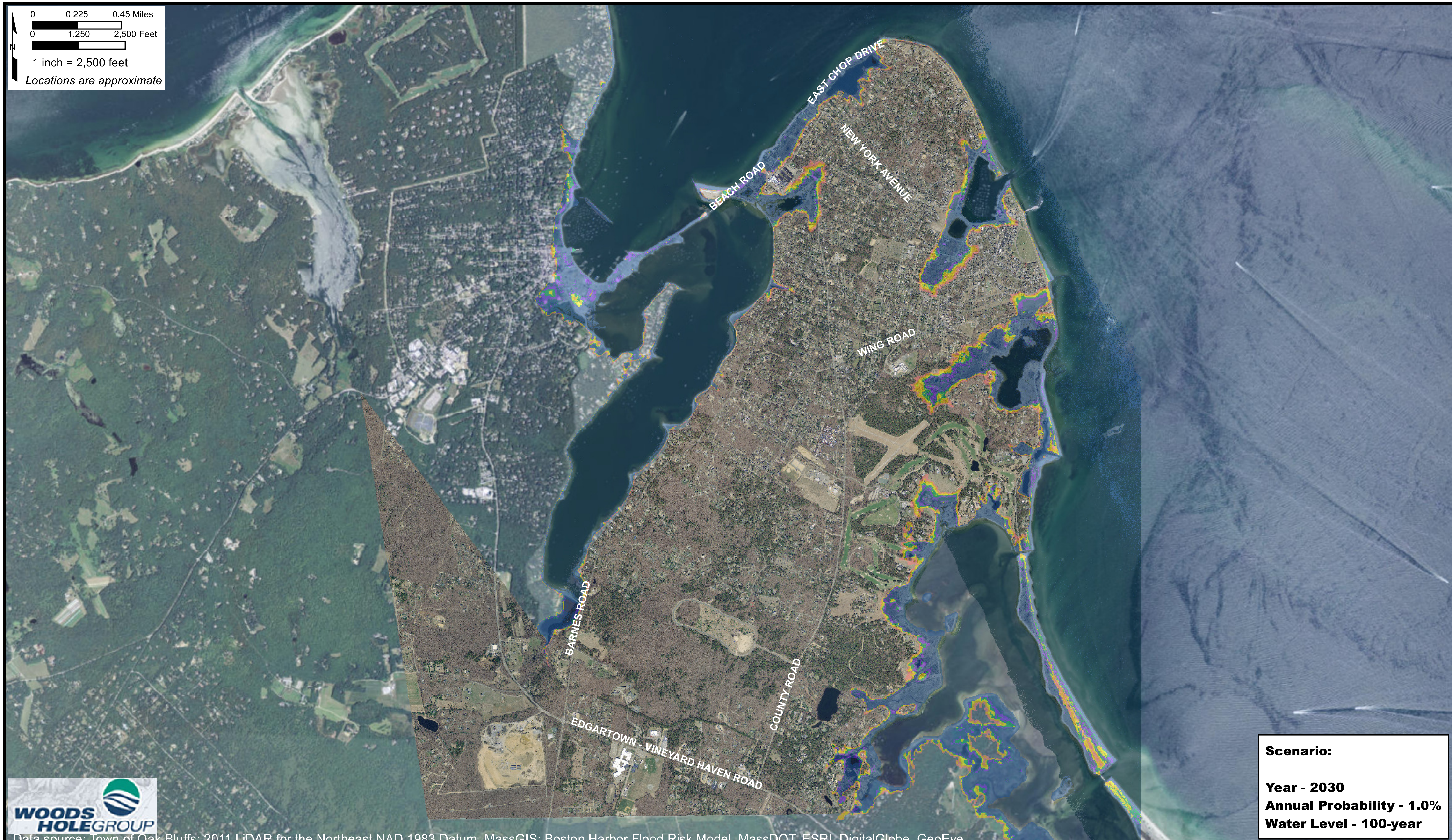
FILE NAME:	OakBluffs_2030_PercentRisk.mxd

Percent Probability of Inundation Map
YEAR 2030

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-1



Legend

Depth of Flooding Above Ground at 1% Probability (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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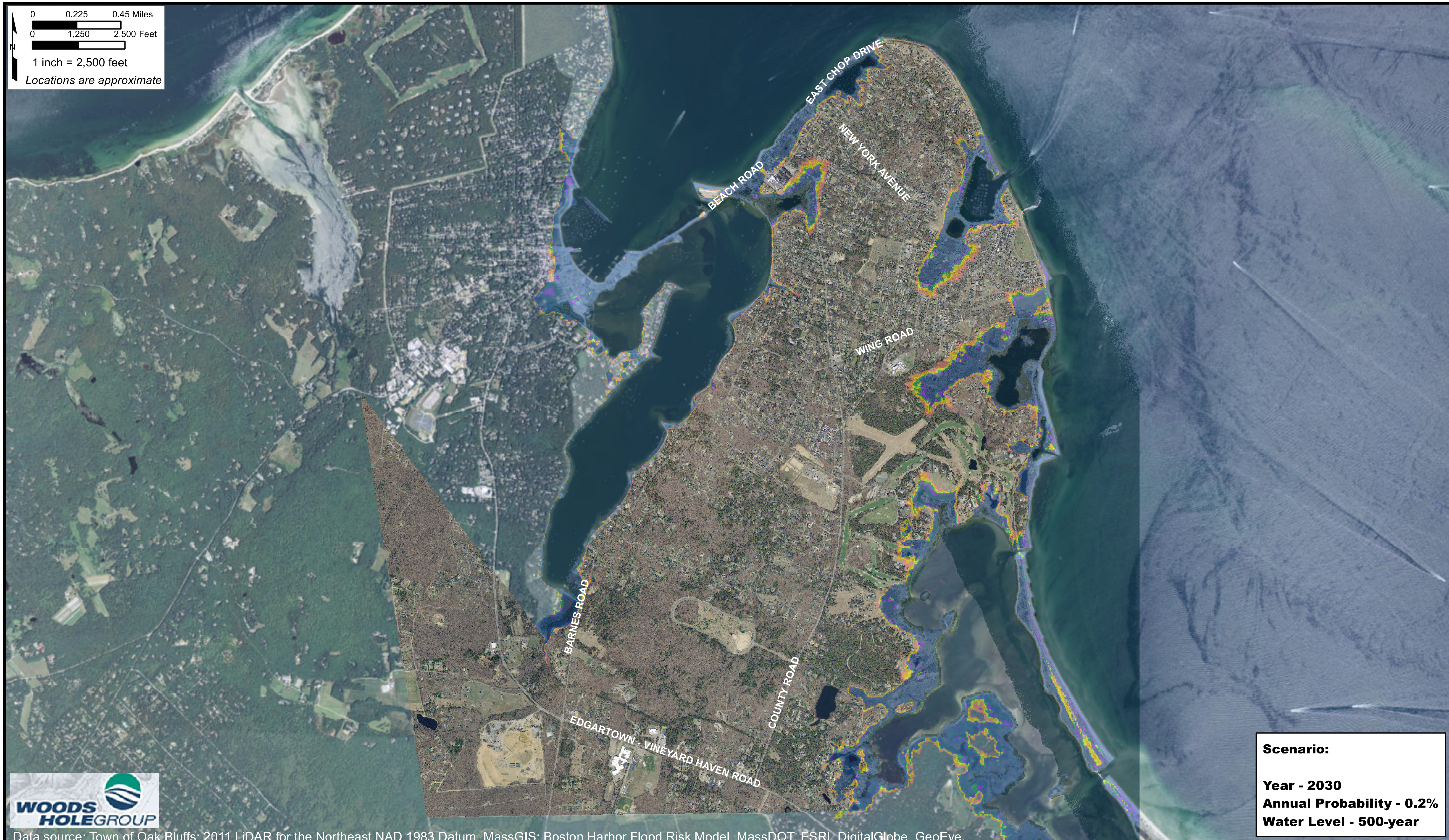
Depth of Flooding Map

