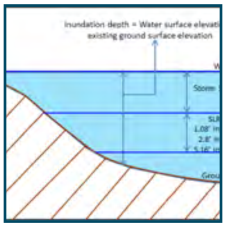
Sea Level Rise Study

Towns of Marshfield, Duxbury, Scituate, MA
July 18, 2013







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INTRODUCTION

The three towns of Marshfield, Duxbury and Scituate are particularly vulnerable to sea level rise because of their geography: extensive floodplains and estuaries that reach into the inland areas of the towns are subject to tidal action. There are extensive salt marshes associated with rivers as well as beaches that are also subject to tidal action. In addition, the densely populated coast is fronted by narrow and fragile coastal and barrier beaches which are exposed to high energy surf from upper Massachusetts and Cape Cod Bays.

The three towns have experienced extensive damage over the years from storm-related flood damage along the coast line. Based on records from the National Flood Insurance Program, for the period from 1978 to 2013, the three towns received a total of $78.3 million in flood related claims as compared to the total of $337.8 million for all of Massachusetts during the same period. This represents 23% of the total Massachusetts claims. During this period, the claims for Marshfield, Duxbury and Scituate were $15.9, $4.7 and $57.7 million, respectively.

Planners for the three towns realized that this is a regional problem and chose to employ a regional approach to identify the effects of sea level rise and possible ways to mitigate its impact. In 2010, the towns collectively applied for and received a Direct Local Technical Assistance Grant (DLTA) from the Metropolitan Area Planning Council (MAPC) to study adaptation and mitigation options for sea level rise. This grant produced the *South Shore Coastal Hazards Adaptation Study* in 2010 which represented a first step in determining coastal vulnerabilities for the three towns and developing a range of adaptation options. This document is available for review at the town offices.

Based on the findings from the initial study, the town planners applied for a second grant from the Gulf of Maine Council on the Marine Environment and the Northeast Regional Council (NROC) to further study sea level rise impacts. The three towns retained the firm of Kleinfelder Northeast Inc. (Kleinfelder) to address the long-term implications of sea level rise and how it might affect public infrastructure, natural resources, businesses, recreational opportunities, and town finances. This report is funded under a combined Gulf of Maine Council and NROC grant.

This project has three primary goals:

1. Produce high-quality maps and graphics showing the extent and magnitude of sea level rise and storm surge vulnerability within the three towns, focusing on public infrastructure.
2. Identify adaptation strategies that will help to mitigate the long-term effects of sea level rise and storm surge.
3. Educate the public, town officials and state legislators about those projected impacts and anticipated increased frequency of extreme events so that the towns can make informed decisions that will avoid future costly impacts to public and private property.

Project Team

The Project team for this sea level rise study included the following members:

- Paul Halkiotis, AICP, Marshfield Town Planner
- Tom Broadrick, AICP, Duxbury Town Planner
- Laura Harbottle, AICP, Scituate Town Planner
- Julia Knisel, Coastal Zone Management
- Jason Burtner, Coastal Zone Management
- Andre Martecchini, PE, Kleinfelder
- Lisa Dickson, PG, Kleinfelder
- Indrani Ghosh, PhD, Kleinfelder

The Project Team worked to coordinate project goals and deliverables. In addition, the Project Team set up a public presentation on May 16, 2013 to present the initial flood inundation results to the public. Additional public presentations will be held in each of the three towns as well as with area legislators to help educate the public on the impacts of rising sea levels.

METHODOLOGY

The team developed inundation maps for the three towns based on sea level rise projections for 25, 50 and 75 year scenarios corresponding to the years 2038, 2063 and 2088. For each year, inundation maps for both sea level rise alone and sea level rise combined with storm surge were developed. The following provides basic information about the methods and processes used as part of this study. The Appendices include more detailed explanations for some scientific data.

