Climate Change Vulnerability, Risk Assessment and Adaptation Study

Town of Hingham, MA

June 29, 2015

KLEINFELDER

Bright People. Right Solutions.

TABLE OF CONTENTS

APPENDICES

INTRODUCTION

The Town of Hingham is particularly vulnerable to sea level rise being a coastal community located on Hingham Bay and the edge of Boston Harbor. The Hingham coastline has extensive floodplains and estuaries that reach into the inland areas of the town and extensive salt marshes associated with rivers as well as beaches that are subject to tidal action and the effects of storm surge. Sections of the Town subject to potential flooding contain public infrastructure, commercial development and residential areas that can be severely affected by flooding.

Given its exposure to the combined effects of sea level rise and storm surge from extreme storm events, the Town of Hingham applied for and was a awarded a Coastal Community Resilience Grant from the Massachusetts Coastal Zone Management Agency (CZM) under CZM's Pilot Grants Program for Fiscal Year 2014.

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, town officials and state legislators about those potential impacts

Project Team

The Town of Hingham 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
- Indrani Ghosh, PhD – Kleinfelder – Project Engineer, Inundation Modeling and Vulnerability Assessment
- Kirk Bosma, PE – Woods Hole Group – Inundation and Natural Resources Modeling

Kleinfelder worked closely with a Town Steering Committee which included the following members:

- Abby Piersall (Town Project Manager)
- Mary Savage Dunham
- Monica Conyngham
- Roger Fernandes
- Scott McIsaac
- Jim Murphy
- Walter Sullivan
- Randy Sylvester
- Richard Cook
- Ken Corson
- Brian Knies

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 strategies available to adapt to those changes over time. The Town organized public outreach events at each project milestone to keep the public abreast of the latest findings, gather input at crucial junctures, and facilitate active engagement over the lifetime of the project. At these events, the Project Team shared information on climate change, flood modeling, Hingham's coastal flood hazards, vulnerability and risk of Hingham's public infrastructure and natural resources, and adaptation options and costs. Following is a list of the public outreach events organized as part of the project:

- Steering Committee meetings
  - September 15, 2014 (Kick-off)
  - October 20, 2014 (Phase I: Study Parameters)
  - February 3, 2015 (Phase II: Vulnerability Assessment)
  - April 6, 2015 (Phase II: Vulnerability Assessment)
  - June 10,2015 (Phase III: Adaptation)
  - July 2015, TBD (Final meeting)
- Board of Selectmen briefings
  - November 6, 2014
  - July 2015, TBD
- Joint meetings of the Planning Board and Conservation Commission (Board of Selectmen invited)
  - November 17, 2014 (Phase I: Study Parameters)
  - April 6, 2015 (Phase II: Vulnerability Assessment)
  - July 2015, TBD
- Project-specific Public Meetings
  - April 16, 2015 (Phase II: Vulnerability Assessment)
  - July 2015, TBD (Phase III: Adaptation) with Planning Board/Conservation Commission

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).

We also wish to acknowledge the participation of Jason Burtner and Tricia Bowen of the Massachusetts Coastal Zone Management (CZM) during Steering Committee meetings and public presentations for this project.

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 coupled with 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 includes the entire greater Boston area, including the Town of Hingham, this model was ideally suited to assess the vulnerability and risk of coastal flooding to Hingham's infrastructure and natural resources. Using this existing model was beneficial to the Town of Hingham 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 Hingham coastline and surrounding upland areas. The spatial resolution of the model is 10 meters or less, sometimes as low as 2-3 meters 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. It models a statistically-robust sample of storms, including tropical (hurricanes) and extra-tropical (nor'easters), based on the region's existing and evolving climatology, calculates associated water elevations, and runs mathematical and geospatial analyses on the water elevations generated to estimate the probability of different water elevations being exceeded at nodal points within the model boundary. 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.

The proposed modeling approach is probability-based, which will be beneficial to the Town to assess the vulnerability and risk of infrastructure, evaluate its resiliency, and plan for adaptation options to mitigate future flooding damage for the Town of Hingham. It will also produce information that can be used to inform engineering design criteria since it provides the probability of an event occurring in this changing regime, such as the "new" 1% event flood levels (equivalent to a 100 year recurrence event). This risk-based approach uses a fully optimized Monte Carlo approach, simulating a statistically robust set of storms (both tropical and extra-tropical) for each sea level rise (SLR) scenario. 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 that can help decision makers to identify areas of existing vulnerability requiring immediate action in Hingham, as well as areas that benefit from present planning for future preparedness.

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 include both tropical storms (hurricanes) and extra-tropical storm (nor'easters). Figure 1 shows the track lines of some of the associated hurricanes included in the model. The storm climatology parameters that are included in the BH-FRM model include, but are not limited to, wind directions and speeds, radius of maximum winds, pressure fields, and forward track of the storms in the Boston 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 is usually 3-4 times that of hurricanes, and therefore they 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, but 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.

Sea Level Rise Scenarios

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 (Figure 2). 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.

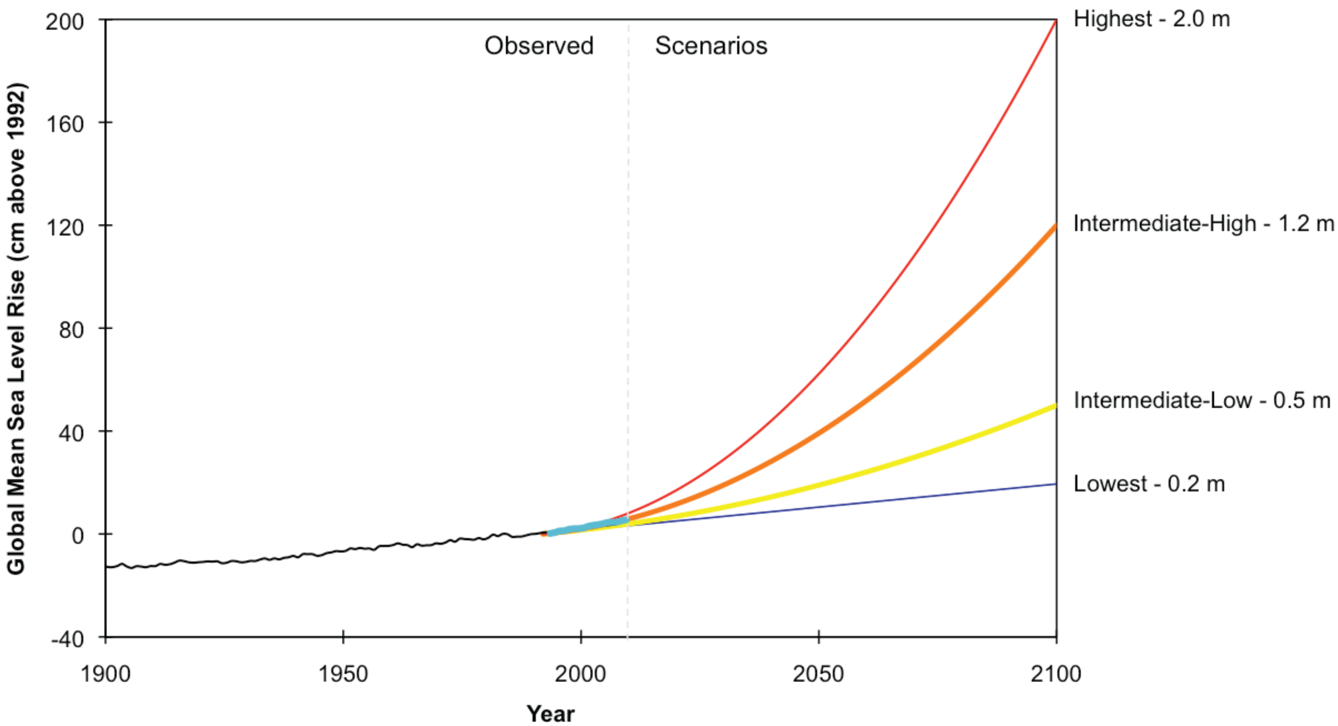


Figure 2 - Global mean sea level rise scenarios

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 tidal gage at Boston Harbor (station ID 8443970) 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 (Figure 3). 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). Since there are no long-term (> 50 years) tidal gages available for the Hingham Bay area, the rate of subsidence recorded at Boston Harbor was deemed appropriate to be factored in with the global SLR scenarios to determine the relative SLR projections for Hingham.

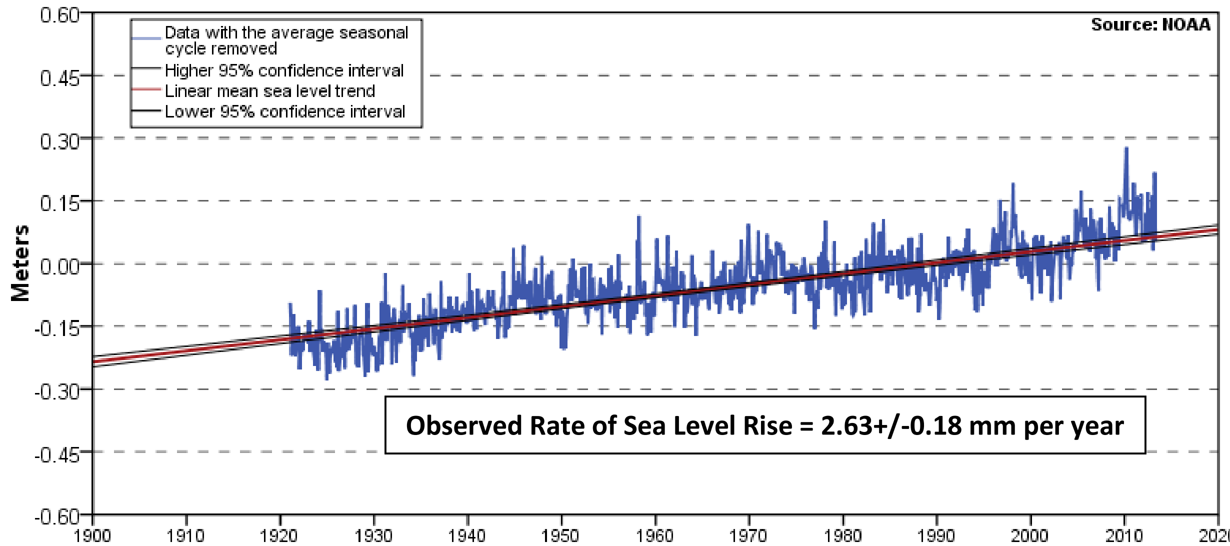


Figure 3 - Mean sea level trend at Boston Tide Gage (#8443970)

Figure 4 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 the Town of Hingham, 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 2015 as the start year, considering 2015 will be the completion year of this project, and it was found that the difference in SLR projections between using 2013 and 2015 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 4 presents the SLR projections for Hingham 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. For example the value for the “Highest” scenario at 2030, is also similar to the “Intermediate-High” value at that same time period, and approximately the “Intermediate-Low” value for 2070.

The SLR scenarios that were utilized in the Hingham vulnerability assessment are:

- Existing conditions for the current time period (considered to be 2013).
- The value for the “Highest” scenario 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 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 4 – Sea level rise estimates for Hingham using the 2012 NOAA NCA SLR scenarios

Planning Horizons

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

The BH-FRM model was developed for the years 2030, 2070, and 2100. Since the Steering Committee requested the study to include only two planning horizons, 2030 and 2070 planning horizons with corresponding sea level rise projections were chosen for the following reasons:

- The BH-FRM model developed for the greater Boston area includes the Town of Hingham. The Town of Hingham 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 well below 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 (e.g. Cities of Cambridge and Boston, MassDOT/FHWA).

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 a substantial portion of upland subject to present and future flooding. A screenshot of the model mesh for part of Hingham is shown in Figure 5.

Figure 5 - Model mesh for BH-FRM ADCIRC/SWAN model

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, 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 a quarter of an 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 Hingham area. The water surface elevation time series comparison had a bias of less than a ¼ inch, root mean square error (RMSE) 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 of a building). Finally, the model was validated to the Perfect Storm of 1991, 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 Hingham area, hence 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 were 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 2013, 2030 and 2070 were used to generate maps of potential flooding and associated water depths throughout the Town if Hingham. Two different types of maps were produced:

- <u>Percent Risk of Flooding Maps</u> - These maps can be used to identify locations, structures, assets, etc. that lie within different flood risk 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 risk of flooding during the study year and existing ground elevations derived from the 2011 Northeast LiDAR (Light Detection and Ranging) survey. For this study, two sets of Depth of Flooding Maps were produced:

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

Depths of flooding maps were also developed for the effects of sea level rise alone, which do not include any effects from storm surge. These maps were developed as "bath-tub models" by creating a planar water surface consisting of the predicted sea level rise (global SLR plus land subsidence) for the years 2030 and 2070 plus the current Mean Higher High Water (MHHW) elevation. As described above, the total SLR values based on the "high" scenario used to develop the sea level rise alone maps are as follows:

- 2030: 0.66 feet
- 2070: 3.39 feet

The following inundation maps are included in Appendix A:

- A-1: 2030 – Percent Risk of Flooding
- A-2: 2070 - Percent Risk of Flooding
- A-3: Present – Depth of Flooding at 1% Annual Probability (≈100 year recurrence)
- A-4: 2030 – Depth of Flooding at 1% Annual Probability (≈100 year recurrence)
- A-5: 2070 - Depth of Flooding at 1% Annual Probability (≈100 year recurrence)
- A-6: Present - Depth of Flooding at 0.2% Annual Probability (≈500 year recurrence)
- A-7: 2030 - Depth of Flooding at 0.2% Annual Probability (≈500 year recurrence)
- A-8: 2070 - Depth of Flooding at 0.2% Annual Probability (≈500 year recurrence)
- A-9: 2030 - Depth of Flooding – Sea Level Rise Only
- A-10: 2070 - Depth of Flooding – Sea Level Rise Only

3D Image Renderings

Based on the inundation results, three critical roadway intersections were identified to generate 3D image renderings to better visualize the flooding impacts in these areas. For each image, the visualization specialist chose key points, and then collected data for each point's exact location and elevation. The elevation data provided the means for creating a 3D terrain of the landscape in each image. Next, massing models were created for all major objects in the images. A digital camera was aligned to view the same vantage point for each image. Sea level rise was simulated to projected levels for each scene, and then the projected water levels were rendered and the rendering was composited into the original photograph to show the results.

NATURAL RESOURCES MODELING

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) is being used to assess the impacts to natural resources for that project. The SLAMM results are also being 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 four out-year scenarios and four projected sea level rise curves. The results of this statewide project were incorporated into this study.

Elevation Information

High resolution elevation data are the most important 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 this project, LiDAR was acquired from MassGIS. The majority of the state was covered with the 2011 USGS LiDAR for the Northeast project, and this covers the Hingham area. 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. For complete details, 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:

- Broad Cove
  - By 2030, Broad Cove shows a reduction in transitional marsh, which has been converted to a mix of low and high marsh. Fringing high marsh begins to transition to low marsh and the estuarine open water (subtidal portions of the Cove) has expanded. There is also a relatively significant loss of upland area in the region.
  - By 2070, there is a major loss of upland area, all existing high marsh has essentially disappeared and has transitioned to low marsh and/or un-vegetated tidal flats. While there is some room for marsh migration, Broad Cove has become a degraded system by 2070.

- Home Meadow - The Home Meadow system shows growth of the Tidal Creeks/ Estuarine Open Waters resources in 2030, and continued expansion by 2070. Due to the restricted tidal signal in this region, the existing marsh regions (including low, high, and transitional areas all remain relatively constant through time.

- Hingham Harbor Shoreline – The shoreline shows retreat through 2030, with conversion of beach and upland to open water areas. By 2070, there is a significant loss of shoreline area transitioning to open water resources. There is also the start of some transitional marsh resources in areas that were previously upland.

- World’s End – The World’s End area, which currently consists of estuarine open water with fringing transitional marsh area, converts to all open water by 2030, and then expands into upland areas and forms un-vegetated tidal flats and some fringing marsh area.

- Foundry Pond and Lyford Lyking Area – These areas, in the northeast corner of Hingham show minor changes by 2030 with slight loss of upland and marsh expansion. By 2070; however, there is a significant transition of high marsh to low marsh, loss of major upland areas, and connection of various marsh regions along the river. Tidal creeks have also expanded and created a system that is transitioning to open water from marsh.

- Back River and Beal Cove – The areas along the Back River show minimal changes between 2011 and 2030, with the exception of minor shoreline retreat. By 2070, the tidal creeks have expanded and there is loss of upland area and estuarine beach. All high marsh has either transitioned to open water or low marsh in this area.

Major changes from 2011 to 2030:

Town-wide there is a significant loss of area identified in three major classifications:

- Loss of approximately 13 acres of irregularly flooded marsh (high marsh). This is loss of high marsh that is transitioning to low marsh, which is not necessarily a problem, at least initially.
- Loss of approximately 10-30 acres of upland area. As expected, this loss occurs along the edges of water bodies (in the areas discussed above).
- Loss of 28 acres of transitional marsh, where marsh is converted to high marsh.

Town-wide there is a significant gain of area identified in two major classifications:

- Gain of approximately 28 acres of regularly flooded marsh (low marsh).
- Gain of approximately 25 acres of tidal flats.

Major changes from 2030 to 2070:

Town-wide there is a significant loss of area identified in three major classifications:

- Loss of approximately 92 additional acres of irregularly flooded marsh (high marsh). This is loss of high marsh that is transitioning to low marsh, which is not necessarily a problem, at least initially.
- Loss of approximately 70 to 100 additional acres of upland area. As expected, this loss occurs along the edges of water bodies (in the areas discussed above).
- Loss of 26 acres of estuarine beach. This occurs along the edge of estuaries and results in the expansion of Tidal Creeks.

Town-wide there is a significant gain of area identified in three major classifications:

- Gain of approximately 100 additional acres of regularly flooded marsh (low marsh), a lot of area that was formerly upland has transitioned all the way to low marsh, especially in the Broad Cove region.
- Gain of approximately 32 additional acres of tidal flats, most occurring in the Broad Cove region.
- Gain of approximately 38 acres of Tidal Creeks, likely expansion of existing creeks and formation of new creeks.

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, major drainage outfalls, and other critical facilities such as schools, police stations, fire stations, etc. owned and operated by the Town of Hingham. Critical infrastructure was selected based on the inundation modeling results, using infrastructure information obtained from the Town of Hingham Hazard Mitigation Plan Update (2012), and by information provided by various Town departments. 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 are not performed on these assets. In some limited cases, several state-owned roadways, which are critical transportation links in Hingham, are included in the vulnerability assessment.

Survey data for both public coastal stabilization structures, including sea walls, revetments and groins, were obtained from Hingham Department of Public Works, as well as the 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).

A risk-based vulnerability assessment was performed for each of the municipally-owned assets impacted by flooding. These assets 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:

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

or

$$R = P \times C$$

For this flood-related vulnerability assessment application, the Probability of Failure (P) is considered as the Percent Risk of Flooding. 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 is 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 are located as an overlay in the GIS project map. The Percent Risk map for flooding for 2070 was then used to screen out assets that show no probability of flooding in 2070. Any assets that show no probability of flooding are excluded from further analysis, but still remain as reference points on the inundation maps.