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-2



Legend

Depth of Flooding Above Ground at 0.2% Probability (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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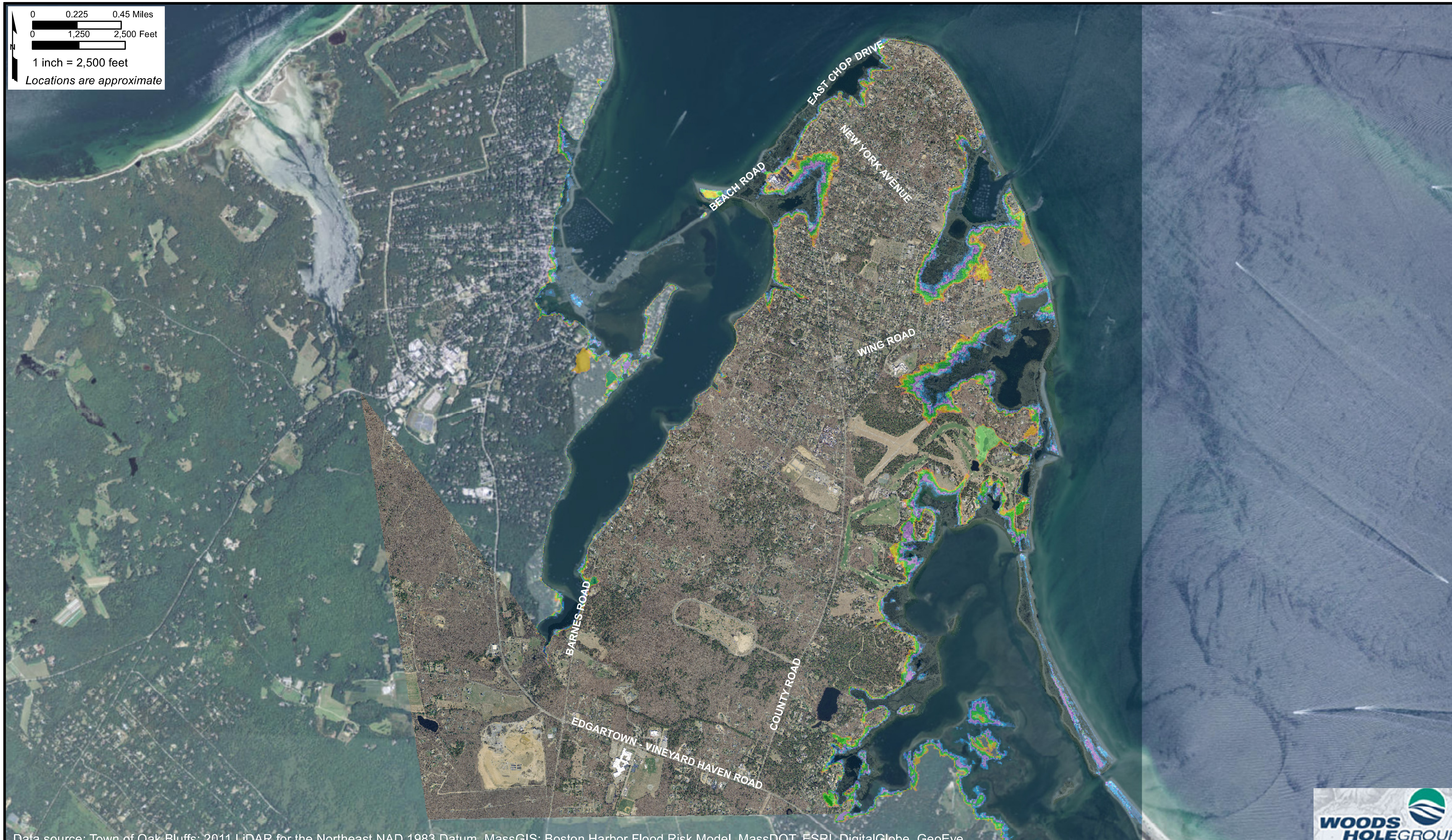
FILE NAME:	OakBluffs_2030_500yr_Depth.mxd

Depth of Flooding Map

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-3



WOODS HOLE GROUP

Legend

Percent Probability of Inundation

0.1%	2%	25%
0.2%	5%	30%
0.5%	10%	50%
1%	20%	100%

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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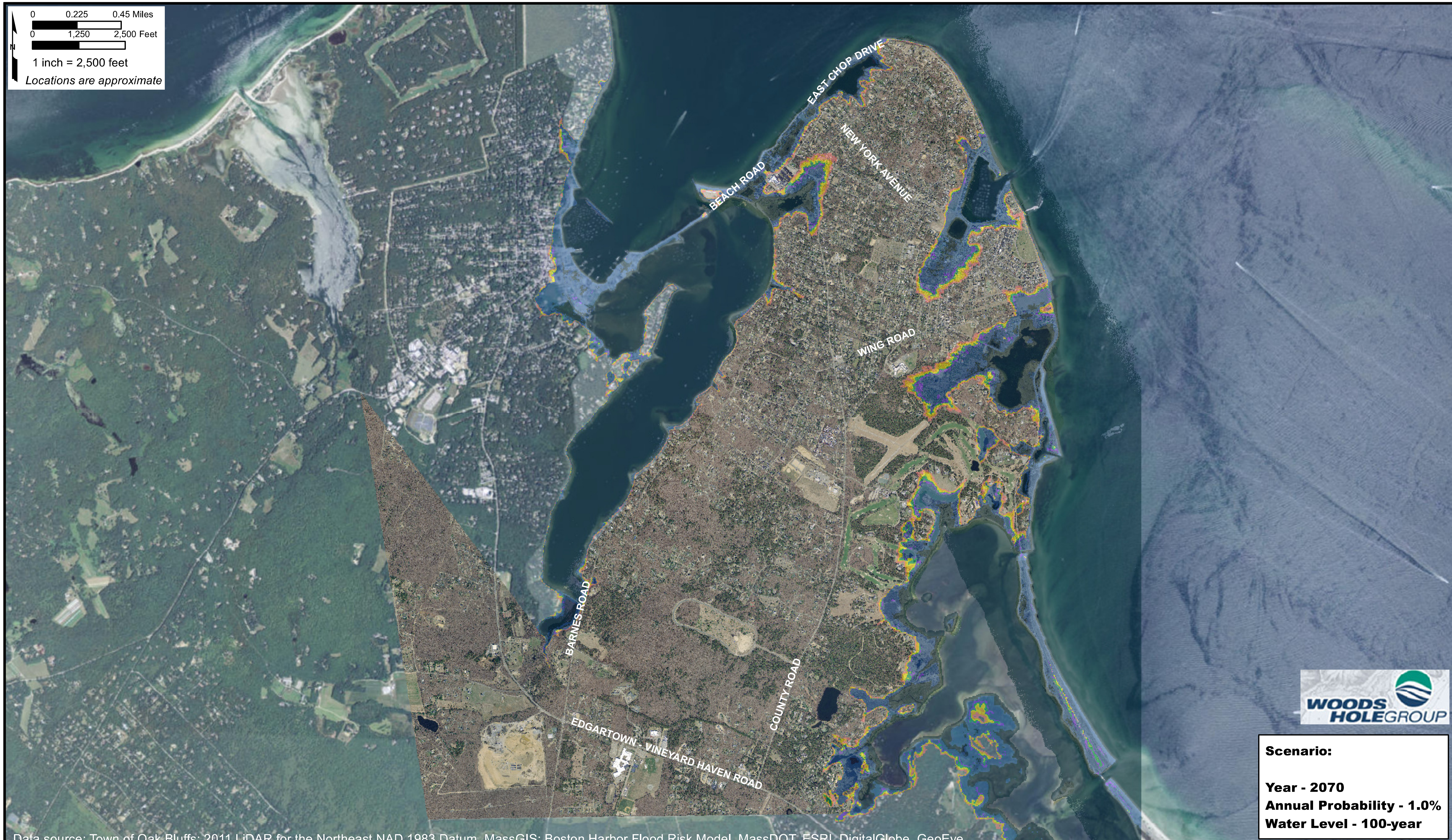
FILE NAME:	OakBluffs_2070_PercentRisk.mxd

Percent Probability of Inundation Map
YEAR 2070

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-4



Scenario:

Year - 2070
Annual Probability - 1.0%
Water Level - 100-year

Legend

Depth of Flooding Above Ground at 1% Probability (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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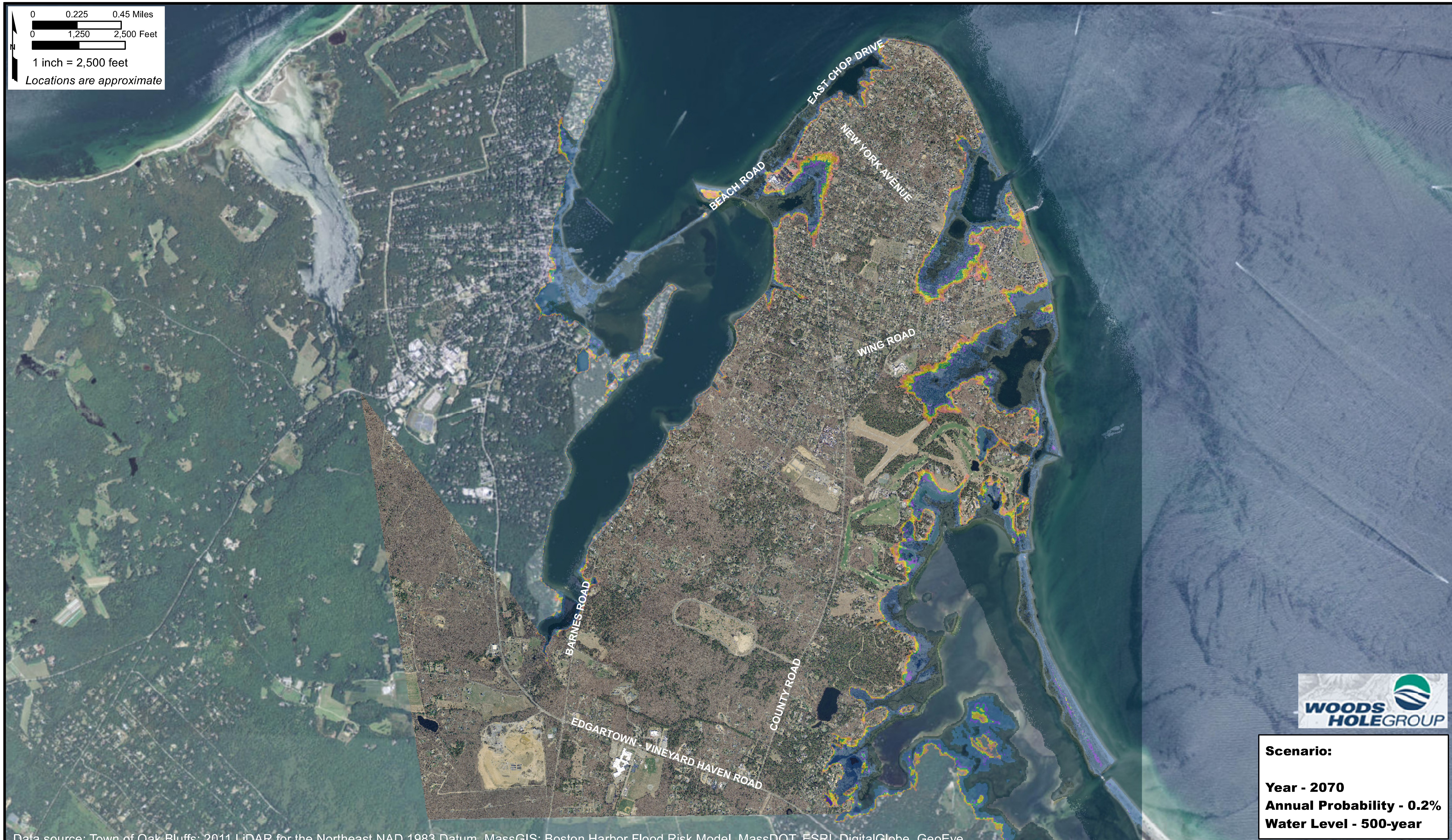
FILE NAME:	OakBluffs_2070_100yr_Depth.mxd

Depth of Flooding Map

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE

A-5



Legend

Depth of Flooding Above Ground at 0.2% Probability (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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Depth of Flooding Map

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE

A-6

Legend

Exposed Critical Infrastructure
- Municipally Owned
- Non-Municipal
- Public Coastal Barrier
- Exposed Roadway

Depth of Flooding Above Ground at 1% Probability (ft)

0 - 1	4 - 5
1 - 2	5 - 10
2 - 3	> 10
3 - 4	

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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Depth of Flooding Map
Oak Bluffs Harbor

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-7

Legend

Exposed Critical Infrastructure
- Municipally Owned
- Non-Municipal
- Public Coastal Barrier
- Exposed Roadway

Depth of Flooding Above Ground at 1% Probability (ft)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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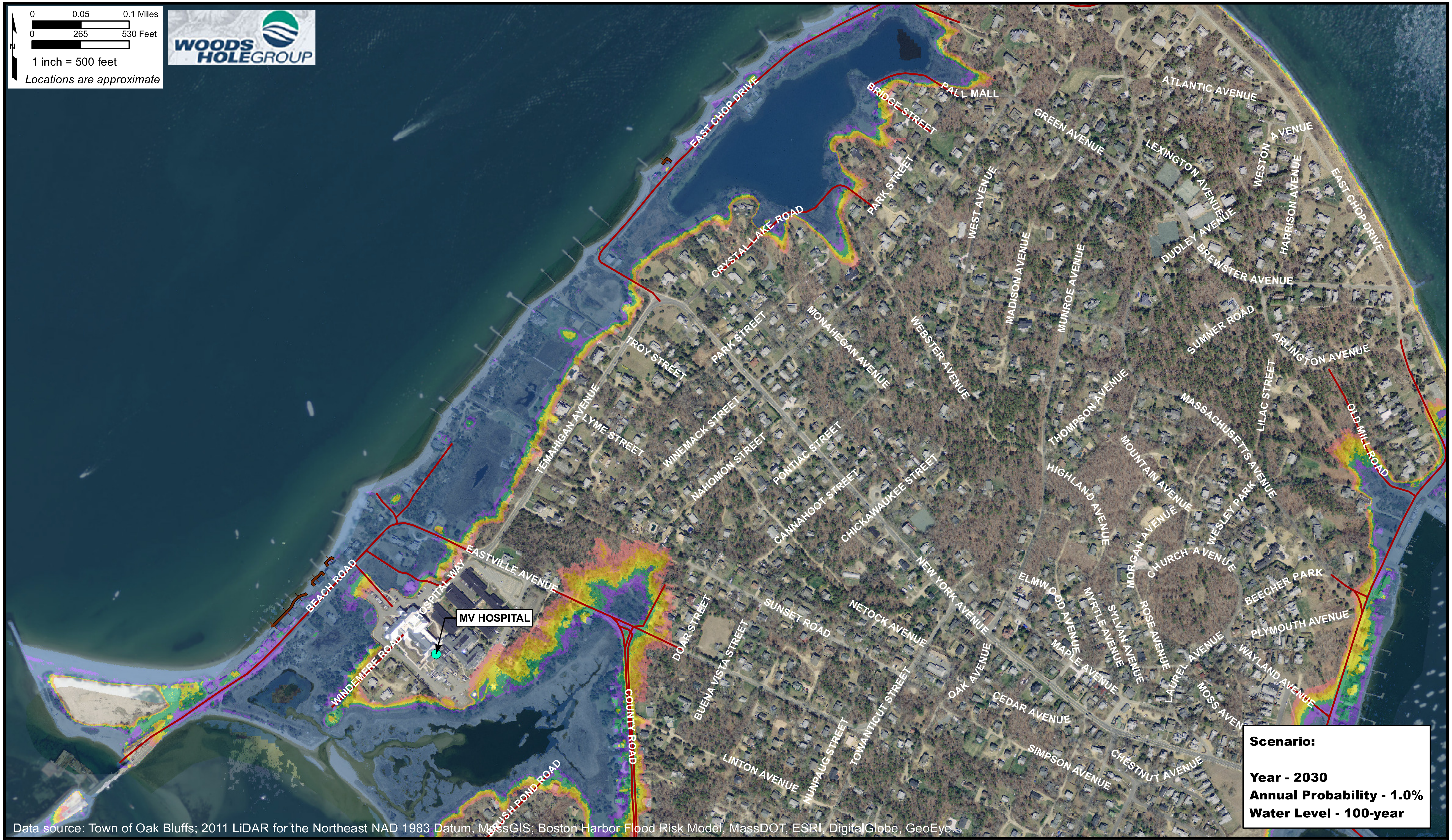
Depth of Flooding Map
Oak Bluffs Harbor

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-8



Legend

Exposed Critical Infrastructure
- Municipally Owned
- Non-Municipal
- Public Coastal Barrier
- Exposed Roadway

Depth of Flooding Above Ground at 1% Probability (ft)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- \> 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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Depth of Flooding Map
Crystal Lake & Hospital

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-9

Legend

Exposed Critical Infrastructure
- Municipally Owned
- Non-Municipal
- Public Coastal Barrier
- Exposed Roadway