Mapping

The maps were developed in ArcGIS based on the methodology used by the National Oceanic and Atmospheric Administration (NOAA) that accounts for local/regional tidal variability and hydrological connectivity (NOAA 2010). The sources for the information included in the maps are described below. Inundation depth was determined by spatial analysis and based on the difference between the projected water surface and existing ground elevations. The inundation areas were evaluated for their hydrological connectivity to the ocean and symbolized according to depths of inundation. Low-lying, hydrologically unconnected areas greater than one acre that may flood due to a breach of flood control structures were also identified. The extent and depth of inundation in the three towns determined their degree of vulnerability.

Ground Elevation Data

The team used existing ground surface elevations for the three towns derived from the 2011 Northeast LiDAR (Light Detection and Ranging) terrain dataset that includes both bare-earth classified points and GIS raster datasets as bare-earth digital elevation models (DEM). LiDAR is a remote sensing technology used to make high resolution maps of land elevations by taking laser measurements from an airplane. Vertical accuracy and horizontal resolution of the elevation dataset are important factors in improving the results of inundation mapping. The 2011 Northeast LiDAR dataset has a vertical accuracy of 0.98 ft. and a horizontal resolution of 3.28 ft.

The bare-earth LIDAR ground data did not accurately account for elevations of coastal structures such as sea walls, revetments and groins. Survey data for public and private coastal stabilization structures in the three towns was provided by the Massachusetts Office of Coastal Zone Management as part of a report titled Mapping and Analysis of Privately Owned Coastal Structures Along the Massachusetts Shoreline (March 28, 2013).

Tidal Elevation Data

For tidal elevations, the team used the NOAA mean higher high water (MHHW) datum. The tidal surface for the three towns was provided by NOAA and was based on VDatum with heights referenced to NAVD88. This is the same datum as the LiDAR ground elevation data. VDatum is software used by NOAA to convert the water surface elevation from a tidal datum to the appropriate geodetic (earth-oriented) datum and to make the tidal information consistent with other elevation data for the towns. This tidal surface captures the tidal variability in the MHHW datum for the three towns.

Sea Level Rise Projections

Sea Level Rise (SLR) projections for the three towns were determined for three forecasting periods: 25, 50, and 75 years corresponding to the years 2038, 2063, and 2088. The SLR projections were based on projections in both Global Mean Sea Level (GMSL) change and Local Mean Sea Level (LMSL) change. At any location, the relative mean sea level change is determined by considering the combined effects of both global and local mean sea level change.

Global Mean Sea Level Change: The primary contributors to global sea level rise are thermal expansion as a result of increased sea surface temperature and contribution of fresh water from melting of glacier ice. The relative contribution of these two factors in increasing global mean sea level is uncertain. However, according to the 2012 NOAA report, ice sheet loss has had a greater contribution to global SLR than thermal expansion over the period of 1993 to 2008.

The global sea level rise scenario used in this project is based on the NOAA Technical Report *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (December, 2012). http://www.cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf The NOAA report provides different sea level rise scenarios, and the difference between these scenarios can mostly be attributed to the differences in the rate and magnitude of ice sheet loss, primarily from Greenland and West Antarctica. The sea level rise scenario that was used in this study corresponds to the "Highest Scenario" in the NOAA report (see Figure 1 below from the NOAA report). The choice of appropriate sea level rise scenario was discussed by the Project Team and the NOAA "Highest" sea level rise scenario was chosen based on consensus among the towns, compatibility with other studies in the region (e.g., City of Cambridge, MASSPORT, Massachusetts Climate Adaptation Report, etc.), and considering scientific evidence that suggests sea level is rising at a substantially higher rate than older historical records. The "Highest" NOAA sea level rise scenario is based on a combination of estimated ocean warming and maximum anticipated glacier and ice sheet loss by the end of the century.

The methodology to calculate global sea level rise presented in NOAA's report is similar to that described in the US Army Corps of Engineers guidance document for incorporating future sea level change considerations in civil works programs (USACE Circular 2011). The detailed methodology and calculation for sea level rise estimates in the next 25, 50, and 75 years are provided in Appendix 1.

