COASTAL CLIMATE CHANGE STUDY
FINAL REPORT

SWAMPSCOTT, MASSACHUSETTS
KLEINFELDER PROJECT 20140177.004A

JUNE 2016

A Report Prepared for:

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Kleinfelder Project Number: 20140177.004A

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EXECUTIVE SUMMARY

The Town of Swampscott recently completed a Coastal Climate Change Study, with a $70,100 grant from the Massachusetts Office of Coastal Zone Management (CZM), matched by 25% in local funding and in-kind support.

The study was a collaborative effort led by the Department of Public Works and the Planning Department. Under their oversight, consultants Kleinfelder and Woods Hole Group executed the study. These consultants were selected for their recognized climate change planning expertise as well as their knowledge of Swampscott from working with the Town for over a decade.

The key findings of the study are summarized in this Executive Summary and further described in a series of Technical Memoranda. The study findings were also presented to the Swampscott Board of Selectmen during a televised meeting on June 15, 2016.

The study had the following primary goals:

1. Model climate change impacts on coastal flooding in Swampscott;
2. Understand the vulnerability of municipal infrastructure to flooding; and
3. Identify potential adaptation strategies, including engineering, regulatory, and policy solutions.

This study did not evaluate flooding impacts on private property, and it is not related to recent Federal Emergency Management Agency (FEMA) flood insurance rate mapping efforts. Maps and data produced as part of this study should be used solely for planning purposes.

CLIMATE CHANGE AND COASTAL FLOOD MODELING

As a first step in the Coastal Climate Change Study, sea level rise and storm surge models were used to estimate the probability, extent, and depth of future coastal flooding in Swampscott. Two time horizons were chosen as the basis for planning: 2030 (medium-term) and 2070 (long-term).

Climate change projections from scientific research provided the basis for subsequent modeling and mapping. It is estimated that sea level in Swampscott will rise approximately 0.7 ft. by 2030 and 3.4 ft. by 2070, over 2013 levels. This is according to the high end projections from the US National Climate Assessment, adjusted for local conditions, which are considered appropriate for planning purposes based on national and state technical guidance and the Town's risk tolerance. In addition, it is anticipated that over the long-term tropical storms like hurricanes will become more powerful and travel further north than in the past, as the warming ocean feeds them with an increasing supply of energy.

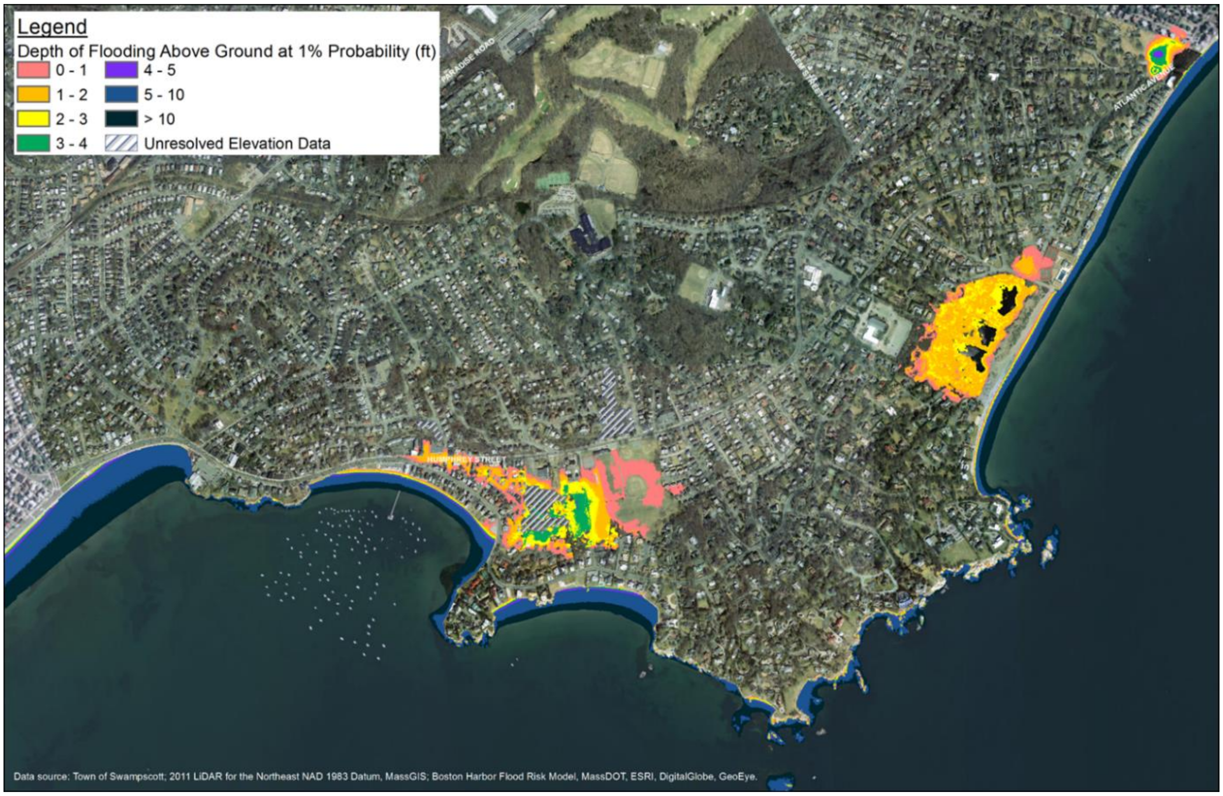
To model and map the combined effects of sea level rise and increasing storm surge on coastal flooding in Swampscott, the Town used the hydrodynamic Boston Harbor – Flood Risk Model (BH-FRM), developed by the Massachusetts Department of Transportation (MassDOT). BH-FRM incorporates the sea level rise projections described above and an increase in more powerful tropical storms beginning in 2050. Almost all agencies and municipalities in Boston Harbor are using BH-FRM for climate change planning and design. This model does not account for the effects of wave run-up or overtopping. It is expected that future refinements of the BH-FRM model will include these effects. The Town should consider revisiting the modeling results and other findings of this study once updated BH-FRM results are available.

Based on the results of modeling sea level rise and increasing storm surge with BH-FRM, four areas of Swampscott are at risk of coastal flooding:

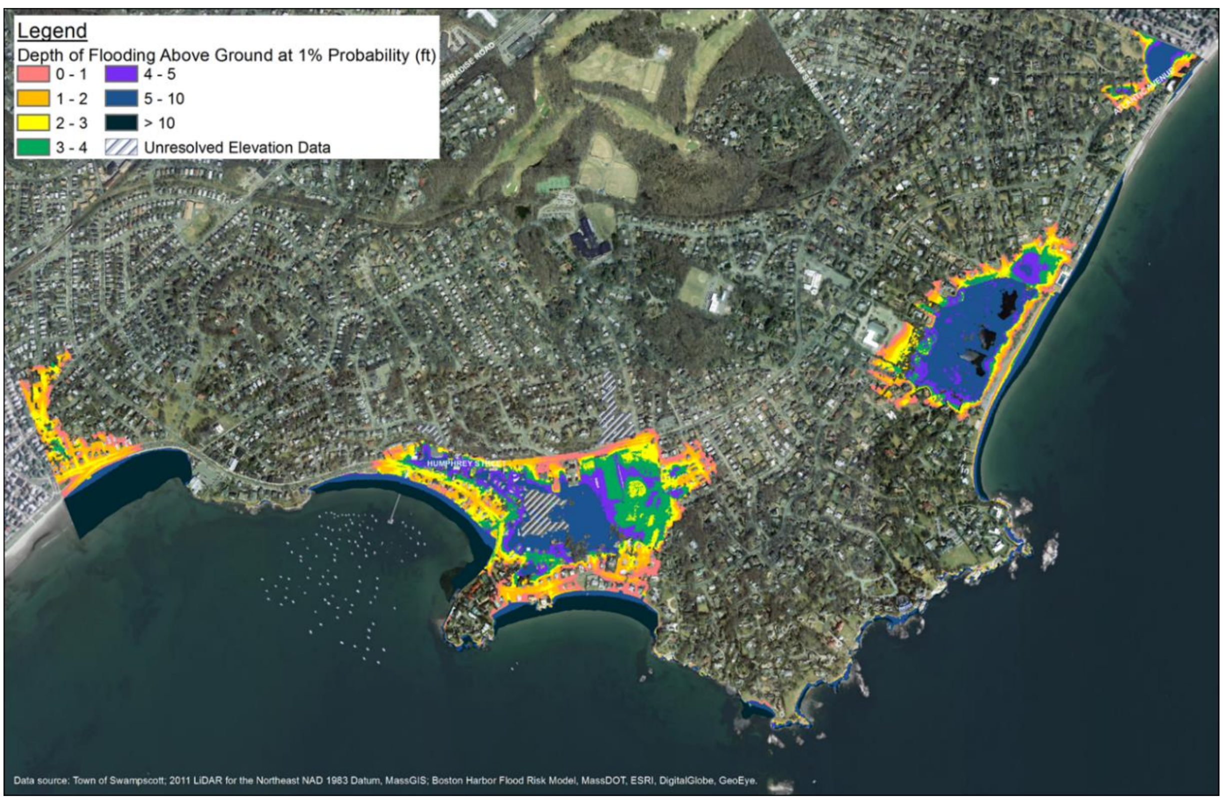
1. Phillips Park area (by 2030);
2. Phillips' Beach/Palmer Pond area (by 2030);
3. Preston Beach area (by 2030); and
4. King's Beach area (by 2070).

Maps below show the location and depth of coastal flooding in Swampscott under scenarios that have a 1% (1-in-100) annual chance of occurring in the medium term (2030) and longer term (2070) based on the modeling described above. Additional scenario maps are presented in Appendix A. Modeling results for 2030 may underrepresent the actual risks of flooding for King's Beach area, based on past experience. This is because the model does not include wave overtopping or take into account the risk of flood waters backing up through the drainage system, which were primary causes of past flooding in this area.

DEPTH OF FLOODING WITH 1% ANNUAL PROBABILITY IN 2030



DEPTH OF FLOODING WITH 1% ANNUAL PROBABILITY IN 2070



VULNERABILITY AND RISK ASSESSMENT

A vulnerability and risk assessment was performed on critical municipal infrastructure located within the areas at risk of flooding in 2030 and 2070. The types of municipal assets at risk in these areas included coastal protection structures, roadways, and drinking water, wastewater, stormwater, public safety, marine-dependent, and recreational facilities.

Almost all of the highest risk assets, considering both the probability and consequences of flooding, were located in the Phillips Park area. This is also the largest flood risk area and has the greatest number and diversity of vulnerable assets. Due to these considerations, this area was identified as the highest near-term priority for developing and implementing adaptation strategies.

Vulnerable assets in the Phillips Park area include:

- Major municipal roads (e.g., Humphrey Street, Puritan Road);
- Single-access roads (e.g., Sutton Place, Smith Lane, Willow Terrace, Robin Lane);
- Swampscott Police Headquarters and Emergency Operations Center;
- Humphrey Street Wastewater Pump Station (most critical wastewater facility in Town);
- Phillips Park (used as heliport, emergency supply distribution location, boat storage, and excess snow storage site);
- Fish House (historic property used by the Harbormaster and local lobstermen);
- Swampscott Pier (the Town's only pier to access boats in the harbor);
- Various seawalls;
- Various beach access ways and boat ramps; and
- Public beaches, parks, and open space.

For the remaining three flood risk areas, the public infrastructure at risk generally consisted of major municipal roads and local roads.

ADAPTATION STRATEGIES - ENGINEERING

Engineering strategies and order-of-magnitude costs to reduce medium- and long-term coastal flood risks have been developed. Some of these alternatives are focused on preventing flooding of the larger areas that vulnerable assets are located in, and others are focused on adapting individual assets.

The study identified several "flood pathways", or low points along the otherwise elevated coastline, through which floodwater would first flow before collecting in large low-lying areas of

Town. The following beach access ways and waterfront facilities owned by the Town, where flooding has occurred in the past, have been identified as primary flood pathways in 2030.

1. Phillips Park area
   - Fisherman's Beach access way at Greenwood Avenue
   - Parking lot and boat ramp access ways at the Fish House
   - Cassidy Park beach access way at Sculpin Way
   - Whales Beach access way and Polisson Park
   - Johnson Park
   - Eiseman's Beach access way
2. Phillips' Beach/Palmer Pond area
   - Phillips' Beach access way at Ocean Avenue
3. Preston Beach area
   - Preston Beach access way at Beach Bluff Avenue
4. King's Beach area
   - King's Beach access area along Humphrey Street

The Town can adjust the grading and increase the top elevation of these low-lying access ways and waterfront facilities, thereby closing off flood pathways and significantly reducing medium-term flood risks to large areas. Based on preliminary analysis, it will likely be possible to use natural or nature-based storm-damage protection techniques (e.g., berms, dunes, and vegetation) at some, but not all, locations. The design of these improvements could be integrated with projects planned or under development by the Department of Public Works and Planning Department, in consultation with relevant Town boards and committees.

Drainage systems will need to be adapted as well, for example by installing more backflow prevention valves at outfalls to the ocean. Without such adaptations, water will enter drainage systems through these outfalls and surcharge drainage manholes and catch basins, leading to possible flooding within the community.

Over the long-term, the Town will potentially face more significant challenges in developing effective engineering strategies to prevent flooding of large areas. Existing publicly-owned seawalls will no longer be high enough to provide effective protection, and efforts to adapt those structures may entail difficult financial, political, and regulatory challenges. In addition, wider flood pathways will open up across private properties along the coastline, for example between Puritan Road and Fisherman's Beach. Potential engineering strategies may include acquiring and elevating storm-damaged properties, raising roadways to act as levees, and installing robust and expansive upland flood barrier systems.

Alternatively the Town may need to revert to protecting individual vulnerable assets, for example by elevating critical equipment and floodproofing buildings. These adaptations can be incorporated as part of the normal schedule of planned improvements to such facilities. This will streamline administrative burdens and integrate adaptation in the culture of various Town departments, boards, and committees.

Due to the complexity and cost of certain long-term measures, as well as greater uncertainties in long-term sea level rise projections, the Town should continue to monitor the observed rate of sea level rise and periodically re-assess projected flooding risks based on the latest scientific research. This will help the Town calibrate the timing and level of investment needed for long-term adaptation.

ADAPTATION STRATEGIES – REGULATIONS AND POLICIES

Existing local regulations were reviewed to identify opportunities to advance the Town's goal of adapting to coastal climate change impacts. Recommended modifications to Town Zoning By-Laws, Subdivision Regulations, and Site Plan Review and Special Permit Regulations were drafted. Such changes would integrate considerations of sea level rise and increasing storm surge in purposes, authorities, definitions, procedures, submission requirements, review considerations, and design guidance of existing regulations. Their effect would be to encourage new developments and substantial improvements to incorporate coastal climate change adaptation strategies.

In addition to regulatory changes, the study identified ways for the Town to advance its adaptation goals through policy and operational initiatives. Such initiatives could include:

- Requiring Town-funded projects in flood risk areas to take sea level rise and storm surge projections into account;
- Updating the Town's Hazard Mitigation Plan based on the Coastal Climate Change Study findings;
- Tracking flooding impacts and progress towards adaptation;
- Developing a robust operational plan for coastal flooding emergencies that formalizes existing practices and incorporates additional actions that may not have been anticipated based on past flooding experience;

- Periodically re-evaluating the administrative costs and insurance benefits of participating in the National Flood Insurance Program's Community Rating System (the Planning Department recently evaluated this program and determined not to participate); and
- Installing an automated tide gauge in Swampscott Harbor to monitor actual sea level rise locally.

NEXT STEPS

The Town is already taking action on the findings of the Coastal Climate Change Study and is committed to implementing priority recommendations within the constraints of available resources and with participation from the community.

The Department of Public Works has already applied for a follow-on grant from the Office of Coastal Zone Management to prepare engineering plans and permits for recommended improvements to various beach access ways and waterfront facilities. Redesigning and elevating these flood pathways would reduce both existing nuisance flooding issues and medium-term risk of flooding in large low-lying areas of Town. A recently Planning Department study carried out by Tufts University already incorporated these recommended strategies in proposed improvements to Johnson Park.

The Planning Department will also be working with various boards and committees to review regulatory and policy recommendations from the study as part of efforts to update local regulations and plans.

Over the long-term, the Town intends to take an incremental approach to adaptation, by planning appropriately and taking advantage of opportunities when they arise. All Town departments are encouraged to consider the findings and long-term recommendations of the Coastal Climate Change Study in their ongoing design, planning, and operational activities.

TECHNICAL MEMORANDUM 1 (TM1)

CLIMATE CHANGE AND COASTAL FLOOD MODELING

1 TM1 CLIMATE CHANGE AND COASTAL FLOOD MODELING

The purpose of this memorandum is to explain the choice of input parameters for the sea level rise and storm surge model, as well as the planning horizons that are used for the model simulations in Swampscott. This memo presents the following parameters, each of which will be explained in subsequent sections:

Parameter	Applied to Swampscott
Choice of coastal flooding model	Boston Harbor – Flood Risk Model (BH-FRM)
Types of storms and storm climatology	Tropical Storms (hurricanes) Extra-tropical Storms (nor'easters) Storm climatology based on historic and 21st century
Selection of sea level rise scenarios	'Highest' scenario for 2030: 0.66 ft. 'Highest' scenario for 2070: 3.39 ft.
Planning horizons	2030, 2070

1.1 CHOICE OF COASTAL FLOODING MODEL

Swampscott's coastal flood modeling was carried out using the Massachusetts Department of Transportation (MassDOT) Boston Harbor Flood Risk Model (BH-FRM) that was developed by the Woods Hole Group (WHG) for the greater Boston area. BH-FRM includes other surrounding communities in Massachusetts, including Swampscott. The BH-FRM model was developed as part of the MassDOT and the Federal Highway Administration (FHWA) project for assessing potential vulnerabilities in the Central Artery tunnel system. The BH-FRM modeling system is comprised of the ADvanced CIRCulation model (ADCIRC), a two-dimensional, depth-integrated, long wave, hydrodynamic model for coastal areas, inlets, rivers, and floodplains that, in this application, is used to predict storm surge flooding, and the Simulating WAves Nearshore model (SWAN), a wave generation and transformation model. Since the BH-FRM model domain includes Swampscott, this model was used to assess the vulnerability and risk of coastal flooding to Swampscott's municipal infrastructure. Impact to Palmer Pond was also qualitatively assessed. Using this existing model was beneficial to Swampscott since much of the upfront work in developing the model was already conducted as part of the MassDOT/FHWA project, and the Town was able to use the results at a low cost.

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 Swampscott coastline. The spatial resolution of the model is 10 meters or less, sometimes as low as 1 meter to capture important changes in topography and physical processes related to storm dynamics. This high-resolution model offers more accuracy than other storm surge models, since the latter does not account for critical physical processes including waves and winds.

The modeling approach is risk-based, which was 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 Swampscott. The risk-based approach also produced 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" 100-year flood or 1% event flood levels. 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, provided at high spatial resolution, was provided that helped decision makers to identify areas of existing vulnerability requiring immediate action in Swampscott, 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; and
- Resolution that resolves physical and energetic processes, while also being able to identify site-specific locations that may require adaptation alternatives.

The BH-FRM model domain in the area of Swampscott does not extend into upland areas, and the boundary of the model in this region is currently located at the shoreline. The limits of the model mesh (nodal points) are shown in Figure 1.1. To determine flooding impacts beyond the model's boundary, the water surface generated by the model is propagated landward until it is exceeded by the ground elevation presented in the LiDAR topographic map. Although the propagated surface is approximate, it gives a relatively accurate first-order representation of the effects of flooding suitable for planning purposes. The BH-FRM model is currently being extended to include the upland areas throughout the state up to approximately the 30 foot contour (NAVD88) and results from the extended model can be used to refine the vulnerability analysis in the near future.

FIGURE 1.1
LIMITS OF BH-FRM MODEL MESH

1.2 TYPES OF STORM EVENTS AND STORM CLIMATOLOGY

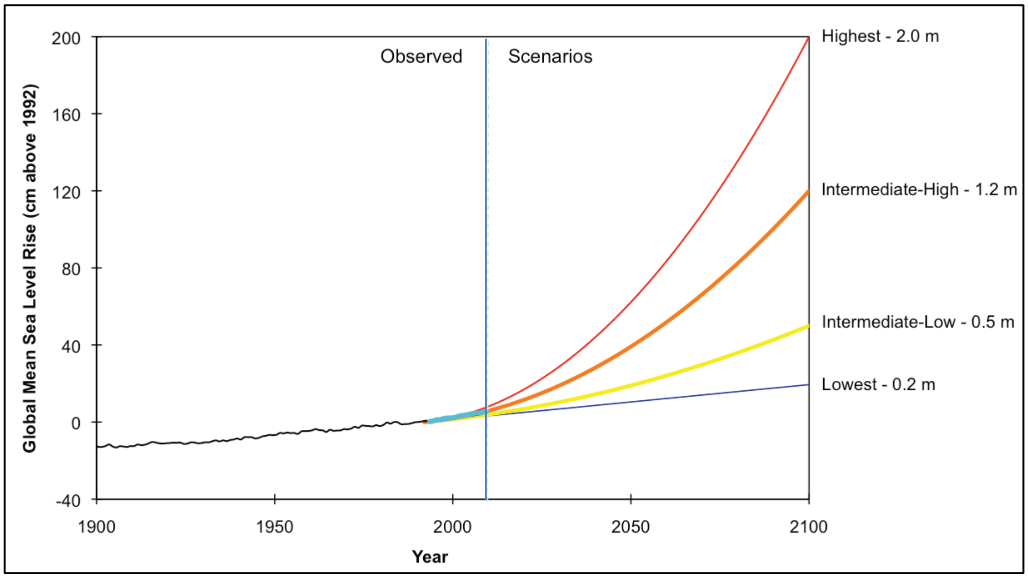
The types of storms that are included in the Monte Carlo simulations are both tropical storms (hurricanes) and extra-tropical storm (nor'easters). The storm climatology parameters that are included in the BH-FRM model include wind directions and speeds, radius of maximum winds, pressure fields, and forward track of the storms in the New England area. While hurricanes are typically shorter duration events that often last over only one tidal cycle, nor'easters are longer duration events that typically last over multiple tidal cycles spanning multiple days. So the probability of a nor'easter occurring or lasting through a high tide is more likely than a hurricane. Also, the diameter of a nor'easter (also commonly called the "fetch") is usually 3-4 times that of hurricanes, and therefore they impact much larger areas of inland as well. Finally, the frequency of nor'easters in Swampscott is also higher than hurricanes. While the Northeast may experience one hurricane landfall every five years, nor'easters occur annually with at least 20-40 in a given year, of which generally at least two are severe. Therefore, 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.

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 the 2050, the 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.