Depth of Flooding Above Ground at 1% Probability (ft)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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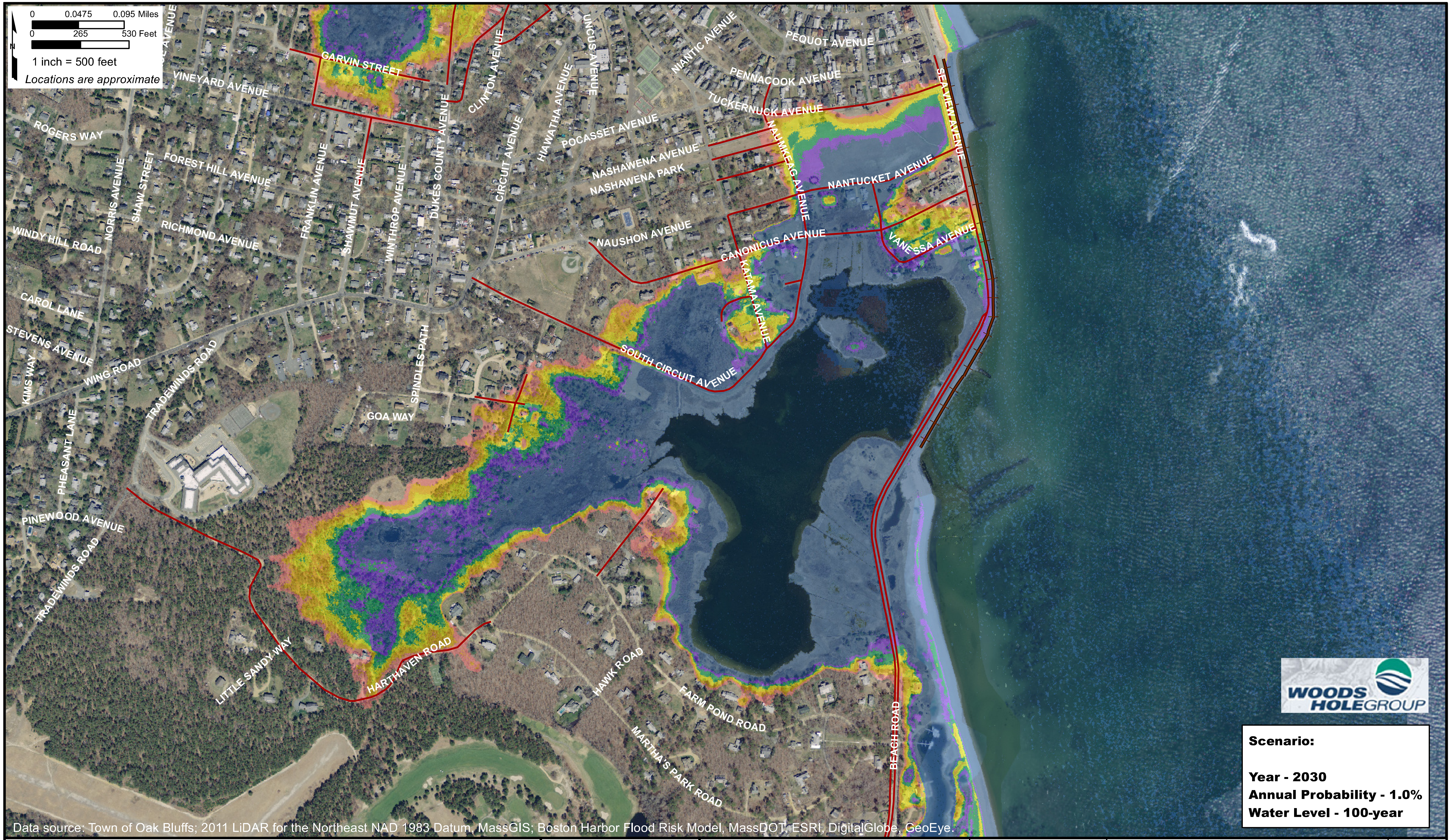
Depth of Flooding Map
Crystal Lake & Hospital

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-10



Legend

Exposed Critical Infrastructure
- Municipally Owned
- Non-Municipal
- Public Coastal Barrier
- Exposed Roadway

Depth of Flooding Above Ground at 1% Probability (ft)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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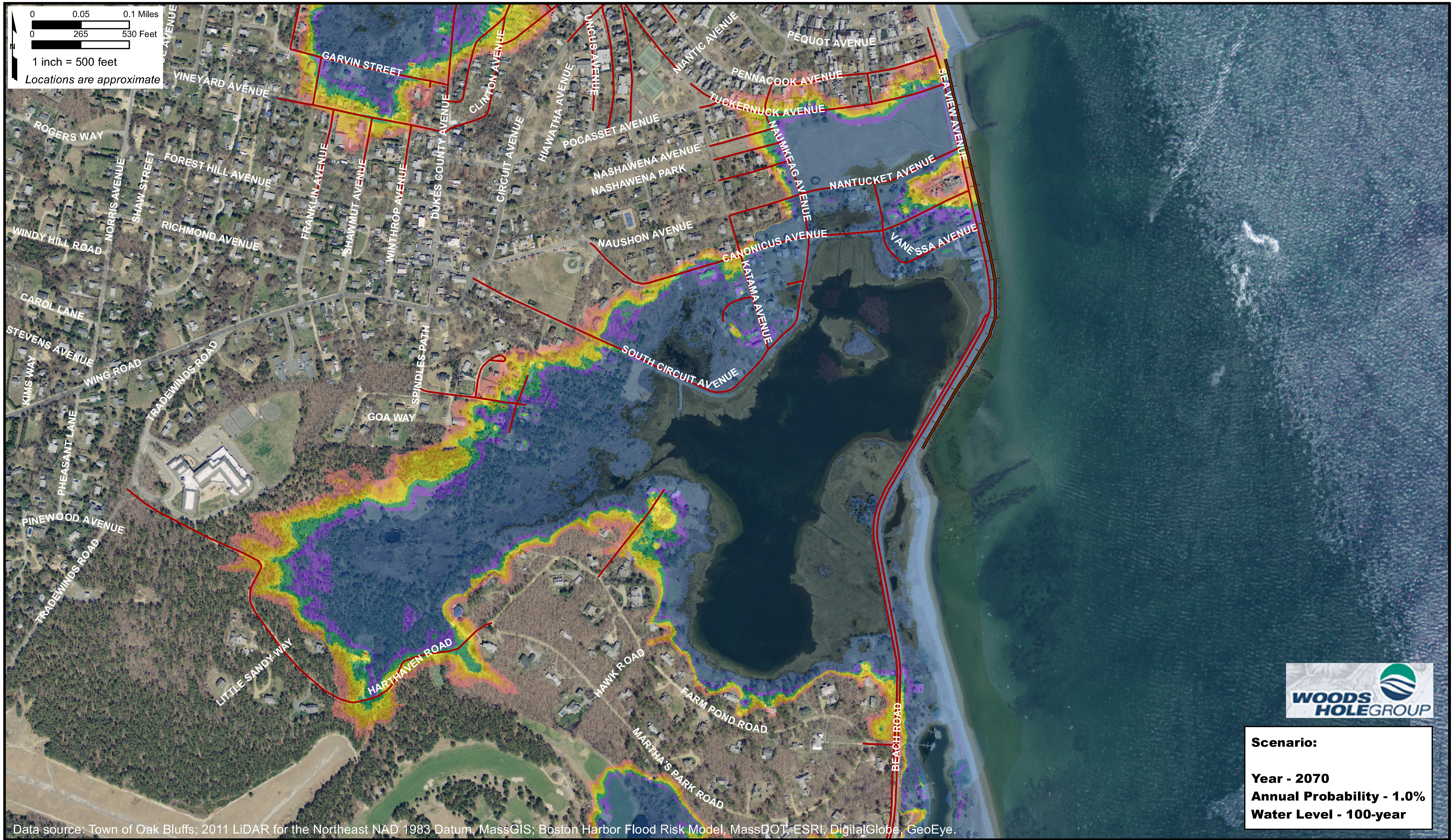
FILE NAME:	OakBluffs_2030_100yr_Closeups.mxd

Depth of Flooding Map
Farm Pond

Oak Bluffs Coastal Climate Change
Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-11



Legend

Exposed Critical Infrastructure
- Municipally Owned
- Non-Municipal
- Public Coastal Barrier
- Exposed Roadway