Local Mean Sea Level Change: The primary source of local mean sea level change is attributed to geologic factors which cause vertical land movement due to tectonics, such as land subsidence or uplift. Local mean sea level change is estimated by considering local, historic tide gage records combined with models or actual measurements of Earth's local tectonic movement. 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 data from 1921 to 2006. Over that same period, the global rate of sea level rise was about 1.7 mm annually. This implies that there is about 1 mm per year local land subsidence (or sinking) in the relative sea level record for the Boston area (MA Adaptation report 2011). The team factored this rate of subsidence for local mean sea level change and added this to the global mean sea level change to determine the relative sea level rise for the project area. Table 1 shows relative sea level rise estimates for the three towns in 10-year increments based on global sea level rise estimates and local subsidence effects.

2013 is the beginning year of interest because the study is being conducted in 2013. Since the objective of this study was to consider the impacts of sea level rise and storm surge in the next 25, 50, and 75 years, the ending years of interest are 2038, 2063, and 2088. As shown in Table 1, the relative sea level rise values for 2038, 2063, and 2088 are 1.08 feet, 2.80 feet, and 5.16 feet, respectively.

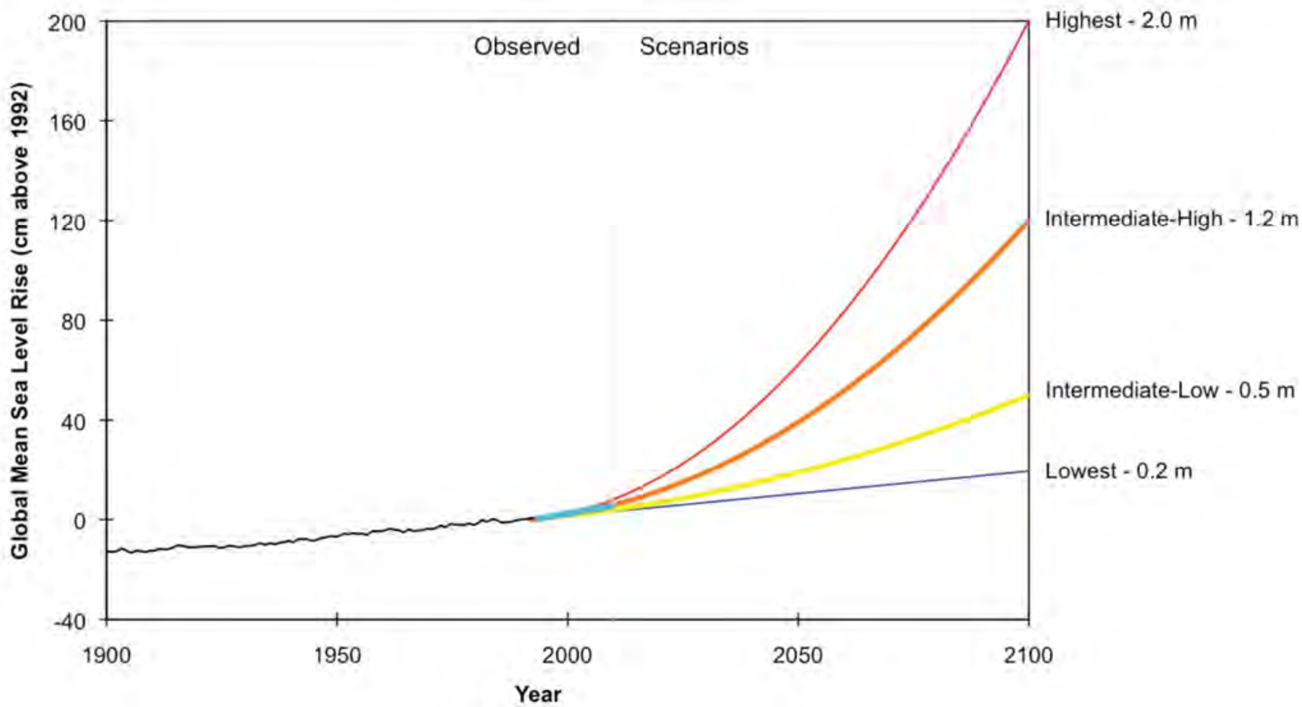


Figure 1: Global mean sea level rise scenarios as published in the NOAA Technical Report *Global Sea Level Rise Scenarios for the United States National Climate Assessment*, December 2012