1.3 SELECTION OF 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) are utilized in this study (Figure 1.2). These scenarios are the same scenarios recommended by Massachusetts Coastal Zone Management for assessing SLR, as well as those being used by MassDOT and other state agencies and communities for vulnerability assessments.

FIGURE 1.2
GLOBAL SEA LEVEL RISE PROJECTIONS



According to the NOAA “Highest” scenario, identified in Figure 1.2, for global SLR from Parris et al., which combines thermal expansion estimates from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) and the maximum possible glacier and ice sheet loss by the end of the century, this scenario “should be considered in situations where there is little tolerance for risk”. As agreed at the project kick-off meeting, the “Highest” SLR scenario for Swampscott was used in order to be consistent with MassDOT and other state agencies and communities for vulnerability assessments.

In addition to global SLR, local mean sea level changes should also be factored in. Local mean sea level changes can be estimated by considering local tide gage records in combination with models or actual measurements of 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. 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). This rate of subsidence is factored in with the global SLR scenarios to determine the relative SLR projections for Swampscott.

Table 1.1 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 Swampscott, considering a start year of 2013 (since 2013 was used as the start year for the SLR calculations in the BH-FRM model). The calculations were also conducted using 2015 as the start year, considering 2015 will be the completion year of this project, and 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 proposed to use the same SLR values that have been used in the BH-FRM model. The highest SLR scenario was selected to allow decision-makers to consider a range of possible future scenarios for which to explore adaptation response options.

The SLR scenarios that are utilized in the Swampscott vulnerability assessment include:

- ‘Highest’ scenario for 2030: 0.66 ft.
- ‘Highest’ scenario for 2070: 3.39 ft.

TABLE 1.1
SEA LEVEL RISE ESTIMATES FOR SWAMPSCOTT

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
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

1.4 PLANNING HORIZONS

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

The BH-FRM model that was used has been developed for the years 2030, 2070, and 2100. The study used 2030 and 2070 planning horizons with corresponding sea level rise projections for the following reasons:

- The BH-FRM model developed for the greater Boston area includes Swampscott. This is a high-spatial resolution model that provides detailed flooding results of combined SLR and storm surge in terms of exceedance probability. This makes it a useful tool for risk-based decision making. Swampscott would benefit 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.
- Using the 2030 (15 years from 2015) planning horizon for near-term inundation modeling results meant the results were readily available and consistent with planning horizons used in the majority of studies in Eastern Massachusetts, therefore allowing for easy comparisons.
- Using the 2070 (55 years from 2015), instead of 2100 (85 years from 2015), results was 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 the public infrastructure that were evaluated for risk is generally closer to a 55 year time frame (the 2070 scenario) than an 85 year time frame (the 2100 scenario); and

c) Finally, the 2070 timeframe is more consistent with other regional climate change vulnerability studies (e.g. Cities of Cambridge and Boston, MassDOT/FHWA).

1.5 DISPLAY OF MODEL RESULTS

One of the primary purposes of developing the sea level rise and storm surge model is to map the extent and magnitude (depth) of flooding caused by tides, sea level rise, associated storm surge, and other key physical processes (e.g., wave set-up, winds, etc.). GIS maps for the Swampscott coastline were developed for the following scenarios:

- Depth of flooding above ground elevation at 1% risk of flooding with storm surge (approximately equivalent to a 100 year flood) for 2030 and 2070;
- Depth of flooding above ground elevation at 0.2% risk of flooding with storm surge (approximately equivalent to a 500 year flood) for 2030 and 2070; and
- Percent risk of flooding one foot above ground elevation for 2030 and 2070 (see Figure 1.3).

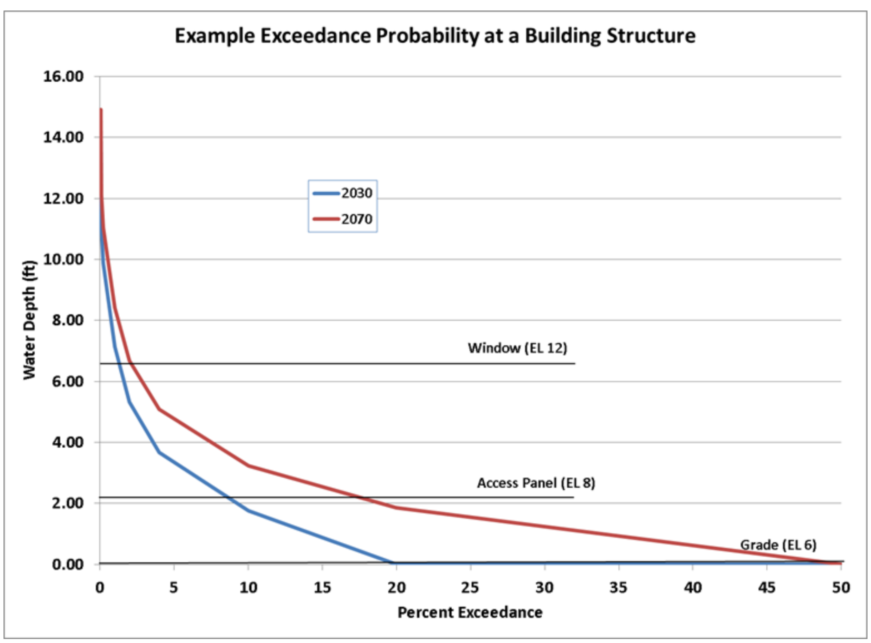
FIGURE 1.3
SAMPLE PROBABILITY OF INUNDATION MAP

Probability of Exceedance (PE) curves were also developed for Town-owned critical infrastructure for 2030 and 2070 (see examples in Table 1.2 and Figure 1.4). A PE curve can be used to understand the risks of flooding at any given water elevation for an asset. This information was very useful information in the later development of adaptation strategies. Table 1.2 and Figure 1.4 show examples of PE tables and curves.

TABLE 1.2
SAMPLE PROBABILITY OF EXCEEDANCE TABLE

Water Surface Elevation (ft. NAVD88)	Depth (ft.)	Exceedance Probability	Exceedance Percent	Recurrence Interval (years)
19.93	13.89	0.001	0.1%	1,000
17.02	10.98	0.002	0.2%	500
15.90	9.86	0.005	0.5%	200
13.18	7.14	0.01	1%	100
11.37	5.33	0.05	5%	20
9.71	3.67	0.1	10%	10
7.80	1.76	0.2	20%	5
Dry	0.00	0.3	30%	3.3
Dry	0.00	0.5	50%	2
Dry	0.00	0.999	99.9%	1

FIGURE 1.4
SAMPLE PROBABILITY OF INUNDATION MAP



2 TM2 VULNERABILITY AND RISK ASSESSMENT

The purpose of this memorandum is to summarize the vulnerability assessment for municipally-owned infrastructure and natural resources within the Town of Swampscott, MA that are subject to the effects of flooding due to projected sea level rise and storm surge from extreme storm events. This memorandum complements Technical Memorandum 1, dated April 2015, and represents a continuation of the Town's climate change study.

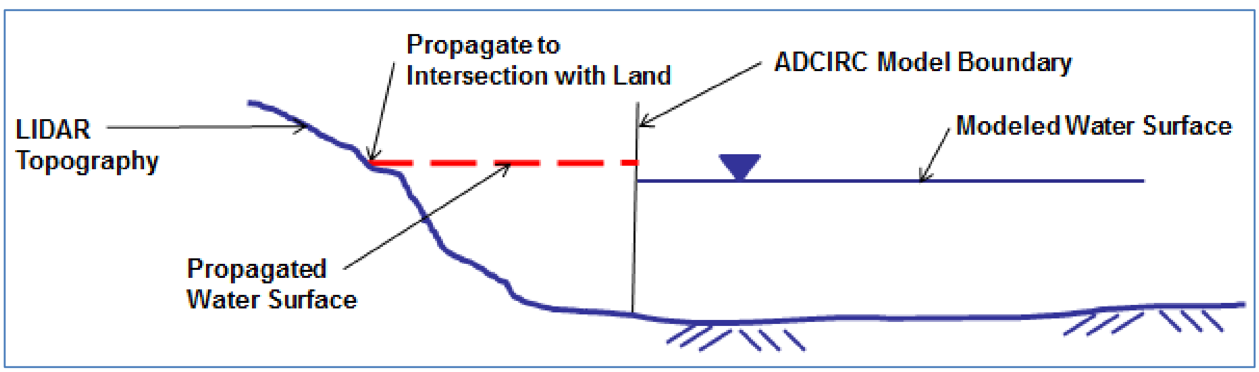
2.1 MODELING THE COASTAL FLOODING EFFECTS OF CLIMATE CHANGE

As discussed in Technical Memorandum 1, the sea level rise and storm surge modeling for the Town of Swampscott was based on using the Boston Harbor Flood Risk Model (BH-FRM) developed by the Woods Hole Group for the Massachusetts Department of Transportation (MassDOT) project. A screenshot of the model mesh for Swampscott was included in Technical Memorandum 1 and is also included here for continuity (Figure 2.1). It can be observed from this model mesh that the boundary of the BH-FRM model is the Swampscott coastline and does not include upland topography.

To determine flooding impacts landward of the model's boundary, the water surface generated by the model is propagated towards the shore as a horizontal plane until it meets the ground elevation as represented by the LiDAR topographic map (Figure 2.2). Although the propagated surface is approximate, it gives a relatively accurate representation of the effects of flooding suitable for planning purposes. Representative model nodes are propagated, so at any given location along the model boundary there may be slight elevation discrepancies between the model surface and the propagated surface as shown in Figure 2.2.

FIGURE 2.1
LIMITS OF BH-FRM MODEL MESH

FIGURE 2.2
WATER SURFACE PROPAGATION FROM MODEL LIMITS



MassDOT is planning to extend the upland modeling of the BH-FRM model to include the upland areas throughout all coastal areas of the Massachusetts, including Swampscott, up to approximately the 30 foot contour (NAVD88). Results from the extended model, when available, could be used to refine the vulnerability analysis presented in this memorandum.

The BH-FRM model was calibrated using both normal tidal conditions and a representative storm, the "Blizzard of 1978", and then validated with the "Perfect Storm of 1991". These storms represented the highest water levels observed at the Boston tide gage and their impacts were well documented. Calibration and validation demonstrated that the BH-FRM model was very good at simulating important coastal storm processes and impacts.

For the purposes of this study, sea level rise (SLR) scenarios were selected for two distinct time periods: 2030, and 2070. As described in Technical Memorandum 1, sea level rise estimates were based on the Global Sea Level Rise Scenarios for the United States National Climate Assessment, NOAA Technical Report, dated December, 2012. The total SLR values, based on the "high" scenario used in the BH-FRM model adjusted for local subsidence, are as follows:

- 2030: 0.66 feet
- 2070: 3.39 feet

Both tropical (i.e., hurricanes) and extra-tropical (i.e., nor'easters) storm conditions were evaluated in the model. The results of BH-FRM simulations for 2030 and 2070 were used to generate maps of potential flooding and associated water depths throughout the Town of Swampscott. Two different types of maps were produced and were submitted to the Town on May 18, 2015.

Percent Risk of Flooding Maps - 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 in the year being analyzed (2030 or 2070). 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 develop and implement a flood operational plan. For this study, Kleinfelder produced Percent Risk of Flooding maps for 2030 and 2070. Town-wide scale maps were produced, along with close-up maps of upland areas at risk of flooding.

Depth of Flooding Maps – These maps show the estimated difference between the projected water surface elevation for a given percent risk of flooding and existing ground elevation derived from the 2011 Northeast LiDAR (Light Detection and Ranging) survey. For this study, two sets of Town-wide scale and close-up Depth of Flooding Maps were produced for each time horizon (2030 and 2070):

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

2.2 DEFINITIONS AND DATA SOURCES

A vulnerability and risk assessment was performed on critical municipally-owned infrastructure subject to flooding. These are built assets and do not include natural resources, which are covered in a subsequent section of this memorandum. Municipally-owned infrastructure was inventoried, including roads, seawalls, major drainage outfalls, pump stations and other critical facilities such as schools, police stations, fire stations, etc., owned and operated by the Town of Swampscott.

Infrastructure was defined as "critical" if it was included in the 2012 Town of Swampscott Hazard Mitigation Plan Update, completed by the Metropolitan Area Planning Council (MAPC), or if it was otherwise identified as such by the Town.

Infrastructure was considered "subject to flooding" if it was located within the extent of an area at risk of flooding in one or more time horizon (e.g., 2030, 2070) based on the study's sea level rise and storm surge modeling and inundation mapping results. Critical infrastructure subject to flooding but not municipally owned (e.g. federal, state or privately owned) was identified, but it was excluded from the detailed vulnerability assessment described in this memorandum. In some limited cases, state-owned roadways, which are critical transportation links in Swampscott, were included in the vulnerability assessment.

Survey data for public sea walls in Swampscott was obtained from the Massachusetts office of Coastal Zone Management (CZM) as part of a report titled Massachusetts Coastal Infrastructure Inventory and Assessment Project – Summary Report (2009) and accompanying report on Marblehead, Swampscott, Lynn, Saugus, and Revere.

2.3 VULNERABILITY AND RISK ASSESSMENT METHODS

The vulnerability and risk assessment involves several steps which are detailed herein.

Risk is generally defined as the product of the probability of an asset failing and the consequence of that asset failing. Put into mathematical terms:

Risk (R) = Probability of Flooding (P) x Consequence of Flooding (C)

or

R = P x C

For this flood-related vulnerability assessment, the Probability of Flooding (P) is considered as the percent risk of flooding above the critical elevation of an asset. Critical elevation of an asset is defined as that elevation at which flood water will impair the intended functionality of the asset. The percent risk of flooding information is taken directly from the BH-FRM model from a representative node for the Town of Swampscott.

The risk assessment process is implemented using the following five steps:

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

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. Similar risk rankings have been used in other infrastructure planning studies to enable Owners to prioritize spending of their capital funds.

2.3.1 DETERMINE CRITICAL ASSETS SUBJECT TO FLOODING

The municipally-owned infrastructure assets that are subject to flooding in either or both the 2030 and 2070 scenarios are identified in the following Tables 2.1, 2.2, and 2.3 and in the map in Appendix B.

TABLE 2.1

FACILITIES AND BUILDINGS VULNERABLE TO FLOODING

Time Horizon	Facility	Location	Map Label
2030	Police Station / Emergency Operations Center	531 Humphrey St	F-1
	Swampscott Pier	425 Humphrey Street	F-2
	Heliport at Phillips Park	Phillips Park	F-3
	Eiseman's Beach Boat Ramp	Eiseman's Beach at Puritan Rd	F-4
	Fisherman's Beach East Boat Ramp	Fisherman's Beach at Swampscott Pier - East	F-5
	King's Beach Vehicle Ramp	King's Beach	F-6
	Fisherman's Beach West Boat Ramp	Fisherman's Beach at Swampscott Pier - West	F-7
	Point of Distribution #2	Phillips Park	F-8
	Whale's Beach Boat Ramp	Whale's Beach at Puritan Rd	F-9
	Greenwood Avenue Boat Ramp	Fisherman's Beach at Greenwood Ave	F-10
	Boat Storage Lot	Phillips Park	F-11
	Humphrey Street Sewage Pump Station	531 Humphrey St	F-12
	Diesel Fueling Station	531 Humphrey St	F-13
	Fish House	425 Humphrey Street	F-14
2070	Chlorination Station	16 New Ocean St	F-15
	Calgon Station	3 New Ocean St	F-16

TABLE 2.2

SEAWALLS VULNERABLE TO FLOODING

Time Horizon	CZM Structure Number	Location	Map Label
2030	071-021-000-038-100	Whale's Beach	B-1
	071-001-000-188-100	King's Beach	B-2
	071-019-000-278A-300	Fisherman's Beach - East Wall	B-3
	071-021-000-040-100	Cassidy Park	B-4
	071-021-000-036-100	Eiseman's Beach	B-5
2070	071-019-000-278A-200	Fisherman's Beach - Center Wall	B-6
	071-019-000-278A-100	Fisherman's Beach - West Wall	B-7

TABLE 2.3

ROADWAYS VULNERABLE TO FLOODING

Time Horizon	Roadway Name	Location
2030	Humphrey Street (East)	Greenwood Avenue To Glen Road
	Puritan Road	Humphrey Street To Humphrey Street
	Atlantic Avenue	Humphrey Street To Marblehead Town Line
	Commonwealth Avenue	Sculpin Way To Humphrey Street
	Sculpin Way	Puritan Road To Puritan Road
	Marshall Street	Humphrey Street To Puritan Road
	Shepard Avenue	Ocean Avenue To Atlantic Avenue
	Sutton Place	Woodbine Avenue To Cul De Sac
	Cedar Hill Terrace	Humphrey Street To Bay View Drive
	Ocean Avenue	Humphrey Street To Dead End
2070	Muriel Road	Bates Road To Dead End
	Humphrey Street (West) & Lynn Shore Drive	Lynn City Line To Phillips Street
	New Ocean Street	Paradise Road To Lynn City Line
	Pine Street	New Ocean Street To Railroad Avenue
	Bates Road	Beverly Road To Humphrey Street
	Curry Circle	New Ocean Street To Dead End
	King's Beach Terrace	Humphrey Street To Dead End
	Lodge Road	Bates Road To Dead End
	Nirvana Drive	Humphrey Street To Cul De Sac
	Smith Lane	Puritan Road To Dead End
	Willow Terrace	Puritan Road To Dead End
	Oceanside Terrace	Lynn City Line To Dead End
	Robin Lane	Puritan Road To Cul De Sac
	Woodbine Avenue	Puritan Road To Puritan Road
	Atlantic Road	Atlantic Avenue To Dead End
	Greenwood Avenue	Humphrey Street To Forest Avenue
	Phillips Beach Avenue	Littles Point Road To Phillips Beach Avenue
	Galloupes Point Road	Puritan Road To Dead End
	Lincoln House Avenue	Puritan Road To Dead End

2.3.2 DETERMINE CRITICAL ELEVATIONS

Critical elevations (NAVD88 datum) for each asset that may be subject to flooding were determined based on the lowest elevation at which exposure to flooding would impair the asset's intended function. For example, the critical elevation may be the first floor elevation of a building.

In another case, the critical elevation could be a basement window sill elevation, above which water can enter the building 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. The critical elevation is unique for each facility or asset being evaluated.

For buildings, pump stations and similar facilities, critical elevations were estimated using the following data sources:

- Information provided by Town staff.
- As-built drawings or other similar documents provided by Town staff
- On-site observations (no surveys were performed for this project)
- LiDAR survey and aerial photography

Critical elevations for roads and bridges were estimated using LiDAR survey data. The low point of a roadway section subject to flooding was used as the critical elevation.

Critical elevations for coastal stabilization structures were estimated using LiDAR survey data.

2.3.3 OBTAIN PROBABILITY OF EXCEEDANCE DATA

Annual probability of exceedance data for 2030 and 2070 time horizons was obtained for seven drainage outfall locations along the coast of Swampscott. Each of these locations corresponded to a node in the BH-FRM model. However, since there was no significant difference in the distribution of the probability of exceedance curves for each of these locations, it was deemed appropriate to use one representative probability of exceedance curve for coastal infrastructure in Swampscott. This representative probability of exceedance data is shown in Table 2.4.

The annual probability of exceedance ranges from 0.1% (very low likelihood) to 100% (near certain likelihood). As an example, the Swampscott Pier (identified as critical infrastructure) located on Humphrey Street has a critical elevation 7.96 ft. NAVD88, which approximately corresponds to the pier elevation at the end of the concrete pedestrian ramp. This data shows some of the following information:

In the 2030 time frame, there is an approximately 10% annual chance that water will exceed the pier's critical elevation of 7.96 feet NAVD88, and the depth of flooding at that probability will be more than 0.5 ft. above the critical elevation of the pier. It also indicates that the 1% flood elevation by 2030 is 9.4 ft. NAVD88, which corresponds to 1.44 ft. of flood depth above the critical elevation of the pier.

In the 2070 time frame, there is an approximately 100% annual chance that water will exceed the critical elevation of 7.96 feet (i.e., it is expected to be an annual occurrence), and the depth of flooding at that probability level will be more than 1.0 ft. above the critical elevation of the pier. It also indicates that the 1% flood elevation by 2070 is 12.8 ft. NAVD88, which corresponds to 4.84 ft. of flood depth above the critical elevation of the Pier.

TABLE 2.4

PROBABILITY OF EXCEEDANCE DATA FOR SWAMPSCOTT PIER

	2030		2070	
Annual Probability (%)	Flood Elevation (ft. NAVD88)	Depth Above Critical Elev. (ft.)	Flood Elevation (ft. NAVD88)	Depth Above Critical Elev. (ft.)
0.1	10.5	2.54	14	6.04
0.2	10.3	2.34	13.9	5.94
0.5	10	2.04	13.4	5.44
1	9.4	1.44	12.8	4.84
2	9.3	1.34	12.5	4.54
5	8.6	0.64	12.1	4.14
10	8.5	**0.54**	11.5	3.54
20	7.9	-0.06	11	3.04
25	7.8	-0.16	10.8	2.84
30	7.7	-0.26	10.6	2.64
50	7.3	-0.66	10.2	2.24
100	6.7	-1.26	9	**1.04**

2.3.4 DETERMINE CONSEQUENCE OF FLOODING SCORE

The consequence of flooding for each infrastructure asset subject to flooding was rated on a scale of 1 through 5 (from low to high consequence) for six different potential impacts in accordance with the guide shown in Table 2.5. Each impact is rated separately and then a composite Consequence of Flooding score is determined by summing the individual scores, dividing by 30, and normalizing to 100 using the following equation:

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

Composite consequence scores can be as low as 20 and as high as 100. Table 2.6 shows a representative example of the Consequence of Flooding rating for the Swampscott Pier with a total rating of 50 out of a possible 100. The higher the rating, the more consequential is the flooding of that asset.