Depth of Flooding Above Ground at 1% Probability (ft)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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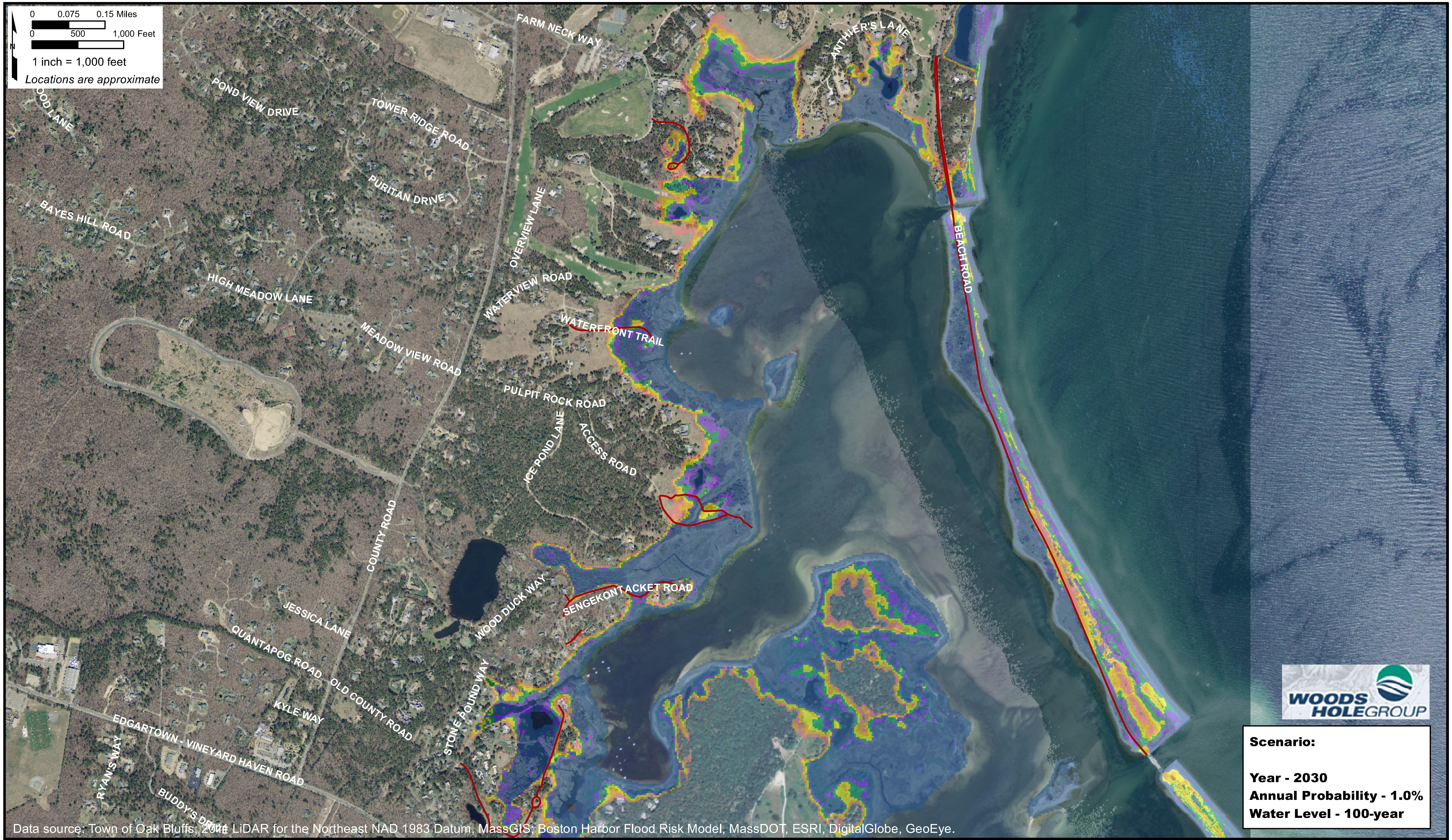
Depth of Flooding Map
Farm Pond

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-12



Legend

Exposed Critical Infrastructure

- Municipally Owned
- Non-Municipal
- Public Coastal Barrier
- Exposed Roadway

Depth of Flooding Above Ground at 1% Probability (ft)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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Depth of Flooding Map
Sengekontacket Pond

Oak Bluffs Coastal Climate Change
Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE

A-13

Data source: Town of Oak Bluffs; 2011 LiDAR for the Northeast NAD 1983 Datum, MassGIS; Boston Harbor Flood Risk Model, MassDOT, ESRI, DigitalGlobe, GeoEye.

Legend

Exposed Critical Infrastructure
- Municipally Owned
- Non-Municipal
- Public Coastal Barrier
- Exposed Roadway

Depth of Flooding Above Ground at 1% Probability (ft)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10

This flood map illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. This flood map expressly does not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on this flood map strictly represents coastal flooding from sea level rise and storm surge. This flood map shall not be used to represent the extent of flooding for which flood insurance is required. Projections depicted on this flood map are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

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Depth of Flooding Map
Sengekontacket Pond

Oak Bluffs Coastal Climate Change Vulnerability Assessment and Adaptation Plan
Oak Bluffs, Massachusetts