Table 1 – Sea Level Rise Estimates

Scenarios	2020	2030	2038	2040	2050	2060	2063	2070	2080	2088	2090	2100
Global SLR (from 2013) - "Highest" (feet)	0.21	0.61	1.00	1.10	1.70	2.40	2.63	3.21	4.11	4.91	5.12	6.23
Land subsidence (feet) @ 0.04 in./ year	0.03	0.06	0.08	0.09	0.12	0.15	0.17	0.19	0.22	0.25	0.25	0.29
Total Relative SLR - "Highest" (feet)	0.24	0.67	1.08	1.19	1.82	2.56	2.80	3.39	4.33	5.16	5.37	6.52

Note: Relative SLR for a scenario is the sum of global SLR for that scenario and land subsidence. For example, relative SLR of 5.16 ft. by 2088 (75 years) according to the "Highest" scenario is the sum of global SLR of 4.11 ft. and land subsidence of 0.22 ft. by 2088.

Storm Surge

Storm surge is an offshore rise of water associated with the advance of a low pressure weather system such as a hurricane or Nor'easter. Storm surges are caused by a combination of high winds associated with the storm pushing water in front of the storm and a local rise in sea level due to the extreme low pressures around the eye of the storm. The extent of damage from storm surge depends on the storm's intensity, size, and direction of movement. Storm surges can cause salt water flooding that can render evacuation routes impassable, disrupt communications, contaminate drinking water supplies, and result in sewer and stormwater back-ups.

Sea level rise combined with the possibility of stronger storms including greater winds, increasing storm surge, and greater amounts of precipitation will lead to increased potential of inundation, flooding, and erosion in coastal areas. Impacts from sea level rise combined with storm surge could severely affect the three towns and have far-reaching operational ramifications. While significant hurricane landfall events are less frequent than extra-tropical storms (Nor'easters) along the Massachusetts coast, it is important to assess the vulnerability of flooding from hurricane storm surges in light of the recent damage caused along the eastern seaboard by Hurricane Sandy. Also, it is important to consider the effects of storm surge from hurricanes based on the recent publication by Mendelsohn et al. (2012), which predicts an increase in the frequency of high-intensity storms in North America as a result of climate change.

The storm surge modeling in this project was conducted using the hydrodynamic Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model developed by the National Weather Service. SLOSH is a computer model used to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes. The National Weather Service has generated composites of several thousand runs of hypothetical hurricanes in the SLOSH model, which have been categorized as MEOWs (Maximum Envelopes of Water) or MOMs (Maximum(s) of the MEOWs). The MEOW is the composite set of highest storm surge values at each grid location for a given storm category, forward speed, and direction of motion. The MOM is the Maximum of the MEOWs, which is the composite of the maximum storm surge height for all hurricanes of a given category at every grid cell. Model simulations for predicted storm surge heights generated using the SLOSH Display Program combined with sea level rise for each the three towns appear in the following Sea Level Rise Impacts section.

The SLOSH model for Marshfield, Duxbury, and Scituate was run for a Category 1 hurricane. There are two reasons why the Category 1 hurricane was selected for storm surge modeling. First, the sustained wind speeds associated with a Category 1 hurricane are closer to the winds typically experienced in nor'easters that are more commonly observed in the three towns. Second, based on historic records, the probability of occurrence of Category 1 hurricanes is higher than the other higher-category hurricanes (Cat 2, Cat 3, etc.) in the three towns. According to the NOAA Storm Tracker database and the Scituate Hazard Mitigation Plan, between 1858 and 2011, Massachusetts has experienced approximately nine Category 1 hurricanes, five Category 2 hurricanes and two Category 3 hurricanes. As a result, inundation maps developed for Marshfield, Duxbury, and Scituate considered the effect of storm surge from a Category 1 hurricane, in addition to sea-level rise.