TABLE 2.5
CONSEQUENCE SCORING CATEGORIES AND SCALES

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	> $5m	Very high	Very high	Very high
4	Multiple neighborhoods	14 - 30 days	$1m - $5m	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

TABLE 2.6
CONSEQUENCE SCORING EXAMPLE FOR SWAMPSCOTT PIER

	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	Consequence Score
Rating	3	3	2	2	3	2	**50**

2.3.5 CALCULATE RISK SCORES AND RANKINGS

The risk score for an infrastructure asset subject to flooding for a given time horizon is calculated using the following equation:

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

Where:

R_{tn} = Risk Score at a given time horizon
P_{tn} = Probability of Exceedance at a given time horizon
C_{tn} = Consequence of Flooding rating at a given time horizon
$_{tn}$ = Time horizon n (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:

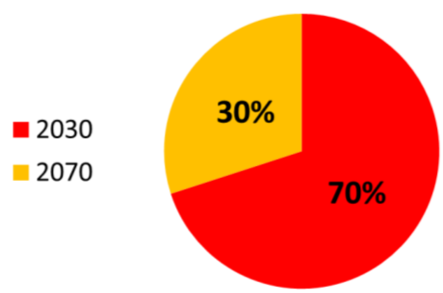
$$\mathbf{R_{comp} = (R_{203}0 \times W_{2030}) + (R_{2070} \times W_{2070})}$$

Where:

R_{comp} = Composite risk score for all time horizons
R_{2030} = Risk score for 2030 time horizon
R_{2070} = Risk score for 2070 time horizon
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 by 2030 should generally be at a higher 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_{2030} = 70% (or 0.70)
W_{2070} = <u>30%</u> (or 0.30)
100%



An Excel spreadsheet was developed which incorporated the probability of exceedance data, consequence of flooding scores and the formulas to automate the risk scoring process. An example of the risk scoring for Swampscott Pier is shown in Table 2.7.

TABLE 2.7

RISK SCORING EXAMPLE FOR SWAMPSCOTT PIER

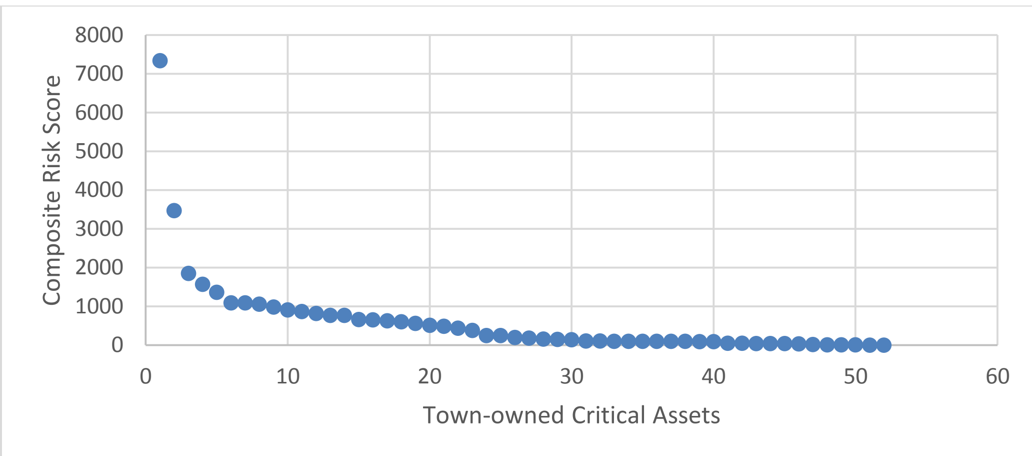
	Annual Probability (%)	Consequence Score (out of 100)	Risk Score	Weight	Composite Risk Score
2030	10	50	500	0.7	1850
2070	100	50	5000	0.3	

Note that the consequence of flooding score remains constant for an asset over the life of the asset, and that only the probabilities of exceedance change over time. The consequence of flooding score would change 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, no future changes that would change the consequence of failure scores have been anticipated.

2.4 VULNERABILITY AND RISK ASSESSMENT RESULTS

Using the risk scoring and ranking methodology described above, the composite risk scores were calculated for each critical municipally-owned asset subject to flooding. The composite risk scores of all the assets are shown on a scatter plot below (Figure 2.3).

FIGURE 2.3
ALL COMPOSITE RISK SCORES



Based on Figure 2.3 there are few assets with risk values above 1,000. Conversely, many assets appear to have a risk score less than 500. For the purposes of this study assets with a risk value of 500 or greater are evaluated for resiliency and adaptation under Technical Memorandum 3. A few lower risk assets of exceptional interest may also be evaluated upon request by the Town.

The highest flood risk assets based on composite risk scores are shown in Tables 2.8, 2.9, and 2.10. Only assets with composite risk scores of 500 and greater are shown.

TABLE 2.8

HIGHEST FLOOD RISK FACILITIES AND BUILDINGS

Name/Number	Location	Consequence Score	2030 Probability (%)	2070 Probability (%)	Composite Risk Score
Swampscott Pier	425 Humphrey Street	50	10	100	1850
Fisherman's Beach East Boat Ramp	Fisherman's Beach at Swampscott Pier - East	27	30	100	1360
Fisherman's Beach West Boat Ramp	Fisherman's Beach at Swampscott Pier - West	27	10	100	987
Fish House	425 Humphrey Street	60	0.2	50	908
Heliport at Phillips Park	Phillips Park	43	0.5	50	665
Point of Distribution #2	Phillips Park	37	2	50	601

TABLE 2.9

HIGHEST FLOOD RISK SEAWALLS

Name/Number	Location	Consequence Score	2030 Probability (%)	2070 Probability (%)	Composite Risk Score
071-021-000-040-100	Cassidy Park	73	100	100	7333
071-021-000-036-100	Eiseman's Beach	53	50	100	3467
071-021-000-038-100	Whale's Beach	50	2	100	1570
071-001-000-188-100	King's Beach	67	2	50	1093
071-019-000-278A-300	Fisherman's Beach - East Wall	70	0.2	50	1060
071-019-000-278A-200	Fisherman's Beach - Center Wall	70	0	30	630

TABLE 2.10

HIGHEST FLOOD RISK ROADWAYS

Name/Number	Location	Consequence Score	2030 Probability (%)	2070 Probability (%)	Composite Risk Score
Humphrey Street (East)	Greenwood Avenue to Glen Road	67	2	50	1093
Puritan Road	Humphrey Street to Humphrey Street	57	0.5	50	870
Atlantic Avenue	Humphrey Street to Marblehead Town Line	50	2	50	820
Commonwealth Avenue	Sculpin Way to Humphrey Street	47	2	50	765
Sculpin Way	Puritan Road to Puritan Road	47	2	50	765
Marshall Street	Humphrey Street to Puritan Road	40	2	50	656
Shepard Avenue	Ocean Avenue to Atlantic Avenue	37	0.5	50	563
Sutton Place	Woodbine Avenue to Cul De Sac	33	0.5	50	512

2.5 NATURAL RESOURCES ASSESSMENT

As part of this assessment, the impacts of sea level rise and storm surge to Palmer Pond was analyzed. Palmer Pond is a salt-water marsh located at Phillips Beach. There are two drainage outfalls that drain into the Pond and there is a 24-inch drain outfall from the Pond that connects to the Ocean at Phillips Beach. The Phillips Beach outfall is typically buried under sand and is installed with a one-way flap valve, called a Tideflex® valve, manufactured by the Red Valve Company.

Under present conditions, the manhole invert elevation leaving Palmer Pond is 5.97 ft. NGVD29 (5.16 ft. NAVD88), which is approximately 0.75 ft. above the present mean higher high water elevation (4.95 ft. NGVD29/4.14 ft. NAVD88). Palmer Pond primarily provides storage during flooding and mitigates flooding impacts in areas upstream that drain to Palmer Pond. Based on the percent probability of flooding maps there is approximately a 2% probability and greater than 50% probability for 2030 and 2070, respectively, that the Pond might be flooded under sea level rise and storm surge scenarios. When flooded, the storage function of the Pond will be compromised and it will be directly influenced by the ocean's tidal fluctuations. Higher tailwater elevations at the Pond could also impose hydraulic restrictions to the upstream areas that drain to the Pond.

2.6 LIMITATIONS

The sea level rise and storm surge predictions made in this report are based on some of the most recent developments in the science of regional climate change. However, it should be noted that the scenarios investigated in this limited study represent only some of the possible scenarios and combinations of sea level rise and storm surge. It should also be noted that there are many uncertainties involving the science of climate change.

The inundation maps show flood levels over land only. Buildings shown on the aerial photographs as being flooded may not actually be fully flooded. For this level of study, it was not possible to create accurate 3D modeling of every building to show how flood waters would actually flow around or through buildings. For example, if a building is raised on pilings, water could be covering the land below the building footprint, but not actually touching the occupied first level of the building. The intent of the inundation maps is to illustrate the impacts, extent, and general water depths of potential sea level rise and storm surge scenarios, but not to indicate any specific damage scenarios for a particular building or structure.

Information shown on the attached flood maps illustrates predicted flooding resulting from coastal flooding caused by storms (such as hurricanes and nor'easters) combined with sea level rise estimates developed by NOAA for the year stated. These flood maps expressly do not include flooding attributed to wave run-up, overtopping of seawalls, backups within municipal drainage infrastructure or precipitation. Therefore, the extent and magnitude of flooding depicted on these flood maps strictly represent coastal flooding from sea level rise and storm surge. These flood maps shall not be used to represent the extent of flooding for which flood insurance is required.

Projections depicted on these flood maps are the best judgment of Kleinfelder and the Project Team, but in no way shall the flood levels depicted be interpreted as any guaranteed predictions of future events, and they shall only be used for general planning purposes.

TECHNICAL MEMORANDUM 3 (TM3)

ADAPTATION STRATEGIES – ENGINEERING

3 TM3 ADAPTATION STRATEGIES – ENGINEERING

The purpose of this memorandum is to provide an overview and examples of different types of adaptation strategies, high-level design considerations, and a discussion of the different scales at which adaptation actions can be implemented in the Town of Swampscott for those vulnerable publically owned infrastructure previously identified in Technical Memorandum 2. The majority of the memorandum describes the risks and adaptation engineering alternatives for each high flood risk area in Town and specific municipal assets within them. The final section of the memorandum describes the assumptions used to develop order-of-magnitude cost estimates for this study.

The Town of Swampscott is already experienced with the impacts of climate change, such as making road detours during extreme weather events leading to coastal flooding. Sea level rise and increasingly intense storm surge caused by climate change will increase these and other impacts over time. The adaptation measures presented herein provide numerous strategies and concepts that can be implemented to mitigate these impacts. These conceptual solutions and order-of-magnitude cost estimates provide the Town with a starting point for long-term adaptation planning. Due to the high-level planning nature of this study, the cost estimates presented herein are based on limited information and in no way are meant to be used for budgeting. Subsequent planning and engineering design will be required to confirm the numerous assumptions required to create the cost estimates.

Moving forward, the Town may choose to further develop the adaptation concepts presented herein for those particular flooded areas or strategies of interest. Some of the tools for future decision making are provided in Technical Memoranda 2 and 3. These include (1) mapping of flood prone areas, (2) a risk evaluation of the particular municipal assets situated within the flood prone areas, (3) a "menu" of adaptation measures, and (4) high level cost information for implemented these adaptation measures. With this information, the Town is better informed about its options moving forward than before this study was completed.

3.1 ADAPTATION OVERVIEW

3.1.1 TYPES OF ADAPTATION STRATEGIES

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

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

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

Accommodation strategies accept that vulnerable areas, infrastructure, and buildings will flood, but aim to minimize and control physical damage and unsafe conditions. Accommodation strategies may include physical, operational, or regulatory measures. Table 3.1 includes several example of accommodation strategies.

TABLE 3.1

EXAMPLES OF ACCOMODATION STRATEGIES

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

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

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

3.1.2 BASE FLOOD ELEVATIONS

Prior to designing and evaluating alternative adaptation strategies, it is important to identify the base flood elevation that will be the minimum level of flooding to which an area or asset is adapted to. **For the purposes of this study, base flood elevations do not include additional height for wave run-up or overtopping, nor do they include "freeboard" - height often added above the expected flood level for additional safety. The design flood elevation should include these factors and will vary from site-to-site, reflecting local conditions, criticality of the facility in question, and the owner's tolerance for risk.** During the preliminary design stage of a flood adaptation project, additional investigations, such as wave run-up and overtopping analysis, should be completed, where applicable (e.g., seawalls and dunes), to determine the design flood elevation. Base and design flood elevations 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.

Table 3.2 below shows representative coastal base flood elevations for Swampscott at different probabilities of exceedance in the 2030 and 2070 time horizons. For the purposes of this study, adaptation options are recommended based on a base flood elevation equivalent to the 1% probability of exceedance flood levels in 2030 and 2070 (100 year recurrence interval). This sets a reasonably conservative base flood elevation on which to base minimum standards for critical assets and large floodplains.

It is important to note that the base flood elevations discussed in this report do not in any way supersede the minimum base flood elevations legally established by the Massachusetts State Building Code or other applicable codes for the design of buildings and infrastructure. The base flood elevations used in this report are presented for the purpose of establishing a reference elevation by which to evaluate various strategies to address flooding impacts from sea level rise and extreme storm events.

TABLE 3.2

PROBABILITY OF EXCEEDANCE IN 2030 AND 2070

Exceedance Probability (%)	2030 Water Surface Elevation (ft. NAVD88)	2070 Water Surface Elevation (ft. NAVD88)
0.1	10.5	14
0.2	10.3	13.9
0.5	10	13.4
1	9.4	12.8
2	9.3	12.5
5	8.6	12.1
10	8.5	11.5
20	7.9	11
25	7.8	10.8
30	7.7	10.6
50	7.3	10.2
100	6.7	9

Recommended Base Flood Elevations

> *In 2030, the difference between the 1% and 0.2% flood elevation is 0.9 feet, and that difference increases slightly to 1.1 feet in 2070.*

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

3.1.3 ADAPTATION AT DIFFERENT SCALES

Adaptation strategies can be implemented at different scales, depending on the goals to be achieved and the resources available to achieve them. In this study, the adaptation recommendations are either regional or asset-specific in nature.

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

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

Asset-specific strategies may be necessary or preferable for specific critical infrastructure assets and buildings. Asset level strategies are particularly needed for assets located in high flood risk areas for which regional strategies have been rejected for technical, political, or financial reasons. It is also necessary for assets that are outside of the scope of regional flood protection strategies (e.g., water-dependent assets like boat ramps and piers). Asset level adaptation is also preferable for very critical assets that cannot afford to wait until regional solutions are implemented.

3.2 RECOMMENDATIONS FOR HIGH RISK AREAS AND ASSETS

This section of the report describes the recommended adaptation strategies for areas and critical Town-owned assets at a high risk of coastal flooding. For each high risk area, the critical municipal assets within it are listed, the potential pathways and sources of coastal flooding are described, and the regional and asset level adaptation options are recommended with additional guidance for decision makers and designers. All of the analysis and maps that are provided in this section are based on the coastal flood modeling conducted for this study.

Specific recommendations, including order-of-magnitude costs, for the following flood-affected areas and municipal assets are described herein (section numbers are listed in parentheses):

1. Phillips Park Area (3.2.1)
    - Strategies for specific assets:
        - Boat Storage Lot
        - Point of Distribution #2
        - Boat Ramps at Fisherman’s Beach, Whales Beach, and Eiseman’s Beach
        - Swampscott Pier
        - Fish House
        - Police Headquarters and Emergency Operations Center

    - Humphrey Street Pump Station
    - Diesel Fueling Station (behind Humphrey Street Pump Station)
2. Palmer Pond/Phillips' Beach Area (3.2.2)
3. Preston Beach Area (3.2.3)
4. King's Beach Area (3.2.4)
    - Strategies for specific assets:
        - Roadways – Humphrey Street and New Ocean Street
        - Calgon Station and Chlorination Station

All estimates of costs presented herein to implement adaptation recommendations are order-of-magnitude estimates, in 2015 dollars, for use in long-term planning purposes. The costs in no way are meant to represent actual estimates of total project costs as no surveying, subsurface exploration, traffic engineering, engineering design, permitting and escalation of costs was performed as part of this project, all of which are necessary to establish true project costs required to construct a project. For more information on data sources and assumptions, see Section 3.3 of this memorandum.

3.2.1 PHILLIPS PARK AREA

Critical Assets at Risk

- The largest area of flood risk in Swampscott, referred to here as the Phillips Park area, also has the greatest number of critical municipal assets located within it.
- This high risk area extends across from Fisherman's Beach, across Humphrey Street and Puritan Road, through Phillips Park, and down to Whales Beach and Eiseman's Beach.
- Included in this area are the Swampscott Pier, historic Fish House, new Police Headquarters and Emergency Operations Center, Humphrey Street Sewer Pump Station, and numerous public boat ramps.
- Phillips Park serves multiple community purposes, including as a boat storage lot, emergency airlift heliport, point of distribution for emergency supplies, and temporary storage location for excess snow.
- The area also includes many businesses and residences that have experienced flooding in the past, and the large majority of flood insurance policy holders in the Town.

Coastal Flood Pathways and Other Sources of Flooding

By 2030, there are three localized flood pathways through which water will likely pass and flood the Phillips Park area (2% probability or lower). All of these pathways are on Town land and at break points in the otherwise continuous system of public and private seawalls that extend along the upland edge of Fisherman's Beach on Humphrey Street and Puritan Road.

(1) Greenwood Avenue beach access way to Fisherman's Beach (Greenwood Avenue and Humphrey Street intersection).
(2) Fisherman's Beach boat ramp/beach access ways on either side of the Fish House (Humphrey Street and Puritan Road intersection)
(3) Cassidy Park beach access way at the north terminus of the Cassidy Park Seawall (Puritan Road and Sculpin Way intersection).
(4) In addition to these overland flood pathways, the drainage systems serving this area will likely be susceptible to backflow under sea level rise and storm surge scenarios for 2030 and 2070. Backups have already occurred in past storm/high-tide events through the Cassidy Park outfall, leading to localized flooding in private properties adjacent to Phillips Park. NOTE: Modeling of the piped drainage system under climate change scenarios to be conducted under the Town-wide Drainage Study has not been completed.

By 2070, flooding of Phillips Park area is projected to be significantly more likely. The probability of flooding from the flood pathways identified in (1), (2), and (3) is as high as 50%. Backflow risks identified in (4) could be exacerbated. In addition, there are new flood pathways with high probabilities of opening up, including through private properties.

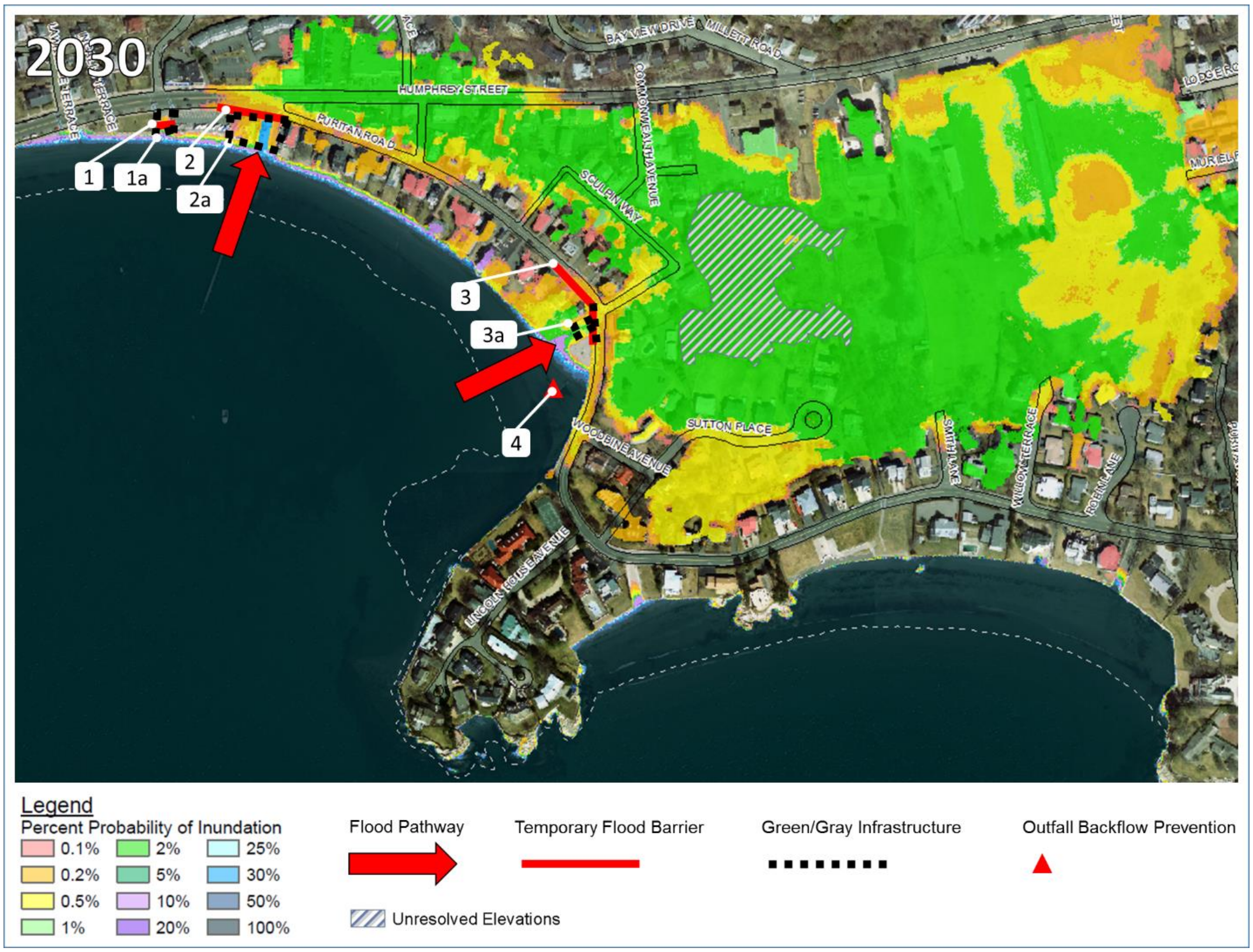
(5) Fisherman's Beach East and Center seawalls (up to 30%)
(6) Private properties along Fisherman's Beach on the ocean-side of Puritan Road (up to 30% probability)
(7) Whales Beach boat ramp/beach access way and seawall/Polisson Park (up to 20% probability)
(8) Private properties along Whales Beach (up to 2% probability)
(9) Eiseman's Beach seawall/Johnson Park (up to 25% probability)
(10) Private properties along Eiseman's Beach (up to 5% probability)
(11) Eiseman's Beach boat ramp/beach access way (up to 2% probability)

Adaptation strategies for this area range from regional solutions to address flood pathways (a more centralized approach to flood management that protects a larger area) to asset-level measures to protect specific critical municipal infrastructure at risk of flooding. These strategies and various options to achieve their goals are detailed below.

3.2.1.1 REGIONAL ADAPTATION STRATEGIES FOR 2030

A regional flood protection strategy for 2030 could have a very high return on investment, as it requires a limited set of relatively low-cost interventions to protect a large area that contains critical infrastructure and significant residential and commercial property. The numbers shown in Figure 3.1 correspond to the numbered recommendations below. These high priority strategies consist of raising elevations, through permanent and temporary measures, at several low areas through which flooding could enter and flood the Phillips Park area.

FIGURE 3.1
PHILLIPS PARK AREA RISKS AND ADAPTATION STRATEGIES (2030)



(1) At the Greenwood Avenue beach access way between the Fisherman's Beach East and Center seawalls (Figure 3.2). A temporary flood barrier system robust enough to withstand wave action could be installed at the base of the ramp. During non-storm conditions, the barrier would not be in place and the vehicle ramp would function as normal.