The following municipally-owned infrastructure assets have been identified in Figures 6, 7 and 8 as being vulnerable to flooding at the indicated time between the present time and 2070:

Time Horizon	Facility/Building Name
Present	Heliport at Bathing Beach
	West Corner Pump Station
	Hingham Bathing Beach Parking Lot
2030	William L. Foster Elementary School
	Mill St. Pump Station
	Bel Air Pump Station
	Broad Cove Sewer Pump Station
	Whitney Wharf
2070	Beal St Sewer Pump Station
	Downer Ave Sewer Pump
	Howe St Pump Station
	Walton Cove Sewer Pump Station

Figure 6 - Facilities/Buildings Vulnerable to Flooding

Time Horizon	Location	Structure Type	CZM Coastal Stabilization Structure Number
Present	Bridge Street	Revetment	034-045-000-002-100
	Bridge Street	Bulkhead/ Seawall	034-045-000-002-200
	Bridge Street	Revetment	034-045-000-002-300
	Bridge Street	Groin/ Jetty	034-045-000-002-400
	Broad Cove Entrance	Revetment	034-039-000-009-100
	Hingham Shipyard	Revetment	034-036-000-106-200
	Hingham Yacht Club Peninsula	Bulkhead/ Seawall	034-016-000-183-100
	Hingham Yacht Club Peninsula	Bulkhead/ Seawall	034-017-000-113-100
	Hingham Yacht Club Peninsula	Revetment	034-016-000-183-200
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-003-100
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-005B-200
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-059-100
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-001-200
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-004-100
	Iron Horse Park Area	Bulkhead/ Seawall	034-050-000-050-200
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-005-100
	Iron Horse Park Area	Revetment	034-050-000-050-100
	Martin's Well	Revetment	034-030-000-011-100
	Martin's Well	Bulkhead/ Seawall	034-030-000-011-200
	Walton Cove	Bulkhead/ Seawall	034-027-000-059-100
2030	Hingham Yacht Club Peninsula	Bulkhead/ Seawall	034-017-000-099-100
	Hingham Yacht Club Peninsula	Revetment	034-011-000-005-100
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-001-300
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-001-100
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-005B-100
	Iron Horse Park Area	Bulkhead/ Seawall	034-051-000-001-400
	Stodders Neck	Revetment	034-034-000-000-100
	Stodders Neck	Revetment	034-035-000-001-100
	Hingham Shipyard	Bulkhead/ Seawall	034-036-000-106-300
2070	Broad Cove Entrance	Revetment	034-050-000-051-100
	Broad Cove Entrance	Revetment	034-039-000-008-100
	Hingham Shipyard	Bulkhead/ Seawall	034-036-000-106-100
	Stodders Neck	Revetment	034-046-000-001-100

Figure 7 – Coastal Stabilization Structures Vulnerable to Flooding

Time Horizon	Roadway Name(s)
Present	Rockland St and Kilby St
	Beach Road and Beach Lane
	Otis St (Rt 3A) at Hingham Bathing Beach
2030	Broad Cove Road (Rt 3A)
	Downer Ave and Condito Rd
	Downer Ave and Planters Field Ln
	Howe St and Parker Dr
	Summer St (Rt 3A) Rotary
	North St
	Eldridge Ct
	Main St and Winter St
	Hull St and Rockland St
	Rockland St and Meadow Rd
	Lincoln St and Broad Cove Rd
2070	Water St
	Andrews Isle
	Fresh River Ave
	Otis St at Walton Cove
	Wompatuck Rd and Wokomis Rd
	Blackberry Ln and Park Circle
	Condito Rd and Langlee Rd
	Hingham Shipyard Rd
	Green St
	George Washington Blvd Bridge (Approach)
	Tupelo Rd and Langlee Rd

Figure 8 – Roadways Vulnerable to Flooding

2. <u>Determine Critical Elevations</u>

Critical elevations (NAVD88 datum) for each asset that may 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 using a variety of data sources, including:

- Survey information provided by the Town of Hingham staff.
- As-built drawings or other similar documents provided by Hingham staff
- LiDAR survey and aerial photography

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

Critical elevations for coastal stabilization structures are determined using either survey data and as-built drawings provided by the Town of Hingham staff or survey elevations included in CZM's *Mapping and Analysis of Privately Owned Coastal Structures Along the Massachusetts Shoreline* (March, 2013).

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 was obtained directly from the BH-FRM ADCIRC model. Data is obtained from the closest mesh node to the asset.

A representative example of Probability of Exceedance data from the Mill Street Pump Station is shown in Figure 9. For this facility, the critical elevation is 8.69 NAVD88. This data shows some of the following information:

- For the present year time frame, the pumping station does not show any probability of flooding.
- In the 2030 time frame, there is a 5% chance that water will exceed the critical elevation of 8.69 feet, and at a 1% (100 year recurrence interval) the water level could be approximately 1.61 feet above the critical elevation.
- In the 2070 time frame, the probability of exceeding the 8.69 feet critical elevation increases to 50% while the depth of water above the critical elevation at a 1% (100 year recurrence interval) increases to about 4.11 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	dry	0	11.8	3.11	14.1	5.41
0.2	dry	0	11.5	2.81	14	5.31
0.5	dry	0	11	2.31	13.5	4.81
1	dry	0	10.3	1.61	12.8	4.11
2	dry	0	10	1.31	12.5	3.81
5	dry	0	9.3	0.61	12.1	3.41
10	dry	0	dry	0	11.5	2.81
20	dry	0	dry	0	11.1	2.41
25	dry	0	dry	0	10.9	2.21
30	dry	0	dry	0	10.8	2.11
50	dry	0	dry	0	9.3	0.61
100	dry	0	dry	0	dry	0

Figure 9 – Probability of Exceedence Data for Mill Street 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 10. 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 11 shows a representative example of the Consequence of Failure rating for the Mill Street Pump Station with a total rating of 63 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 10 – 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
Rating	2	4	2	1	5	5	63

Figure 11 – Consequence of Failure Scoring Example for Mill Street 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:

$$R_{tn} = P_{tn} \text{ x } C_{tn}$$

Where:

R_{tn} = Risk Score at a given time horizon
P_{tn} = Probability of Exceedence 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:

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

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 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 following factors were selected:

- $W_{Present}$ = 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 Mill Street Pump Station is shown in Figure 12.

	Probability of Exceedance	Consequence Score	Risk Score	Weight	Composite Risk Score
Present	0	63	0	0.5	728
2030	5	63	317	0.3	
2070	50	63	3167	0.2	

Figure 12 - Risk Scoring Example Matrix for Mill Street Pump Station (Note - Multiplication not exact due to round-off of Consequence Score)

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

Using the risk-based ranking methodology described above, the top 20 ranked assets in terms of vulnerability to flooding based on composite scores are shown in Figure 13.

The top 20 ranked assets in terms of vulnerability to flooding based on risk scores for the present day time horizon are shown in Figure 14.

The top 20 ranked assets in terms of vulnerability to flooding based on risk scores for the 2030 time horizon are shown in Figure 15.

The top 20 ranked assets in terms of vulnerability to flooding based on risk scores for the 2070 time horizon are shown in Figure 16.

Asset Name	Type	Consequence Score	Present Probability (%)	2030 Probability (%)	2070 Probability (%)	Composite Risk Score
Walton Cove 034-027-000-059-100	Bulkhead/ Seawall	37	100	100	100	3667
Iron Horse Park Area 034-051-000-003-100	Bulkhead/ Seawall	60	25	50	100	2850
Iron Horse Park Area 034-051-000-005B-200	Bulkhead/ Seawall	57	30	50	100	2833
Bridge Street 034-045-000-002-100	Revetment	50	30	50	100	2500
Iron Horse Park Area 034-051-000-059-100	Bulkhead/ Seawall	33	50	50	100	2000
Iron Horse Park Area 034-051-000-001-200	Bulkhead/ Seawall	60	5	30	100	1890
Bridge Street 034-045-000-002-200	Bulkhead/ Seawall	50	10	30	100	1700
Bridge Street 034-045-000-002-300	Revetment	50	10	30	100	1700
William L. Foster Elementary School	Facility	63	0	10	100	1457
Iron Horse Park Area 034-051-000-004-100	Bulkhead/ Seawall	60	2	10	100	1440
Iron Horse Park Area 034-050-000-050-200	Bulkhead/ Seawall	40	10	30	100	1360
Rockland St and Kilby St	Roadway	30	10	50	100	1200
Otis St (Rt 3A) at Hingham Bathing Beach	Roadway	50	1	10	100	1175
Martin's Well 034-030-000-011-100	Revetment	23	30	50	100	1167
Bridge Street 034-045-000-002-400	Groin/ Jetty	23	30	50	100	1167
Iron Horse Park Area 034-051-000-005-100	Bulkhead/ Seawall	50	1	10	100	1163
Broad Cove Entrance 034-039-000-009-100	Revetment	47	2	10	100	1120
West Corner Pump Station	Facility	50	1	5	100	1088
Broad Cove Rd (Rt 3A)	Roadway	47	0	10	100	1073
Beach Rd and Beach Ln	Roadway	33	5	25	100	1000

Figure 13 – Top 20 Ranked Infrastructure Assets Vulnerable to Flooding, Ranked by Composite Risk Score
(Note – Multiplication not exact due to round-off of Consequence Score)

Asset Name	Type	Consequence Score	Present Probability (%)	Present Risk Score
Walton Cove 034-027-000-059-100	Bulkhead/Seawall	37	100	3667
Iron Horse Park Area 034-051-000-005B-200	Bulkhead/Seawall	57	30	1700
Iron Horse Park Area 034-051-000- 059-100	Bulkhead/Seawall	33	50	1667
Iron Horse Park Area 034-051-000-003-100	Bulkhead/Seawall	60	25	1500
Bridge Street 034-045-000-002-100	Revetment	50	30	1500
Martin's Well 034-030-000-011-100	Revetment	23	30	700
Bridge Street 034-045-000-002-400	Groin/Jetty	23	30	700
Bridge Street 034-045-000-002-200	Bulkhead/Seawall	50	10	500
Bridge Street 034-045-000-002-300	Revetment	50	10	500
Iron Horse Park Area 034-050-000-050-200	Bulkhead/Seawall	40	10	400
Iron Horse Park Area 034-051-000-001-200	Bulkhead/Seawall	60	5	300
Rockland St and Kilby St	Roadway	30	10	300
Beach Rd and Beach Ln	Roadway	33	5	167
Iron Horse Park Area 034-051-000-004-100	Bulkhead/Seawall	60	2	120
Broad Cove Entrance 034-039-000-009-100	Revetment	47	2	93
Martin's Well 034-030-000-011-200	Bulkhead/Seawall	33	2	67
Otis St (Rt 3A) at Hingham Bathing Beach	Roadway	50	1	50
Iron Horse Park Area 034-050-000-050-100	Revetment	23	2	47
Hingham Yacht Club Peninsula 034-016-000-183-100	Bulkhead/Seawall	33	1	33
Heliport at Bathing Beach	Facility	27	1	27

Figure 14 – Top 20 Ranked Infrastructure Assets Vulnerable to Flooding, Ranked by Present Day Risk Scores (Note – Multiplication not exact due to round-off of Consequence Score)

Asset Name	Type	Consequence Score	2030 Probability (%)	2030 Risk Score
Walton Cove 034-027-000-059-100	Bulkhead/Seawall	37	100	3667
Iron Horse Park Area 034-051-000-003-100	Bulkhead/Seawall	60	50	3000
Iron Horse Park Area 034-051-000-005B-200	Bulkhead/Seawall	57	50	2833
Bridge Street 034-045-000-002-100	Revetment	50	50	2500
Iron Horse Park Area 034-051-000-001-200	Bulkhead/Seawall	60	30	1800
Iron Horse Park Area 034-051-000-059-100	Bulkhead/Seawall	33	50	1667
Bridge Street 034-045-000-002-200	Bulkhead/Seawall	50	30	1500
Bridge Street 034-045-000-002-300	Revetment	50	30	1500
Rockland St and Kilby St	Roadway	30	50	1500
Iron Horse Park Area 034-050-000-050-200	Bulkhead/Seawall	40	30	1200
Martin's Well 034-030-000-011-100	Revetment	23	50	1167
Bridge Street 034-045-000-002-400	Groin/Jetty	23	50	1167
Beach Rd and Beach Ln	Roadway	33	25	833
Martin's Well 034-030-000-011-200	Bulkhead/Seawall	33	20	667
Hingham Yacht Club Peninsula 034-016-000-183-100	Bulkhead/Seawall	33	20	667
William L Foster Elementary School	Facility	63	10	633
Iron Horse Park Area 034-051-000-004-100	Bulkhead/Seawall	60	10	600
Otis St (Rt 3A) at Hingham Bathing Beach	Roadway	50	10	500
Iron Horse Park Area 034-051-000-005-100	Bulkhead/Seawall	50	10	500
Broad Cove Entrance 034-039-000-009-100	Revetment	47	10	467

Figure 15 – Top 20 Ranked Infrastructure Assets Vulnerable to Flooding, Ranked by 2030 Risk Scores(Note – Multiplication not exact due to round-off of Consequence Score)

Name/Number	Type	Consequence Score	2070 Probability (%)	2070 Risk Score
William L Foster Elementary School	Facility	63	100	6333
Iron Horse Park Area 034-051-000-003-100	Bulkhead/Seawall	60	100	6000
Iron Horse Park Area 034-051-000-001-200	Bulkhead/Seawall	60	100	6000
Iron Horse Park Area 034-051-000-004-100	Bulkhead/Seawall	60	100	6000
Iron Horse Park Area 034-051-000-005B-200	Bulkhead/Seawall	57	100	5667
Bridge Street 034-045-000-002-100	Revetment	50	100	5000
Bridge Street 034-045-000-002-200	Bulkhead/Seawall	50	100	5000
Bridge Street 034-045-000-002-300	Revetment	50	100	5000
Otis St (Rt 3A) at Hingham Bathing Beach	Roadway	50	100	5000
Iron Horse Park Area 034-051-000-005-100	Bulkhead/Seawall	50	100	5000
West Corner Pump Station	Facility	50	100	5000
Broad Cove Entrance 034-039-000-009-100	Revetment	47	100	4667
Broad Cove Rd (Rt 3A)	Roadway	47	100	4667
Hingham Bathing Beach Parking Lot	Facility	43	100	4333
Iron Horse Park Area 034-050-000-050-200	Bulkhead/Seawall	40	100	4000
Walton Cove 034-027-000-059-100	Bulkhead/Seawall	37	100	3667
Hingham Yacht Club Peninsula 034-017-000-113-100	Bulkhead/Seawall	37	100	3667
Iron Horse Park Area 034-051-000-059-100	Bulkhead/Seawall	33	100	3333
Beach Rd and Beach Ln	Roadway	33	100	3333
Martin's Well 034-030-000-011-200	Bulkhead/Seawall	33	100	3333

Figure 16 – Top 20 Ranked Infrastructure Assets Vulnerable to Flooding, Ranked by 2070 Risk Scores
(Note – Multiplication not exact due to round-off of Consequence Score)

ADAPTATION STRATEGIES

General

There are three general approaches for adapting to the long-term effects of flooding due to sea level rise and storm surge from extreme weather events:

- Protection
- Accommodation
- Retreat

Protection - Protection includes adaptation strategies that try to prevent damage to essential infrastructure by creating a barrier between the flood water and the infrastructure being protected. Sea walls, dikes, bulkheads, levees, revetments, flood gates, temporary flood protection barriers, and hurricane barriers are all examples of protection strategies that aim to prevent water from reaching sensitive areas. To be truly effective over the long term, many of these types of structures need to be massive to withstand the forces of the sea and can be costly and difficult to get permitted under our current regulatory system. Infrastructure outside of these structures is left unprotected.

Accommodation - Accommodation adaptation strategies allow flood waters to reach essential infrastructure, but damage to the infrastructure is minimized and controlled. Accommodation strategies acknowledge that structures and infrastructure will be exposed to flood water and will get wet, but actions are taken to minimize potential damage. Examples of accommodation adaptation strategies include raising structures above flood elevations, constructing 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, protecting utilities in waterproof enclosures; flood-proofing structures, instituting new building codes and zoning, such as increased setbacks, that require accommodation strategies to be implemented for all new construction and major renovation projects.

Retreat - Retreat adaptation 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 the structures and infrastructure from harm's way. Retreat strategies relocate affected infrastructure away from the ocean to higher ground and transform the affected areas back to natural barriers which can migrate landward naturally. Examples of retreat adaptation strategies include property buyouts, relocation of roads, buildings and infrastructure, and implementation of new zoning or other regulations limiting new construction, reconstruction, or expansion of existing structures.

Adaptation strategies investigated in this study are a combination of protection and accommodation strategies. In the Town of Hingham, true retreat strategies do not appear to be warranted or will likely not be politically feasible given the extent of expected inundation by 2070. However, retreat strategies may become more important by 2100 if sea levels continue to rise as currently predicted.

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 a structure or infrastructure asset is adapted to.

Figure 17 shows representative flood elevations at different probabilities of exceedance for present, 2030 and 2070 time horizons. These flood elevations do not include additional height for wave run-up, nor do they include "freeboard" - height often added above the expected flood level for additional safety.

For the purposes of this study, we have based recommended adaptation options on a base flood elevation equivalent to the 0.2% probability of exceedance flood levels in 2030 and 2070 (approximately 500 year recurrence interval). This decision reflects the high criticality of the facilities in question and sets a relatively conservative design parameter from which to begin planning. These recommendations should periodically be reviewed (e.g., once every five to ten years) and adjusted as needed based on the latest climate change science and sea level rise observations and projections.

Selecting a conservative base flood elevation can have an impact on the feasibility and cost of adaptation strategies, especially if planning for the longer term (i.e., 2070). In 2030, the difference between the 1% and 0.2% events is only 0.2 feet. However, in 2070, the difference between the 1% event (12.8 ft) and the 0.2% event (14.0 ft.) is much greater at 1.2 ft. In addition, the 0.2% event in 2070 is 3.8 ft. higher than the 2030 0.2% event, whereas the 1% event in 2070 is only 2.8 ft. higher than the 1% event in 2030. Higher base flood elevations introduce more significant design challenges and costs to modify what exists today in vulnerable areas.

Exceedance Probability (%)	Present Water Surface Elevation (ft-NAVD88)	2030 Water Surface Elevation (ft-NAVD88)	2070 Water Surface Elevation (ft-NAVD88)
0.1	9.1	11.8	14.1
0.2	9	10.2	14
0.5	9	10.1	13.5
1	8.5	10	12.8
2	8.4	9.9	12.5
5	8	9	12.1
10	7.7	8.8	11.6
20	7.2	8.3	11
25	7.1	8.2	10.8
30	6.9	8.1	10.7
50	5	7.2	10.2
100	3.4	4.5	9.1

Recommended Base Flood Elevations

Figure 17 – Water Levels at Different Probabilities of Exceedance for Present, 2030 and 2070

Recommendations for Infrastructure

The highest risk municipal infrastructure assets, according to Composite Risk ranking, are shown in Figure 13. They are predominantly seawalls and other coastal stabilization structures. These structures are located right at the water's edge and have higher probabilities of flooding than most roadways and facilities, which are generally located further inland and upland. However, there are a few low-lying critical facilities and roadways with high composite risks scores. One characteristic that all of these assets share is that they are projected to flood annually by the 2070 timeframe, if climate change continues as projected. In the sections below, adaptation priorities and options for high risk assets are described.