FIGURE
A-14

APPENDIX B – WETLAND CLASSIFICATION MAPS AND DATA

Figure B-1: 2011 Wetland Classification Areas in Oak Bluffs

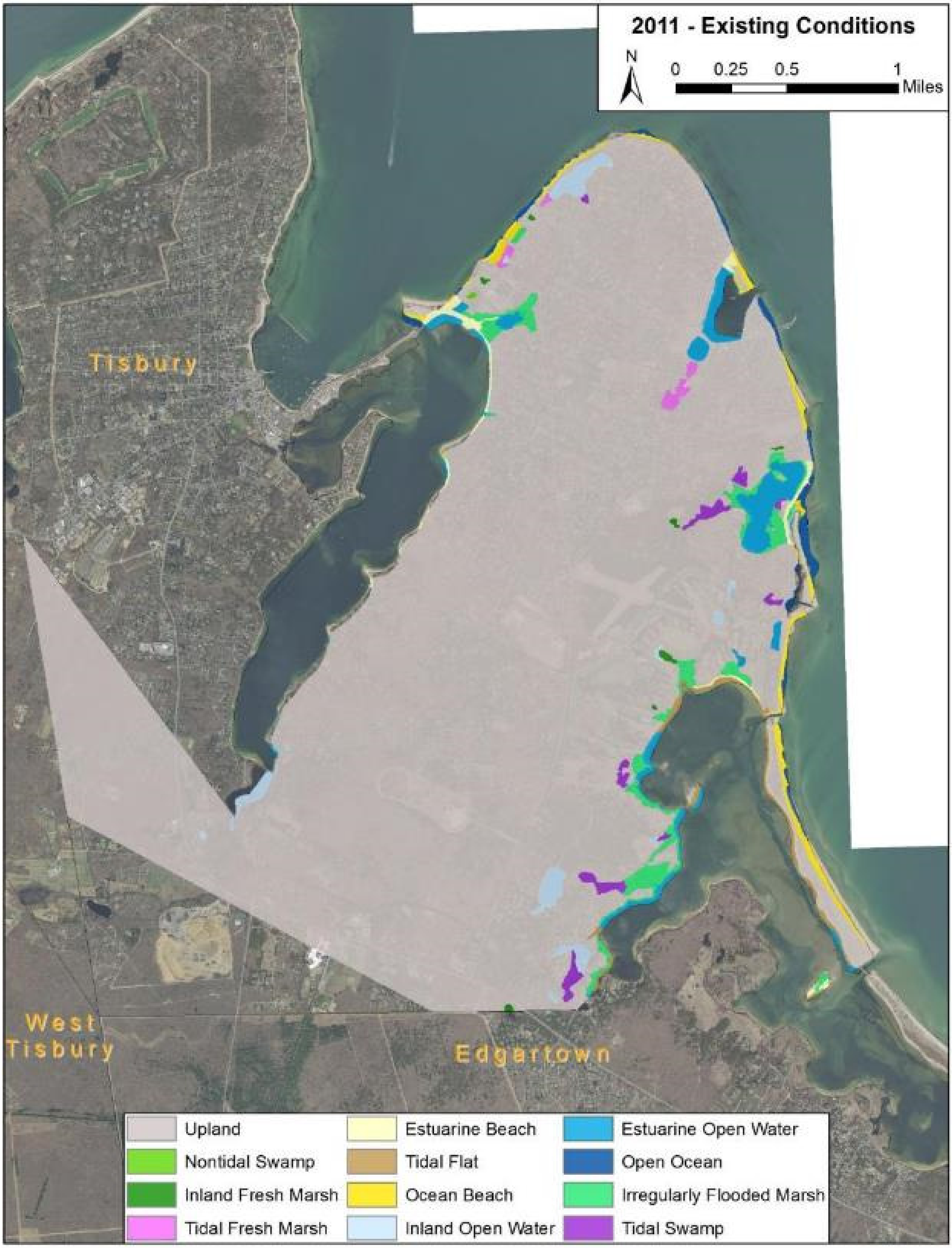

Figure B-2: 2030 Wetland Classification Areas in Oak Bluffs

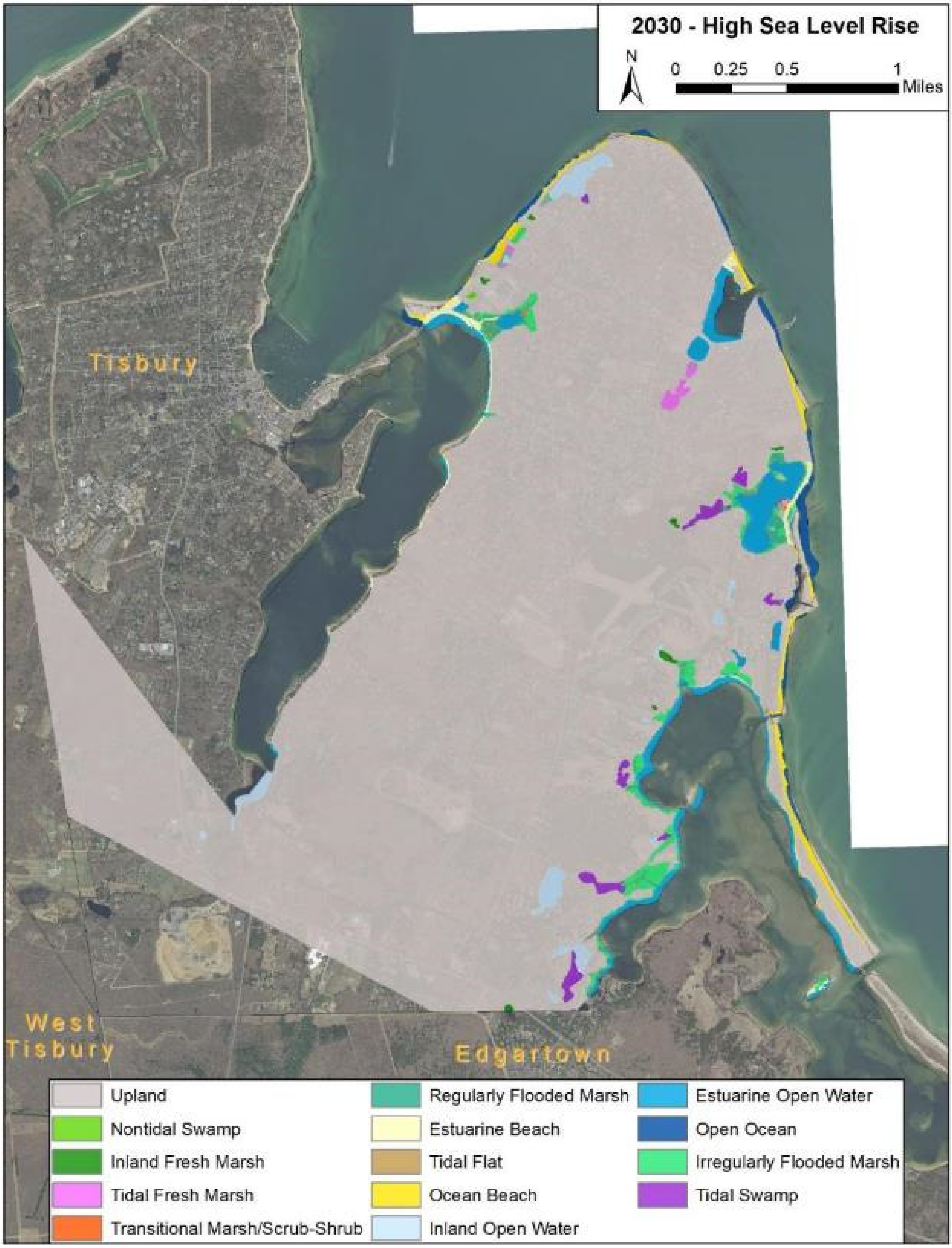

Figure B-3: 2070 Wetland Classification Areas in Oak Bluffs

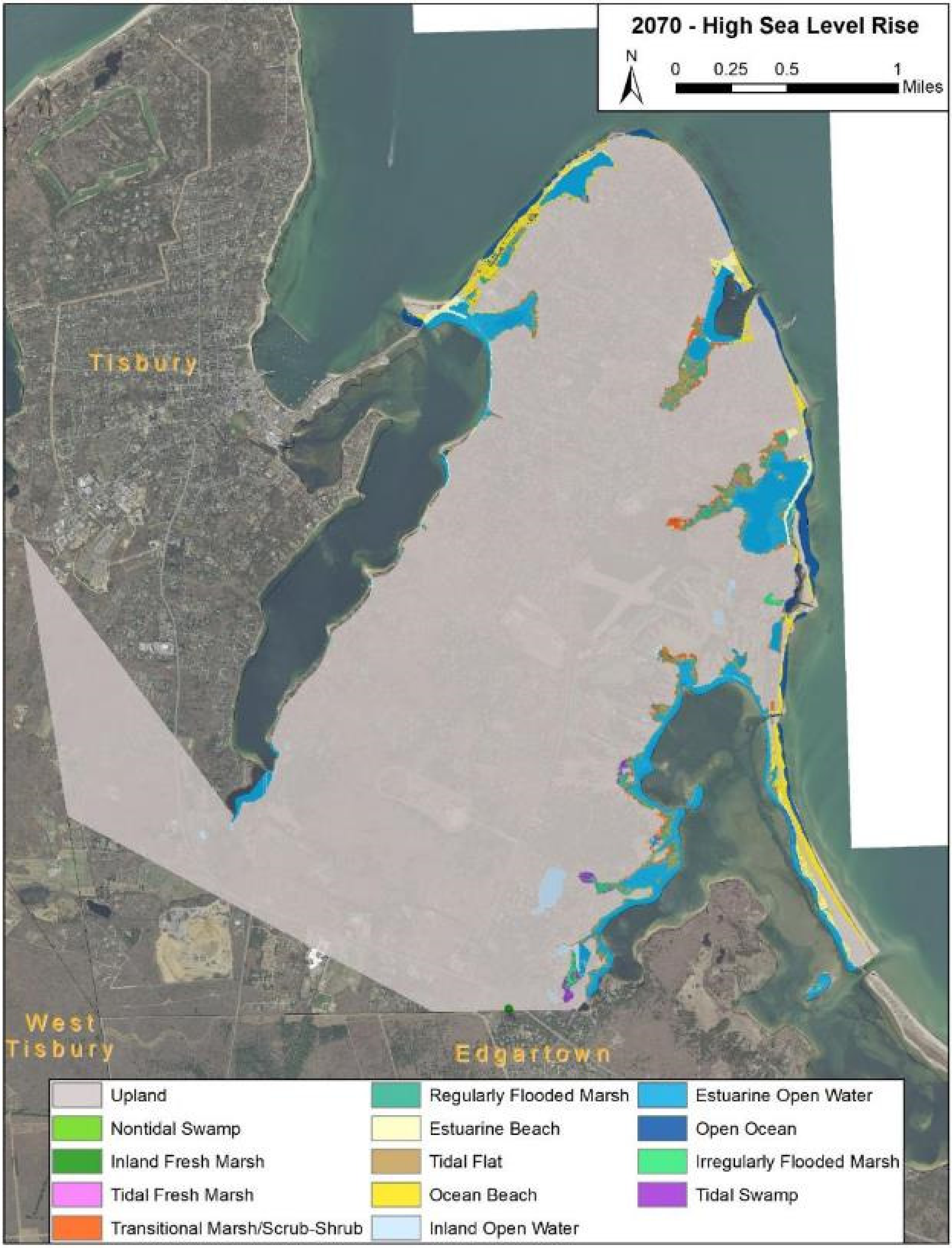

Table B-1: NWI Category to SLAMM Code Conversion Table.