FIGURE 3.2
GREENWOOD AVE BEACH ACCESS WAY

a) A permanent measure that could be implemented to reduce medium-term risks would be to adjust the grading of the ramp using appropriate materials such that the access way no longer represents a low point, but has the same top elevation as the adjacent seawalls and parking lot. A berm made of compatible sediment should be built on the ocean-side of the access way. The berm could be vegetated with native vegetation and stabilized with a narrow environmental access mat for pedestrians to use to cross over the berm. The addition of vegetation will eliminate vehicle use of this access way. The boat ramp on the west side of the Fish House could still be used for maintenance vehicles to access the beach. This strategy could be integrated in existing plans by the Town to redesign this access way with raised planters, vegetation, and porous pavement.

(2) At the boat ramp access ways on either side of the Fish House that lead to Fisherman's Beach (Figure 3.3). A robust temporary barrier system with limited footprint could be installed either on the ocean-side of the Fish House or on the Humphrey St/Puritan Rd sidewalk. The Fish House itself is not likely effective as a barrier to flooding, so the temporary barrier should also span across one side of the building.

FIGURE 3.3
FISHERMAN'S BEACH BOAT RAMP ACCESS WAYS

a) A permanent measure that could be implemented to reduce medium-term risks would be to adjust the grading and elevate the top elevation of the access ways using appropriate materials to meet or exceed (where feasible) the foundation elevation of the Fish House. Nature-based techniques such as building berms are not feasible at this location due to its active use by vehicles to access the boat ramps and the beach for beach management activities.

(3) At Cassidy Park across the beach parking area and access way (Figure 3.4). This barrier would connect to the north terminus of the Cassidy Park seawall and extend past several private properties. The barrier could be installed on the sidewalk or partially/fully on the roadway. Either the sidewalk or the roadway (maximum one lane) may need to be temporarily closed to traffic prior to and during an extreme storm, with appropriate signage to warn pedestrians and vehicles and advanced notice to emergency responders.

a) A permanent measure that could be implemented to reduce medium-term risks, without sacrificing the public parking, would be to reconstruct the existing parking area, raising it to a higher elevation using appropriate materials, and building a berm of compatible sediment between the parking area and the beach. An environmental access mat should be purchased and placed over the berm for pedestrian access and/or in advance of vehicles using the access way. This will reduce the impact of foot traffic and vehicles on the berm's integrity. The transition from the roadway to the parking area would need to be graded as a ramp up, which would leave an unprotected gap between the elevated parking area and the north terminus of the Cassidy Park seawall. Elevation of the adjacent sidewalk sections or construction of a low concrete wall, southward to the Cassidy Park seawall, and northward in front of private properties, would complete the elevated barrier.

FIGURE 3.4
CASSIDY PARK ACCESS WAY

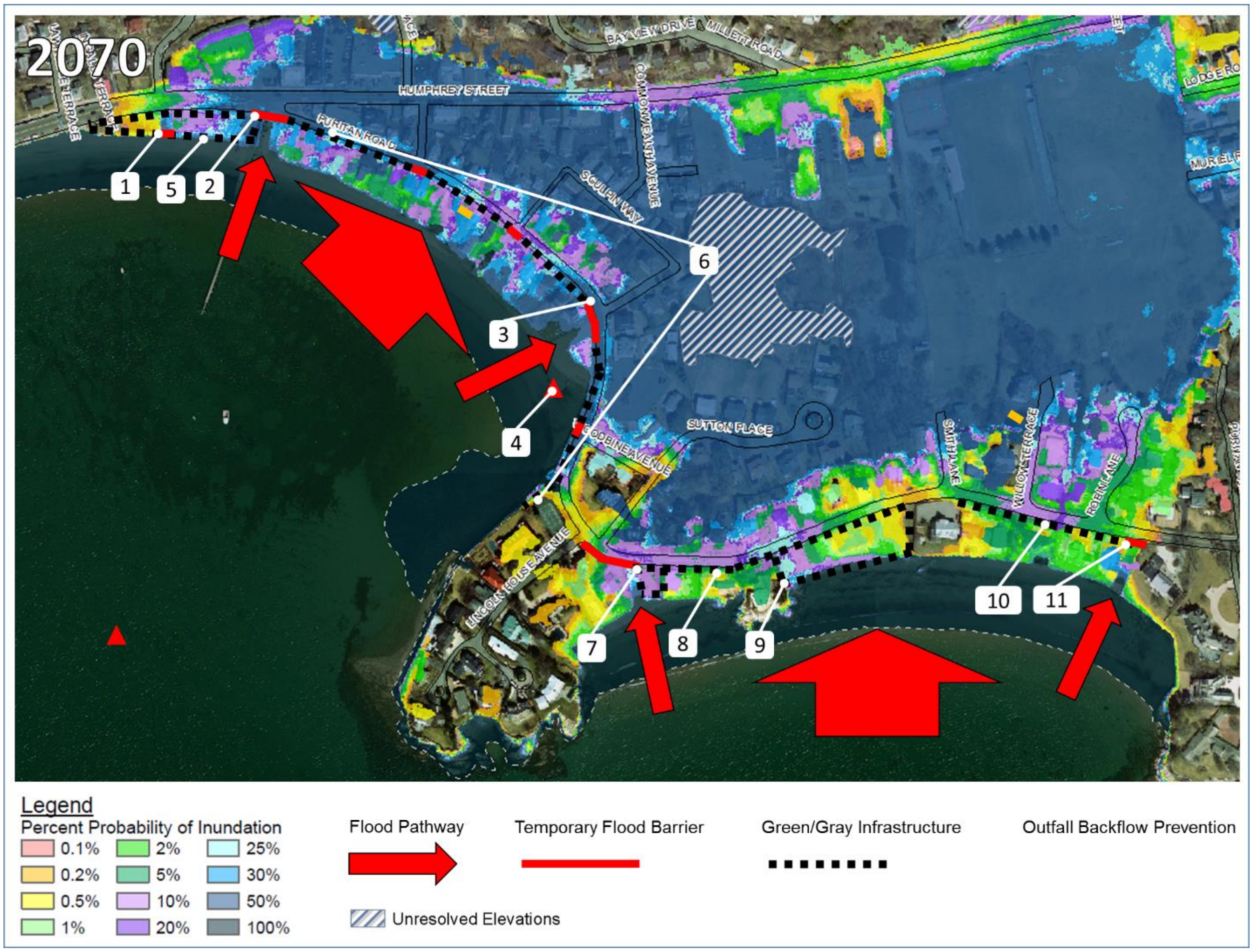
(4) The existing outfall at Cassidy Park was previously fitted with a backflow prevention device, but it was removed and never replaced. The Town should investigate installing an appropriate replacement (e.g., tide-flex/duckbill type or other).

Order-of-Magnitude Costs

- The cost of implementing all temporary components of the 2030 regional strategy described above is estimated to be approximately $330,000.
- The cost of implementing all permanent components of the 2030 regional strategy described above is estimated to be approximately $148,000.

3.2.1.2 REGIONAL ADAPTATION STRATEGIES FOR 2070

FIGURE 3.5
PHILLIPS PARK AREA RISKS AND ADAPTATION STRATEGIES (2070)



The numbers shown in Figure 3.5 correspond to the numbered recommendations below and include recommendations (1) through (4) above (Regional Adaptation Strategies for 2030).

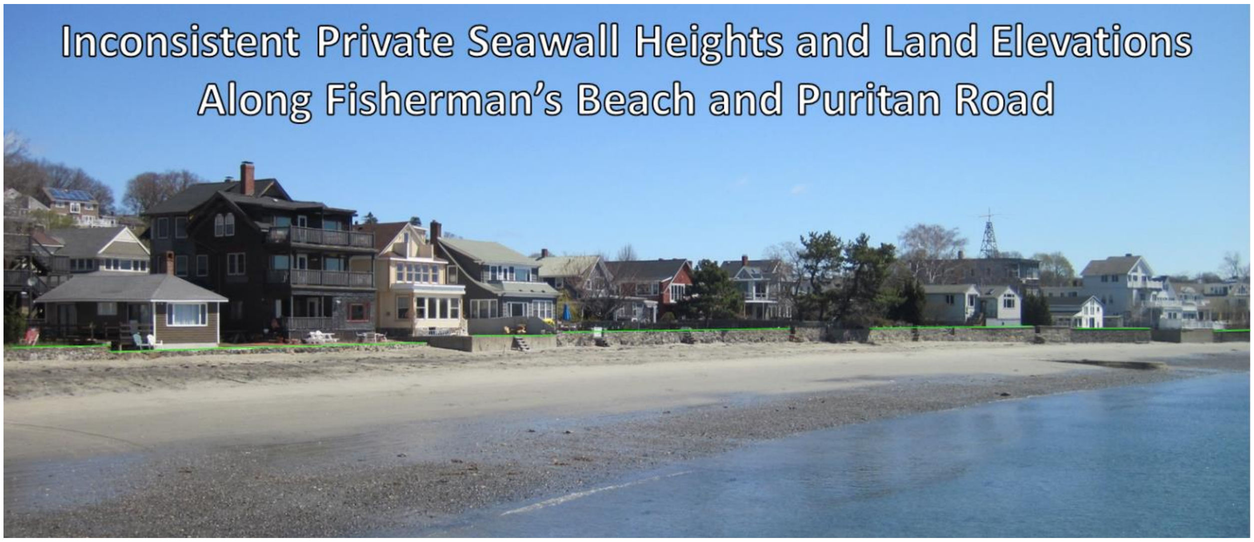
(5) The Fisherman's Beach Center and East seawalls should be raised to a higher and consistent elevation (Figure 3.6). The East Seawall is a higher priority for elevation, given its lower elevation and poorer condition (i.e., higher probability of flooding). The park behind the Center Seawall could also be raised to create a landscaped berm to provide a more robust barrier. Elevating the parking lot behind the East Seawall using appropriate materials and possibly constructing a higher curb wall along the edge shared by the parking lot and the sidewalk than what currently exists would add additional protection.

FIGURE 3.6
FISHERMAN'S BEACH SEAWALLS AT HUMPHREY ST

(6) There are several options outlined below for protecting the Phillips Park area from longer-term risks of flooding across private properties located on the ocean-side of Puritan Road along Fisherman's Beach (Figure 3.7). However, they are all challenging from a technical, political, and/or financial perspective. Projected flood levels are significantly higher than Puritan Road and existing private land and coastal defenses on the ocean-side of Puritan Road.

a) The most reasonable strategy would be for the Town to acquire the existing private seawalls, including easements for maintenance, and rebuild them to a consistent, higher, and more robust standard. The type of seawall could resemble a similar type as the Fisherman's Beach Center seawall. Without acquiring the seawalls, the Town may find it difficult to compel or incentivize property owners to raise the seawalls themselves, leaving a large area of town at risk of flooding. Flood protection could be considered a public good and a basis for betterments or eminent domain takings.

FIGURE 3.7
FISHERMAN'S BEACH SEAWALLS AT PURITAN RD



b) Without acquiring private property along the ocean-side of Puritan Road from Fisherman's Beach to Little's Point, the Town only has the footprint of the roadway and sidewalks to work with for a possible built solution. It would be technically and politically challenging to do so, but the Town could use the roadway or the right-of-way to create a flood barrier that would protect the broader Phillips Park area, while in practice "sacrificing" land and property on the ocean-side. This could be achieved by raising the road or installing a permanent or temporary flood wall along one of the sidewalks or down the center of the roadway.

- Raising the road would be the most challenging option, due to the limited space (the road is already narrow, with only 22-23 feet from sidewalk-to-sidewalk in some sections) and the difficulty of designing transitions to existing driveways. The road would most likely need to be narrowed to a single one-way lane in order for this option to be potentially feasible.

- Installing a flood wall on a sidewalk (either ocean- or land-side) would be complicated due to conflicts with underground utilities and numerous gaps that would need to be left for access to driveways and building entrances.

- Another challenging possibility would be to install a mixed temporary-permanent flood barrier down the roadway centerline. Due to limited available footprint, certain sections may need to be entirely temporary in nature. Sidewalks may also have to be adjusted or even alternated. In sections with more room, a permanent raised island down the center of the road could be designed with breaks at intersections and crosswalks leading to the beach. Temporary closures would be installed in these openings in advance of a storm. A permanent island could also be perceived as improving safety, reducing the likelihood of head-on collisions. However, maintaining the island, which could be damaged by vehicles, might be more costly. A temporary wall would be less expensive but more challenging from an operational perspective because significant organization and labor would be required to install it in advance of a storm. Also, the change in grade may prevent a full temporary wall from being technically feasible.

c) If neither (a) nor (b) are feasible, the Town would have to tolerate significant residual flood risks. Over time, storms would likely damage properties in the area, particularly along the ocean-side of Puritan Road. At that time, the Town may become more open to the possibility of limited or more transformative retreat from the ocean-side of the road. With federal and/or state disaster and hazard mitigation assistance, the Town could acquire damaged properties that pose a particular risk due to low elevation or poor upkeep of seawalls through a rolling easements program. The land could eventually be improved to serve multiple functions, including park space, beach parking, and flood protection. While a limited retreat approach would reduce flood risk, it would be difficult to eliminate the risks this way. A more controversial and transformative possibility, though highly unlikely, is that the entire beach front would be retreated from. This would involve acquiring and removing residential structures from the Fish House to Cassidy Park. Land on the ocean-side could then be transformed into green infrastructure (e.g., multi-use levee, beach dune system, terraced park), structural defenses (i.e., seawall), and/or vehicle parking. There would be sufficient land in such a scenario to raise, widen, and realign Puritan Road to accommodate driveway transitions, widen lanes and sidewalks, and add bicycle lanes. Again, retreat is generally an extremely controversial and costly strategy and is not the recommended alternative at this point in time.

(7) There are high priority risks of flood pathways opening up to Puritan Rd and the broader Phillips Park area, either through the Whales Beach boat ramp access way (up to 20% probability), or over Polisson Park (up to 10% probability). Strategies for preventing these flood pathways from opening up are as follows:

a) Install a temporary or permanent flood barrier/closure across the boat ramp access way AND

b) Raise the seawall that runs along the ocean-side of the park OR

c) Raise the park elevation with fill OR

d) Build a low berm along the sidewalk/park edge OR

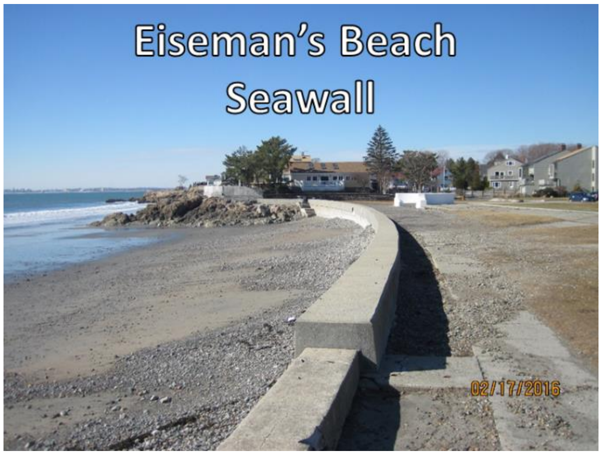
e) Build a decorative retaining wall along the sidewalk/park edge

FIGURE 3.8
WHALES BEACH ACCESS WAY AND POLISSON PARK

(8) To prevent coastal flooding from passing over private properties on Whales Beach, east of the boat ramp access way, the temporary or permanent flood barriers proposed in (7a) and (7e) should be incrementally extended to the edge of Johnson Park behind the Eiseman's Beach Seawall. However, due to the lower probability of this flood pathway (up to 5%), this is a lower priority than strategies noted under (7) and (9).

(9) There is up to a 25% probability that flood levels will exceed the height of the Eiseman's Beach Seawall, cross Johnson Park behind it onto Puritan Rd, and flood the Phillips Park area. To prevent this from happening, the seawall and/or the park should be elevated as a matter of high priority.

FIGURE 3.9
EISEMAN'S BEACH SEAWALL AND JOHNSON PARK

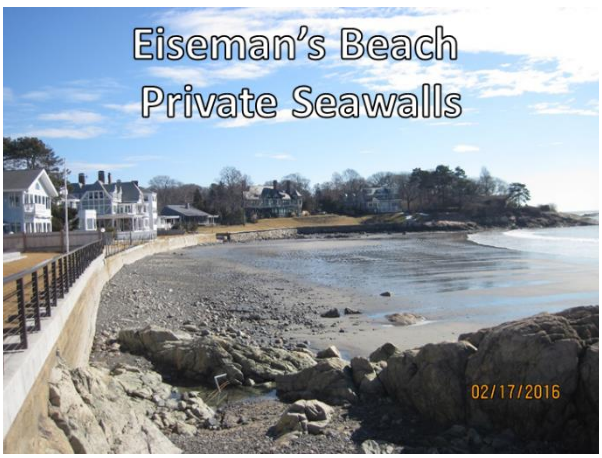


(10) To address flood pathways through private properties on Eiseman's Beach, between Smith Lane and the Eiseman's Beach boat ramp access way, there are a couple of options. However, due to the relatively low probability of this flood pathway (up to 5%), this is a lower priority than strategies noted under (7) and (9).

a) Strategies described in (6a) and (6b) could be implemented. For example, low-lying property could be acquired, or some elevational changes to the sidewalk or roadway in front of these properties could be implemented.

b) Alternatively, temporary barriers proposed in (11) could be extended across this area in advance of a storm.

FIGURE 3.10
EISEMAN'S BEACH SEAWALLS AND ACCESS WAY



(11) There is also a 2% or lower probability that a flood pathway will open up through the boat ramp access way to Puritan Rd and the Phillips Park area. While waves, this flood pathway is far less likely than others to be a major source of flooding in the Phillips Park area. The most straightforward solution to the boat ramp access way flood pathway is to regrade and elevate the access way using appropriate materials so that the top elevation of the access way meets the top elevations of adjacent seawalls. An alternative would be to install a temporary or permanent flood barrier/closure across the access way.

Order-of-Magnitude Costs

- The costs of implementing the 2070 regional strategies to prevent overland coastal flooding from Fisherman's Beach, Cassidy Park, Whales Beach, and Eiseman's Beach over Humphrey Street and Puritan Road, and into the Phillips Park area vary widely depending on the alternatives selected.

- *Fisherman's Beach at Humphrey Street:*

    - A full length temporary flood barrier system is estimated to cost approximately $910,000.
    - To raise the Fisherman's Beach East and Center seawalls and incorporate temporary flood barriers at access ways is estimated to cost approximately $2,150,000. Raising the park and parking lot areas behind the seawalls would add an estimated $360,000 to the total cost.
- *Fisherman's Beach at Puritan Road:*

    - The cost of building a new seawall, of similar construction to the Fisherman's Beach Center seawall, in front of existing private properties along the ocean-side of Puritan Road and obtain property via easements or eminent domain is estimated to be approximately $9,000,000.
    - The cost of adapting Puritan Road to function as a protective levee, either by raising the road or installing a mixed permanent-temporary barrier along the road centerline, is estimated to range from $550,000 to $2,550,000. This does not include the cost of private impacts or impacts to travel times.
    - The strategy of retreating from the ocean-side of Puritan Road and converting the area to a more compatible land use is not likely to be considered for implementation for the variety of reasons discussed above. The cost of implementing this strategy would include the cost of the new seawall, the

adaptation of Puritan Road or similar costs of land filling, plus the approximately $800,000 per property estimated cost of acquiring and demolishing existing structures.

- *Cassidy Park:*
    - The cost of implementing the 2070 regional strategies for the Cassidy Park area is estimated to be approximately $3,550,000, which would include raising the existing seawall and extending the temporary barrier solutions from the 2030 strategy.
- *Whales Beach and Eiseman's Beach:*
    - The base cost of raising Puritan Road along Whales Beach and Eiseman's Beach, not taking into account private impacts, is estimated to be approximately $1,500,000.
    - The average estimated cost of strategies that do not involve raising the Town's seawalls at Whales Beach and Eiseman's Beach, but instead rely on creating berms or retaining walls and installing temporary barriers selectively along the corridor total approximately $1,100,000 for the entire corridor.
    - Strategies that include raising the existing seawalls, possibly raising park areas, and installing a mix of temporary barriers and retaining walls are estimated to cost approximately $1,300,000 on average for Whales Beach and $2,500,000 for Eiseman's Beach.

3.2.1.3 SITE LEVEL STRATEGIES

As an alternative to implementing regional strategies that offer protection to the larger Phillips Park area from coastal flooding, the Town could selectively implement site level strategies to limit risks only for critical municipal assets.

<u>Boat Storage Lot</u>

The Town currently raffles leases to store boats in the parking area of Phillips Park. The lot itself does not contain infrastructure that merits specific protection. However, the Town should review the lease terms from a liability perspective. Leases could be revised to advise boat owners of the potential flood risk at the storage site and inform them that they store boats there at their own risk.

Order-of-Magnitude Costs

- There are no capital costs assigned for the recommended operational measures.

Point of Distribution #2

The Town designates the parking area of Phillips Park as a point of distribution for emergency supplies in the event of a disaster affecting the community. This site should have a back-up location in a more elevated area not subject to coastal flooding risks. Town Police and Fire Departments should review the flood maps to pre-identify an alternate location from which to serve the communities in the Phillips Park area that may be subject to significant flooding.

Order-of-Magnitude Costs

- There are no capital costs assigned for the recommended operational measures.

Boat Ramps at Swampscott Beaches

The Town's boat ramps at Fisherman's Beach (Figure 3.11), Eiseman's Beach, and Whales Beach do not warrant a high priority in terms of adaptation in the near to medium term. However, over that time horizon, they may be impacted by storm surge events that erode or undermine their concrete slabs. In the longer term, sea level rise will result in more permanent inundation of the ramps, in addition to more frequent or intense storm surge impacts.

FIGURE 3.11
FISHERMAN'S BEACH BOAT RAMPS

It is recommended that if the boat ramps are damaged by a major storm, and depending on the timeframe, they be redesigned in two ways:

- To accommodate sea level rise, for example by changing the elevation and grade of the slabs and moving them further up the shore line, and
- To accommodate more frequent intense wave forces, for example by adding armoring or other means of wave energy dissipation and erosion control. Cut-off walls (concrete or steel sheet piles) should be included in any new ramp to prevent undermining of the ramp.

Order-of-Magnitude Costs

The estimated costs of replacing the existing boat ramps with regraded concrete slab boat ramps with concrete cut-off walls are as follows:

- Fisherman's Beach - West side of the Fish House: $160,000
- Fisherman's Beach - East side of the Fish House: $136,000
- Whales Beach: $170,000
- Eiseman's Beach: $181,000

Swampscott Pier

Swampscott Pier's construction consists of wood piles, wood planks, and metal guardrails. Storm damages in the near-to-medium term should simply be repaired, as needed. Over the longer term the Pier's deck height should be raised to a higher elevation, if possible. The length of the pier is too long to consider replacing the fixed dock structure with a more versatile system of floating docks that can rise and fall with the height of the storm surge.