The following input parameters were used in the SLOSH model for the three towns:

- 2010 updated SLOSH basin for Providence/Boston (pv2)
- Category 1 MOM at mean tide
- Wind forward speed: 10-60 mph
- Angle of approach to coast: N, NE, NNE, NNW, NW, WNW

Limitations:
There are some limitations to the SLOSH model which should be noted:

- The predicted surge values are mean surge values and do not include the effect of wave run-up on top of the surge. Therefore, wave crests above the surge will actually result in greater inundation, especially in ocean-facing areas. It is beyond the scope of this project to determine wave height impacts due to storm surge.

- The predicted surge does not account for increased river flooding due to rain fall.
- There were certain areas in the project where there appeared to be some discontinuities in the SLOSH basin grids which means that the surge values in these areas may not be correct. Unfortunately, it is beyond the scope of this project to more accurately model surge values in these areas.

3D Image Renderings

Based on the inundation results, five publically-owned sites were identified in each town for a more detailed vulnerability analysis and 3D imaging. For each image, the visualization specialist chose key points, and then collected data for each point's exact location and elevation. The elevation data provided the means for creating a 3D terrain of the landscape in each image. Next, massing models were created for all major objects in the images. A digital camera was aligned to view the same vantage point for each image. Sea level rise was simulated to projected levels for each scene, and then the projected water levels were rendered and the rendering was composited into the original photograph to show the results.

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 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. Therefore, projections made in this report are the best judgment of Kleinfelder and the Project Team, but in no way shall they be interpreted as any guaranteed predictions of future events and should only be used for general planning purposes.

It should be noted that 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 buildings. Similarly, if a building is on raised 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.

The storm surge modeling using the SLOSH model does not take into account the effects of wave-run-up. Actual wave heights will be higher than those predicted in the SLOSH model. Modeling of wave run-up and the additional flooding component due to overtopping of sea walls is beyond the scope of this project.

SEA LEVEL RISE IMPACTS

The projected impacts from sea level rise and storm surge made in this study are organized separately by town for ease of future separation. The inundation mapping results are shown for each town for the 25, 50, and 75 year scenarios considering sea level rise only and sea level rise and storm surge combined. Each town's results section contains maps (town-wide and area-specific) of the study results, and 3D renderings of the specific areas selected by each town. All information is specific to each town.

The inundation maps show both the extent and depth of flooding. Depth of flooding is defined as the depth of water above existing ground elevations. The flooding depths in the maps are shaded in grades of blue (from light to dark) using two-feet increments, with lighter shades for lower depth of flooding and darker shades of blue for higher depths of flooding. Figure 2 below shows a schematic representation of the flood depths and a corresponding typical snapshot from an inundation map. Note that the shades of blue in the map below (bottom left) correspond to the shades of blue for flood depths in the figure on bottom right.