Coastal Stabilization Structures

Inner Harbor/Iron Horse Park

Recommended Base Flood Elevation for 2030:
- 10.2 ft NAVD88

Recommended Base Flood Elevation for 2070:
- 14.1 ft NAVD88

Figure 18 - Inner Harbor Seawalls

The seawalls along the Inner Harbor/Iron Horse Park are of varying heights, condition, and construction type (Figure 18). Due to this variation, they provide an inconsistent level of protection for Route 3A, public spaces, and the various public and private infrastructures in the downtown business overlay district behind them. Eight of the twelve structures have critical elevations (meaning the lowest elevation along the top of the structure) which are too low to prevent the 1% flood from exceeding them, even based on present day climate and sea levels (Figure 19). Inundation maps in Appendix A show that, over time, sea level rise due to climate change will increase the likelihood that the downtown area will experience flooding due in part to the insufficient height of these structures.

Type	Name/Number	Critical Elevation	Conseq. Score	Present Prob. (%)	2030 Prob. (%)	2070 Prob. (%)	Comp. Risk Score
Bulkhead/Seawall	034-051-000-003-100	7.0	60	25	50	100	2850
Bulkhead/Seawall	034-051-000-005B-200	6.6	57	30	50	100	2833
Bulkhead/Seawall	034-051-000-059-100	4.8	33	50	50	100	2000
Bulkhead/Seawall	034-051-000-001-200	7.8	60	5	30	100	1890
Bulkhead/Seawall	034-051-000-004-100	8.4	60	2	10	100	1440
Bulkhead/Seawall	034-050-000-050-200	7.3	40	10	30	100	1360
Bulkhead/Seawall	034-051-000-005-100	8.5	50	1	10	100	1163
Revetment	034-050-000-050-100	8.3	23	2	10	100	560
Bulkhead/Seawall	034-051-000-001-300	10.6	60	0	0	30	362
Bulkhead/Seawall	034-051-000-001-100	10.4	60	0	0	30	362
Bulkhead/Seawall	034-051-000-005B-100	9.7	33	0	2	50	353
Bulkhead/Seawall	034-051-000-001-400	10.9	60	0	0	20	242

Figure 19 - Inner Harbor/Iron Horse Park Seawall and Revetment Flood Risk

Recommendation:

- (Present) Design, permit, and construct improvements to existing waterfront structures and landscape:
    - Raise top elevations of seawalls, grounds, wharves, and revetments to provide a continuous and consistent level of protection no lower than the base flood elevation of 10.2 NAVD88.
    - Take into account additional design variables (e.g., wave run-up) in the determination of the design flood elevation to determine an acceptable freeboard level.
    - Incentivize or compel (e.g. through betterment) private seawall owner to meet the adjoining structures at the appropriate height.
    - If possible, design seawall upgrades to lie landward of existing seawall footprint to minimize permitting effort. An example of this would be to leave the existing seawalls and construct new sheet-pile supported seawalls on the landward side. This will minimize the need to dewater and allow all construction to be land-based.
    - Design new seawalls to be modular to allow incremental construction over time to meet rising sea levels. Building new walls to meet high flood levels in 2070, which may or may not actually occur, can be costly and very disruptive today. However, designing a system that can accommodate the future potential heights, but not building it all at once, allows for future planned adaptation capability with minimal disruption.
    - Assuming a total wall length of approximately 5,000 ft. and unit costs ranging from \$1,000 - \$3,000 per foot to raise and replace the existing seawalls, the estimated cost to raise the sea walls to elevation 10.2 NAVD88 would be in the range of \$5,000,000 to

$15,000,000. The 5,000 ft. wall length does not include Kimball's Wharf which is privately owned. The length of seawall along Kimball Wharf is approximately 450 ft. The cost range to raise and replace the Kimball's Wharf seawall would be approximately $450,000 to $1,3500,000.

<u>Lincoln Street/Bridge Street/Route 3A Bridge</u>

Recommended Base Flood Elevation for 2030:
- 10.6 ft NAVD88

Recommended Base Flood Elevation for 2070:
- 14.1 ft NAVD88

The seawalls and revetments located around the base of the Lincoln Street/Bridge Street/Route 3A Bridge are in relatively good condition, according to CZM (2013). Despite the relatively high probability of flood waters exceeding the heights of these structures and the significant consequences for mobility if the bridge itself were to fail, neither the bridge nor the roadway approach are predicted to be exceeded by flood waters, even under the 0.2% event in 2070.

Recommendation:
- (Present) Continue monitoring structures for condition and scour, which could be worsened by more frequent and extreme flooding events.
- (2030) Carry out regular maintenance as needed over the lifetime of the structures.
- (2070) During next bridge replacement, design all associated structures according to the 2070 base flood elevation plus appropriate wave run-up and freeboard, taking into account their long-term design life.

<u>Walton Cove</u>

The dilapidated seawall structure at Walton Cove has not been in service for some time. The Town has indicated that this it is unlikely to be restored to service and may eventually be removed.

Recommendation:
- No adaptation is recommended.

<u>Facilities/Buildings</u>

<u>William L. Foster Elementary School</u>

Recommended Design Flood Elevation for 2030:
- 10 ft NAVD88

Recommended Design Flood Elevation for 2070:
- 14 ft NAVD88

The Foster School is located at the northwest corner of the Broad Cove wetland. The parking lot on the south side of the school, directly adjacent to the wetlands, ranges in elevation from approximately 5.5 ft

NAVD88 to 6.5 ft NAVD88. Flooding at the school from sea level rise and storm surge would emanate from the Broad Cove wetland, pass across the parking lot, and flow down a small staircase that leads from the parking lot down to the HVAC crawl space below the building. If flood levels were higher, they could enter the crawl space through vents in the building exterior close to the ground. The first floor of the school building is about 2 ft. higher in elevation than the parking lot, but in the 2030, the 0.2% flood water would inundate the first floor (Figure 20). While it is unlikely that the school grounds will experience flooding from sea level rise and storm surge in the present time frame due to tidal attenuation at the Broad Cove culvert, by 2030 projections show water overtopping Route 3A at the Broad Cove entrance putting the Foster School at greater risk of flooding. By 2070, sea level rise alone could cause daily flooding of the parking lot and sports facilities at high tide (Figure 21).

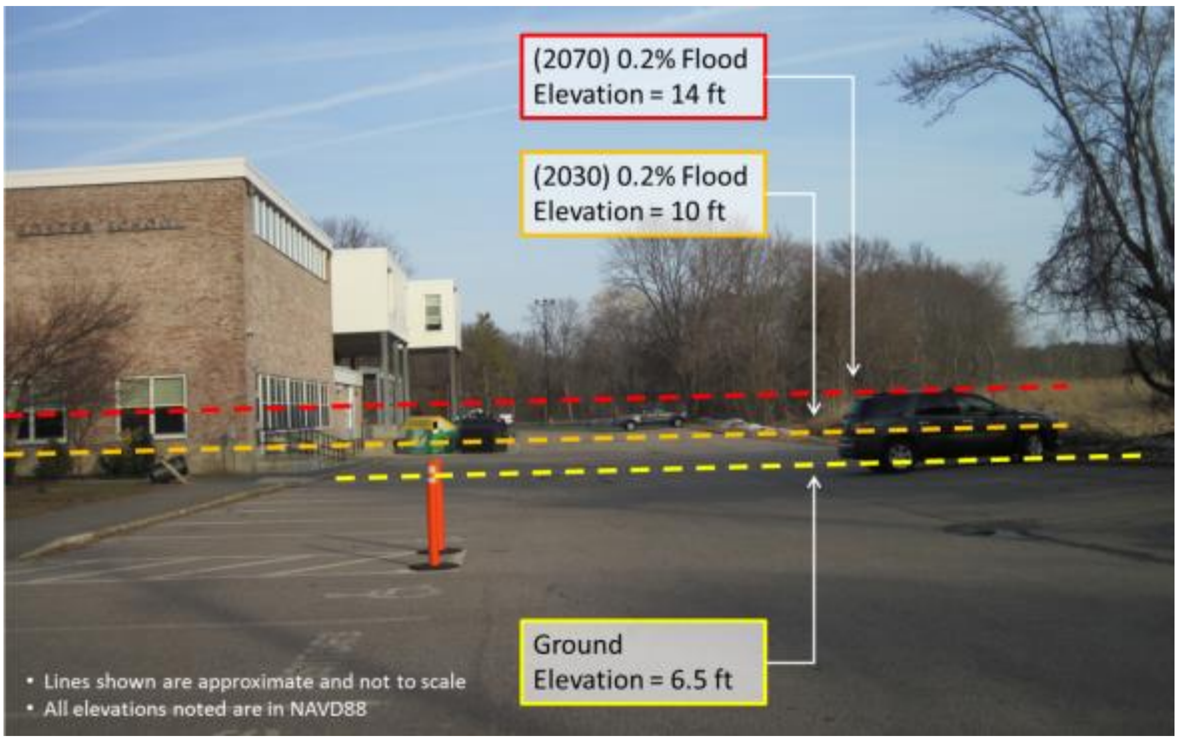


Figure 20 - Foster Elementary School Elevation and Flood Risk (SLR and Storm Surge)

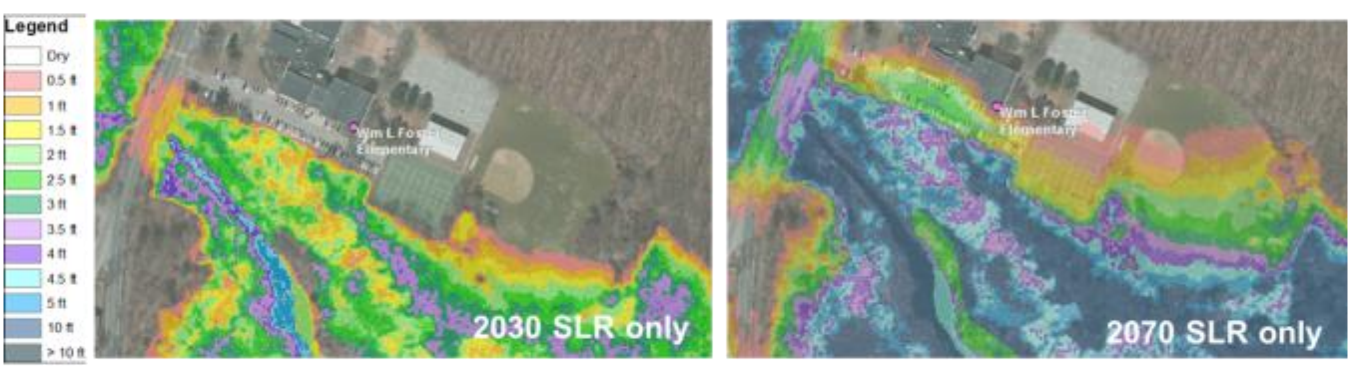


Figure 21 - Depth of Flooding at High Tide in 2030 and 2070 at Foster Elementary School with Highest SLR

Recommendation:

- (Present) Develop an emergency student relocation plan for the scenario that the school is flooded and unable to be occupied for an extended period of time.
- (2030) Install a high level water alarm and sump pump system tied to an emergency generator to allow for monitoring of and pumping out of any water that leaks into the crawl space. (Approximate cost = $10,000)
- (2030) Replace metal railings around HVAC crawl space staircase with concrete enclosure walls to 10 ft NAVD88. Add drop-in flood panel at opening to staircase prior to storm events to prevent water from entering HVAC crawl space. (Approximate cost = $10,000)
- (2030) Build concrete enclosures to 10 ft NAVD88 around vents to prevent water from entering HVAC crawl space. (Approximate cost = $15,000)
- (2030) Install drop-in flood panels at vulnerable doorways. (Approximate cost = $15,000)
- (2030) Seal or install shut-off valves for other conduits for water entry. (Approximate cost = $5,000)
- (2070) Design, permit and construct perimeter flood protection barrier system to 14 ft NAVD88, using retaining walls and/or levees. (Approximate cost = $820,000)

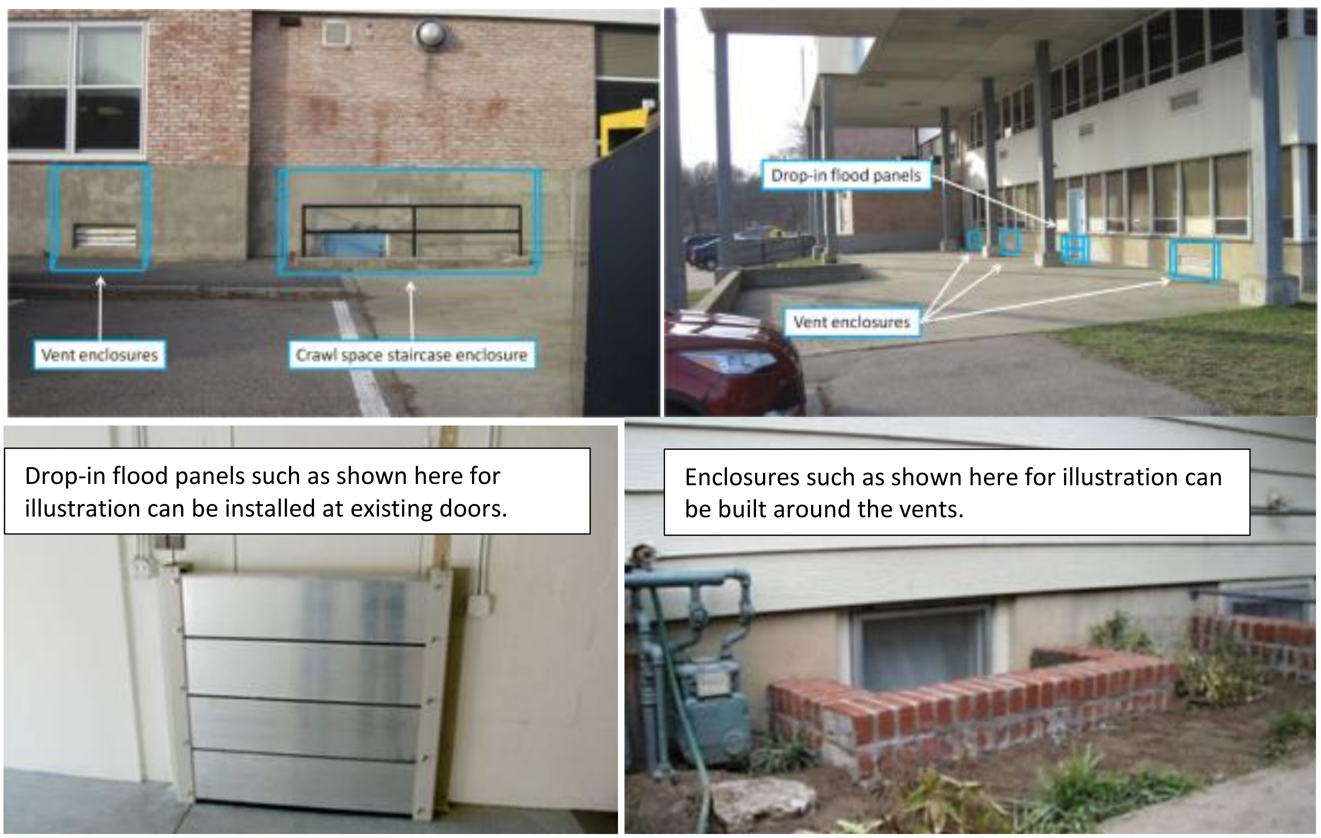


Figure 22 - Foster School Adaptation Options for 2030

Alternative Recommendations:

- By raising Route 3A at the Broad Cover culvert and installing a tide gate control as described later in the roadway adaptation section, the flooding at the Foster School can be eliminated and the adaption measures described above would not be required.

West Corner Pump Station

Recommended Design Flood Elevation for 2030:

- 9.7 ft NAVD88

Recommended Design Flood Elevation for 2070:

- 13.9 ft NAVD88

West Corner Sewer Pump Station is located near the intersection of Rockland Street and Hull Street, adjacent to a marsh. The wet well rim elevation is located under the manhole shown in Figure 23, while much of the pumping equipment is located on the first floor of the building elevated approximately 4 ft above grade. There are two other manholes located at grade. Utility meters are attached to the building exterior.

Figure 23 - West Corner Pump Station

Recommendation:

- (2030) Install water-tight manhole covers over the wet well and others to prevent above ground flood waters from entering the well and others. (Approximate cost = $4,500)
- (2030) Seal underground utility connections and other conduits for water entry. (Approximate cost = $2,000)
- (2070) Raise/relocate utility meters on building exterior to 13.9 ft NAVD88. (Approximate cost = $5,000)

Mill Street Pump Station

Recommended Design Flood Elevation for 2030:

- 11.5 ft NAVD88

Recommended Design Flood Elevation for 2070:

- 14 ft NAVD88

The Mill Street Sewer Pump Station is located in a parking lot on the corner of Mill Street and Water Street. An emergency generator, raised 1-2 ft above grade, is located adjacent to the main pump station building (Figure 24). The ground elevation is approximately 9.3 ft NAVD88, while the wet well rim, located inside the building, is at the lower elevation of 8.7 ft NAVD88. For this facility to flood from sea level rise and storm surge, water would have to pass over or around the Inner Harbor/Iron Horse Park seawalls, over Route 3A and down North Street and/or Water Street. Water would then enter through building exterior openings and into the wet well. In 2030, the probability of flood water exceeding Route 3A is projected to be 5%.

Figure 24 - Mill Street Pump Station

Recommendation:

- (2030) Purchase and have ready to deploy a 5 ft. high temporary flood barrier (approximately 160 ft. long) around perimeter of pump station and generator. (Approximate cost = $56,000)
- (2030) Seal interior conduits for water entry (e.g., through-floor/wall pipes, utility conduits) to 14.0 ft NAVD88.   (Approximate cost = $2,000)
- (2030) Install a high level water alarm and sump pump system tied to the emergency generator to allow for monitoring of and pumping out of any water that leaks through the temporary flood barrier. (Approximate cost = $10,000)

Alternative Recommendation:

- By raising Route 3A as described later in the roadway adaptation section, the flooding at the Mill Street Pump Station can be eliminated and the adaption measures described above would not be required.

Broad Cove Pump Station

Recommended Design Flood Elevation for 2030:

- 10 ft NAVD88

Recommended Design Flood Elevation for 2070:

- 14 ft NAVD88

Broad Cove Sewer Pump Station is located on the corner of Downer Ave and Lincoln Street, adjacent to the Broad Cove wetland (Figure 25). To flood from sea level rise and storm surge, water would have to overtop Route 3A and raise the Broad Cove water elevation sufficiently to spill over its current banks and into the pump station building via exterior openings. The first floor of the pump station is sufficiently elevated to prevent flooding predicted for 2030 with a 0.2% probability of exceedance.

Figure 25 - Broad Cove Pump Station

Recommendation:

- (2070) Seal interior conduits for water entry (e.g., through-floor/wall pipes, utility conduits) to 14 ft NAVD88. (Approximate cost = $2,000)
- (2070) Install drop-in flood panels on doorways. (Approximate cost = $6,000)
- (2070) Raise or enclose utility boxes on the building exterior. (Approximate cost = $5,000)
- (2070) Alternative: Purchase and have ready to deploy a temporary flood barrier around the pump station and purchase portable fuel-powered pumping system to pump out any leakage through the temporary barrier (Approximate cost = $56,000).