Order-of-Magnitude Costs

- The replacement cost of rebuilding the pier is estimated to be approximately $828,000.

Fish House

Swampscott's historic Fish House is likely to face repeated flooding over the coming decades. In the past, the Town has used plywood to strengthen the structure to the damaging impacts of waves during powerful storms. Structural and non-structural damage, such as mold growth from interior flooding, are major concerns in the future. Because of the Fish House's location in the wave velocity zone, dry floodproofing is not permitted by code.

One option is to raise the Fish House structure to a safe level. However, this may alter the historic character of the facility, as well as impact its existing uses.

An alternative would be to wet floodproof the interior of the building, including replacing interior furnishing with flood damage resistant materials and reinforcing structural elements. This would allow the interior to become floodable space. The exterior of the building could be re-fitted with wood cladding to maintain its historic façade.

FIGURE 3.12
FISH HOUSE FLOOD RISKS

<u>Order-of-Magnitude Costs</u>

- The cost of wet-floodproofing the first floor interior of the Fish House is estimated to be approximately $18,000.
- Raising the building is estimated to cost approximately $193,000.
- These costs do not include any structural strengthening which are difficult to estimate without more detailed engineering analysis.

Police Headquarters and Emergency Operations Center

The recently constructed Swampscott Police Headquarters also serves as the Town's Emergency Operations Center (EOC). Both of these functions can be impacted by flooding in the near-to-medium and longer term if the regional solutions discussed above are not implemented.

The building's first floor and garage level are substantially elevated above flood levels predicted for the 2030 timeframe. However, by 2070, they have a 2% and 10% probability of flooding, respectively. In addition, important building systems equipment (i.e., HVAC, electrical) are located around the building exterior and might be at lower elevations, slightly increasing their risk of flooding.

FIGURE 3.13
POLICE HEADQUARTERS AND EOC RISKS

The functioning of the Police Headquarters and EOC also depends on the broader site the building is located on. Police cruisers and other vehicles, trailers, and equipment are stored in the low-lying parking lot behind the building, where there is a 2% chance of flooding in 2030 and 50% chance in 2070. In the 1% flood in 2070 areas of the parking lot could be flooded with over 5 ft. of water. Access to and from the building from the roadway are also critical, but as discussed above, large sections of Humphrey St. are at risk of flooding in 2030 and 2070. Therefore, while the building itself can be floodproofed to prevent damage to critical systems, structural components, and interior spaces, the building cannot serve effectively as a base for public safety, law enforcement, and emergency management during or immediately after a major coastal flooding event.

It is recommended that in the near-to-medium term (present to 2030) the Swampscott Police Department implement the following operational measures in advance of a forecasted coastal flood:

- If an alternate EOC location is not already established, it is recommended that such a location be identified, such as the Fire Department Headquarters, which is in an area of Town not subject to flooding based on the Percent Risk of Flooding maps and with better access to non-flooded roadways.
- Temporarily relocate all vehicles, trailers, and equipment from the Police Headquarters parking lot to a pre-designated alternative parking location in an area of Town not subject to flooding based on the Percent Risk of Flooding maps. Ensure this area is accessible via non-flooded roadways.

In addition, over the long-term (by 2070), the following recommendations can be implemented to protect the Police Headquarters building and exterior building systems equipment:

- Install low (1-2 ft. high) demountable flood panels across all exterior doorways, including garage bay doors. Demountable panels remain in storage during normal operations and are installed temporarily in advance of a forecasted flood. Once installed they prevent water from entering the opening.
- Install portable or permanent sump pumps in the garage (this is where interior water will flow, given its lower elevation) to remove water that seeps/leaks into the building.
- Seal incoming telecommunications and electrical conduits to prevent leakage.
- Install a shut-off valve or other device in the building's sewer line to prevent backflow of flood water into the building.
- Enclose exterior equipment (e.g., HVAC, electrical transformers, generator) in temporary flood barriers or raise them upon normal retirement/replacement.

Order-of-Magnitude Costs

- The cost of floodproofing the Police Headquarters, including temporary flood barriers, conduit sealing, a sewer shut-off valve, and a portable pump is estimated to be approximately $74,000.
- Exterior equipment could be either enclosed in a temporary barrier at an estimated cost of $29,000 or raised at an estimated cost of $125,000.
- There are no capital costs assigned for the recommended operational measures.

Humphrey Street Pump Station

Humphrey Street Pump Station is critical for the functioning of the Town’s wastewater system. Fortunately, the main pump station building’s first floor is estimated to be at 13.2 ft. NAVD88 elevation (Figure 3.14). That is 0.5 ft. above the 1% (1-in-100) probability flood elevation in 2070. Even in the least probable scenario in 2070 (0.1% or 1-in-1,000), the maximum depth of flooding above the first floor is estimated to be 0.8 ft. While precise survey data was not collected as part of this project, but it appears that most ancillary buildings and sensitive components of exterior equipment associated with the pump station are at a similar elevation as the main building. The main exception is the emergency generator which could experience approximately 0.7 ft. of flooding in the 2070 1% probability scenario (Figure 3.14). When the generator is next upgraded or replaced, it should be elevated by about 1.0 ft. Otherwise, it can be enclosed in a temporary flood barrier.

FIGURE 3.14
HUMPHREY STREET PUMP STATION RISKS

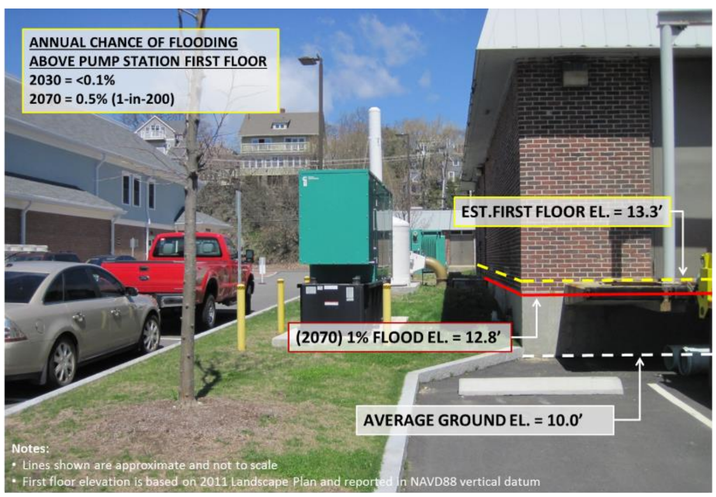
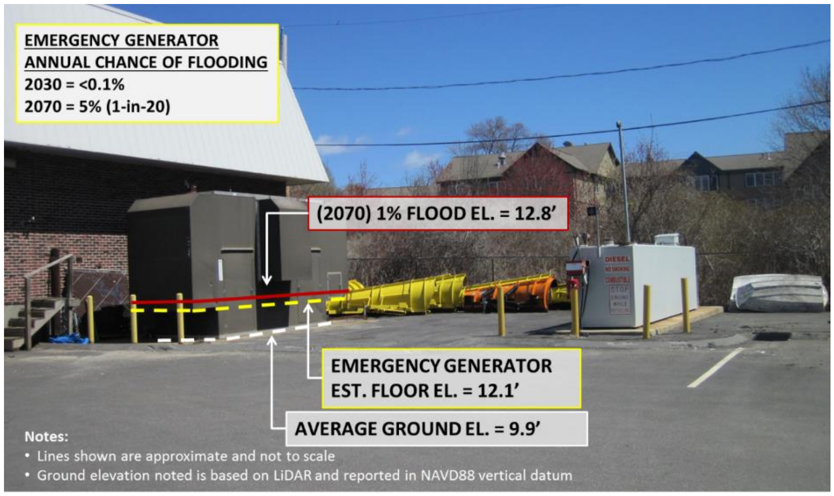


FIGURE 3.15
PUMP STATION EMERGENCY GENERATOR FLOOD RISKS



Similar to the Police Headquarters, the area surrounding the Humphrey Street Pump Station is exposed to flooding in the 2030 and 2070 timeframes. This includes Humphrey Street and the parking lot and loading dock area in the rear of the Pump Station (Figure 3.15). Flooding could prevent worker access to the site and deliveries of essential materials and equipment, thereby impacting operations. As illustrated in the image below, the loading dock and parking lot area in the rear of the main pump station building are low-lying and susceptible to flooding.

It is recommended that in the near-to-medium term (present to 2030) the Town implement the following operational measures in advance of a forecasted coastal flood:

- Temporarily relocate all vehicles, trailers, and equipment from the loading dock and parking lot area to a pre-designated alternative parking location in an area of Town not subject to flooding based on the Percent Risk of Flooding maps. Ensure this area is accessible via non-flooded roadways.

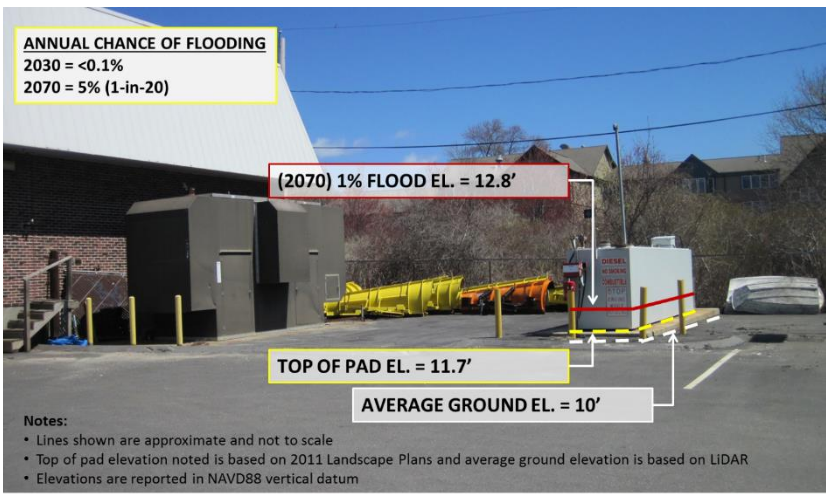
<u>Order-of-Magnitude Costs</u>

- The estimated cost of raising the emergency generator is approximately $150,000. The cost would be lower if incorporated in the design and construction of a new emergency generator upon the retirement of the existing one.
- A temporary barrier around the perimeter of the emergency generator is estimated to cost approximately $210,000.
- There are no capital costs assigned for the recommended operational measures.

Diesel Fueling Station

The Diesel Fueling Station near the Humphrey Street Pump Station loading docks is located in a low-lying area that could be exposed to significant flooding. In a major flood, it is possible that diesel would be released into the flood waters if the fuel station was inundated and/or impacted by waterborne debris. Furthermore, although these is additional fuel storage at the Department of Public Works yard, damage to this fueling station will still impact the Town's ability to re-fuel emergency generators and emergency response vehicles after the storm, particularly if there is a regional fuel shortage. In times of major natural disasters, fuel shortages and power outages are common, so Town-owned fuel resources should be treated as important assets.

FIGURE 3.16
DIESEL FUELING STATION FLOOD RISKS



In the near to medium term (by 2030), the Town should establish operational measures and purchase equipment to maintain the emergency function of the diesel fueling station after a storm:

- Before a flood, top off the fuel tank. This does not mitigate the risk of a fuel release into floodwaters, but it does reduce the buoyancy of the tank and can ensure some fuel supplies are available after the flood.
- To mitigate the risks of debris damaging the fueling station, clear the area of vehicles, fallen branches, scrap materials, and any other potential projectiles.
- Also inspect the fuel tank for leaks, and if any are found take action to seal them. Finally, pre-position a hazardous materials spill kit at either the Pump Station or Police Headquarters and assign someone with the appropriate training to use it to monitors the site and respond after a flood.

- During a flood, the fueling station should be powered down to limit the damage to equipment from water exposure and protect against electrocution risks.
- Purchase an emergency fuel pump to be used after a flood, if needed. These relatively inexpensive portable devices can be connected to the fuel tank of a fueling station with damaged pumps to access the fuel stored inside. If you cannot get the fuel out of the tank, it has the same effect as if you did not have any fuel to begin with. An emergency fuel pump solves that problem.

A more permanent, physical adaptation measure would be to raise the entire fueling station so that any equipment that is susceptible to damage from exposure to water is elevated above the future (2030 or 2070) 1% flood elevation or higher. Raising existing equipment can be costly. However, if the fueling station is to be replaced in the future, and regional solutions for Phillips Park area discussed in this document have not been implemented, the new station should be elevated to accommodate future flood levels.

Order-of-Magnitude Costs

- The estimated cost of purchasing an emergency fuel pump is approximately $35,000.
- A temporary barrier around the perimeter of the fueling station is estimated to cost approximately $54,000.
- The estimated cost of raising the fueling station is approximately $125,000.
- There are no capital costs assigned for the recommended operational measures.

3.2.2 PALMER POND/PHILLIPS’ BEACH AREA

Critical Assets at Risk

- Numerous residences, minor roadways, and non-municipal critical infrastructure (e.g., synagogue) are at risk, representing a reasonably-high cumulative flood risk.
- However, the risk levels of individual municipal assets are not high.

Coastal Flood Pathways and Other Sources of Flooding

(1) Overtopping and possible breaches are likely to occur in the protective dune system separating Palmer Pond and surrounding uplands from coastal waters, creating dynamic flood pathways. Based on satellite imagery, it is assumed that that overtopping and breaches already occur.

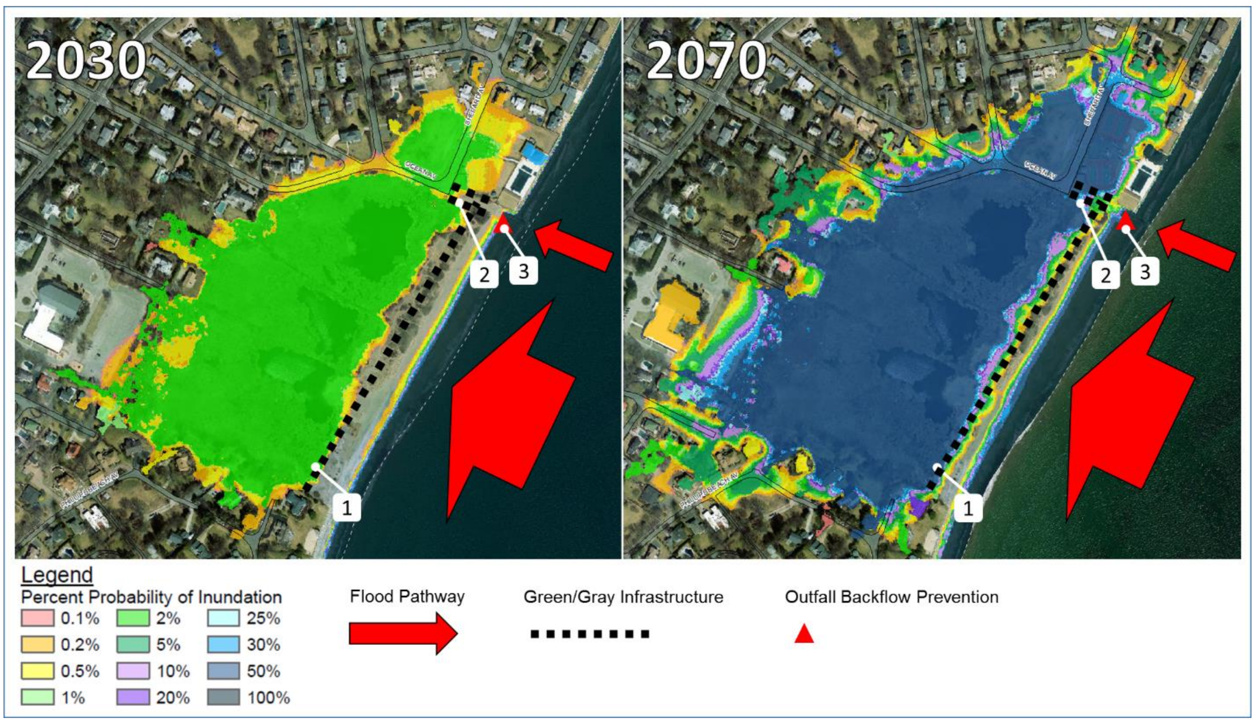
(2) The beach access way at Ocean Avenue and the Beach Club is a flood pathway to Ocean Avenue, Shepard Avenue, and the broader Palmer Pond area.

(3) Similar to the outfall at Preston Beach, the existing stormwater outfall at the beach will likely be a source of backflow under future high tides/storm surge conditions, with or without rain. NOTE: Modeling of the piped drainage system under climate change scenarios to be conducted under the Town-wide Drainage Study has not been completed.

(4) The two stormwater outfalls that drain to Palmer Pond could overwhelm the Pond's storage capacity in an extreme rainfall event, leading to further backup flooding through the system.

3.2.2.1 REGIONAL ADAPTATION STRATEGIES FOR 2030 AND 2070

FIGURE 3.17
PALMER POND/PHILLIPS' BEACH RISKS AND ADAPTATION STRATEGIES

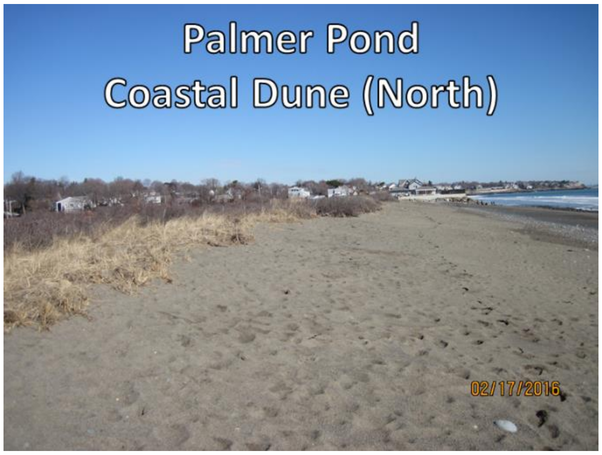


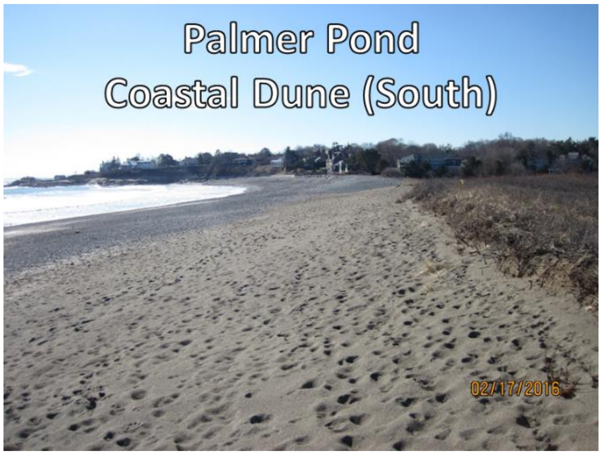
The numbers shown in Figure 3.17 correspond to the numbered recommendations below.

(1) The Town should implement dune restoration and enhancements, including plantings, combined with beach nourishment to bring the dune and beach systems to their full potential as a natural flood protection feature (green infrastructure). The existing dune system provides

a protective function by dissipating wave energy during storms and physically blocking the entry of coastal flood water into the pond and its surrounding uplands. However, the dune itself is vulnerable to overtopping and breaching, limiting its protective function. In addition, certain areas of the dune system are more vulnerable to erosion due to lack of vegetation possibly from uncontrolled pedestrian traffic. The Town may consider installing additional signage and pedestrian facilities (e.g., environmental access mats or raised boardwalks) to prevent damage to existing or restored dune areas. The designer should investigate the dune system and beach from a coastal processes/sediment transport perspective to properly engineer a protective solution with a reasonable protection level, lifespan, and maintenance cost. All proposed designs must comply with the Town's approved Beach Management Plan.

FIGURE 3.18
PHILLIPS' BEACH AND DUNES AT PALMERS POND





(2) The beach access way should be raised to a higher elevation using compatible sediment and graded into a berm of sufficient height to reduce the risk of overtopping. The Town should purchase an environmental access mat to be temporarily installed over the berm when vehicles need to access the beach. Environmental access mats displace the weight of the vehicles and reduce the impact of traffic on the berm's integrity. The Town should also consider redesigning, elevating, and extending the wooden pedestrian walkway once above improvements are made to reduce negative impacts of pedestrian traffic on the berm.

FIGURE 3.19
PHILLIPS' BEACH ACCESS WAY

(3) The existing stormwater outfall at Ocean Avenue and the beach is undergoing consideration for redesign as part of the Town's ongoing town-wide drainage system study. That study should assess the risk of backflow in the context of future climate change impacts, and the redesign of the outfall should address the risks identified, if any.

Order-of-Magnitude Costs

- 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.
- It is not possible to generate an accurate construction cost estimate for a major dune restoration and beach nourishment project without a coastal processes study, and sufficient survey, bathymetric data, subsurface exploration, and engineering design.

3.2.3 PRESTON BEACH AREA

Critical Assets at Risk

- Atlantic Avenue is a critical regional transportation asset with a high risk ranking.