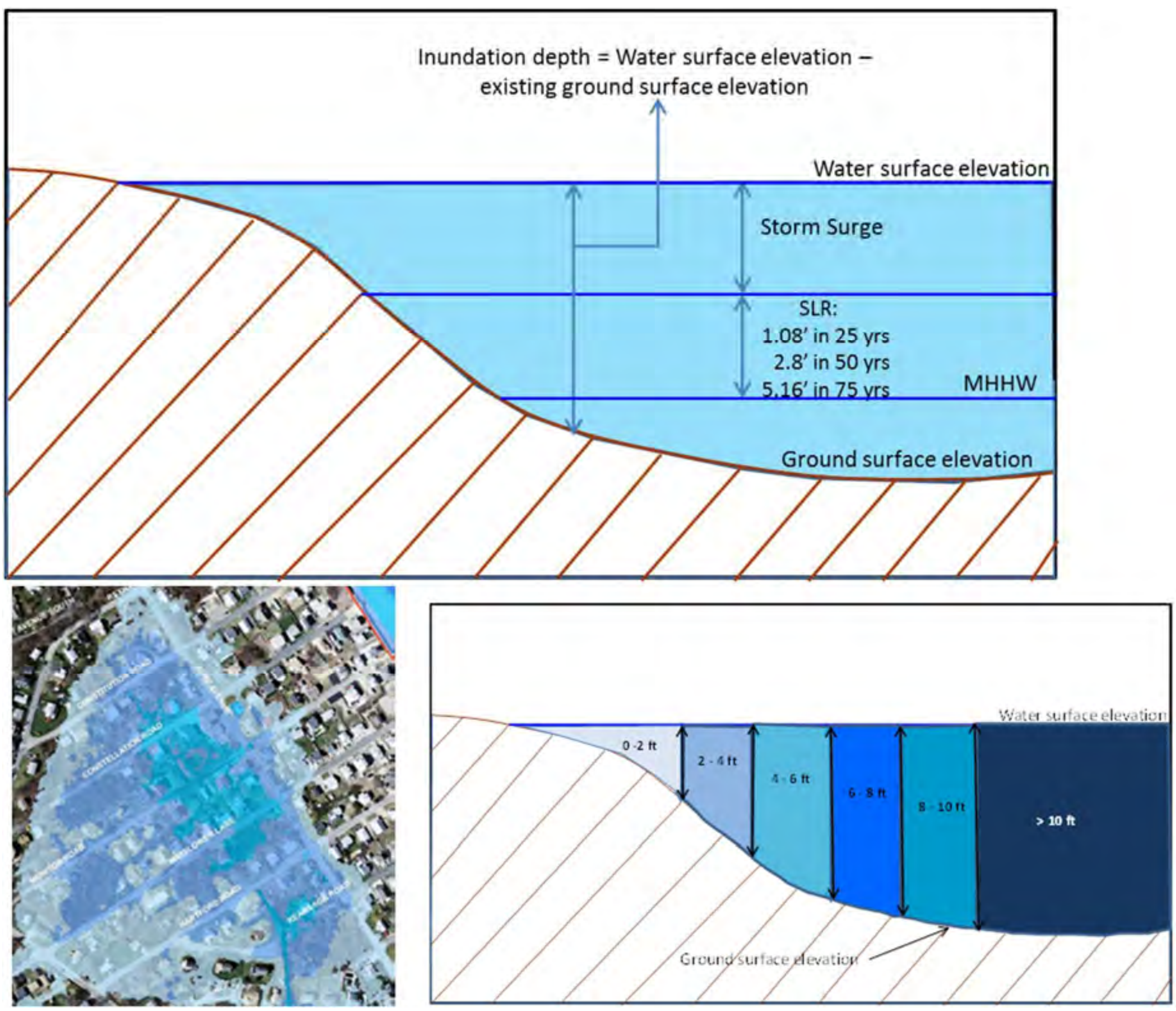


Figure 2: Schematic representation of flood depths in inundation maps

An important impact of sea level rise is the change in the definition of the current base 100-year floodplain. This includes both changes in the base flood elevation, as well as the landward migration of the inland limit of coastal flooding over time. Base flood elevation is associated with the "100-year flood" and refers to the elevation below which flooding has a 1% annual chance of occurrence. The impact of sea level rise on floodplain definition is illustrated in the schematic in Figure 3. This figure explains how the current 100-yr flood elevations and the inland flood limit can potentially be changed as a result of sea level rise. For example, the current average 100-yr base flood elevation (stillwater elevation) for the three towns is 9.5 ft NAVD88. Based on the sea level rise projections for the towns of 1.08 ft, 2.80 ft, and 5.16 ft, respectively in the next 25, 50, and 75 years, the future 100-yr base flood elevations are projected to be 10.58 ft NAVD88, 12.3 ft NAVD88, and 14.66 ft NAVD88, respectively for the next 25, 50, and 75 years. Also, based on the future base flood elevation, the inland flood limit is projected to migrate further landward. This means that areas that are currently not prone to flooding from a 100-yr flood (a flood that has 1% annual chance of occurrence), are most likely to become vulnerable to flooding in the future.