<u>Bel Air Pump Station</u>

Recommended Design Flood Elevation for 2030:

- 10.1 ft NAVD88

Recommended Design Flood Elevation for 2070:

- 14 ft NAVD88

Bel Air Sewer Pump Station is located on the edge of a marsh in a wooded, low-density residential area (Figure 26). The wet well access hatch (elevation 11.4 ft NAVD88) is located on the top of a concrete pad adjacent to the main pump station building in which the equipment is located. The building and wet well are located on a sufficiently elevated area so as to be protected from the 0.2% coastal flood in 2030. However, by 2070 it becomes significantly more vulnerable to flooding.

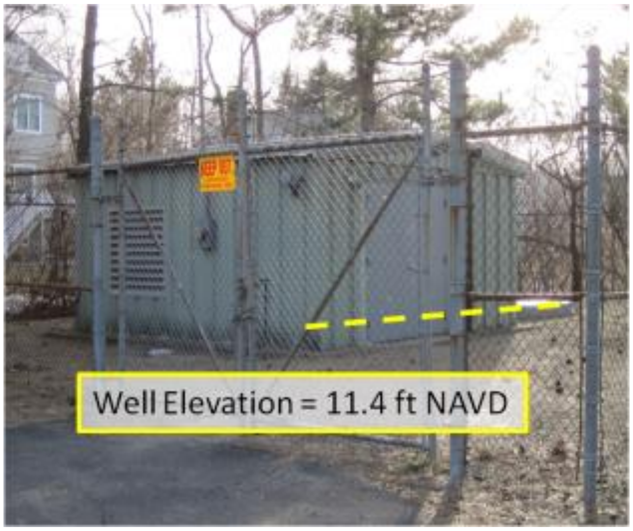


Figure 26 - Bel Air Pump Station

Recommendation:

- (2070) Construct a low flood wall inside the perimeter fence with a temporary access closure for drop-in flood panels at the gate. (Approximate cost = $120,000)
- (2070) Seal interior conduits for water entry (e.g., through-floor/wall pipes, utility conduits) to 14.0 ft NAVD88. (Approximate cost = $2,000)
- (2070) Purchase portable fuel-powered pumping system. (Approximate cost = $2,000)

Roadways

Route 3A/Otis Street/Summer Street

Recommended Design Flood Elevation for 2030:

- 10.2 ft NAVD88

Recommended Design Flood Elevation for 2070:

- 14 ft NAVD88

In the 2030 time horizon and beyond, sections of Route 3A in Hingham are at relatively high risk of flooding, including at the entrance to Broad Cove, at Hingham Bathing Beach, between North Street and Water Street, and at the Rotary (Figure 27). In addition to the negative impacts for mobility, the flooding of these roadway sections would have significant impact on public and private infrastructure located on the landward side of Route 3A.

If Route 3A is exceeded at the Broad Cove entrance, for example, the following assets could be flooded (Figure 28):

- Broad Cove Road, Downer Ave, and Lincoln Street
- Foster Elementary School and Derby Academy
- Broad Cove Sewer Pump Station

- Harbor House Nursing Center
- Pharmacy, gas station, and other businesses, and
- Residences.

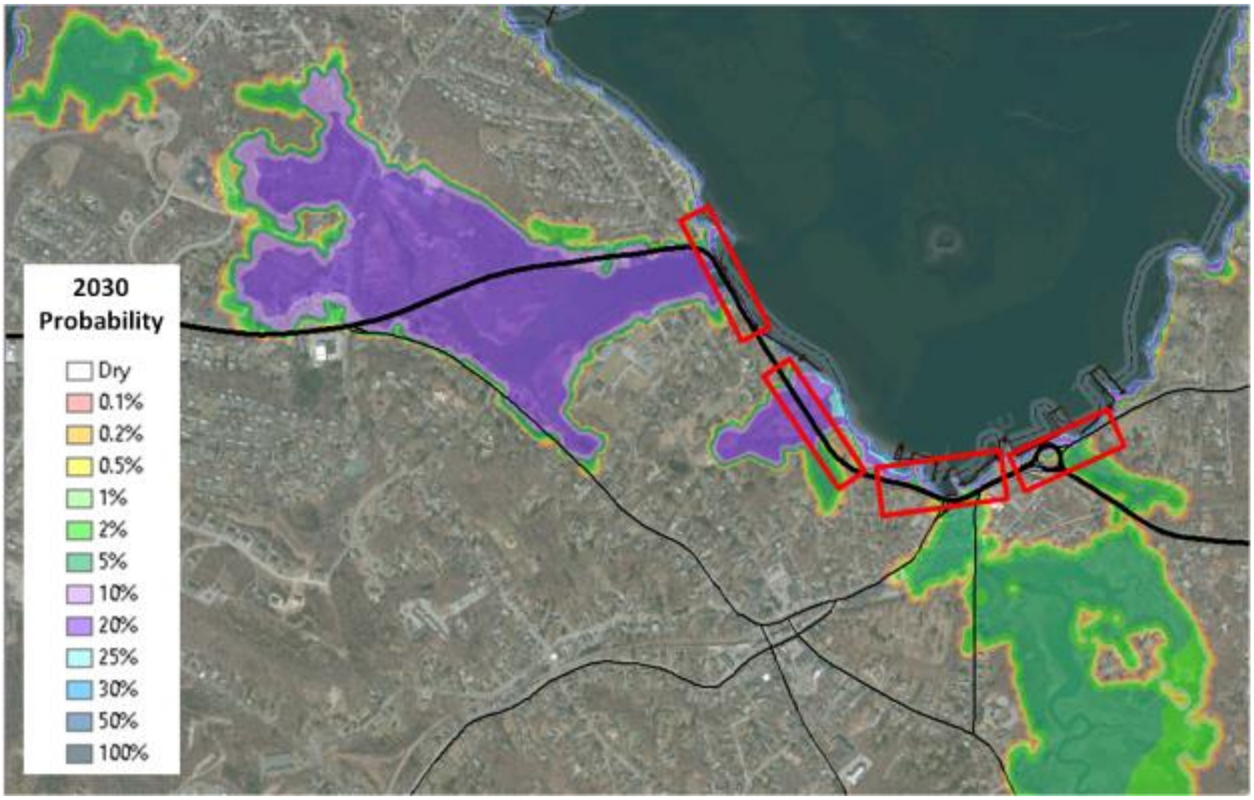


Figure 27 - Probability of Flooding along Route 3A in 2030

Figure 28 - Route 3A at Broad Cove Entrance in 2070 1% Flood (Elevation 12.8 ft NAVD88)

Inundation of Route 3A between North Street and Water Street could result in flooding of the following critical assets (Figure 29):

- Route 3A, North Street, Water Street, Mill Street, Green Street, Eldridge Court and Station Street
- Downtown overlay district
- Mill Street Pumping Station
- Telephone and natural gas infrastructure
- MBTA rail line

Route 3A is a State roadway, so the Town of Hingham does not have direct control over how it is adapted over time. However, the Town can influence the planning process. While Route 3A poses a significant risk, it also provides an opportunity to shore up Hingham's long-term resilience if addressed as a matter of priority. Route 3A could be repurposed and redesigned as a levee from rising sea levels and more intense storm surge. Because of the relatively low density of development along the roadway right-of-way and the presence of large public spaces and natural systems, MassDOT and the Town of Hingham have a number of adaptation options not available in other municipalities and at other locations.

Figure 29 - Route 3A from North Street to Water Street in the 2070 1% Flood (Elevation 12.8 ft NAVD88)

Recommendations:

- (Present) Prepare evacuation planning and education for floodplain residents, businesses, and institutions.
- (Present) Purchase electronic warning signs for road closures / evacuation if none already available. (Approximate cost = $40,000)
- (Present) Identify alternate heliport location for use during flooding events.
- (Present) Carry out planning, engineering design, environmental assessment on options to raise ~1,880 linear feet of Route 3A and/or the right-of-way to minimum elevation of 10.2 ft NAVD88 (Approximate cost in today's dollars = $475,000)
    - Raising the roadway where feasible, but especially at low points is a robust solution that allows the flexibility to add additional protection later, utilizing the right-of-way.
    - Roadway improvements should incorporate green infrastructure, best management practices for storm water management, aesthetic improvements, and other elements that enhance natural systems without exacerbating flood risks (e.g., self-regulating tide gates at Broad Cove).
    - Right-of-way improvements could include berms or permanent decorative floodwalls along the water-side edge of the sidewalk, and/or temporary flood barrier closures (e.g., drop-in flood panels) at driveways and parking lot access.
- (2030) Prior to 2030, as soon as funding becomes available, implement the preferred alternatives described above for raising Route 3A. (Approximate cost in today's dollars = $4,750,000)
- (2070) If needed, raise ~4,250 ft of right-of-way incrementally to a minimum of 14 ft NAVD88. This can be achieved by raising the roadway, or by more likely adding permanent and/or temporary flood barriers. Assuming a representative flood barrier cost of $500 per foot, an approximate cost to construct a flood barrier to bridge the gap between elevation 10.2 and 14

NAVD88, including 10% for engineering, would be $2,337,000 in today's dollars. Where space permits, such as at the bathing beach area, options exist for either "gray" infrastructure such as vertical concrete or glass barriers, or more "green" infrastructure such as landscaped berms. Unfortunately, in developed areas, such as much of the Route 3A corridor where there is limited Right of Way to work with, opportunities for "green" flood barriers are somewhat limited.

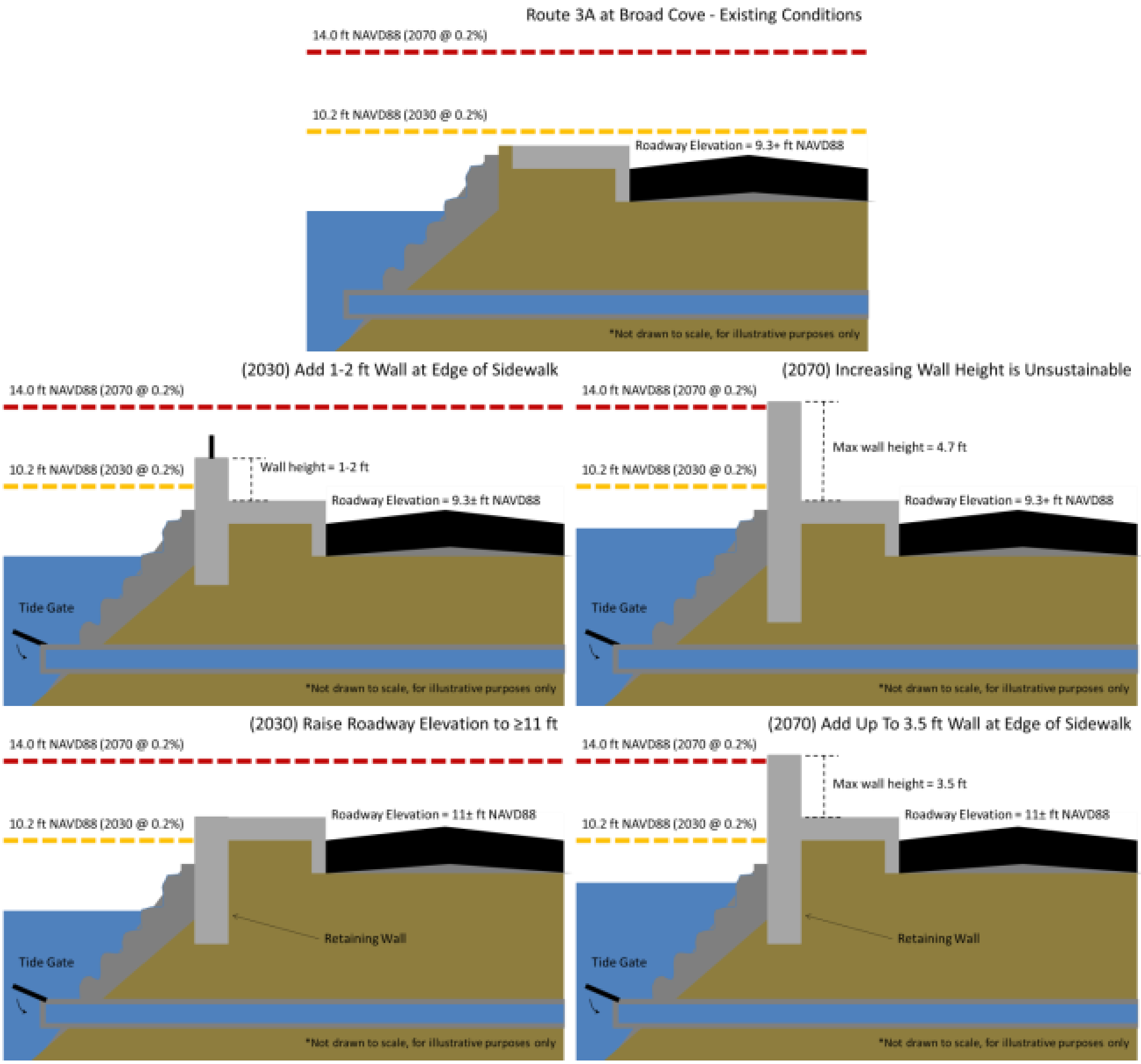


Figure 30 – Route 3A at Broad Cove Entrance – Incremental Adaptation Options

George Washington Boulevard

Recommended Design Flood Elevation for 2030:

- 10.2 ft NAVD88

Recommended Design Flood Elevation for 2070:

- 14 ft NAVD88

George Washington Boulevard is an important economic and emergency connector between the Towns of Hingham and Hull. Low points in the roadway, north and south of the Hingham District Court, could be impacted by sea level rise and storm surge, particularly in later time horizons (Figure 31). The low-lying roadway sections have few if any developments along them, allowing for the possibility that the roadway could be raised with minimal impact on adjacent uses. However, such improvements should be designed to minimize impacts to wetland resources and, where possible, to improve the quality of environmental resources along the roadway.

Figure 31 - George Washington Boulevard South of Hingham District Court in 2070 1% Flood (Elevation 12.8 ft NAVD88)

Recommendation:

- (Present) Coordinate closely with Hull on road closures / evacuations through Hingham.
- (Present) Establish a debris management and roadway/bridge inspection protocol to re-establish access to Hull via Hingham roads after a flooding event.
- (2030) Design, permit, and implement a roadway improvement project to raise approximately 850 ft. of George Washington Boulevard at low-lying sections to a minimum elevation of 10.2 ft NAVD88

  - Raising the roadway where feasible, but especially at low points is a robust solution that allows the flexibility to add additional protection later, utilizing the right-of-way.
  - Roadway improvements should incorporate green infrastructure, aesthetic improvements, and other elements that enhance natural systems without exacerbating flood risks (e.g., using vertical retaining walls to minimize expansion into adjacent salt marsh).
  - Approximate cost in today's dollars to raise the roadway to elevation 10.2 ft. NAVD88, including engineering costs, is $2,448,000
- (2070) If needed, raise the roadway and/or right-of-way incrementally over a total distance of approximately 2,000 ft. to a minimum elevation of 14 ft NAVD88. This can be achieved by raising the roadway, or by more likely adding permanent and/or temporary flood barriers. Where space permits, "green" flood barriers such as landscaped berms can be utilized. Assuming a representative flood barrier cost of $500 per foot, an approximate cost to construct a flood barrier to bridge the gap between elevation 10.2 and 14 NAVD88, including 10% for engineering, would be $1,100,000 in today's dollars.

<u>Rockland Street to Hull Street</u>

Along with George Washington Boulevard, and Hull Street, Rockland Street is an economic and emergency connector between the Towns of Hingham and Hull. Rockland Street is the roadway with the highest estimated probability of flooding in Hingham. The roadway has a reasonable potential of flooding in 2030 at the Weir River crossing near Kilby Street and along a segment of roadway from Weir Street Extension to Hull Street at the Straits Pond Dam. The Straits Pond Dam section at Hull and Rockland has a mix of commercial and residential developments. The long section to Hull Street is adjacent to sensitive marsh habitat, separated from the roadway by a small strip of low-lying uplands with residential developments. The Weir River crossing location is significant also because Hull's main electric transmission substation is located near this intersection. The high risk of flooding along the long section of low-lying roadway up to Hull Street is also an indicator of the even higher risk of flooding faced by residents who live between the roadway and the marsh. Raising low-lying sections of Rockland Street would pose financial challenges due to the length of the roadway that would need to be raised (approximately 6,000 ft.), technical challenges of mitigating impacts to adjacent properties and environmental resources, and the political challenges of protecting the roadway and properties on the landward side of the road while letting the other side flood.

Recommendation:
- (Present) Coordinate closely with Hull on road closures / evacuations through Hingham.
- (Present) Purchase electronic warning signs for road closures / evacuation I not already available (Approximate cost = $40,000)
- (Present) Establish a debris management and roadway/bridge inspection protocol to re-establish access to Hull via Hingham roads after a flooding event.
- (Present & 2030) Maximize the protective ecosystem functions that the adjacent salt marsh provides, including through restoration and management programs to maintain a healthy marsh that helps to absorb energy from wave action during a storm event which helps to minimize damage.
- (2030) Design, permit and raise the roadway to a minimum elevation of 10.2 NAVD88 over an approximate length of 6,000 ft. (Approximate cost = $16,686,000)
- (2070) If needed, raise the roadway and/or right-of-way incrementally over a total distance of approximately 6,000 ft. to a minimum elevation of 14 ft NAVD88. This can be achieved by raising the roadway, or by more likely adding permanent and/or temporary flood barriers.

Assuming a representative flood barrier cost of $500 per foot, an approximate cost to construct a flood barrier to bridge the gap between elevation 10.2 and 14 NAVD88, including 10% for engineering, would be $3,300,000 in today's dollars.

- (Alternative Recommendation) Allow the roadway to flood until the nature of development along the corridor changes to better accommodate raising the roadway or otherwise protecting the roadway and properties on the landward side of the road.

Note: Extensive changes to roadway elevations or the introduction of flood control structures, such as flood walls or raised sea walls, <u>could</u> have a significant positive effect on the flood characteristics depicted in future FEMA Flood Insurance Rate Maps (FIRM) for the Town of Hingham which <u>could</u> have the positive benefit of causing a reduction in flood insurance premiums for the Town, home owners and commercial interests.

Recommendations for Natural Resources

Broad Cove

An existing study was performed in 2011 by Woods Hole Group to evaluate the feasibility of habitat restoration in Broad Cove by improving tidal exchange between Hingham Harbor and Broad Cove by making changes to the existing hydraulic constrictions at Route 3A (Otis St). The existing small culvert severely restricts the amount of flow from Hingham Harbor into Broad Cove during daily tidal cycles, reducing the water quality and thus the health of the ecosystem in the Cove. Broad Cove is projected to undergo some of the largest natural resource changes in Town due to predicted sea level rise.

The previous study concluded that the maximum size culvert without tidal controls that could be constructed was 10 ft. wide by 4 ft. high without impacting daily flooding of adjacent roadways.