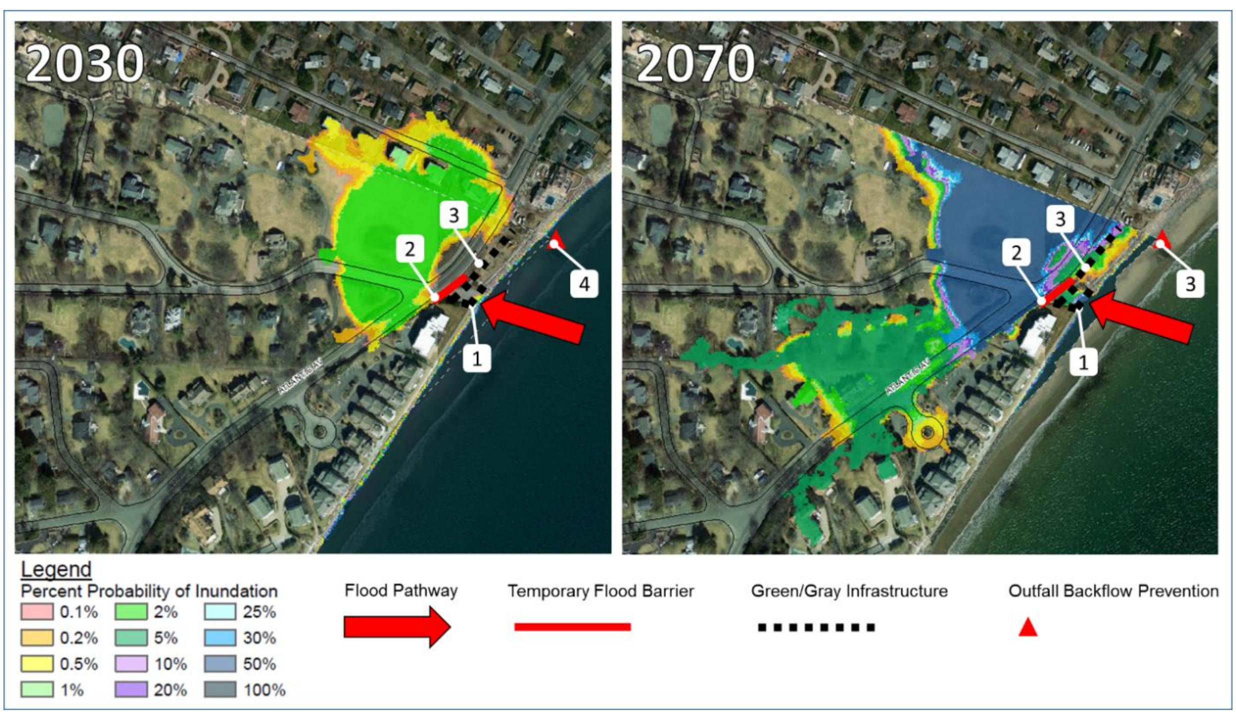
Coastal Flood Pathways and Other Sources of Flooding

- The beach access way at Beach Bluff Avenue is the primary flood pathway to Atlantic Avenue and the surrounding area (up to 2% probability of flooding by 2030 and 50% by 2070).
- Wave overtopping at the Marblehead town line has also caused flooding on Atlantic Avenue during past nor'easters.
- The existing stormwater outfall in this area is likely a source of backflow under future high tides/storm surge conditions, with or without rain. NOTE: Modeling of the piped drainage system under climate change scenarios to be conducted under the Town-wide Drainage Study has not yet been completed. However, this statement is made based on applied knowledge of tidewater elevations and the elevation of Atlantic Avenue.

3.2.3.1 REGIONAL ADAPTATION STRATEGIES FOR 2030 AND 2070

The regional strategies for this area are the same for 2030 as they are for 2070, although by 2070 the conditions to which they will be exposed will become more extreme. Re-evaluation of their performance and any needed improvements should be made during their useful lifetimes, as conditions evolve.

FIGURE 3.20
PRESTON BEACH RISKS AND ADAPTATION STRATEGIES

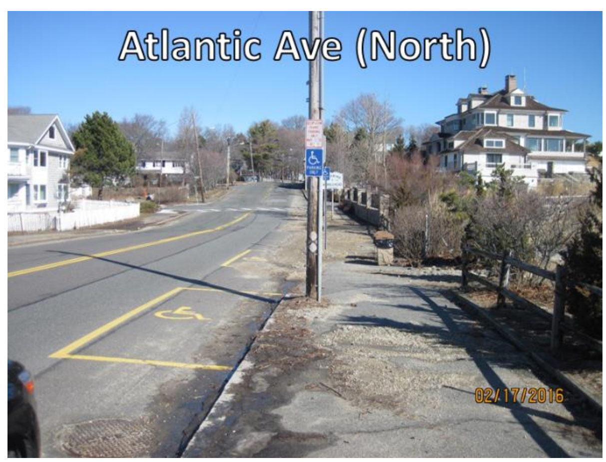


The numbers shown in Figure 3.20 correspond to the numbered recommendations below.

(1) The beach access way at Beach Bluff Avenue is rarely used for vehicle access, except when seawall repairs are needed along Preston Beach and across the Marblehead Town Line. Surplus cobble from a nearby project on Preston Beach has been placed in the access way, in between the revetment and seawall of adjacent properties, but is not graded. The Town should elevate and regrade the access way and use compatible sediment to build a robust berm at the end of the access way between the adjacent coastal barriers. Raising the elevation of the access way in this manner will help reduce the flooding impacts on Atlantic Avenue. An environmental access mat (e.g., Mobi-mat) should be purchased and placed over the berm for pedestrian access and/or in advance of vehicles using the access way. This will reduce the impact of foot traffic, vehicles, and construction equipment on the berm's integrity.

(2) The Town should install a temporary flood barrier across the beach access way at Beach Bluff Avenue. This would provide Atlantic Avenue with significant protection from future stillwater flooding. The barrier type must be robust enough to withstand wave action and debris. The designer should investigate options for connecting the temporary system to the existing retaining wall south of the access way and set a common top elevation to maximize the system's protective value.

FIGURE 3.21
PRESTON BEACH ACCESS WAY AT ATLANTIC AVE



(3) The land between the access way and the Marblehead town line is not owned by the Town. It has been re-developed as a park space with natural protective features. As a second layer of protection, the Town or the owners should install a decorative retaining wall, serving as a permanent flood barrier, at the property line in the roadway right-of-way (i.e., along the

sidewalk). The top elevation should meet the elevation of the adjacent property's wall so that temporary barrier (1) can provide a consistent level of protection. Temporary barriers should be installed at access points from the sidewalk into the park.

(4) The Town should consider installing a tide-flex/duckbill-type valve at the discharge end of each of the outfall's two pipes to prevent ocean water from flowing into the piped drainage system. This technology is not applicable for outfalls with significant exposure to sand deposition, so further exploration of site conditions would be required. NOTE: Modeling of the piped drainage system under climate change scenarios to be conducted under the Town-wide Drainage Study has not been completed.

Order-of-Magnitude Costs

- Implementing the regional strategies for Preston Beach described above is estimated to cost at around $225,000. This cost includes the temporary barrier for the beach access way, back-of-curb retaining wall with temporary closures, and outfall backflow prevention. Costs for elevating the access way and building the berm have not been estimated, as important design information (e.g., wave conditions) is not available from this study.

3.2.4 KING'S BEACH AREA

The low-lying triangular area north of King's Beach (between the Lynn line on the west, Humphrey Street at Phillips Street on the east, and extending towards Superior Street to the north) was identified to have a 10% flood risk in the 2070 time frame, but no risk in the 2030 time frame. However, this area already floods today due to seawall overtopping and backup of the Stacey's Brook stormwater culvert. This discrepancy underscores that the overland flood modeling conducted for this study did not include either of these modes of flooding. Since flooding exists today and is projected to worsen by the 2070 time frame, this area is an important risk area for evaluation.

Critical Assets at Risk

- Numerous residences, minor and major roadways, and critical assets in this area are at risk of coastal flooding, representing a relatively high cumulative risk by 2070.
- Humphrey Street, Lynn Shore Drive, and New Ocean Street are critical regional transportation assets.
- Two municipally-owned critical assets in this area are the Calgon Station and Chlorination Station. The continued functioning Chlorination Station was recently made unnecessary

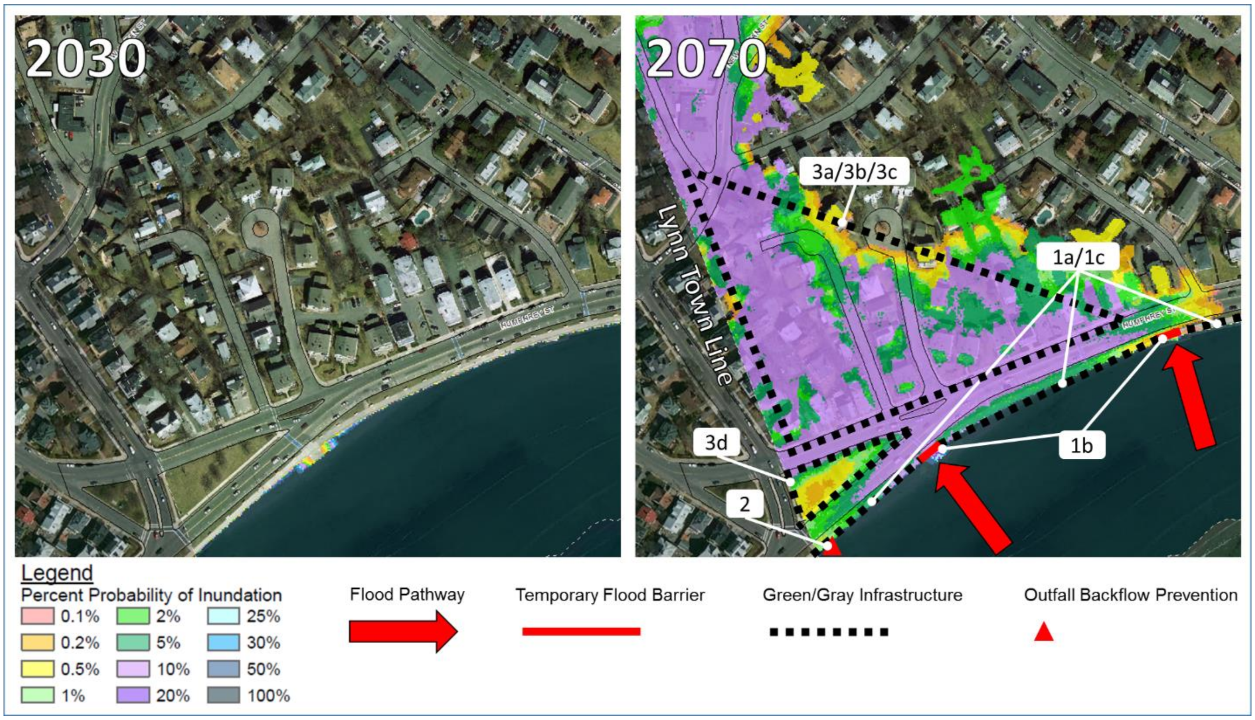
by a regulatory agreement with the Massachusetts Department of Environmental Protection. The Calgon Station is very rarely used and will be studied as part of a future planning for the Town's water supply and distribution system. In addition, there is no evidence of historical flooding at either of these facilities. Based on current available information, installing flood protection measures is not recommended at either of these stations.

Coastal Flood Pathways and Other Sources of Flooding

(1) Coastal flood water elevations (without wave run-up and overtopping) could exceed the elevation of seawalls along King's Beach by 2070, beginning at low points (e.g., King's Beach vehicle access ramp).
(2) Storm surge is known to back up through the Stacey's Brook Outfall at King's Beach and surcharge into the community causing flooding. This has occurred in past coastal storm surge events, causing flooding at the intersection of Eastern Avenue and Humphrey Street.
(3) Extreme precipitation, when paired with a coastal storm surge event or extreme high tide, will likely overwhelm the hydraulic and storage capacity of the existing drainage system. NOTE: Modeling of the piped drainage system under climate change scenarios to be conducted under the Town-wide Drainage Study has not been completed.

3.2.4.1 REGIONAL ADAPTATION STRATEGIES FOR 2030 AND 2070

FIGURE 3.22
KING'S BEACH RISKS AND ADAPTATION STRATEGIES



The numbers shown in Figure 3.22 correspond to the numbered recommendations below.

(1) The Town should plan to raise the elevation of the seawall and/or land on the ocean-side of Humphrey Street and Lynn Shore Drive between Phillips Street and the Lynn line. Currently, multiple layers of protection on the Lynn side of King's Beach end at the Swampscott line (Figure 3.23), including a grassy berm and a seawall that is elevated approximately 2 ft. above grade (see photos below). It is notable that the Department of Conservation and Recreation (DCR) owns the seawall within Lynn, but ownership of the wall transitions to the Town of Swampscott at the town line. In evaluating the recommendations below, the Town should coordinate with DCR. These strategies must be implemented in concert with measures under (2) and (3) below to address other flood sources that could render the seawall alone ineffective at protecting the area from flooding.

FIGURE 3.23
KING'S BEACH WATERFRONT FROM LYNN TO SWAMPSCOTT

a) The King's Beach Seawall should be raised (at minimum) to match the Lynn seawall height, if not higher to account for waves (run-up and overtopping analysis should be conducted during preliminary design). The seawall is the area's first line of defense from coastal flooding and wave action. Raising the seawall and filing a Letter of Map Revision request with FEMA could result, not only in better public safety and protection for the area, but also in reduced or eliminated flood insurance requirements and expenses. Swampscott's seawall could likely be extended using a simple anchored concrete cap system as was done on the Lynn seawall. There are various design alternatives that would provide more flexibility to incrementally raise the seawall height over time, such as:

- Designing the seawall footing with extra capacity to accommodate a higher seawall (and higher water levels) in the future without full reconstruction

- Installing higher permanent glass barriers to preserve views.
- Installing temporary flood barriers that can be erected prior to a storm and taken down afterwards.

b) Temporary flood barriers should be installed across the vehicle and pedestrian access ramps leading to King's Beach as part of the seawall design and construction. These access ways would remain open under normal conditions and be closed with temporary barriers in advance of forecasted extreme coastal storms.

c) The Town should also consider raising the grassy area between the road and the walkway and creating a landscaped berm, or building a low retaining wall around it, with temporary barrier closures at pedestrian paths, to act as a second layer of protection (Figure 3.24).

FIGURE 3.24
HUMPHREY STREET RIGHT-OF-WAY TO SEAWALL

d) Breakwaters should be constructed in the harbor to reduce the impacts of wave run-up and overtopping both at King's Beach and Fisherman's Beach.

(2) The Town should install a flood gate or other tide control structure at the Stacey's Brook Outfall to prevent storm surge from backing up into the area's drainage system and surcharging through catch basins to flood areas behind the sea wall (Figure 3.25 – Stacey's Brook outfall is on the right, and Lynn's outfall is on the left). The structure could be designed to function automatically or manually. Operational procedures governing the use of the control structure would need to be developed.

FIGURE 3.25
STACEY'S BROOK OUTFALL AT KING'S BEACH

(3) The following strategies can be used independently or in combination to mitigate the risk of stormwater backup due to high tailwater conditions from the ocean or closure of the proposed flood gate:

a) Install a temporary emergency bypass pumping system to pump stormwater out from the drainage system into the ocean. The Town would need to investigate volumetric flow rates to estimate pumping equipment needs and determine feasibility. Equipment rental and ownership options should be considered.

b) Install metal collars or enclosures around surface openings in the drainage system, such that the head inside the collar would be matched to the ocean level and surcharge would be contained within the enclosure. The designer should evaluate the appropriate height and top elevation of such collars and identify any openings (e.g., roadway drainage inlets) for which custom collars might be needed or for which this strategy is not otherwise feasible.

c) Modify existing green space so that it can temporarily be enclosed to contain and store flood/stormwater. For example the grassy area at the Lynn Shore Drive/Humphrey Street/Eastern Avenue intersection could be modified by constructing a low perimeter wall with temporary barrier closures at access points. Intentional outlets from the drainage system to this area could be installed to direct the flow of surcharge into the enclosed space. As with (b), the designer should evaluate the appropriate wall height and top elevation.

FIGURE 3.26
OPEN SPACE AT EASTERN AVE

d) Implement policies to mitigate peak stormwater flow in the Stacy Brook catchment area (capture, store, and slow discharge). This could be accomplished through green and gray infrastructure.

Order-of-Magnitude Costs

- The costs of implementing the regional strategies to prevent overland coastal flooding in the King's Beach area vary considerably among options:
    - To raise the King's Beach seawall, either in its current concrete form or with a combination of concrete and glass, and provide temporary closures at beach access ways, the cost is estimated to cost between $22,000,000 and $25,000,000.
    - Raising the grassy right-of-way area to a berm or raised planters, with temporary barriers at crosswalks from Humphrey Street to the boardwalk, is estimated to cost between $90,000 (berm) and $4,500,000 (planters).
    - A full-length temporary barrier is estimated to cost approximately $1,560,000. This cost does not account for the cost of labor to actually install the barrier in advance of a storm and dismantle the barrier after it has passed.
    - Constructing breakwaters in Swampscott Harbor has been estimated by the Town's consultants to cost approximately $7,000,000.
- Strategies to reduce the risk of storm surge and rainfall back-up through the Stacey's Brook drainage system are additive in their costs and level of protection:
    - To install a tide gate on the Stacey's Brook Outfall is estimated to cost $250,000.
    - To build an above ground "green" storage area at Humphrey Street and Eastern Avenue is estimated to cost $110,000.
    - To install a catch basin and manhole enclosures in the area is estimated to cost $160,000.

- Implementation of green streets and low-impact development policies has not been assigned a cost.
- The cost of purchasing or renting an emergency pumping system to help clear stormwater from the Stacey's Brook drainage area has not been estimated.

3.2.4.2 ASSET LEVEL STRATEGIES

Instead of implementing regional strategies that offer protection to the larger King's Beach area from coastal flooding, the Town could selectively implement site level strategies to limit risks only for critical municipal assets.

Humphrey St and New Ocean St

To protect Humphrey St and New Ocean St – two critical roadways – from heightened risks of coastal flooding, the regional strategies discussed above (e.g. raising seawall, installing outfall tide gate) and relevant operational actions (e.g., evacuation planning, temporary roadway closures) are the preferred solutions.

Another coastal flooding adaptation option often considered is to raise vulnerable roads. Raising Humphrey Street, to function like a levee, could protect properties on the landward side of the road from overland coastal flooding. However, it would not mitigate the risk of backflow through the drainage system, and may in fact create new flooding problems on adjacent private properties in extreme rainfall events. Currently these properties are graded to drain to the roadway. Raising New Ocean St would present significant technical, political, and jurisdictional challenges. As a state road, Swampscott does not have direct control over the road's design. The affected roadway section also crosses the Swampscott-Lynn border. In both cases, significant private impacts would occur, including to drainage, driveways, and other site grading. Given the relatively higher benefit of the regional strategies discussed earlier, along with the technical challenges, cost, disruption, and jurisdictional issues, raising these roads is not the recommended alternative.

Order-of-Magnitude Costs

- The base cost of raising the roadways, not taking into account private impacts, is estimated to be approximately $2,000,000.

Calgon Station and Chlorination Station

The Calgon Station (Figure 3.27) and Chlorination Station (Figure 3.28) in this area could be protected at the site level by installing temporary flood barrier systems around their perimeters or implementing more permanent floodproofing measures such as raising equipment or building a low flood wall with openings for temporary closures. Both options would require sealing incoming conduits and installing sump pump systems and possibly installing emergency generators. However, for the reasons described above, these site-level adaptation investments should not be high priorities for the Town.

FIGURE 3.27
CALGON STATION FLOOD RISKS

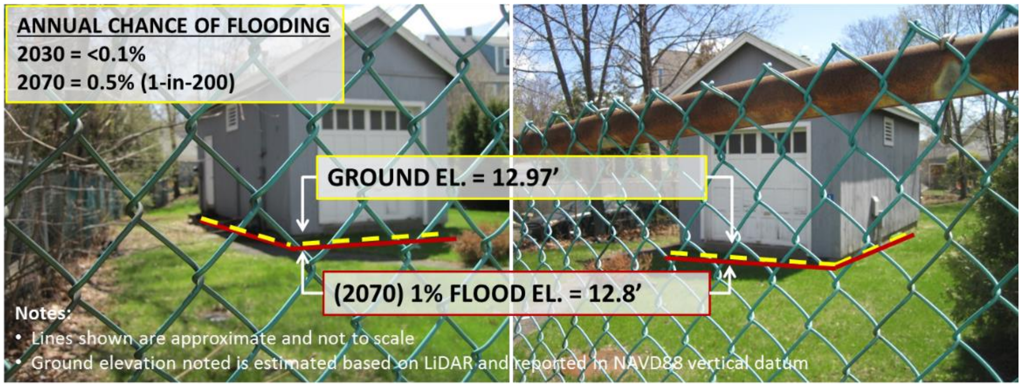
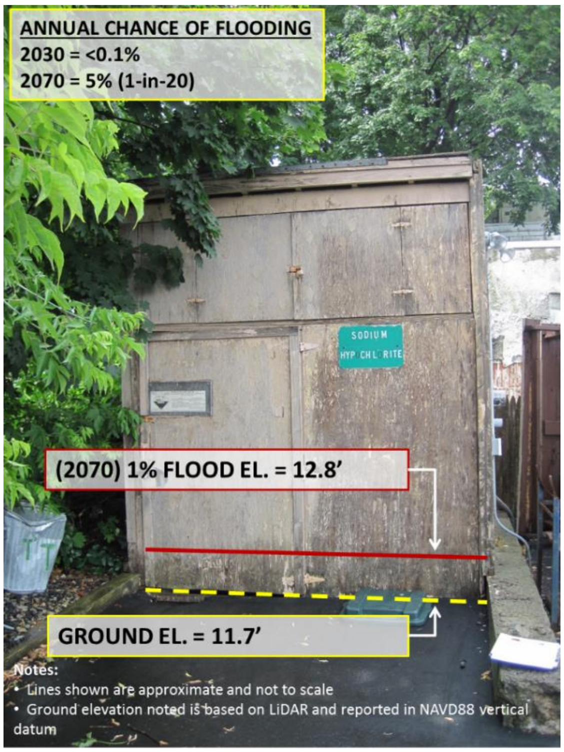


FIGURE 3.28
CHLORINATION STATION FLOOD RISKS



Order-of-Magnitude Costs

- The cost of floodproofing the Calgon Station is estimate to be approximately $26,000 for a low retaining wall with temporary closures to $121,000 for a full perimeter temporary barrier. Both estimates include the cost of a portable pumping system and sealing conduits, but neither includes the cost of an emergency generator.
- For the Chlorination Station, the cost of building a low retaining wall with temporary closures, sealing conduits, and a portable pumping system is estimated to be approximately $16,000.

3.3 INPUTS TO ORDER-OF-MAGNITUDE COST ESTIMATES

All estimates of costs presented herein to implement adaptation recommendations are order-of-magnitude estimates, in 2015 dollars, for use in long-term planning purposes. The costs in no way are meant to represent actual estimates of total project costs as no surveying, subsurface exploration, traffic engineering, engineering design, permitting and escalation of costs was performed as part of this project, all of which are necessary to establish true project costs required to construct a project. For these reasons, the costs presented require additional refinement before it would be appropriate for use for budgeting.

The sources of cost data used varied from actual bid information for some design elements, to high level costs utilizing 'rule of thumb' information. As such, the costs of design elements are not always directly comparable to one another.

Elevating Roadways

For elevating roadways up to 2 ft., an average cost of $875 per foot per lane was assumed (assumes 12 ft. lanes, 5 ft. shoulder, 8 ft. sidewalks on both sides of the road, granite curbing, guardrail on both sides, replacement of 5 underground utilities at $100/ft. each, asphalt pavement, traffic management, engineering at 10% and 25% contingency).

Retaining Walls

Concrete foundation dimensions were estimated based on the approximate widths and depths equal to the barrier height divided by 2. Material cost of concrete was estimated based on a unit price of $550/cubic yard installed Permitting and geotechnical costs were not included. Customary factors for civil site work, engineering, contractor overhead and profit, construction phase services, and contingency were applied.