		NWI Code Characters					
SLAMM Code	SLAMM Name	System	Subsystem	Class	Subclass	Water Regime	Notes
1	Developed Dryland	U					Upland
2	Undeveloped Dryland	U					Upland
3	Nontidal Swamp	P	NA	FO, SS	1, 3 to 7, None	A,B,C,E,F,G,H,J,K, None or U	Palustrine Forested and Scrub-Shrub
4	Cypress Swamp	P	NA	FO, SS	2	A,B,C,E,F,G,H,J,K, None or U	Needle-leaved Deciduous Forest and Scrub-Shrub
5	Inland Fresh Marsh	P	NA	EM, f**	All, None	A,B,C,E,F,G,H,J,K, None or U	Palustrine Emergents; Lacustrine and Riverine Nonpersistent Emergents
		L	2	EM	2, None	E,F,G,H,K, None or U	
		R	2, 3	EM	2, None	E,F,G,H,K, None or U	
6	Tidal Fresh Marsh	R	1	EM	2, None	Fresh Tidal N, T	Riverine and Palustrine Freshwater Tidal Emergen
		P	NA	EM	All, None	Fresh Tidal S, R, T	
7	Transitional Marsh / Scrub Shrub	E	2	FO, SS	1, 2, 4 to 7, None	Tidal M, N, P, None or U	Estuarine Intertidal, Scrub-shrub and Forested (ALL except 3 subclass)
8	Regularly Flooded Marsh	E	2	EM	1, None	Tidal N, None or U	Only regularly flooded tidal marsh; No intermittently flooded "P" water regime
9	Mangrove	E	2	FO, SS	3	Tidal M, N, P, None or U	Estuarine Intertidal Forested and Scrub-shrub, Broad-leaved Evergreen
10	Estuarine Beach	E	2	US	1,2	Tidal N,P	Estuarine Intertidal Unconsolidated Shores
		E	2	US	None	Tidal N,P	Only when shores
11	Tidal Flat	E	2	US	3,4, None	Tidal M, N, None or U	Estuarine Intertidal Unconsolidated Shore (mud or organic) and Aquatic Bed; Marine Intertidal Aquatic Bed
		E	2	AB	All, Except 1	Tidal M, N, None or U	
		E	2	AB	1	P	Specifically for wind-driven tides on the south coast of TX
		M	2	AB	1, 3, None	Tidal M, N, None or U	
12	Ocean Beach	M	2	US	1, 2	Tidal N, P	Marine Intertidal Unconsolidated Shore, cobble-gravel, sand
		M	2	US	None	Tidal P	
13	Ocean Flat	M	2	US	3, 4, None	Tidal M, N, None or U	Marine Intertidal Unconsolidated Shore, mud or organic, (low energy coastline)
14	Rocky Intertidal	M	2	RS	All, None	Tidal M, N, P, None or U	Marine and Estuarine Intertidal Rocky Shore and Reef
		E	2	RS	All, None	Tidal M, N, P, None or U	
		E	2	RF	2, 3, None	Tidal M, N, P, None or U	
		E	2	AB	1	Tidal M, N, None or U	
15	Inland Open Water	R	2	UB, AB	All, None	All, None	Riverine, Lacustrine, and Palustrine Unconsolidated Bottom, and Aquatic Beds
		R	3	UB, AB, RB	All, None	All, None	
		L	1, 2	UB, AB, RB	All, None	All, None	
		P	NA	UB, AB, RB	All, None	All, None	
		R	5	UB	All	Only U	
16	Riverine Tidal Open Water	R	1	All, Except EM	All, None, Except 2	Fresh Tidal S, R, T, V	Riverine Tidal Open Water
17	Estuarine Open Water	E	1	All	All, None	Tidal L, M, N, P	Estuarine subtidal
18	Tidal Creek	E	2	SB	All, None	Tidal M, N, P; Fresh Tidal R, S	Estuarine intertidal streambed
19	Open Ocean	M	1	All	All	Tidal L, M, N, P	Marine Subtidal and Marine Intertidal Aquatic Bed and Reef
		M	2	RF	1, 3, None	Tidal M, N, P, None or U	
20	Irregularly Flooded Marsh	E	2	EM	1, 5, None	P	Irregularly Flooded Estuarine Intertidal Emergent marsh
		E	2	US	2, 3, 4, None	P	Only when these salt pans are associated with E2EMN or P
21	NotUsed						
22	Inland Shore	L	2	US, RS	All	All Nontidal	Shoreline not pre-processed using tidal range elevations
		P	NA	US	All, None	All Nontidal, None or U	
		R	2, 3	US, RS	All, None	All Nontidal, None or U	
		R	4	SB	All, None	All Nontidal, None or U	
23	Tidal Swamp	P	NA	FO, SS	All, None	Fresh Tidal R, S, T	Tidally influenced swamp

APPENDIX C – RISK ASSESSMENT DATA

Table C-1 Risk Assessment Summary Table for All Asset

Type	Name/Number	Address/ Location	Critical Elevation	Consequence Score	Present Probability (%)	Present Risk Score	2030 Probability (%)	2030 Risk Score	2070 Probability (%)	2070 Risk Score	Composite Risk Score
Bulkhead/Seawall	221-008-000-293-001	Circuit Ave Ext to Sea View Ave Ext	2.5	63	50	3167	100	6333	100	6333	4750
Roadway	East Chop Drive	New York Avenue to Temahigan Avenue	3.2	50	50	2500	100	5000	100	5000	3750
Roadway	Central Avenue	Lake Avenue to Montgomery Avenue	2.1	37	100	3667	100	3667	100	3667	3667
Roadway	Canonicus Avenue	Seaview Avenue to Nauchon Avenue	3.1	33	50	1667	100	3333	100	3333	2500
Roadway	Nantucket Avenue	Nauchon Avenue to Seaview Avenue	2.1	33	50	1667	100	3333	100	3333	2500
Revetment	221-006-000-034-001	East Chop Dr at Hospital Rd	1.6	30	100	3000	100	3000	100	3000	3000
Roadway	Eastville Avenue	Dead End to Towanticut Street	2.2	57	30	1700	50	2833	100	5667	2833
Revetment	221-001-000-003-001	330 East Chop Dr	0.5	27	100	2667	100	2667	100	2667	2667
Bulkhead/Seawall	221-005-000-001-002	East Chop Dr at Hospital Rd	2.2	27	100	2667	100	2667	100	2667	2667
Revetment	221-005-000-003-003	East Chop Dr at Hospital Rd	2.7	27	50	1333	100	2667	100	2667	2000
Revetment	221-001-000-013-001	East Chop Dr at Marginal St	3.0	27	30	800	100	2667	100	2667	1733
Facility	Island Queen Ferry Dock	Circuit Ave Ext at Seaview Ave	3.9	47	30	1400	50	2333	100	4667	2333
Facility	Sewer Pump Station	13 School St	3.1	47	30	1400	50	2333	100	4667	2333
Facility	Sewer Substation	14 Siloam Ave	2.8	43	50	2167	50	2167	100	4333	2600
Roadway	Hospital Road	Beach Road to Dead End	2.8	43	0	0	50	2167	100	4333	1517
Roadway	Commonwealth Avenue	Siloam Avenue to Montgomery Avenue	4.1	40	30	1200	50	2000	100	4000	2000
Roadway	New York Avenue	Temahigan Avenue to East Chop Drive	4.3	40	25	1000	50	2000	100	4000	1900
Bulkhead/Seawall	221-009-000-058-003	Sea View Ave Ext	5.2	57	10	567	30	1700	100	5667	1927
Roadway	County Road	Eastville Avenue to Edgartown Vineyard Haven Road	4.9	57	10	567	30	1700	100	5667	1927
Roadway	Oak Bluffs Avenue	Lake Avenue to Seaview Avenue	4.9	57	0	0	30	1700	100	5667	1643
Facility	Electrical Panel	1 East Chop Dr	3.9	33	30	1000	50	1667	100	3333	1667
Roadway	Montgomery Avenue	Trinity Park to Commonwealth Avenue	4.1	33	30	1000	50	1667	100	3333	1667
Roadway	Siloam Avenue	Jordan Crossing to Dukes County Avenue	3.3	33	30	1000	50	1667	100	3333	1667
Roadway	Frazier Circle	First Avenue to Dead End	3.9	30	30	900	50	1500	100	3000	1500
Roadway	James Street	Greenleaf Avenue to Huntington Avenue	4.3	30	25	750	50	1500	100	3000	1425
Facility	Oak Bluffs Harbor Master	10 Circuit Ave Ext	4.6	47	20	933	30	1400	100	4667	1820
Roadway	Huntington Avenue	Dead End to James Street	4.3	27	25	667	50	1333	100	2667	1267
Roadway	Circuit Avenue Extension	Oak Bluffs Avenue to Seaview Avenue Extension	3.5	53	10	533	25	1333	100	5333	1733
Revetment	221-018-000-032-001	Beach Rd at Farm Pond	5.3	50	10	500	25	1250	100	5000	1625
Roadway	Sengekontacket Road	County Road to Dead End	5.2	37	10	367	30	1100	100	3667	1247
Roadway	North Bluff Lane	Circuit Avenue Extension to Seaview Avenue Extension	3.5	37	0	0	30	1100	100	3667	1063
Roadway	South Circuit Avenue	Circuit Avenue to Naumkeag Avenue	2.8	33	25	833	30	1000	100	3333	1383
Roadway	Franklin Street Extension	Vineyard Avenue to Garvin Street	5.1	33	10	333	30	1000	100	3333	1133
Roadway	Saco Avenue	Circuit Avenue Extension to Seaview Avenue Extension	3.5	37	10	367	25	917	100	3667	1192
Roadway	Bridge Street	Park Street to Marginal Street	4.6	30	20	600	30	900	100	3000	1170
Roadway	Marginal Street	Dead End to East Chop Drive	5.1	30	10	300	30	900	100	3000	1020
Roadway	Calves Pasture Lane	Hidden Cove Road to Dead End	5.5	33	5	167	25	833	100	3333	1000
Roadway	Eddy Avenue	Crystal Lake Road to Park Street	4.5	27	25	667	30	800	100	2667	1107
Roadway	Pall Mall	Park Street to Winemack Street	5.2	27	10	267	30	800	100	2667	907
Bulkhead/Seawall	221-009-000-058-001	Sea View Ave Ext at Ferry Terminal	6.0	63	5	317	10	633	50	3167	982
Bulkhead/Seawall	221-003-000-028-001	East Chop Dr at East Chop Beach Club	5.4	23	10	233	25	583	100	2333	758
Bulkhead/Seawall	221-009-000-001-001	Beach Rd at Farm Pond	5.9	53	5	267	10	533	100	5333	1360
Roadway	Katama Avenue	Tuckernuck Avenue to South Circuit Avenue	6.2	33	5	167	10	333	50	1667	517
Roadway	Acushnet Avenue	South Circuit Avenue to Dead End	6.2	30	5	150	10	300	50	1500	465
Roadway	Pawtucket Avenue	Trinity Park to Dukes County Avenue	3.3	30	2	60	10	300	25	750	270
Roadway	Sea View Avenue	Oak Bluffs Avenue to Beach Road	7.8	57	0	0	5	283	25	1417	368
Roadway	Lake Avenue	New York Avenue to Seaview Avenue	3.4	53	2	107	5	267	30	1600	453
Bulkhead/Seawall	221-009-000-001-002	Beach Rd at Waban Park	6.6	50	5	250	5	250	50	2500	700
Roadway	Kennebec Avenue	Samoset Avenue to Oak Bluffs Avenue	7.1	50	5	250	5	250	30	1500	500
Roadway	Circuit Avenue	Dukes County Avenue to Lake Avenue	4.0	43	5	217	5	217	30	1300	433