Increasing the size of the culvert under Route 3A is an important element to increase the overall health of the Broad Cove ecosystem by improving tidal flow from Hingham Harbor. However, the increased culvert size should also include tidal controls and raising Route 3A, as part of a flood barrier system to protect infrastructure and roadways along Broad Cove. (see Route 3A recommendations above). Further engineering and habitat/ecological studies will be required to properly size the larger culvert and the appropriate tidal control structure. Woods Hole Group already has a model of this area in place and could do some simple simulations with sea level rise and storms to assess alternatives in more detail.

Worlds End Reservation

This is a Trustees of Reservations-owned property and should be left to naturally evolve. There is no significant infrastructure, and some of the potential transitions at this location are ecologically positive.

Hingham Harbor Shoreline

The section of shoreline at the Hingham Harbor warrants a further site-specific coastal processes and adaptation study to evaluate potential gray and green adaptation options. There is a mix of important natural and infrastructure components along this shoreline, and it also protects some significant upland assets. Some possible adaptations include beach and dune restoration at the bathing beach and enhancement with modular seawalls along Hingham Harbor Marina. A site-specific coastal processes study, which includes modeling of local tidal currents, sea level rise an storm surge, wave action and sediment characteristics, will provide more detailed information on factors affecting long-term rates of erosion, sediment transport mechanisms, and the types and characteristics of hard and soft coastal protection systems that will provide the most resilient shore front. The cost of a site-specific coastal processes study may range between $100,000 and $200,000, depending on the level of detail desired. A construction project for improvements to the area, including the beach, is currently close to implementation. It is unclear how future effects of climate change, including sea level rise, have been incorporated into the design.

Home Meadow

Restoration work in Home Meadow has been implemented by the Town and MBTA as part of the mitigation for impacts caused by the commuter rail improvements. In terms of impacts to natural resources from sea level rise, it appears there is adequate time to react here as the natural resources don't show significant changes until later out years. For the time being, this area could be left to naturally evolve.

Foundry Pond and Lyford Lyking Area

There are some positive ecological enhancements that occur by 2030, and no additional natural resource conservation action would be required to combat sea level rise impacts until at least 2070. A wait and see approach is reasonable here.

Beal Cove

Beal Cove is a good location for some potential green resilience design that would benefit the natural resources and fringing marsh in this area. Some potential adaptations to consider in this location include thin layer deposition projects, marsh expansion projects, and/or living shorelines. For example, marsh elevations in this area could be made more resilient and/or expanded through a thin-layer deposition project for the cove. Since there is limited wave energy expected to influence this area, marsh resiliency could be fostered to provide storm damage protection. Another approach for this region would be implementation of biodegradable type solutions to provide an expanded natural resource area and "living" shoreline seaward of the roads in this area.

Policy/Regulations

<u>Potential Amendments to Hingham Wetlands Regulations</u>

- Amend Section 2.0 (Jurisdiction), subsection (6): Consider changing the reference from (1-4) to (1-5) which will then include land within a minimum distance of 100 feet from land subject to flooding or inundation.

- Amend Section 7.4 (Notice of Intent), subsection (b): Consider adding a subsection 7.4.b.9 requiring applicants to submit a discussion on how the effects of sea level rise are being addressed and mitigated for applications affecting Land Subject to Coastal Storm Flowage and Bordering Land Subject to Flooding within the local buffer zone. Also consider that the applicant be required to submit a cost-benefit analysis of mitigation alternatives.

- Update and combine the performance standards in Sections 20.0 (Land Subject to Coastal Storm Flowage) and 24.0 (Additional Protection of Special Flood Hazard Zones). These two performance standards have some conflicting standards and should be reviewed for both consistency and appropriateness of performance standards. Some issues to consider:

    - In section 20.1.d.4, consider specifying a specific sea level rise curve rather than allowing use of "*at a minimum, the historic rate of relative sea level rise in Massachusetts of 1 foot per 100 years*….". Based on the results of this study, the results are dramatically different over the long term life of project.

    - In section 20.1.d.5.b, prohibition of impermeable paving is not realistic for major roadway work, such as those contemplated for Route 3A or George Washington Boulevard.

    - In sections 20.1.d.5.c and 20.1.d.6.b, the current language only permits expansion of coastal engineering structures that are loose, slope-stone design (revetments). As discussed above, this may not be the best solution to flood prevention, if such revetments would need to extend beyond the existing land limits. This prevents use of innovative green infrastructure, limits raising existing flood protection structures, and construction of permanent or temporary flood protection walls. More definition of what will be permitted should be provided.

    - Consider adding performance standards for the use of temporary flood protection barriers.

    - Section 20.1.d.10 references buffer zone requirements for Land Subject to Coastal Storm Flowage (LSCSF), however LSCSF is included in buffer zone standards. Further the reference to section 23.0 should be 22.0.

    - In both sections 20.0 and 24.0 there are references to expansion of structures in flood zones. There have apparently been a number of recent questions during hearings as to what defines expansion. Consider clarifying the definition of expansion of existing structures in flood zones.

- Consider increasing the width of the buffer zone for LSCSF. The current buffer zone if 100 ft. in accordance with the distance in 310 CMR 10.00. The Conservation Commission could increase its local jurisdictional area to review projects in the context of potential impacts to wetlands due to predicted sea level rise.

Potential Zoning By-Law Changes

- Consider establishing a Coastal Management Zone (CMZ) district which would amend the Flood Plain and Watershed protection District defined in Section III-C of the Hingham. This section currently references the FEMA FIRM map adopted in 2012 which does not include projections for future sea level rise. The CMZ could extend minimum flood plain regulations to the 0.2% risk (500-year) FIRM floodplain (X Zones) which is beyond the existing 1% risk (100-year) limit in the current Flood Plain District. It will likely not be possible to completely eliminate reference to the FEMA FIRM map because doing so would eliminate eligibility under the National Flood Insurance Program (NFIP) for the Town of Hingham, which is not recommended. Instead, the CMZ could incorporate performance standards based on the 0.2 percent (500 year recurrence) mapping, and attempt to incorporate higher freeboard standards for structures being rebuilt or substantially reconstructed. Specific performance standards would need to be developed for evaluation of projects during Zoning Board of Appeals/Planning Board Special Permit and/or Site Plan review processes. Performance criteria in this zone could be developed using No Adverse Impacts principles.

    - When developing performance standards for commercial structures in the CMZ zone, consideration should be given to permit wet-proofing or dry-proofing of structures in lieu of elevating structures. Elevating structures can have very costly impacts on meeting the accessibility requirements of the Americans with Disabilities Act (ADA) on commercial and public structures. Allowing for wet or dry-proofing of existing buildings will help to improve their resiliency, while minimizing costly ADA modifications.

    - Consider including provisions in the CMZ performance standards for temporary flood barrier protection. One element that needs to be addressed is how means of egress is addressed. During a flood event, while the building is surrounded with a temporary flood protection barrier, egress routes may not be operational. Requiring that the building be unoccupied during a flood while temporary barriers are in place helps to address this building code issue.

- Consider amending the Zoning By-Law to provide incentives to residential and commercial property owners to raise/protect structures to improve resilience and flood protection of private properties.

    - Consider allowing higher maximum height restrictions in section IV-A in the case of existing structures being elevated to improve flood protection.

    - Consider adopting a “freeboard incentive” for residential and commercial building elevation projects or for new construction. As an example, the Town of Hull adopted a “freeboard incentive” that reduces building department application fees by $500 if an elevation certificate is provided to verify that the building is elevated a minimum of two feet above the highest federal or state requirement for the flood zone. Additional fee reductions could apply for additional freeboard.

Potential Changes to the Planning Board Rules and Regulations for Subdivisions

- Consider modifying the subdivision rules and regulations to allow for cluster development in the CMZ and other wetland protection districts which could provide a density bonus for projects that provide open space to accommodate expanding wetlands.

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 Town's Open Space Acquisition Committee should use the natural resource information provided in this study to identify priority areas for acquisition through easements, fee interest or purchase of development rights to accommodate project effects of sea level rise. These priorities could be included in the 2015-2016 update to the Towns Open Space and Recreation Plan.
    - Investigate the possibility of implementing a rolling easements program in which the town can purchase an easement from a landowner today in exchange for a promise to surrender the property to the town once it is substantially damaged by a flood event. This program is part of a retreat policy to be implemented in areas subject to severe and repeated flooding. Rolling easements are a way to provide cash to a homeowner today with the understanding that when the home is substantially damaged, it will not be rebuilt and will be turned over to the town. This program is part of a retreat policy to be implemented in areas subject to severe and repeated flooding. Based on information provided in the 2012 Hingham Hazard Mitigation Plan Update, there are seven single or multi-family homes in Hingham that are defined by the Community Rating System (CRS) of the National Flood Insurance Program as repetitive loss properties. These seven properties, 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 flood damage in the past, and the chance that they will experience more claims in the future is very high.

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.
    - Evaluate the costs and benefits of becoming a Green Community.

- Evaluate the Town'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.

- Evaluate opportunities to relocate snow storage areas away from the Town bathing beach parking lot.

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

<u>Install a Tide Gauge in Hingham Harbor</u>

- Consider installing an automated tide gauge in Hingham Harbor to help monitor actual sea level rise locally. The nearest tide gauge is in Boston Harbor. Although it is very reliable, it does not provide localized data for Hingham Harbor. Having a local tide gauge will provide important data for the design and implementation of future adaptation projects. (Approximate cost = $5,000)

<u>Develop a Coastal Flood Operations Plan</u>

- 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 Town's overall emergency response planning documents.

LIMITATIONS

General

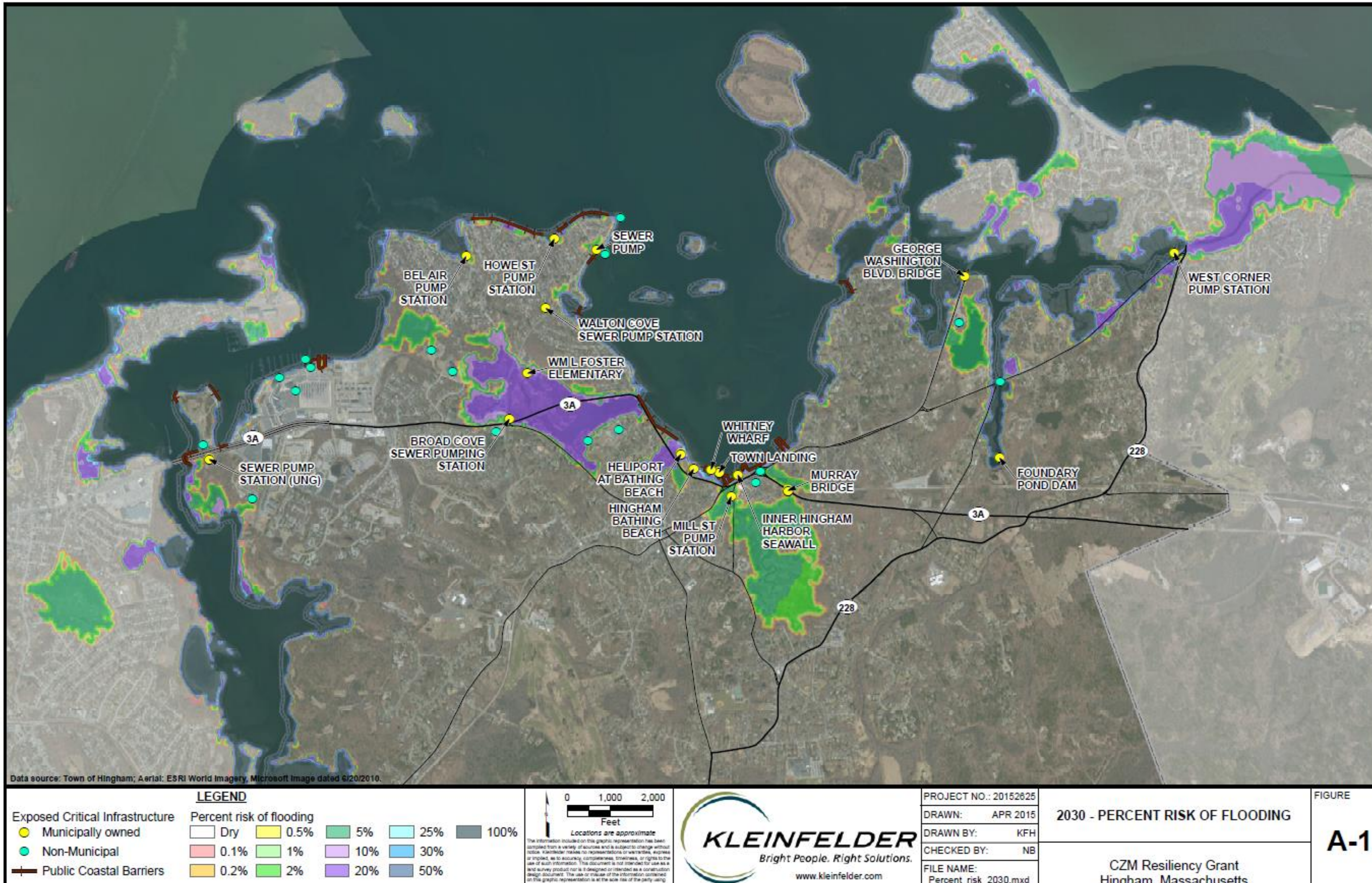
The science of climate change and translating climate risks into design criteria are new and evolving practices, involving many uncertainties. Therefore, the projections made in this report only reflect the professional judgment of the Project Team applying a standard of care consistent with the practice 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.

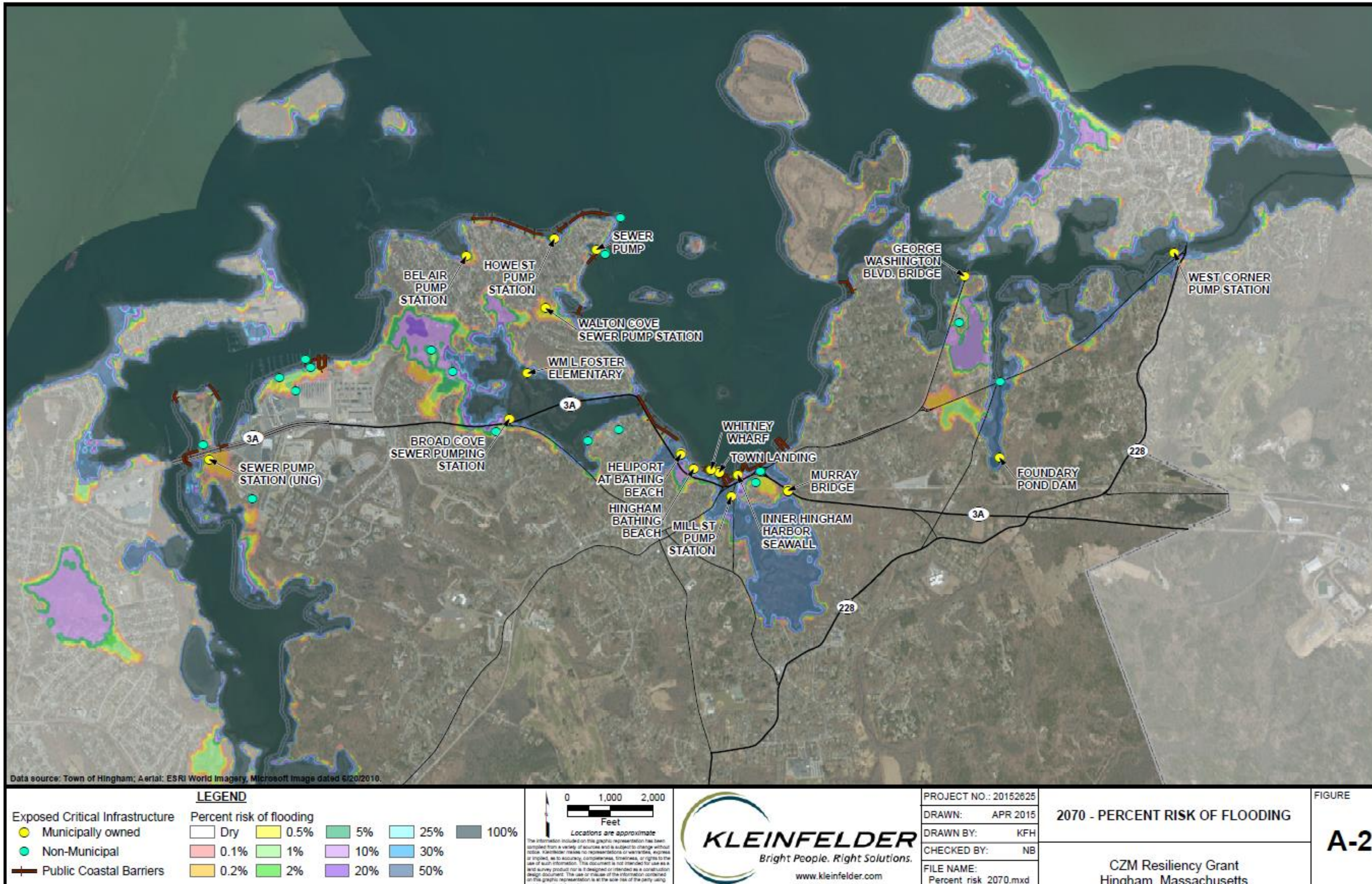
The scope of this contract did not include a full review of building and facility drawings, material testing, survey or structural analysis of the building's ability to withstand the projected hydrostatic forces due to flooding. The findings include certain assumptions based on reasonable engineering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