Temporary Barriers

Material costs on a linear foot basis for four different barrier types were estimated based on research conducted for another project. Barrier costs ranges from $300/linear ft. to $700/linear ft.

For barrier systems requiring concrete foundations, foundation dimensions were estimated based on the approximate widths and depths equal to the barrier height divided by 2. Permitting and geotechnical costs have not been included. Customary factors for civil site work, engineering, contractor overhead and profit, construction phase services, and contingency were applied.

Labor costs and cost for mobilization, demobilization, and remobilization were not included for temporary barrier installation.

Catch Basin and Manhole Enclosures

A material unit price of $3,000/enclosure was estimated based on a 2015 bid for a similar product. Customary factors for civil site work, engineering, contractor overhead and profit, construction phase services, and contingency were applied.

Portable Pumps

Portable pumps are proposed to collect leakage and accumulated rainfall from within the protected areas of permanent and temporary flood barrier systems and discharge them into flood waters on the “wet” side of the barrier system. An estimate of $1,000/pump, included hoses, was obtained from a similar floodproofing project and a 35% contingency was applied. The pump referenced is gasoline powered 2 in. pump with a capacity of 164 gal/min.

Outfall Backflow Prevention

For typical outfalls, ranging from 12 in. to 30 in. diameter, order-of-magnitude cost estimates from several public sources were obtained and averaged at $35,000/outfall. Types varied from flap gate to duckbill check valves.

For Stacey’s Brook outfall at King’s Beach, the project cost was estimated based on the total cost of a similar tide gate installation project in Massachusetts.

Permanently Elevating Equipment

Order-of-magnitude cost estimates were obtained from a similar floodproofing project and scaled according to the number and size of equipment components to be raised. Original costs included markups for general conditions, contractor overhead and profit, escalation for one year from June 2014, design contingency, insurance & bonds, and owner project costs.

Creating Berms and Filling Land

The cost of filling land or creating a berm was estimated at $100/cubic yd. ($200/cubic yd. for asphalt). Berms were assumed to have a 4:1 slope to allow for mowing. An additional 45% contingency was applied due to unknowns.

Acquisition and Demolition

Order-of-magnitude acquisition costs for properties on the Fisherman's Beach side of Puritan Road were estimated by summing the assessed total values of said properties, as shown on the Town of Swampscott assessor's website. No other costs (e.g., legal services, permits) were included.

Order-of-magnitude home demolition costs were obtained from various online sources reporting average, high, and low costs. The higher end estimate of $30,000/building was selected and multiplied by the number of buildings to estimate the total cost.

Raising Seawalls

The order-of-magnitude cost estimates for raising seawalls in Swampscott are based on the estimates and methods reported in Massachusetts Coastal Infrastructure Inventory and Assessment Report Update (2014), prepared by Bourne Consulting for MA Department of Conservation and Recreation. As part of that study, the original cost of each structure in Swampscott was estimated, and an "upgrade factor" was applied to take into account current wave and beach conditions as well as 2 ft. of sea level rise. The authors noted that these costs "do not account for regulatory construction limitations and public impacts that are likely to have a major influence on what level of improvements can actually be implemented." Those estimates were scaled up to account for a total of 6 ft. sea level rise by the end of the century. To do so, the original cost of the structure was multiplied by the "upgrade factor" one level higher than the one used in the 2014 study.

For the glass seawall alternative, the glass barrier material cost ($220/square ft.) was obtained from a vendor and customary markups for civil site work, engineering, contractor overhead and profit, construction phase services, and contingency, were added. This total was then added to the original order-of-magnitude upgrade cost estimates from the 2014 study. It was assumed the glass wall would be 4 ft. high.

<u>Elevating Existing Buildings</u>

An order-of-magnitude estimate for the cost of elevating the Fish House was based on $55/square ft. of building footprint. According to the source of this estimate, these costs include foundation, existing utilities, and miscellaneous items.

<u>Wet Floodproofing Existing Buildings</u>

An order-of-magnitude estimate for cost of wet floodproofing an existing building was obtained from several sources. These sources indicate that the cost is $1.80 - $17.00 per square ft. of building footprint. An estimate of $5/square foot for the Fish House was used for the purposes of this project.

<u>Breakwaters</u>

The cost of the proposed breakwaters in Swampscott harbor is based on the upper range cost of $7 million, as reported in local media.

<u>Replacing Existing Pier</u>

An order-of-magnitude estimate of the replacement cost of the Swampscott Pier was calculated based on a $500 per linear foot cost, 250% contractor markup, and customary factor for engineering.

<u>Replacing Existing Boat Ramps</u>

Order-of-magnitude boat ramp replacement cost estimates were based on an $800 per cubic yard cost of concrete for new slab, caps, and cut-off walls, and applying customary factors for excavation, sediment control / cofferdams, engineering, and contingency.

4 TM4 ADAPTATION STRATEGIES – REGULATIONS AND POLICIES

The Town of Swampscott's existing policies and planning documents were reviewed and recommended modifications were developed that would advance the Town's goal of adapting to climate change. This memorandum summarizes these recommendations.

4.1 POTENTIAL CHANGES TO ZONING BY-LAWS

Article I (Purpose and Authority)

- Consider adding a subsection "h" as follows:

  (h) Reduce the hazard from coastal flooding caused by sea level rise and storm surge.

Article II (Use, Dimensional and Timing Regulations)

- Article II, Section 2.2.7.5 (Reconstruction of Nonconforming Structures) – Consider modifying the first line in both paragraphs by adding flooding to the list of qualifying events for reconstruction of a nonconforming structure.

- *Article II, Section 2.3.6.5* – This Section permits the maximum height of a structure granted under a Special Permit, to be increase a maximum of 10%. For example, where the underlying dimensional requirement for building height is 35 ft., the maximum relief that can be granted is 10% of 35 ft., or 3.5 ft. This may not be sufficient height relief for a structure in an area vulnerable to coastal flooding to be elevated above the base flood elevation. Consider providing some additional possible dimensional height relief to better encourage structures vulnerable to flooding to be elevated.

Article IV (Special Regulations – Coastal Flood Area Overlay District (CFAOD))

- Article IV, Section 4.2.1.0 (Purpose) – Consider modifying subsection 4.2.1.6 as follows:

  4.2.1.6. Reduce damage to public and private property resulting from flooding waters ***taking into account the effects of sea level rise and storm surge***.

- Article IV, Section 4.2.2.0 (Definitions) – Some proposed recommendations for changes to the Swampscott Zoning By-Law refer to long-term sea level rise. If references to sea level rise will be included in the By-Law, it is important to define what this means so that both applicants and reviewing agencies have a clear understanding of performance requirements. Consider adding a subsection 4.2.2.1 as follows:

4.2.2.1 The effects of long-term sea level rise, as referenced in the CFAOD, shall be determined using the "Highest" curve from the U.S. National Climate Assessment (Global Sea Level Rise Scenarios for the United States National Climate Assessment, NOAA Technical Report OAR CPO-1, December 12, 2012) for a 50 year time horizon, unless the approving authority determines that other, more appropriate methods for determining sea level rise or other time horizons, are more appropriate for the specific project.

- Article IV, Section 4.2.4.2 (Base Flood Elevation Data) – Consider amending this section to eliminate the 50 lot and 5 acre thresholds. If a goal of the Town is to reduce future impacts from sea level rise and storm surge, then all subdivisions within the CFAOD should have base flood elevations established so that proposed subdivision plans can be effectively evaluated considering sea level rise and storm surge.

- Article IV, Section 4.2.5.2.e – Consider modifying section 4.2.5.2.e as follows:

  e. All subdivision proposals shall ***take into consideration the long-term effects of sea level rise, and shall*** be reviewed to assure that …

- Article IV, Section 4.2.6.2. – The Massachusetts State Building Code does not take into account the effects of long-term sea level rise. As has been demonstrated by the climate change vulnerability study, existing storm drainage systems are vulnerable to surcharge from high tides and storm surge, which can cause backing up through catch basins in inland areas. Therefore future storm drain systems should take into account the long-term effects of sea level rise and storm surge. Consider modifying Section 4.2.6.2. as follows:

  4.2.6.2. Storm drainage systems shall be designed in accordance with the Massachusetts State Building Code (780 CMR), ***and shall take into consideration the long-term effects of sea level rise.***

- Article IV, Section 4.2.6.3. – The Massachusetts State Building Code does not take into account the effects of long-term sea level rise. Every effort should be made to encourage, whenever feasible and economically cost effective, that all utilities (telephone, power supply, communications, wastewater treatment, and stormwater and wastewater pumping systems) be elevated above the base flood elevation plus appropriate freeboard taking into account long-term sea level rise. Consider modifying Section 4.2.6.3. as follows:

4.2.6.3. All utility systems, including power, communications and gas shall be designed in accordance with the Massachusetts State Building Code, Section 3107.0, ***and shall take into consideration the long-term effects of sea level rise. Critical elements of all power and communications systems that are sensitive to water exposure shall be constructed in waterproof enclosures or elevated to or above the base flood elevation, and shall take into consideration the long-term effects of sea level rise in determining additional freeboard height above the base flood elevation.***

- Article IV, Section 4.2.7.5. – Consider modifying the first sentence of this section to take into account long-term sea level rise as follows:

4.2.7.5 All new construction and substantial improvements within Zone VE shall be elevated on adequately anchored piles or columns, and securely anchored to such piles or columns so that the lowest portion of all structural members supporting the lowest floor (excluding the piles or columns) is elevated to or above the base flood elevation***, and shall take into consideration the long-term effects of sea level rise in determining additional freeboard height above the base flood elevation.***

Article V (Administration and Procedures)

- Article V, Section 5.4.5.0. (Contents of Plan – Commercial) – Consider adding a new subsection 5.4.5.7. with specific submission requirements for site plan review for commercial developments in the CFAOD as follows:

5.4.5.7. Discussion on the Effects of Long-Term Sea Level Rise – For developments located in the CFAOD, provide a discussion on how the proposed project mitigates the effects of long-term sea level rise. Include calculations showing the projected sea level rise over a 50-year period, what temporary and permanent measures are proposed to control potential flooding, and any adverse effects these measures may have on adjacent properties.

- Article V, Section 5.4.6.0. (Contents of Plan – Residential) – Consider adding a new subsection 5.4.6.1.e. with specific submission requirements for site plan review for residential developments in the CFAOD as follows:

  5.4.5.7. Discussion on the Effects of Long-Term Sea Level Rise – For developments located in the CFAOD, provide a discussion on how the proposed project mitigates the effects of long-term sea level rise. Include calculations showing the projected sea level rise over a 50-year period, what temporary and permanent measures are proposed to control potential flooding, and any adverse effects these measures may have on adjacent properties.

- Article V, Section 5.4.8.0. (Approval) – Consider adding a new subsection 5.4.8.10 as follows:

  5.4.8.10. Minimize the effects of coastal flooding taking into account the effects of long-term sea level rise and storm surge.

- Article V, Section 5.6.2.2. (Surface Water and Subsurface Conditions) – Consider adding a new subsection 5.6.2.2.e. as follows:

  5.6.2.2.e. Describe the effects of long-term sea level rise for developments located in the CFAOD, and provide a discussion on how the proposed project mitigates the effects of long-term sea level rise over a 50-year period, what temporary and permanent measures are proposed to control potential flooding, and any adverse effects these measures may have on adjacent properties.

Article VI (Definitions)

- Consider adding a definition of Long-Term Sea Level Rise as follows:

  Long-Term Sea Level Rise: The future increase in Mean Sea Level above the current Mean Sea Level in the Town of Swampscott (defined as Elevation XXXX NAVD88 datum) as determined using the "Highest" curve from the U.S. National Climate Assessment (Global Sea Level Rise Scenarios for the United States National Climate Assessment, NOAA Technical Report OAR CPO-1, December 12, 2012) for a 50 year time horizon.

Miscellaneous

- Consider adopting a freeboard incentive for residential and commercial building elevation projects. Town of Hull adopted a $500 permit fee reduction for an additional 2 ft. of freeboard.

4.2 POTENTIAL CHANGES TO SUBDIVISION REGULATIONS

Preliminary Plan

- Consider adding the following (i) to the list of plan preliminary requirements on page 4:

  (i) The limits of any flood zones as shown on the Flood Insurance Rate Map (FIRM), issued by the Federal Emergency Management Agency (FEMA) for the administration of the National Flood Insurance Program (NFIP) as further defined in Section 4.2.3.0 of the Swampscott Zoning By-Law. Limits of Moderate Wave Action designated by FEMA shall also be identified.

- Consider adding the following (j) to the list of preliminary plan requirements on page 7:

  (j) The limits of any flood zones as shown on the Flood Insurance Rate Map (FIRM), issued by the Federal Emergency Management Agency (FEMA) for the administration of the National Flood Insurance Program (NFIP) as further defined in Section 4.2.3.0 of the Swampscott Zoning By-Law. Limits of Moderate Wave Action designated by FEMA shall also be identified.

Definitive Plan

- Consider adding the following (z) to the list of definitive plan submission requirements:

  (z) The limits of any flood zones as shown on the Flood Insurance Rate Map (FIRM), issued by the Federal Emergency Management Agency (FEMA) for the administration of the National Flood Insurance Program (NFIP) as further defined in Section 4.2.3.0 of the Swampscott Zoning By-Law. Limits of Moderate Wave Action designated by FEMA shall also be identified.

Section V (Required Improvements for an Approved Subdivision)

- Consider requiring that all above-ground points of connection to underground utilities located in subdivisions included in the Coastal Flooding Area Overlay District, including power distribution, street lighting, and communications systems (including telephone and Cable TV), be constructed in waterproof enclosures or elevated to or above the base flood elevation taking into account the long-term effects of sea level rise in determining additional freeboard above the base flood elevation; and that all critical elements of such utilities, including transformers, switches and other equipment, be elevated to or above the base flood elevation, or otherwise protected, taking account the long-term effects of sea level rise in determining additional freeboard above the base flood elevation.

- Consider requiring that all sewer connections require backflow prevention technology.
- Consider requiring that all critical water and sewer facilities that are sensitive to water exposure located in subdivisions included in the Coastal Flooding Overlay District be elevated above the base flood elevation, or otherwise protected, taking account additional freeboard requirements from the long-term effects of sea level rise.

Miscellaneous

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

4.3 POTENTIAL CHANGES TO SITE PLAN REVIEW AND SPECIAL PERMIT RULES AND REGULATIONS

Section 1.2 (Review Considerations)

- Consider adding a subsection (viii) as follows:

(viii) Potential impacts from coastal flooding taking into account the effects of long-term sea level rise and storm surge.

Section 2.2 (Application Materials)

- Consider adding the following submission requirements for commercial and residential site plans for projects located in the CFAOD:
    - ***The limits of any flood zones as shown on the Flood Insurance Rate Map (FIRM), issued by the Federal Emergency Management Agency (FEMA) for the***

administration of the National Flood Insurance Program (NFIP) as further defined in Section 4.2.3.0 of the Swampscott Zoning By-Law. Limits of Moderate Wave Action designated by FEMA shall also be identified.

- ***Discussion on the Effects of Long-Term Sea Level Rise – Provide a discussion on how the proposed project mitigates the effects of long-term sea level rise. Include calculations showing the projected sea level rise over a 50-year period, what temporary and permanent measures are proposed to control potential flooding, and any adverse effects these measures may have on adjacent properties.***

4.4 LAND/RESOURCE ACQUISITION

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

- Investigate the possibility of implementing a rolling easements program in which the Town can purchase an easement from a property owner today in exchange for a promise to surrender the property to the Town once it is substantially damaged by a flood event. This program would be part of a "retreat" policy to be implemented in areas subject to severe and repeated flooding. Rolling easements are a potential way to provide cash to a property owner today with the understanding that when the property is substantially damaged, it will not be rebuilt and will be turned over to the Town. Based on information provided in the latest Town of Swampscott Hazard Mitigation Plan Update dated August, 2012, there are thirty-seven (37) total "repetitive loss" properties in Swampscott, each having had at least two or more flood claims of $1,000 or more in any given 10-year period since 1978. These properties might be ideal candidates for such a program as they have already experience repeated flood damage in the past. It is likely that these properties will experience more claims in the future unless they have been elevated or otherwise protected from flooding. Four of these properties have experienced five or more claims related to flooding.

4.5 POTENTIAL POLICIES FOR PUBLIC PROJECTS

- Develop policies for public projects that incorporate the anticipated effects of climate long-term sea level rise and promote more sustainable practices throughout the community.
  - Require that all Town-funded projects take into account predicted impacts of long-term sea level rise.
  - Update 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.
  - Develop a regular (perhaps bi-annual) inventory/report of actions taken by the community to improve resilience to climate change and sea level rise.

4.6 COASTAL FLOOD OPERATIONS PLANNING

- 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.

4.7 NATIONAL FLOOD INSURANCE PROGRAM COMMUNITY RATING SYSTEM

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

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

- <u>Series 300 - Public Information Activities:</u> This series credits programs that advise people about flood hazards, flood insurance, and ways to reduce flood damage. The activities also provide data that insurance agents need for accurate flood insurance rating. It includes the possible following activities:
  - 310 Elevation Certificates (Required)
  - 320 Map Information Service
  - 330 Outreach Projects
  - 340 Hazard Disclosure
  - 350 Flood Protection Information
  - 360 Flood Protection Assistance
  - 370 Flood Insurance Promotion
- <u>Series 400 - Mapping and Regulations:</u> This series credits programs that provide increased protection to new development. It includes the possible following activities:
  - 410 Floodplain Mapping

   - 420 Open Space Preservation
   - 430 Higher Regulatory Standards
   - 440 Flood Data Maintenance
   - 450 Stormwater Management
- Series 500 - Flood Damage Reduction Activities: This series credits programs that reduce the flood risk to existing development. It includes the possible following activities:
   - 510 Floodplain Management Planning (required)
   - 520 Acquisition and Relocation
   - 530 Flood Protection
   - 540 Drainage System Maintenance
- Series 600 - Warning and Response: This series credits flood warning, levee safety, and dam safety projects. It includes the possible following activities:
   - 610 Flood Warning and Response
   - 620 Levee Safety
   - 630 Dam Safety

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

Many of the recommendations in this study, if implemented, will qualify toward the above CRS activities.

The Town recently evaluated the costs and benefits of participating in the CRS and determined not to participate. However, this decision should be reevaluated periodically, especially after changes to FEMA Flood Insurance Rate Maps and National Flood Insurance Program regulations are implemented.

4.8 LOCAL SEA LEVEL RISE AND STORM SURGE MONITORING

Consider installing an automated tide gauge in Swampscott Harbor to monitor actual sea level rise and storm surge locally. This information will be very valuable for longer-term planning as a database of tidal data is collected. It can also be used for waterfront project design.

APPENDIX A: COASTAL FLOODING MAPS FOR 2030 AND 2070

lved Elev.

Legend

Percent Probability of Inundation

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

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

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PROJECT NO.	20140177.004
DRAWN:	07/11/2015
DRAWN BY:	KFH
CHECKED BY:	IG
FILE NAME:	Swampscott 2030 Percent Risk.mxd

Percent Probability of Inundation Map
YEAR 2030

FIGURE

Town Wide Drainage Study
Swampscott, Massachusetts

Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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PROJECT NO.	20140177.004
DRAWN:	07/17/2015
DRAWN BY:	KFH
CHECKED BY:	IG
FILE NAME:	Swampscott 2030_100yr_Depth.mxd

Depth of Flooding Map

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE

Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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PROJECT NO.	20140177.004
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DRAWN BY:	KFH
CHECKED BY:	IG
FILE NAME:	Swampscott 2030_500yr_Depth.mxd

Depth of Flooding Map

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE

Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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PROJECT NO.	20140177.004
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FILE NAME:	Swampscott 2070_100yrD_specific.mxd

Depth of Flooding Map
Phillips Park Area

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE

Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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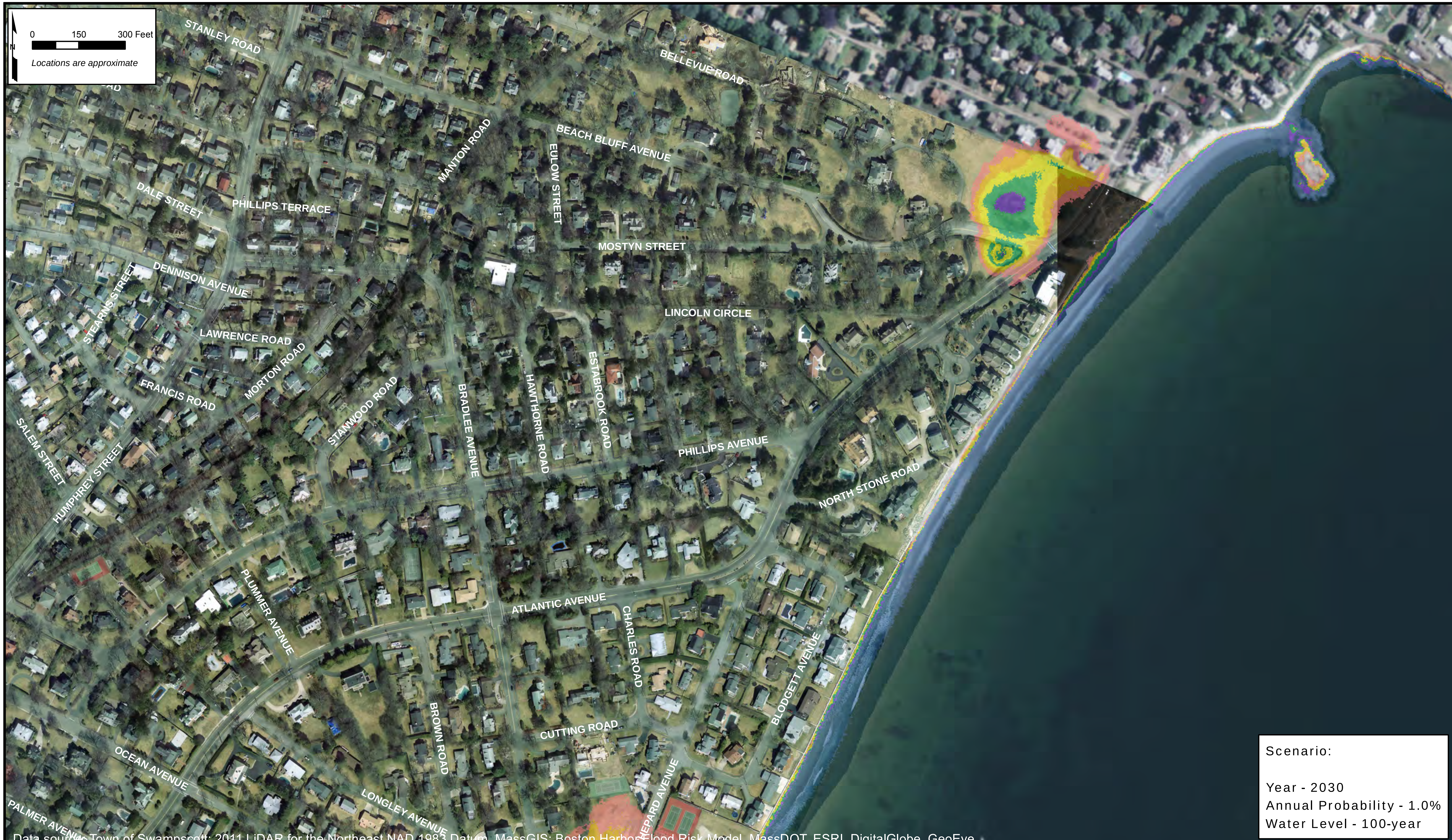
FILE NAME:	Swampscott 2070_100yrD_specific.mxd