Type	Name/Number	Address/ Location	Critical Elevation	Consequence Score	Present Probability (%)	Present Risk Score	2030 Probability (%)	2030 Risk Score	2070 Probability (%)	2070 Risk Score	Composite Risk Score
Roadway	Crystal Lake Road	New York Avenue to Eddy Avenue	3.7	37	2	73	5	183	25	917	275
Roadway	Clinton Avenue	Dukes County Avenue to Jordan Crossing	7.9	37	2	73	5	183	25	917	275
Roadway	Tuckernuck Avenue	Seaview Avenue to Circuit Avenue	8.0	37	2	73	5	183	25	917	275
Roadway	Debettencourt Place	Spindles Path to Dead End	7.0	33	5	167	5	167	30	1000	333
Roadway	Jordan Crossing	Siloam Avenue to Cul-De-Sac	3.8	33	5	167	5	167	30	1000	333
Roadway	Naumkeag Avenue	Ocean Avenue to Canonicus Avenue	7.1	33	5	167	5	167	30	1000	333
Roadway	Garvin Street	Second Avenue to Dukes County Avenue	7.8	33	2	67	5	167	25	833	250
Roadway	Roque Avenue	Faith Avenue to Dorothy West Avenue	7.9	33	2	67	5	167	25	833	250
Roadway	Greenleaf Avenue	Rowland Avenue to Dukes County Avenue	3.7	33	2	67	5	167	20	667	217
Roadway	Wapello Street	Eastville Avenue to Dead End	5.5	30	5	150	5	150	50	1500	420
Roadway	Heather Lane	Dead End to Dead End	7.0	30	5	150	5	150	30	900	300
Revetment	221-009-000-001-009	Sea View Ave at Ferry Terminal	8.6	63	1	63	2	127	10	633	196
Bulkhead/Seawall	221-009-000-058-004	Sea View Ave Ext	9.0	57	0.5	28	2	113	10	567	162
Facility	Ssa Ferry Terminal	1 Seaview Ave	8.6	53	1	53	2	107	10	533	165
Roadway	Goodwin Road	Naumkeag Avenue to Katama Avenue	7.1	20	5	100	5	100	30	600	200
Roadway	Beach Road	Tisbury Town Line to Eastville Avenue	7.3	47	2	93	2	93	10	467	168
Roadway	Harthaven Road	Martha's Park Road to Tradewinds Road	8.9	47	0.5	23	2	93	10	467	133
Roadway	Gull Landing	Lagoon Road to Dead End	5.6	33	2	67	2	67	20	667	187
Roadway	Butler Avenue	Victorian Park to Hope Avenue	9.3	33	0.2	7	2	67	10	333	90
Roadway	Farm Pond Road	Edgartown - Oak Bluffs Road to Martha's Park Road	9.2	33	0.2	7	2	67	10	333	90
Roadway	Barnes Road	County Road to Edgartown Vineyard Haven Road	8.6	27	1	27	2	53	10	267	83
Roadway	Newton Avenue	Lagoon Road to Linden Avenue	8.5	27	1	27	2	53	10	267	83
Roadway	Pasque Avenue	Circuit Avenue Extension to Seaview Avenue Extension	2.9	37	0.2	7	1	37	10	367	88
Roadway	Vineyard Avenue	Dukes County Avenue to County Road	9.5	33	0.2	7	1	33	10	333	80
Roadway	Rock Avenue	Central Avenue to Commonwealth Avenue	9.5	33	0.2	7	1	33	10	333	80
Facility	Oak Bluffs Police Dept	2 Oak Bluffs Ave	10.9	57	0	0	0.2	11	1	57	15
Roadway	Ocean Avenue	Seaview Avenue to Seaview Avenue	10.8	53	0	0	0.2	11	2	107	25
Roadway	Dukes County Avenue	Circuit Avenue to Lake Avenue	4.1	47	0	0	0.2	9	2	93	21
Roadway	West Clinton Avenue	Dukes County Avenue to Clinton Avenue	9.9	33	0.1	3	0.2	7	2	67	17
Roadway	Lady Slipper Way	Sengekontacket Road to Dead End	10.6	33	0	0	0.2	7	5	167	35
Roadway	Windemere Road	Hospital Road to Dead End	4.3	33	0	0	0.2	7	5	167	35
Roadway	School Street	Pacific Avenue to Dukes County Avenue	9.4	33	0	0	0.2	7	2	67	15
Roadway	Rural Circle	Circuit Avenue to Cul-De-Sac	11.0	33	0	0	0.1	3	2	67	14
Roadway	Victorian Park	Clinton Avenue to Rural Circle	11.1	33	0	0	0.1	3	2	67	14
Roadway	Hidden Cove Road	to Calves Pasture Lane	11.2	27	0	0	0.1	3	2	53	11
Roadway	Waterfront Trail	Old Harbor Lane to Dead End	6.5	23	0	0	0.1	2	2	47	10
Roadway	Tamarack Lane	Farm Neck Way to Cul-De-Sac	8.3	33	0	0	0	0	2	67	13
Roadway	Rustic Avenue	Central Avenue to Hebron Avenue	11.5	33	0	0	0	0	2	67	13
Roadway	Brush Pond Road	Shirley Avenue to Dead End	11.6	30	0	0	0	0	2	60	12
Facility	Lagoon Pond Well	Barnes Road at Head Of Pond Rd	12.2	53	0	0	0	0	1	53	11
Roadway	Chapman Avenue	New York Avenue to Wayland Avenue	12.6	30	0	0	0	0	0.5	15	3