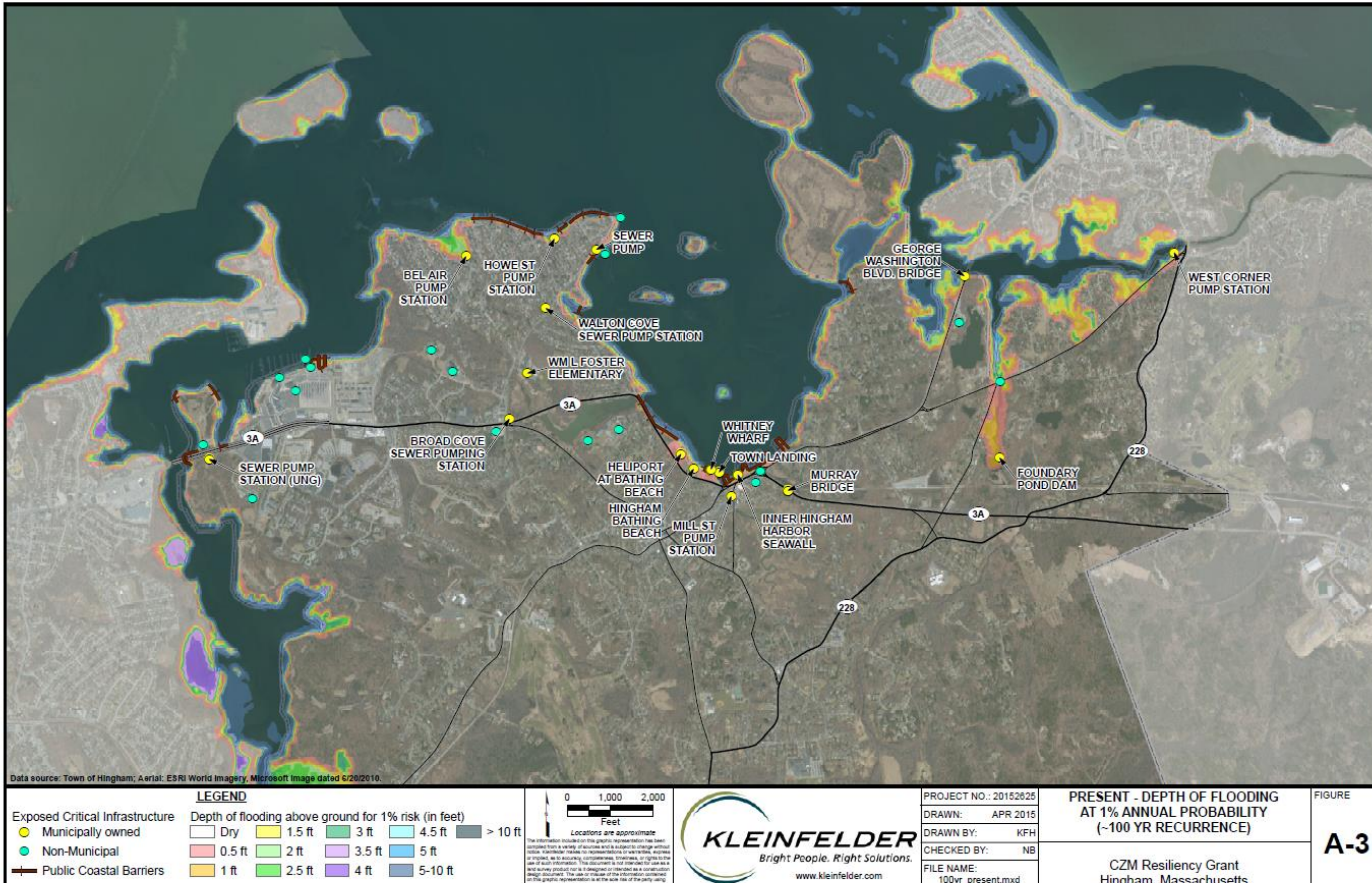
Flood Maps

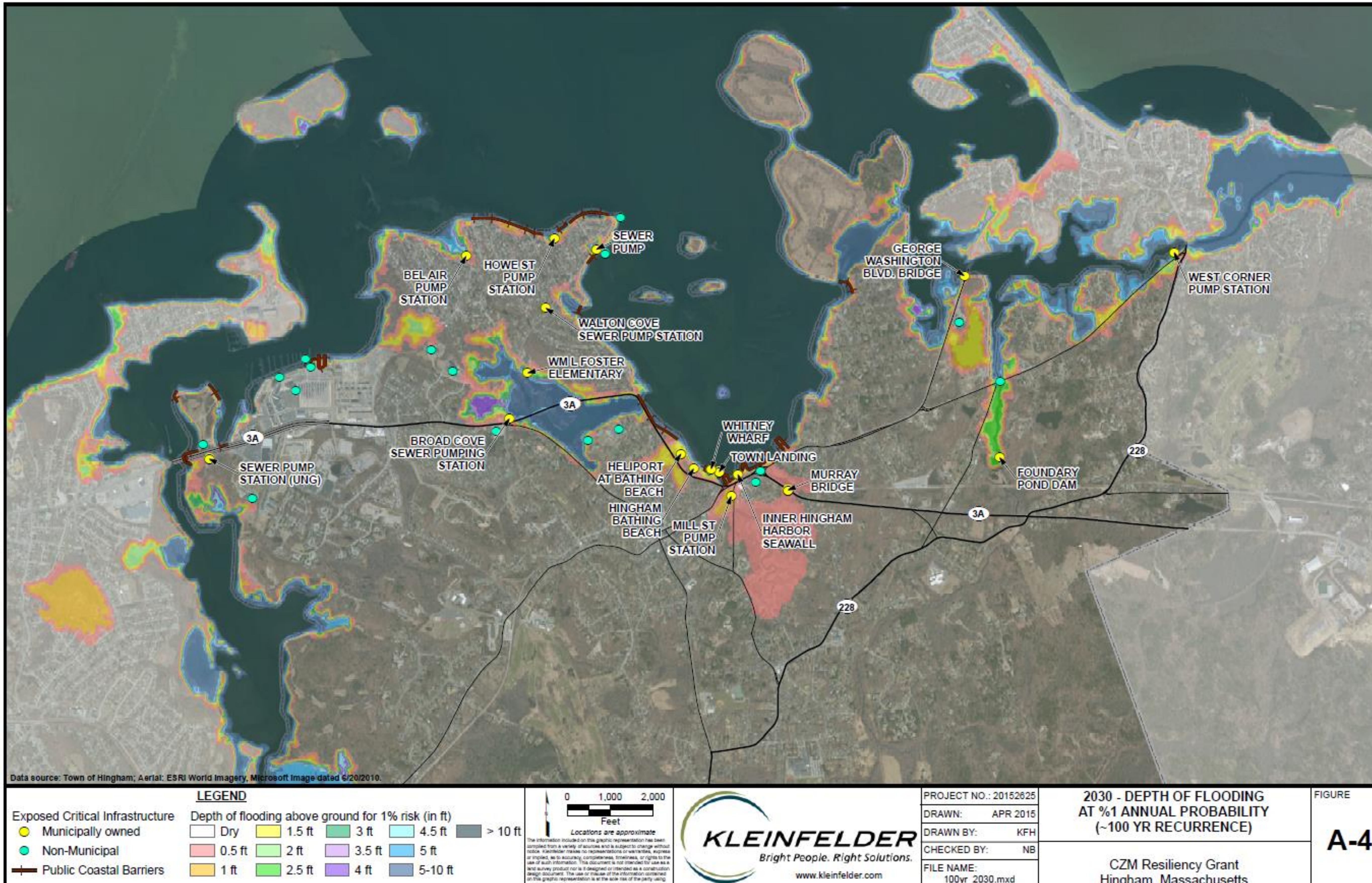
The flood maps included in this report illustrate predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the years stated. These flood maps expressly do not include flooding attributed to wave 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 in these maps be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

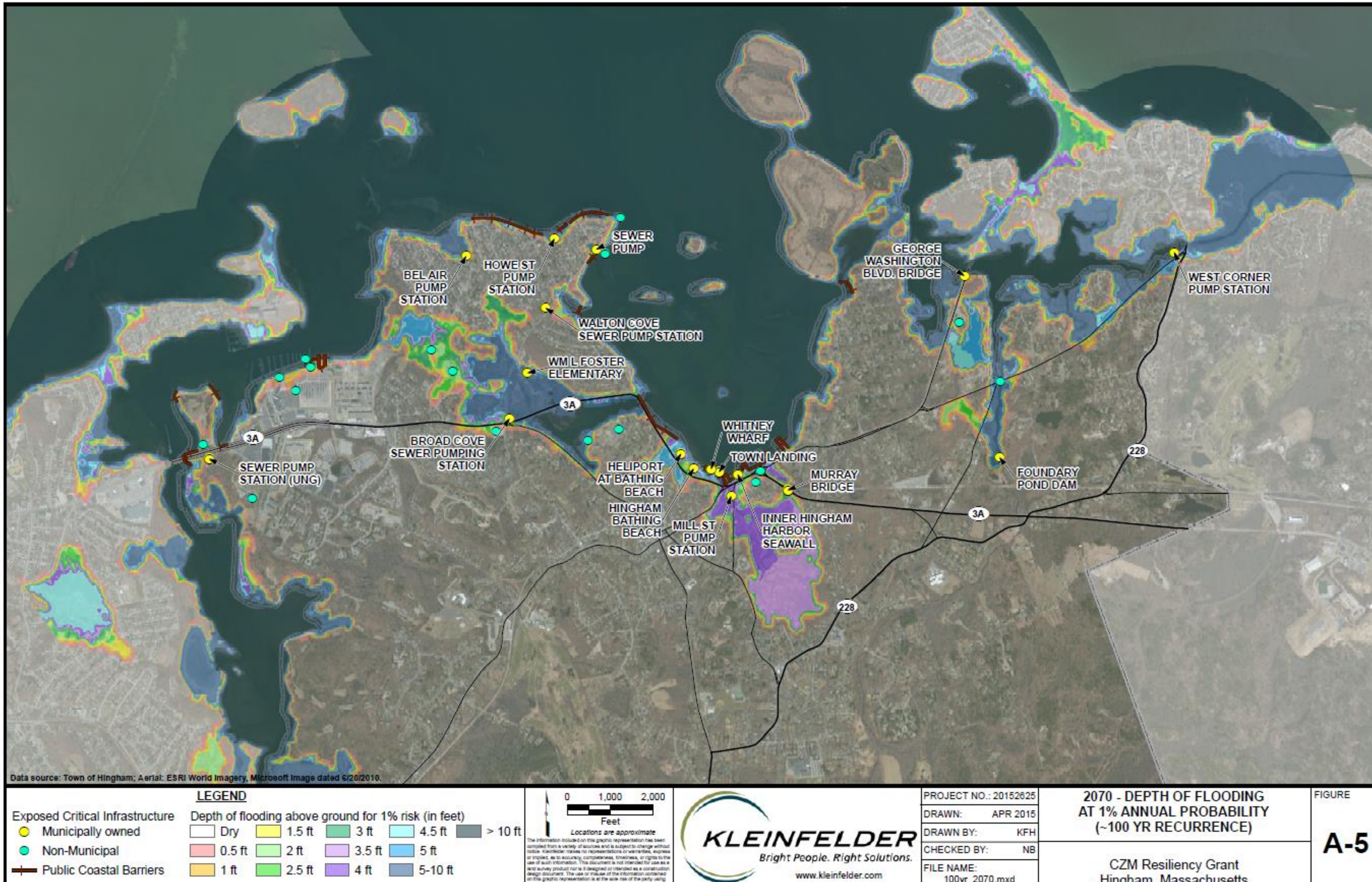
APPENDIX A – INUNDATION MAPS

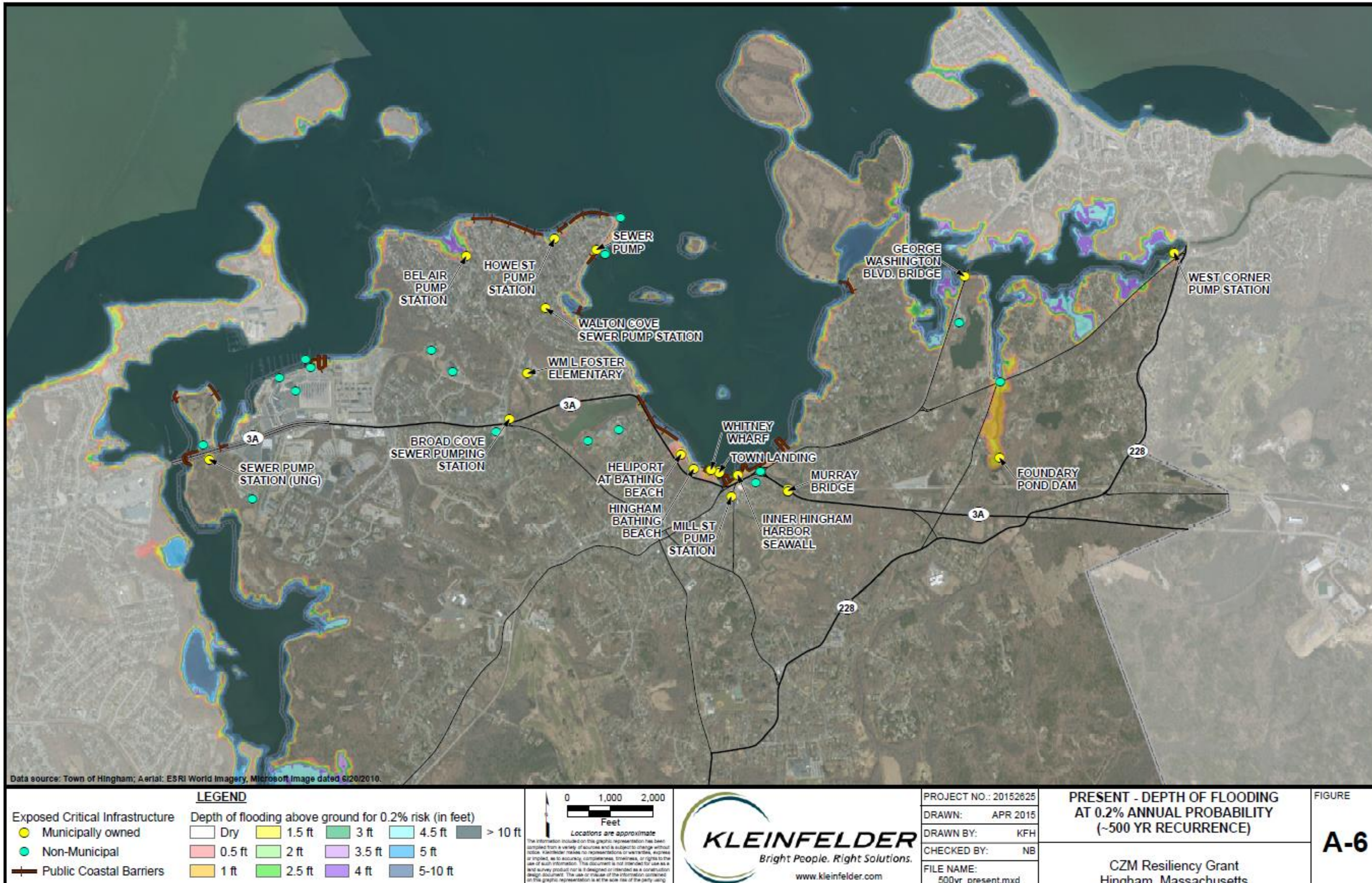

SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
BROAD COVE SEWER PUMPING STATION
SEWER PUMP STATION (UNG)
WHITNEY WHARF
TOWN LANDING
HELIPORT AT BATHING BEACH
MURRAY BRIDGE
FOUNDARY POND DAM
HINGHAM BATHING BEACH
MILL ST PUMP STATION
INNER HINGHAM HARBOR SEAWALL
3A
228
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft Image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Percent risk of flooding
Dry
0.1%
0.2%
0.5%
1%
2%
5%
10%
20%
25%
30%
50%
100%
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: Percent_risk_2030.mxd
2030 - PERCENT RISK OF FLOODING
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-1

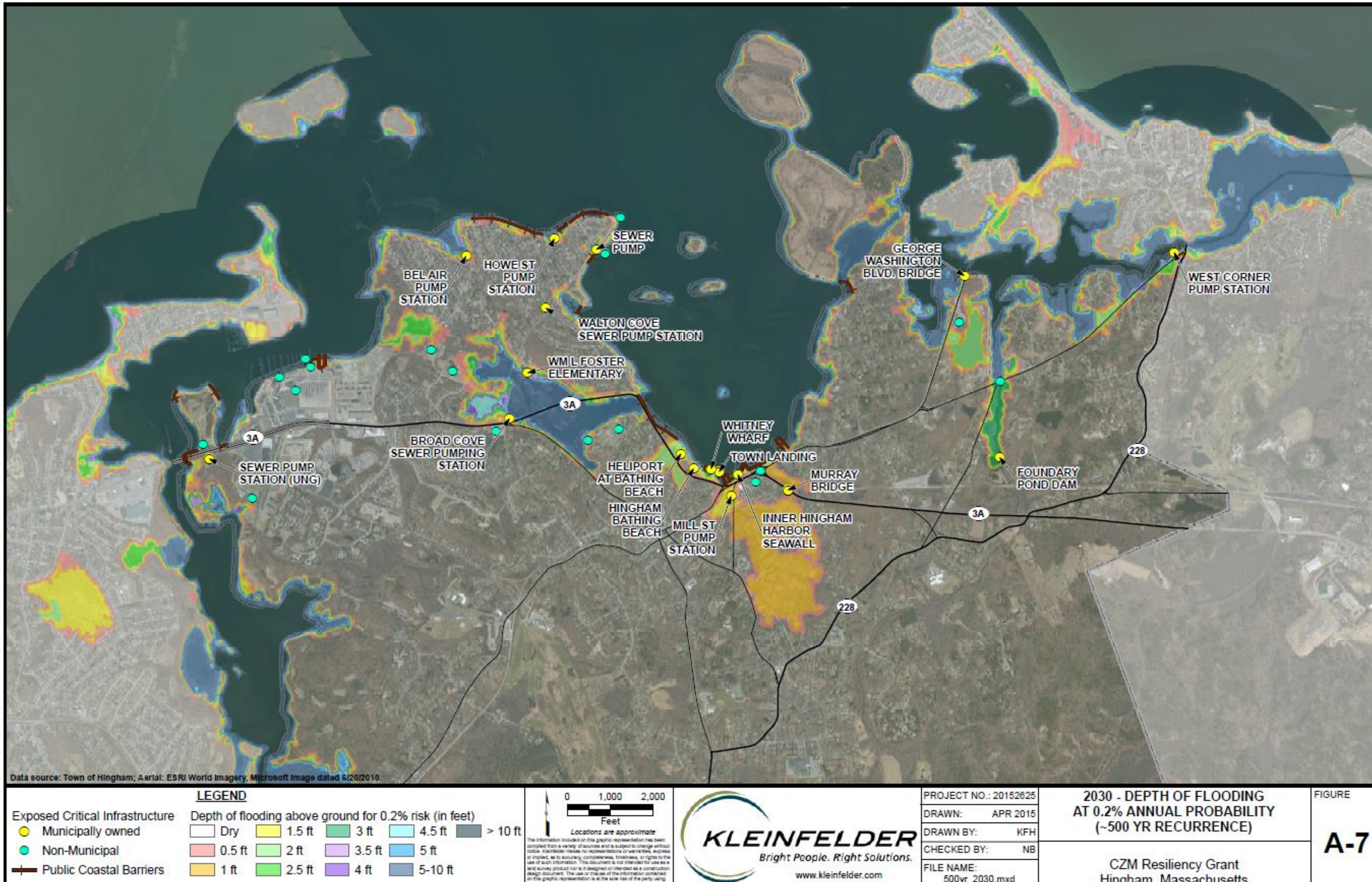

SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
3A
BROAD COVE SEWER PUMPING STATION
SEWER PUMP STATION (UNG)
WHITNEY WHARF
TOWN LANDING
HELIPORT AT BATHING BEACH
MURRAY BRIDGE
FOUNDARY POND DAM
228
HINGHAM BATHING BEACH
MILL ST PUMP STATION
INNER HINGHAM HARBOR SEAWALL
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft Image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Percent risk of flooding
Dry
0.1%
0.2%
0.5%
1%
2%
5%
10%
20%
25%
30%
50%
100%
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: Percent_risk_2070.mxd
2070 - PERCENT RISK OF FLOODING
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-2