Depth of Flooding Map
Palmer Pond/Phillips' Beach

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE



Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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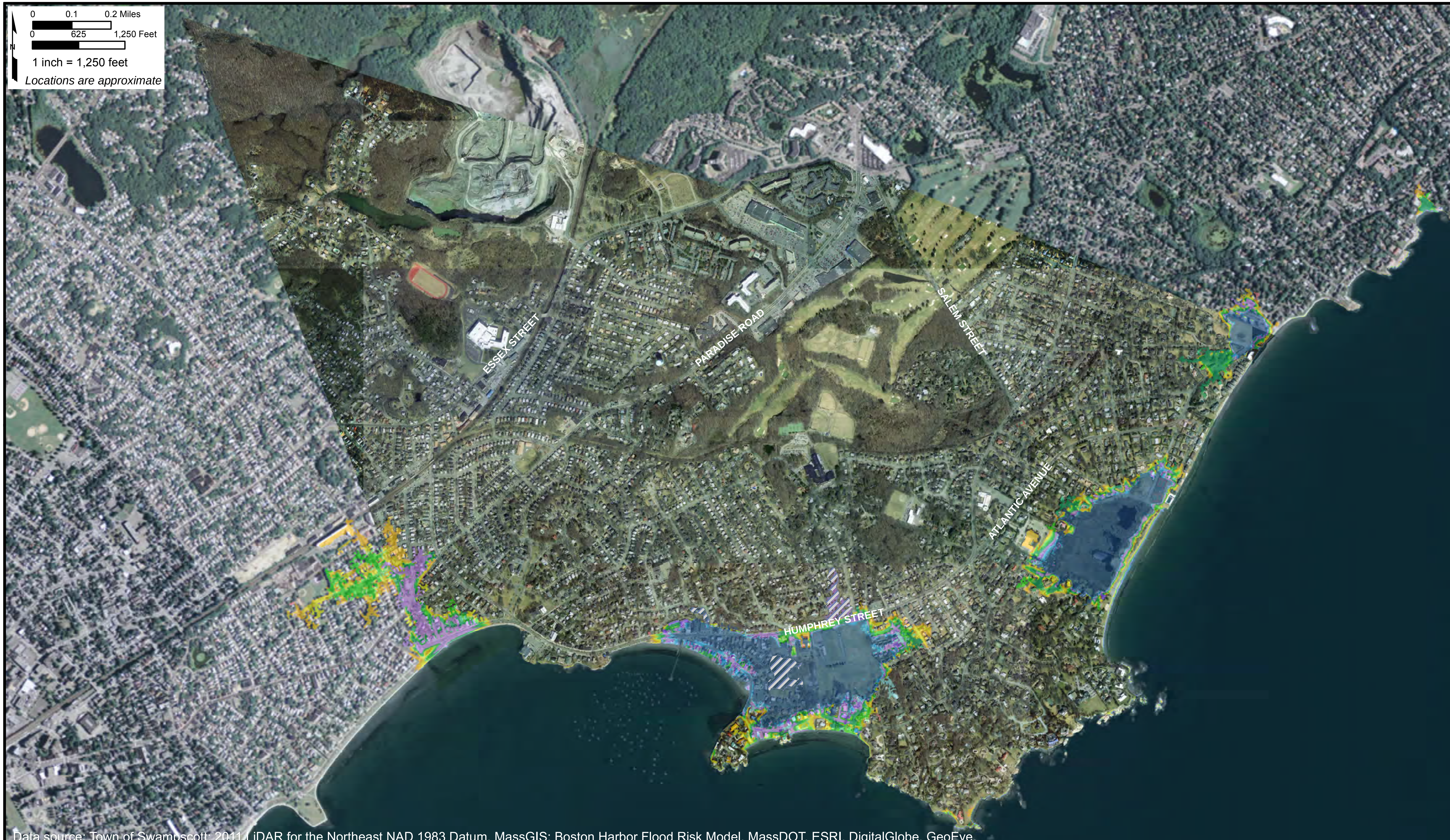
FILE NAME:	Swampscott 2030_100yrD_specific.mxd

Depth of Flooding Map
Preston Beach

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE



Legend

Percent Probability of Inundation

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

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

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PROJECT NO.	20140177.004
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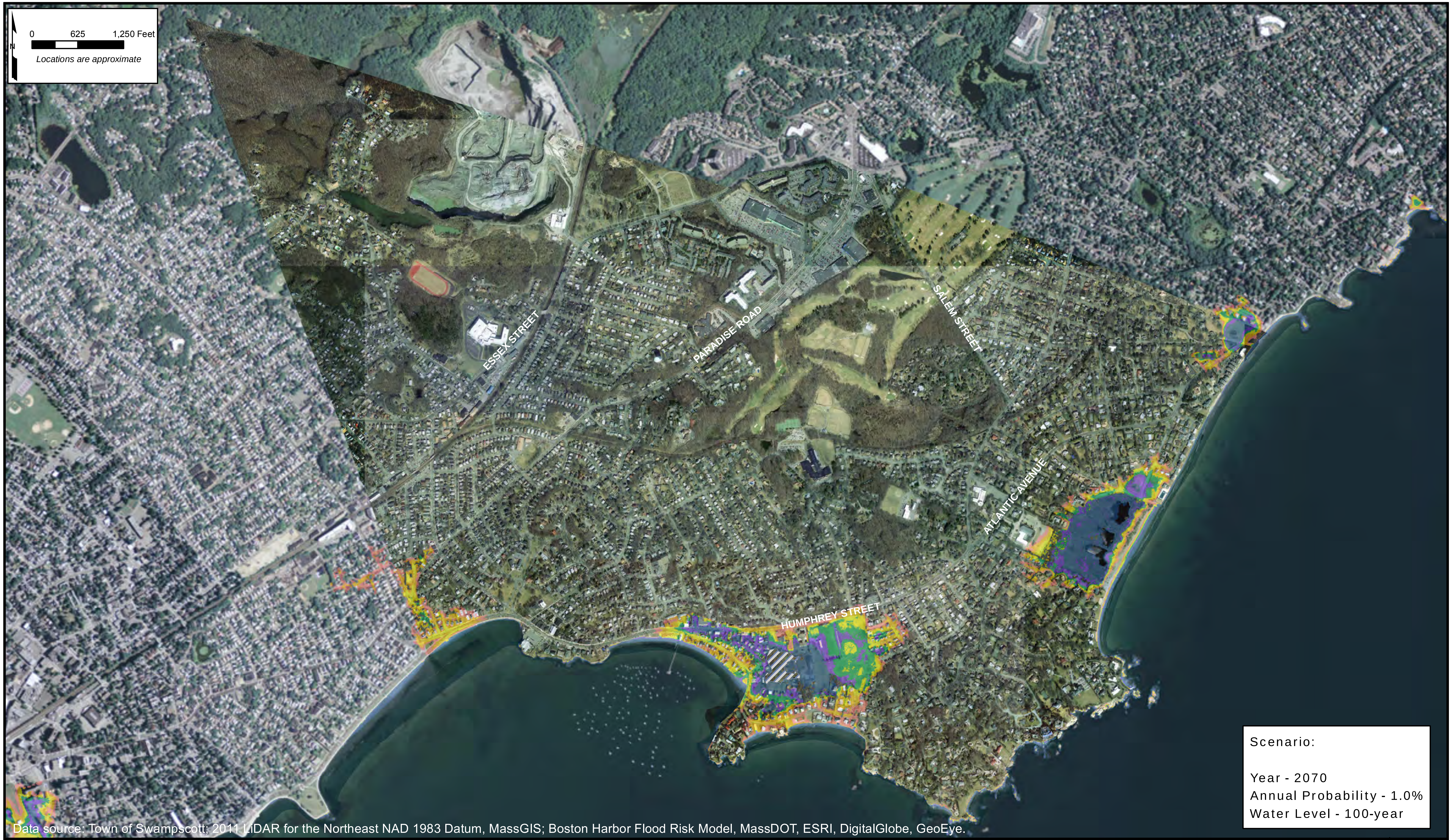
CHECKED BY:	IG
FILE NAME:	Swampscott 2070 Percent Risk.mxd

Percent Probability of Inundation Map YEAR 2070

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE



Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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PROJECT NO.	20140177.004
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FILE NAME:	Swampscott 2070_100yr_Depth.mxd

Depth of Flooding Map

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE

Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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FILE NAME:	Swampscott 2070_500yr_Depth.mxd

Depth of Flooding Map

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE

Scenario:

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

Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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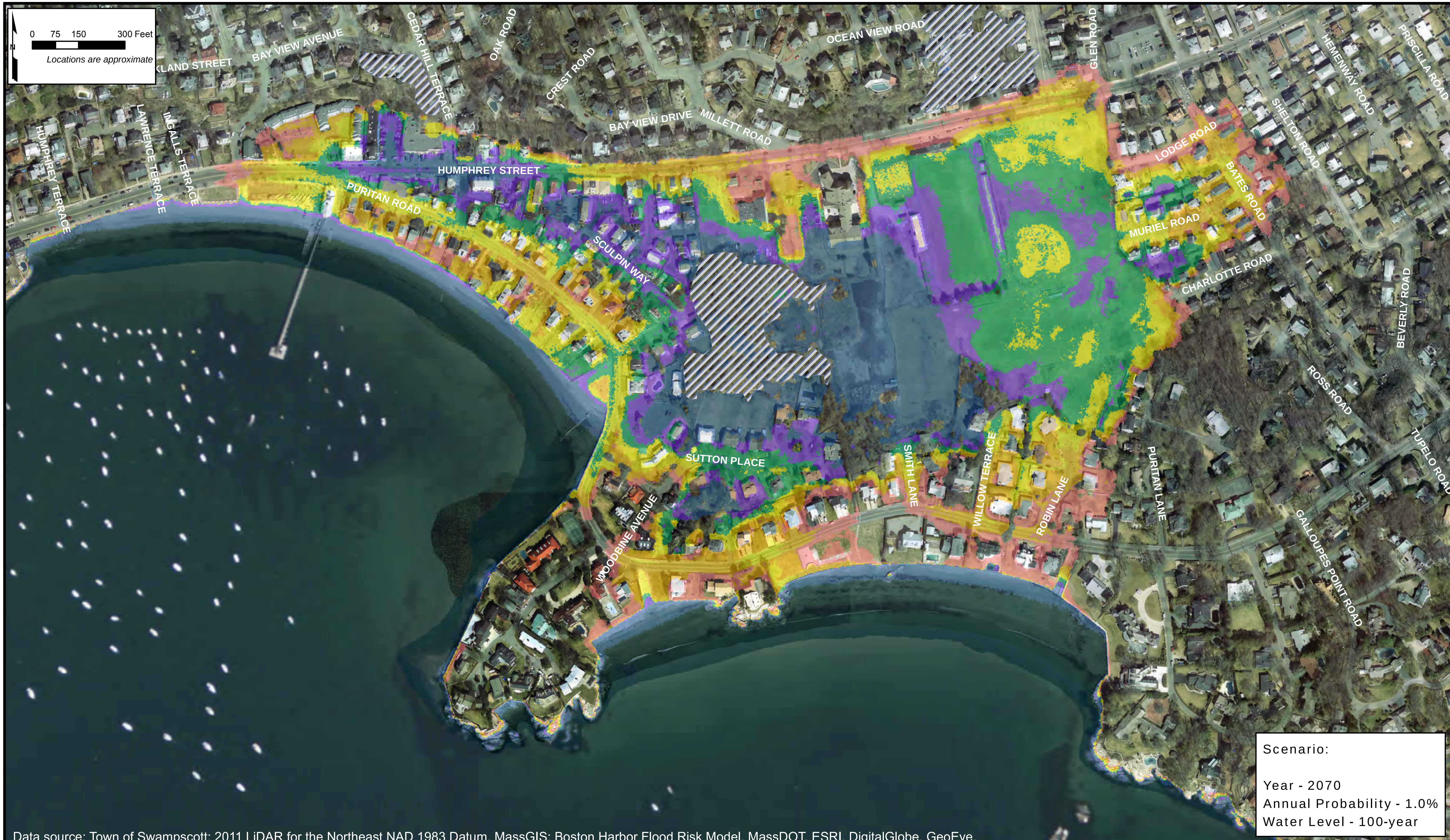
FILE NAME:	Swampscott 2070_100yrD_specific.mxd

Depth of Flooding Map
King's Beach

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE



Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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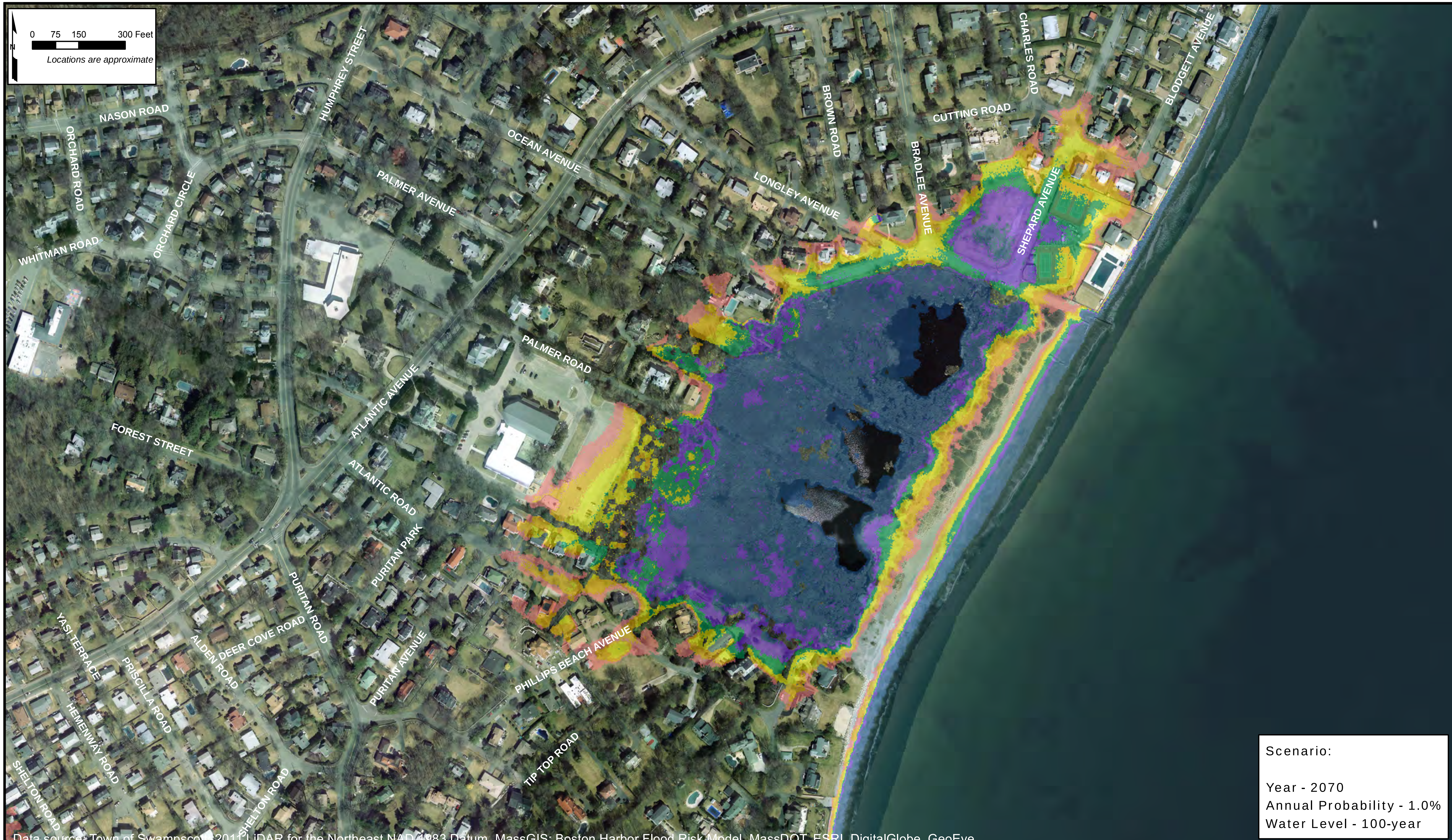
FILE NAME:	Swampscott 2070_100yrD_specific.mxd

Depth of Flooding Map
Phillips Park Area

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE



Scenario:

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

Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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Depth of Flooding Map
Palmer Pond/Phillips' Beach

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE

Legend

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

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- > 10
- Unresolved Elevation Data

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

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Depth of Flooding Map
Preston Beach

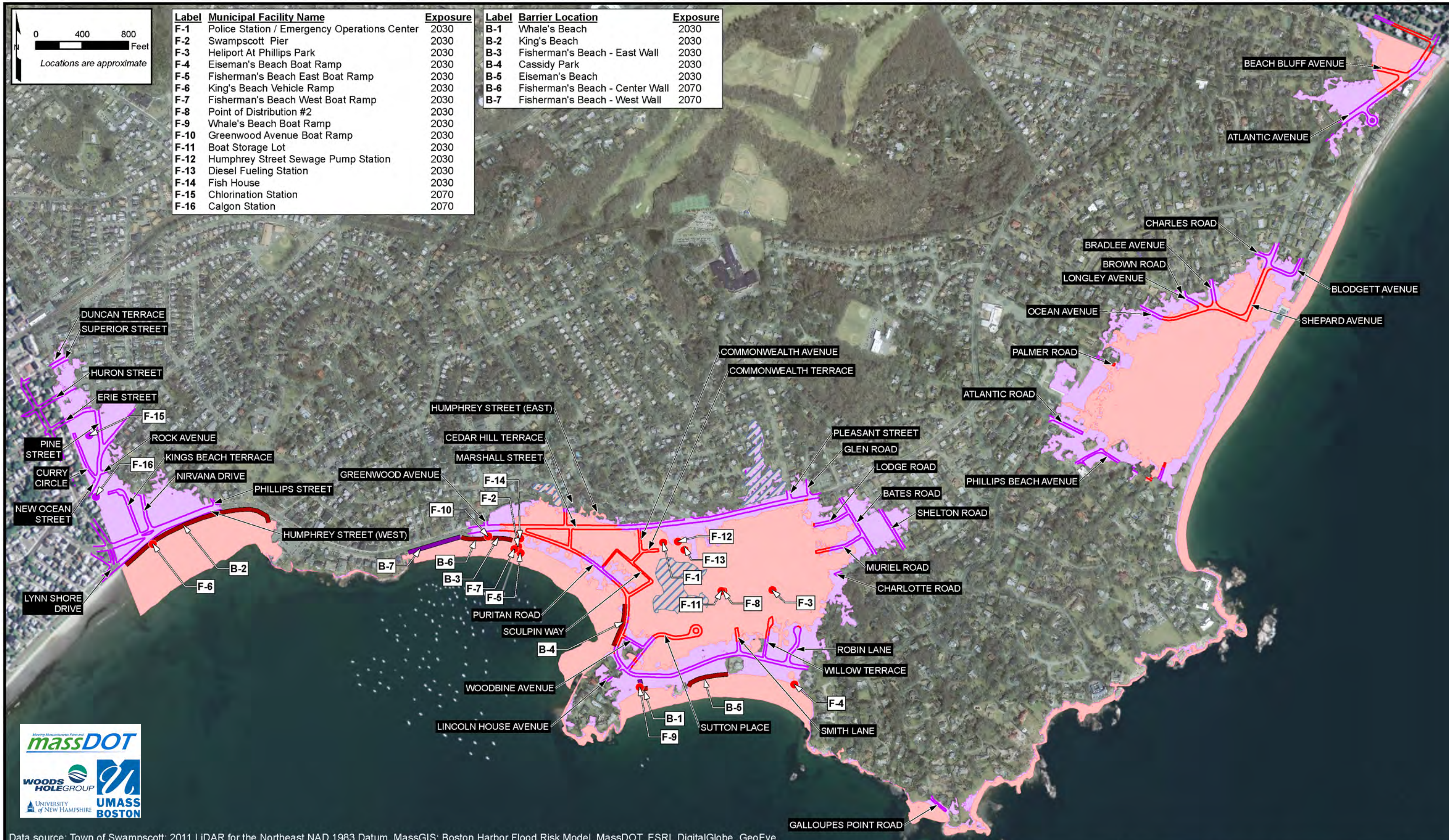
Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE

APPENDIX B: MAP OF VULNERABLE MUNICIPAL INFRASTRUCTURE

Label	Municipal Facility Name	Exposure
F-1	Police Station / Emergency Operations Center	2030
F-2	Swampscott Pier	2030
F-3	Heliport At Phillips Park	2030
F-4	Eiseman's Beach Boat Ramp	2030
F-5	Fisherman's Beach East Boat Ramp	2030
F-6	King's Beach Vehicle Ramp	2030
F-7	Fisherman's Beach West Boat Ramp	2030
F-8	Point of Distribution #2	2030
F-9	Whale's Beach Boat Ramp	2030
F-10	Greenwood Avenue Boat Ramp	2030
F-11	Boat Storage Lot	2030
F-12	Humphrey Street Sewage Pump Station	2030
F-13	Diesel Fueling Station	2030
F-14	Fish House	2030
F-15	Chlorination Station	2070
F-16	Calgon Station	2070

Label	Barrier Location	Exposure
B-1	Whale's Beach	2030
B-2	King's Beach	2030
B-3	Fisherman's Beach - East Wall	2030
B-4	Cassidy Park	2030
B-5	Eiseman's Beach	2030
B-6	Fisherman's Beach - Center Wall	2070
B-7	Fisherman's Beach - West Wall	2070



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

Legend

- Unresolved Elevations
- Exposed Facility, 2030
- Exposed Road, 2030
- Exposed Barrier, 2030
- Exposed Facility, 2070
- Exposed Road, 2070
- Exposed Barrier, 2070
- Inundation Risk Area, 2030
- Inundation Risk Area, 2070

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

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Exposed Critical Infrastructure
2030 and 2070 Scenarios

Town Wide Drainage Study
Swampscott, Massachusetts

FIGURE