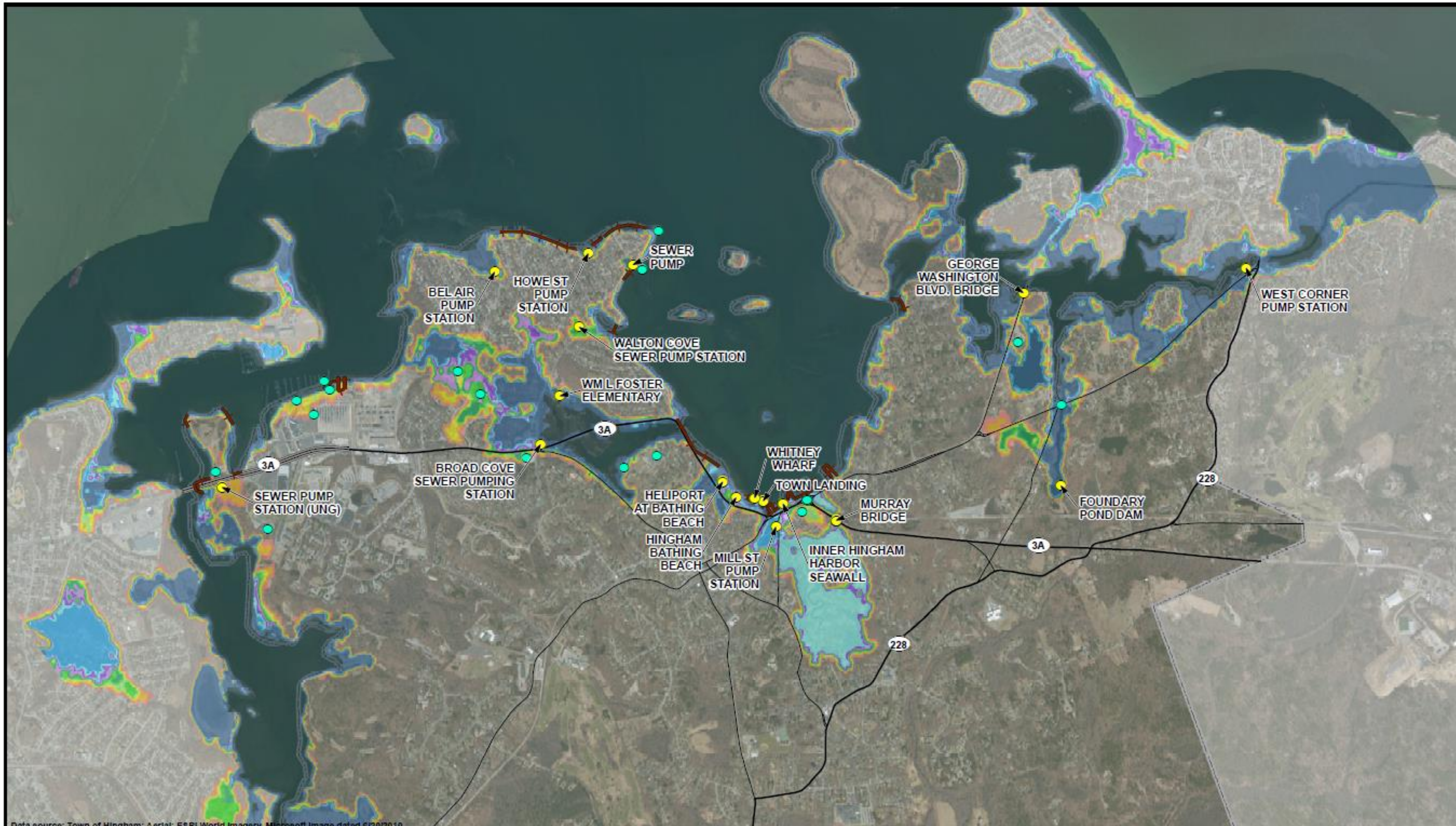

SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
3A
BROAD COVE SEWER PUMPING STATION
SEWER PUMP STATION (UNG)
WHITNEY WHARF
TOWN LANDING
HELIPORT AT BATHING BEACH
HINGHAM BATHING BEACH
MILL ST PUMP STATION
MURRAY BRIDGE
INNER HINGHAM HARBOR SEAWALL
FOUNDARY POND DAM
228
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft Image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Depth of flooding above ground for 1% risk (in feet)
Dry
0.5 ft
1 ft
1.5 ft
2 ft
2.5 ft
3 ft
3.5 ft
4 ft
4.5 ft
5 ft
5-10 ft
> 10 ft
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: 100yr_present.mxd
PRESENT - DEPTH OF FLOODING AT 1% ANNUAL PROBABILITY (~100 YR RECURRENCE)
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-3


SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
3A
BROAD COVE SEWER PUMPING STATION
SEWER PUMP STATION (UNG)
WHITNEY WHARF
TOWN LANDING
HELIPORT AT BATHING BEACH
MURRAY BRIDGE
FOUNDARY POND DAM
228
HINGHAM BATHING BEACH
MILL ST PUMP STATION
INNER HINGHAM HARBOR SEAWALL
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft Image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Depth of flooding above ground for 1% risk (in ft)
Dry
0.5 ft
1 ft
1.5 ft
2 ft
2.5 ft
3 ft
3.5 ft
4 ft
4.5 ft
5 ft
5-10 ft
> 10 ft
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: 100yr_2030.mxd
2030 - DEPTH OF FLOODING AT %1 ANNUAL PROBABILITY (~100 YR RECURRENCE)
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-4


SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
3A
BROAD COVE SEWER PUMPING STATION
SEWER PUMP STATION (UNG)
WHITNEY WHARF
TOWN LANDING
HELIPORT AT BATHING BEACH
HINGHAM BATHING BEACH
MILL ST PUMP STATION
MURRAY BRIDGE
INNER HINGHAM HARBOR SEAWALL
FOUNDARY POND DAM
228
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft Image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Depth of flooding above ground for 1% risk (in feet)
Dry
0.5 ft
1 ft
1.5 ft
2 ft
2.5 ft
3 ft
3.5 ft
4 ft
4.5 ft
5 ft
5-10 ft
> 10 ft
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: 100yr_2070.mxd
2070 - DEPTH OF FLOODING AT 1% ANNUAL PROBABILITY (~100 YR RECURRENCE)
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-5


SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
3A
BROAD COVE SEWER PUMPING STATION
SEWER PUMP STATION (UNG)
WHITNEY WHARF
TOWN LANDING
HELIPORT AT BATHING BEACH
HINGHAM BATHING BEACH
MILL ST PUMP STATION
MURRAY BRIDGE
INNER HINGHAM HARBOR SEAWALL
FOUNDARY POND DAM
228
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft Image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Depth of flooding above ground for 0.2% risk (in feet)
Dry
0.5 ft
1 ft
1.5 ft
2 ft
2.5 ft
3 ft
3.5 ft
4 ft
4.5 ft
5 ft
5-10 ft
> 10 ft
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: 500yr_present.mxd
PRESENT - DEPTH OF FLOODING AT 0.2% ANNUAL PROBABILITY (~500 YR RECURRENCE)
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-6


SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
3A
BROAD COVE SEWER PUMPING STATION
SEWER PUMP STATION (UNG)
WHITNEY WHARF
TOWN LANDING
HELIPORT AT BATHING BEACH
MURRAY BRIDGE
FOUNDARY POND DAM
228
HINGHAM BATHING BEACH
MILL ST PUMP STATION
INNER HINGHAM HARBOR SEAWALL
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft Image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Depth of flooding above ground for 0.2% risk (in feet)
Dry
0.5 ft
1 ft
1.5 ft
2 ft
2.5 ft
3 ft
3.5 ft
4 ft
4.5 ft
5 ft
5-10 ft
> 10 ft
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: 500yr_2030.mxd
2030 - DEPTH OF FLOODING AT 0.2% ANNUAL PROBABILITY (~500 YR RECURRENCE)
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-7



LEGEND

Exposed Critical Infrastructure
- Municipally owned
- Non-Municipal
- Public Coastal Barriers

Depth of flooding above ground for 1% risk (in feet)
Dry | 1.5 ft | 3 ft | 4.5 ft | > 10 ft
0.5 ft | 2 ft | 3.5 ft | 5 ft
1 ft | 2.5 ft | 4 ft | 5-10 ft

0 1,000 2,000
Feet
Locations are approximate

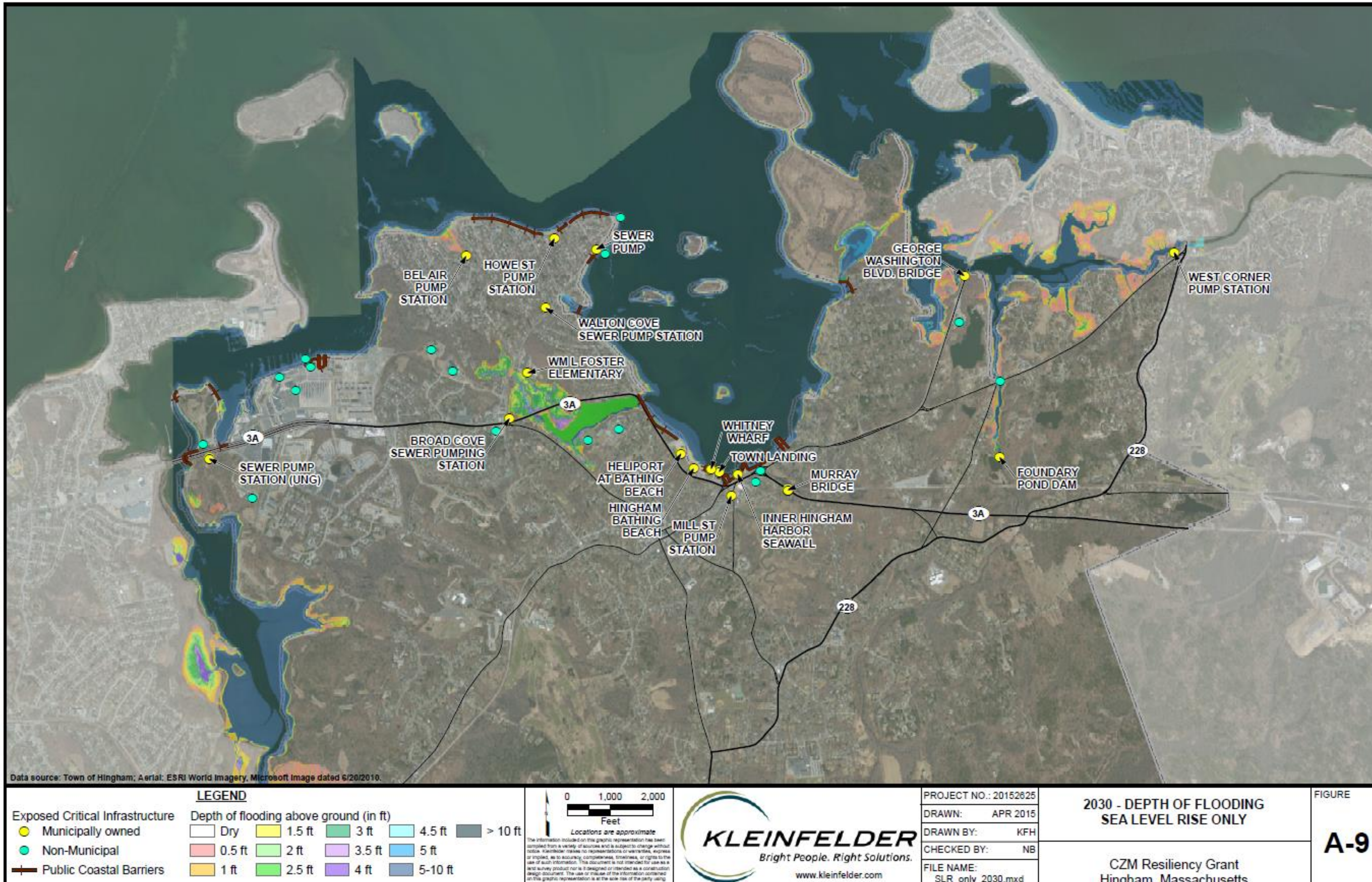
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com

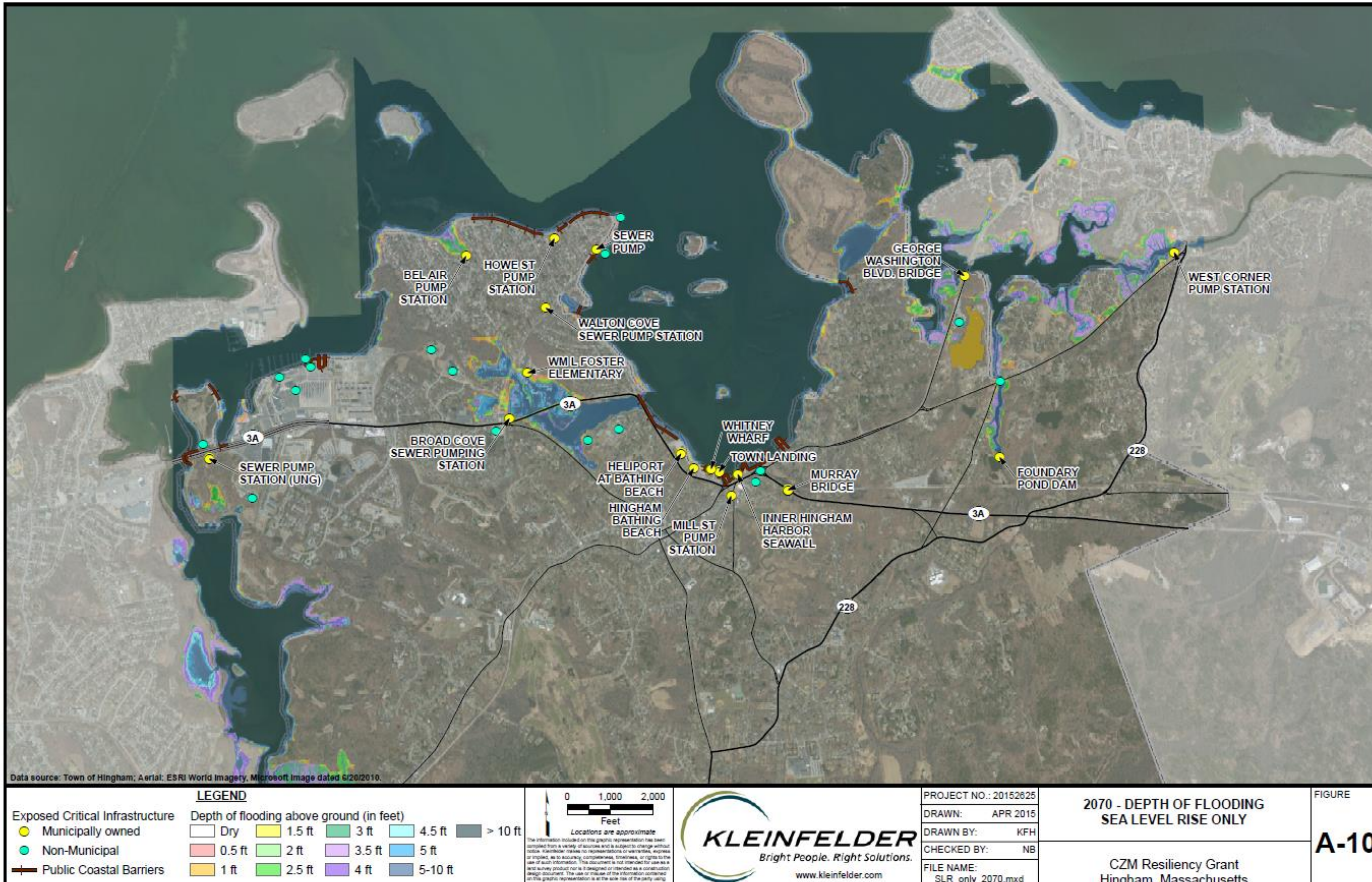
PROJECT NO.:	20152625
DRAWN:	APR 2015
DRAWN BY:	KFH
CHECKED BY:	NB
FILE NAME:	500yr_2070.mxd

2070 - DEPTH OF FLOODING AT 0.2% ANNUAL PROBABILITY (~500 YR RECURRENCE)

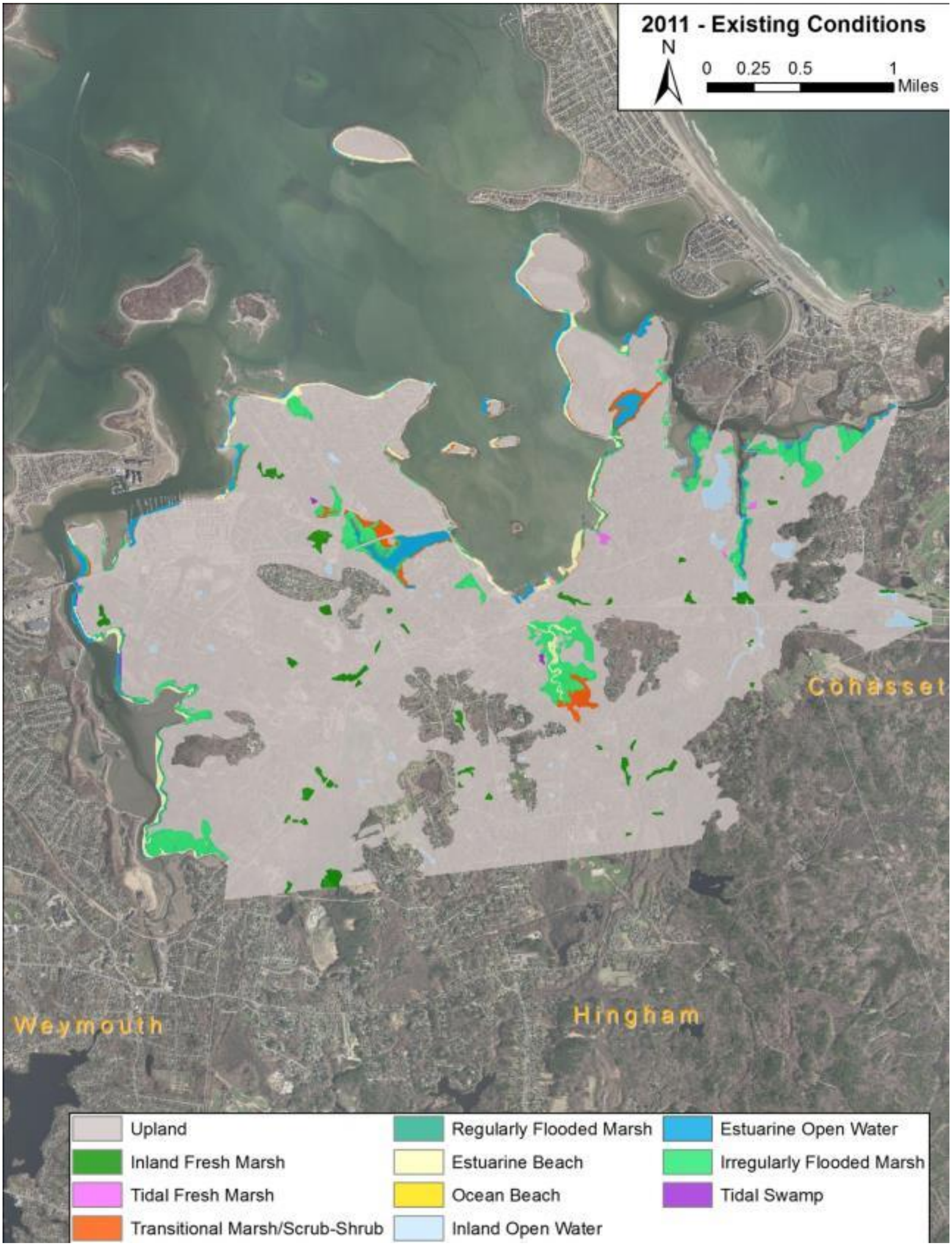
CZM Resiliency Grant
Hingham, Massachusetts

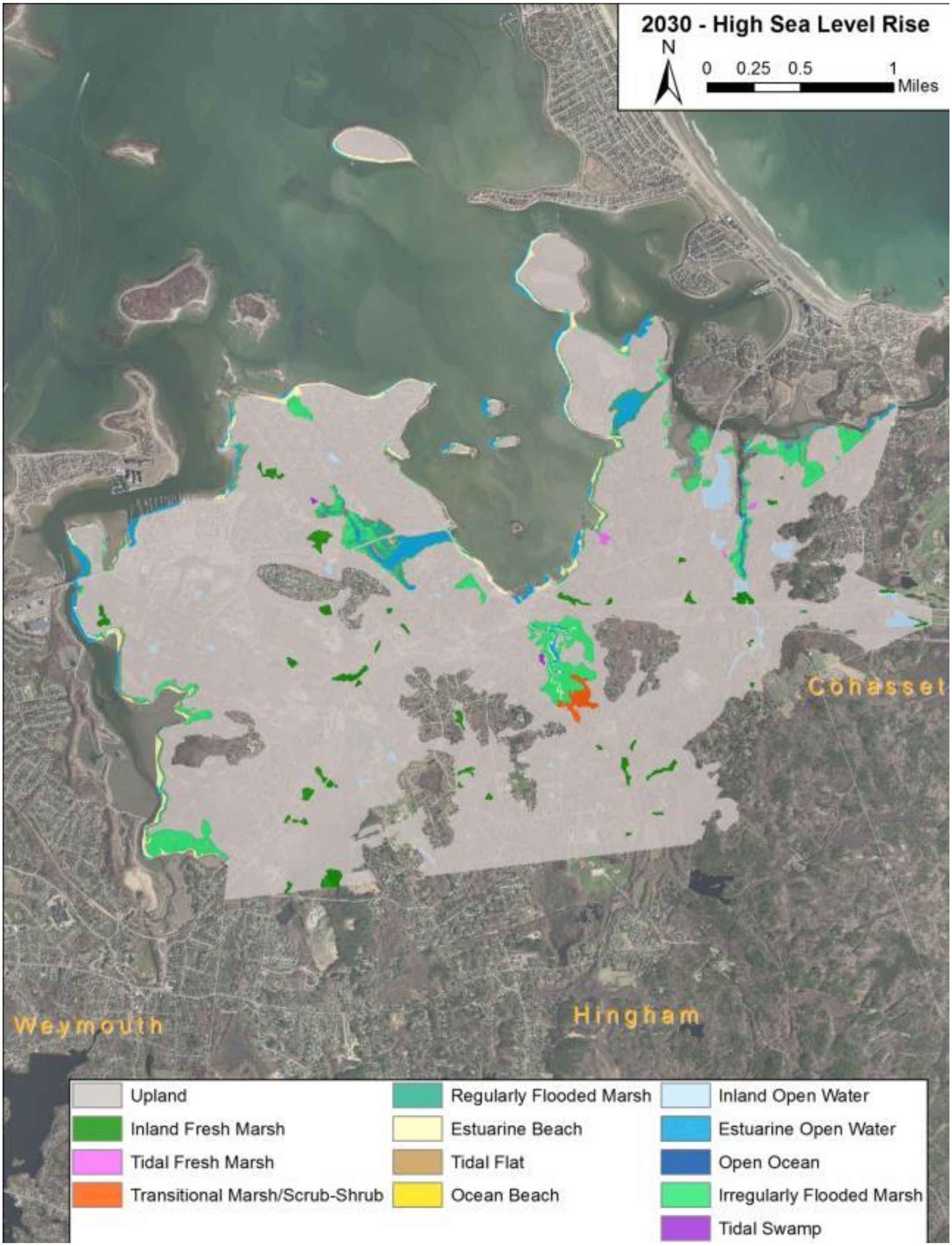
FIGURE
A-8


SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
3A
BROAD COVE SEWER PUMPING STATION
WHITNEY WHARF
TOWN LANDING
SEWER PUMP STATION (UNG)
HELIPORT AT BATHING BEACH
MURRAY BRIDGE
FOUNDARY POND DAM
228
HINGHAM BATHING BEACH
MILL ST PUMP STATION
INNER HINGHAM HARBOR SEAWALL
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft Image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Depth of flooding above ground (in ft)
Dry
0.5 ft
1 ft
1.5 ft
2 ft
2.5 ft
3 ft
3.5 ft
4 ft
4.5 ft
5 ft
5-10 ft
> 10 ft
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: SLR_only_2030.mxd
2030 - DEPTH OF FLOODING
SEA LEVEL RISE ONLY
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-9


SEWER PUMP
BEL AIR PUMP STATION
HOWE ST PUMP STATION
WALTON COVE SEWER PUMP STATION
WM L FOSTER ELEMENTARY
GEORGE WASHINGTON BLVD. BRIDGE
WEST CORNER PUMP STATION
3A
228
BROAD COVE SEWER PUMPING STATION
SEWER PUMP STATION (UNG)
WHITNEY WHARF
TOWN LANDING
HELIPORT AT BATHING BEACH
MURRAY BRIDGE
FOUNDARY POND DAM
HINGHAM BATHING BEACH
MILL ST PUMP STATION
INNER HINGHAM HARBOR SEAWALL
Data source: Town of Hingham; Aerial: ESRI World Imagery, Microsoft image dated 6/20/2010.
LEGEND
Exposed Critical Infrastructure
Municipally owned
Non-Municipal
Public Coastal Barriers
Depth of flooding above ground (in feet)
Dry
0.5 ft
1 ft
1.5 ft
2 ft
2.5 ft
3 ft
3.5 ft
4 ft
4.5 ft
5 ft
5-10 ft
> 10 ft
0 1,000 2,000
Feet
Locations are approximate
KLEINFELDER
Bright People. Right Solutions.
www.kleinfelder.com
PROJECT NO.: 20152625
DRAWN: APR 2015
DRAWN BY: KFH
CHECKED BY: NB
FILE NAME: SLR_only_2070.mxd
2070 - DEPTH OF FLOODING
SEA LEVEL RISE ONLY
CZM Resiliency Grant
Hingham, Massachusetts
FIGURE
A-10

APPENDIX B – WETLAND CLASSIFICATION MAPS AND DATA


2011 - Existing Conditions
N
0 0.25 0.5 1
Miles
Cohasset
Hingham
Weymouth
Upland
Inland Fresh Marsh
Tidal Fresh Marsh
Transitional Marsh/Scrub-Shrub
Regularly Flooded Marsh
Estuarine Beach
Ocean Beach
Inland Open Water
Estuarine Open Water
Irregularly Flooded Marsh
Tidal Swamp


2030 - High Sea Level Rise
N
0 0.25 0.5 1
Miles
Cohasset
Weymouth
Hingham
Upland
Inland Fresh Marsh
Tidal Fresh Marsh
Transitional Marsh/Scrub-Shrub
Regularly Flooded Marsh
Estuarine Beach
Tidal Flat
Ocean Beach
Inland Open Water
Estuarine Open Water
Open Ocean
Irregularly Flooded Marsh
Tidal Swamp

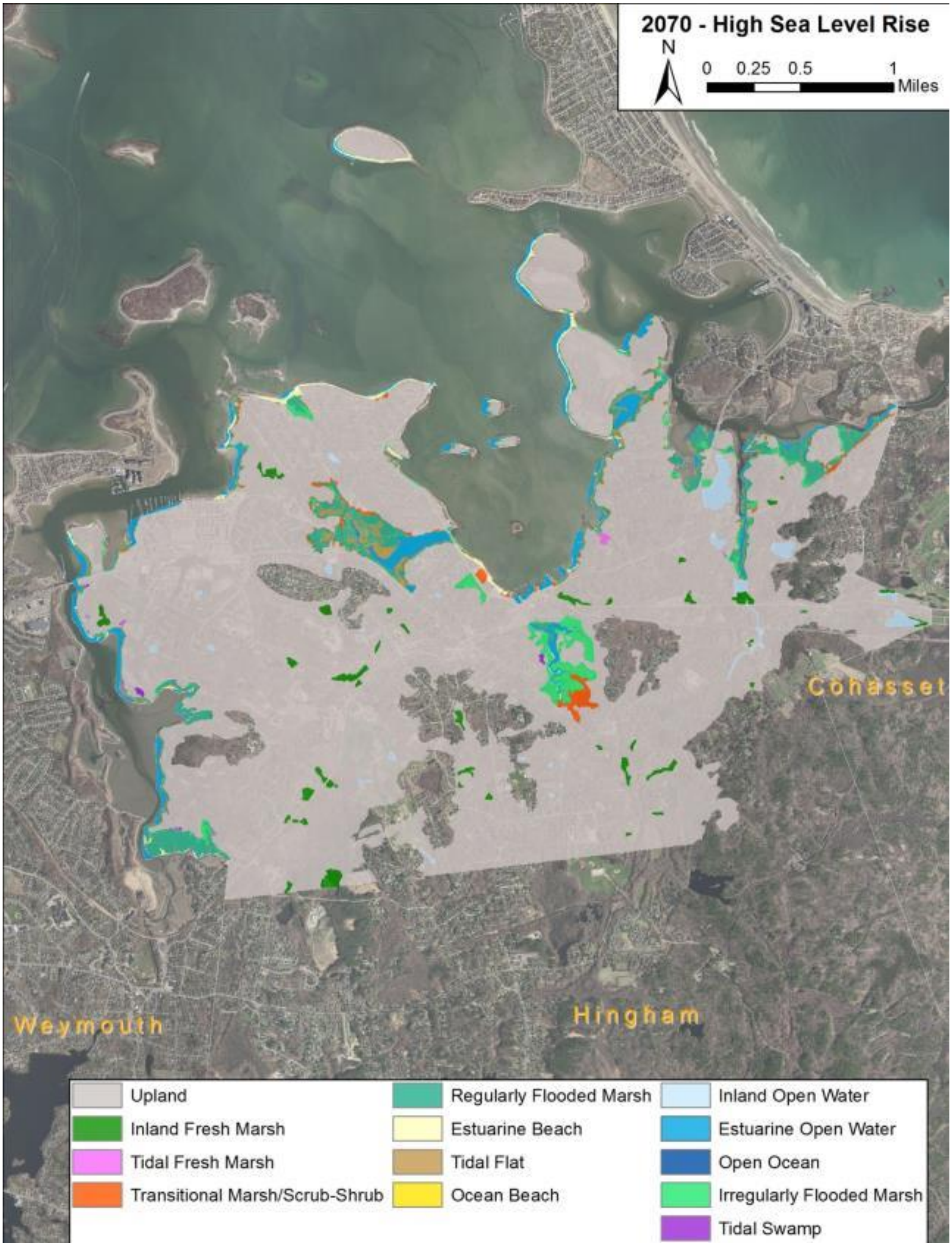

2070 - High Sea Level Rise
N
0 0.25 0.5 1
Miles
Cohasset
Weymouth
Hingham
Upland
Inland Fresh Marsh
Tidal Fresh Marsh
Transitional Marsh/Scrub-Shrub
Regularly Flooded Marsh
Estuarine Beach
Tidal Flat
Ocean Beach
Inland Open Water
Estuarine Open Water
Open Ocean
Irregularly Flooded Marsh
Tidal Swamp

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	034-027-000-059-100	Walton Cove	0.4	37	100	3667	100	3667	100	3667	3667
Bulkhead/ Seawall	034-051-000-003-100	Iron Horse Park Area	7.0	60	25	1500	50	3000	100	6000	2850
Bulkhead/ Seawall	034-051-000-005B-200	Iron Horse Park Area	6.6	57	30	1700	50	2833	100	5667	2833
Revetment	034-045-000-002-100	Bridge Street	6.6	50	30	1500	50	2500	100	5000	2500
Bulkhead/ Seawall	034-051-000-059-100	Iron Horse Park Area	4.8	33	50	1667	50	1667	100	3333	2000
Bulkhead/ Seawall	034-051-000-001-200	Iron Horse Park Area	7.8	60	5	300	30	1800	100	6000	1890
Bulkhead/ Seawall	034-045-000-002-200	Bridge Street	7.6	50	10	500	30	1500	100	5000	1700
Revetment	034-045-000-002-300	Bridge Street	7.7	50	10	500	30	1500	100	5000	1700
Facility	William L Foster Elementary School	55 Downer Ave	6.1	6	0	0	10	633	100	6333	1457
Bulkhead/ Seawall	034-051-000-004-100	Iron Horse Park Area	8.4	60	2	120	10	600	100	6000	1440
Bulkhead/ Seawall	034-050-000-050-200	Iron Horse Park Area	7.3	40	10	400	30	1200	100	4000	1360
Roadway	Rockland St and Kilby St		7.6	30	10	300	50	1500	100	3000	1200
Roadway	Otis St (Rt 3A) at Hingham Bathing Beach		8.7	50	1	50	10	500	100	5000	1175
Revetment	034-030-000-011-100	Martin's Well	5.3	23	30	700	50	1167	100	2333	1167
Groin/ Jetty	034-045-000-002-400	Bridge Street	6.8	23	30	700	50	1167	100	2333	1167
Bulkhead/ Seawall	034-051-000-005-100	Iron Horse Park Area	8.5	50	1	25	10	500	100	5000	1163
Revetment	034-039-000-009-100	Broad Cove Entrance	8.5	47	2	93	10	467	100	4667	1120
Facility	West Corner Pump Station	338 Rockland St	8.2	8	1	25	5	250	100	5000	1088
Roadway	Broad Cove Rd (Rt 3A)		6.3	47	0	0	10	467	100	4667	1073
Roadway	Beach Rd and Beach Ln		7.8	33	5	167	25	833	100	3333	1000
Facility	Hingham Bathing Beach Parking Lot	100 Otis St	9.1	9	1	22	5	217	100	4333	943
Bulkhead/ Seawall	034-030-000-011-200	Martin's Well	8.2	33	2	67	20	667	100	3333	900
Bulkhead/	034-016-000-183-100	Hingham	8.4	33	1	33	20	667	100	3333	883

Seawall		Yacht Club Peninsula									
Bulkhead/ Seawall	034-017-000-113-100	Hingham Yacht Club Peninsula	9.0	37	0.1	4	2	73	100	3667	757
Facility	Mill St. Pump Station	70 Water St	8.7	9	0	0	5	317	50	3167	728
Revetment	034-016-000-183-200	Hingham Yacht Club Peninsula	8.8	33	1	17	5	167	100	3333	725
Roadway	Howe St and Parker Dr		8.8	33	0	0	5	167	100	3333	717
Roadway	Summer St (Rt 3A) Rotary		9.1	57	0	0	5	283	50	2833	652
Revetment	034-036-000-106-200	Hingham Shipyard	9.1	30	0	6	5	150	100	3000	648
Facility	Heliport at Bathing Beach	95 Otis St	8.1	8	1	27	10	267	100	2667	627
Roadway	North St		9.6	50	0	0	5	250	50	2500	575
Revetment	034-050-000-050-100	Iron Horse Park Area	8.3	23	2	47	10	233	100	2333	560
Roadway	Eldridge Ct		9.3	47	0	0	5	233	50	2333	537
Roadway	Downer Ave and Condito Rd		6.9	23	0	0	10	233	100	2333	537
Roadway	Downer Ave and Planters Field Ln		5.3	23	0	0	10	233	100	2333	537
Facility	Broad Cove Sewer Pump Station	1 Downer Ave	10.1	10	0	0	0	5	50	2667	535
Roadway	Water St		9.3	9	0	0	0	0	50	2667	533
Roadway	Hull St and Rockland St		9.1	43	0	0	2	87	50	2167	459
Roadway	Rockland St and Meadow Rd		8.7	43	0	0	2	87	50	2167	459
Roadway	Lincoln St and Broad Cove Rd		9.2	43	0	0	1	22	50	2167	440
Bulkhead/ Seawall	034-051-000-001-300	Iron Horse Park Area	10.6	60	0	0	0	6	30	1800	362
Bulkhead/ Seawall	034-051-000-001-100	Iron Horse Park Area	10.4	60	0	0	0	6	30	1800	362
Bulkhead/ Seawall	034-051-000-005B-100	Iron Horse Park Area	9.7	33	0	0	2	67	50	1667	353
Roadway	Main St and Winter St		9.8	30	0	0	5	150	50	1500	345
Bulkhead/ Seawall	034-017-000-099-100	Hingham Yacht Club Peninsula	10.0	33	0	0	0	3	50	1667	334
Roadway	Andrews Isle		10.2	10	0	0	0	0	50	1667	333
Revetment	034-011-000-005-100	Hingham Yacht Club Peninsula	9.5	30	0	0	2	60	50	1500	318
Roadway	Fresh River Ave		9.1	30	0	0	0	0	50	1500	300
Bulkhead/	034-051-000-001-400	Iron Horse	10.9	60	0	0	0.1	6	20	1200	242

Seawall		Park Area									
Bulkhead/ Seawall	034-036-000-106-300	Hingham Shipyard	10.2	33	0	0	0.2	7	30	1000	202
Roadway	Otis St at Walton Cove		10.1	20	0	0	0	0	50	1000	200
Revetment	034-034-000-000-100	Stodders Neck	10.3	27	0	0	0.2	5	30	800	162
Revetment	034-035-000-001-100	Stodders Neck	10.4	27	0	0	0.2	5	30	800	162
Facility	Whitney Wharf	Otis St	10.4	10	0	0	0.1	3	30	800	161
Facility	Bel Air Pump Station	55 Bel Air Rd	11.4	11	0	0	0.1	5	10	500	102
Facility	Downer Ave Sewer Pump	176 DOWNER AVE	10.5	10	0	0	0	0	10	500	100
Roadway	Wompatuck Rd and Wokomis Rd		11.3	11	0	0	0	0	10	333	67
Roadway	Blackberry Ln and Park Circle		10.5	11	0	0	0	0	10	333	67
Roadway	Condito Rd and Langlee Rd		11.9	12	0	0	0	0	10	333	67
Facility	Howe St Pump Station	62 Howe St	11.7	12	0	0	0	0	5	233	47
Revetment	034-050-000-051-100	Broad Cove Entrance	12.0	33	0	0	0	0	5	167	33
Revetment	034-039-000-008-100	Broad Cove Entrance	12.0	23	0	0	0	0	5	117	23
Bulkhead/ Seawall	034-036-000-106-100	Hingham Shipyard	12.1	27	0	0	0	0	2	53	11
Roadway	Hingham Shipyard Rd		12.6	13	0	0	0	0	1	33	7
Roadway	Green St		12.4	12	0	0	0	0	1	27	5
Revetment	034-046-000-001-100	Stodders Neck	13.4	50	0	0	0	0	1	25	5
Roadway	George Washington Blvd Bridge (Approach)		12.8	43	0	0	0	0	1	22	4
Roadway	Tupelo Rd and Langlee Rd		13.0	13	0	0	0	0	1	17	3
Facility	Beal St Sewer Pump Station (UNG)	Beal Street	13.0	13	0	0	0	0	0.2	10	2
Facility	Walton Cove Sewer Pump Station	211 Downer Ave	11.1	11	0	0	0	0	0.2	10	2