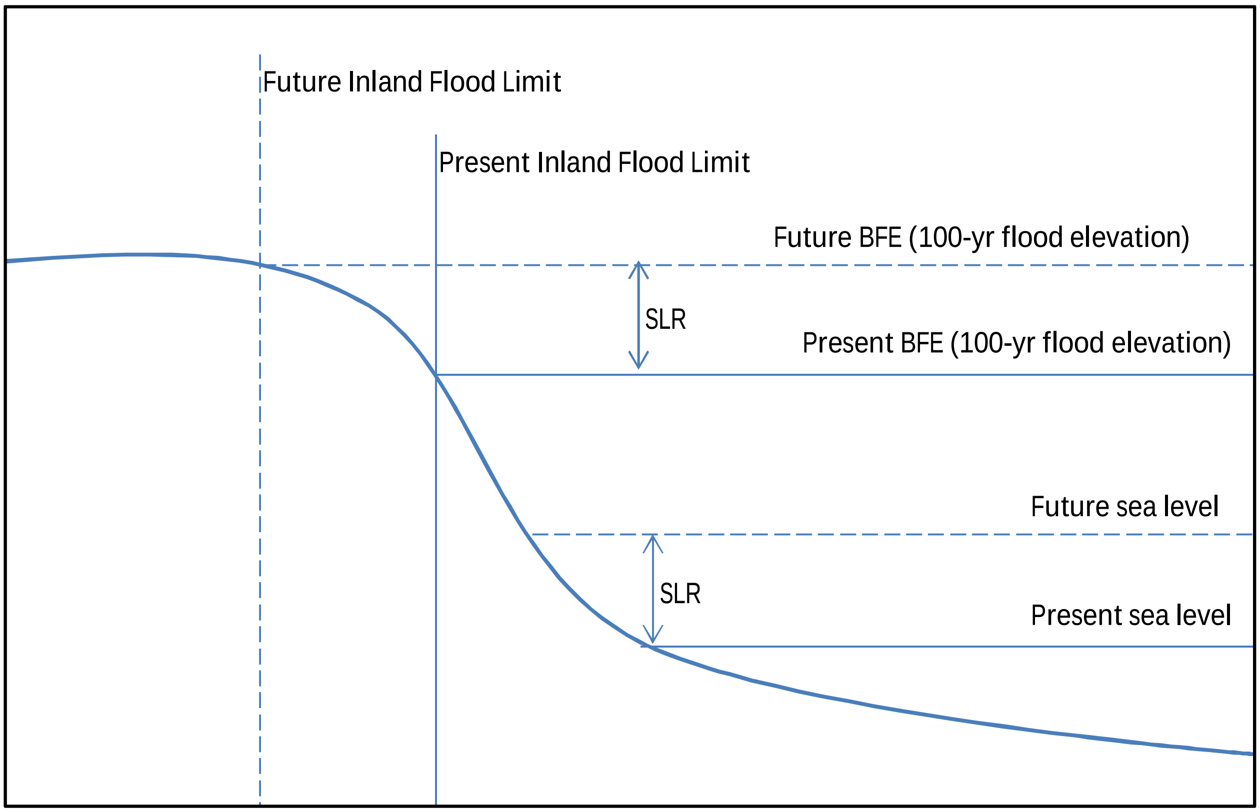


Figure 3: Schematic representation of changes in extent and elevation of the present Base Flood Elevation (BFE) as a result of sea level rise

In addition to the impacts of sea level rise and storm surge, another important contribution to flooding is from the effects of wave runup and wave height. According to the FEMA definition (from the report "Guidelines and Specifications for Flood Hazard Mapping Partners, February 2007), "wave runup is the uprush of water from wave action on a shore barrier intercepting still water level". Based on FEMA's National Flood Insurance Program, the 2-percent wave runup height (obtained from FEMA's RUNUP 2.0 model) is added to the 1-percent annual chance stillwater level to obtain the total wave runup elevation. Since stillwater elevations are projected to increase as a result of sea level rise, wave runup elevations are also projected to increase by the corresponding rise in sea level. The impacts of sea level rise on wave runup elevation and limit of wave runup are illustrated in the schematic in Figure 4. Effects of wave runup and migration of the limit of wave runup inwards to land, could lead to increased flooding (for example, more frequent overtopping of coastal structures, overtopping sooner in the tidal cycle, to a greater degree, and for a longer duration) in coastal areas. Also, any changes in the magnitude of the wave runup in the future as a result of bigger/taller waves will also cause increased damage to coastal infrastructure from direct wave impacts.

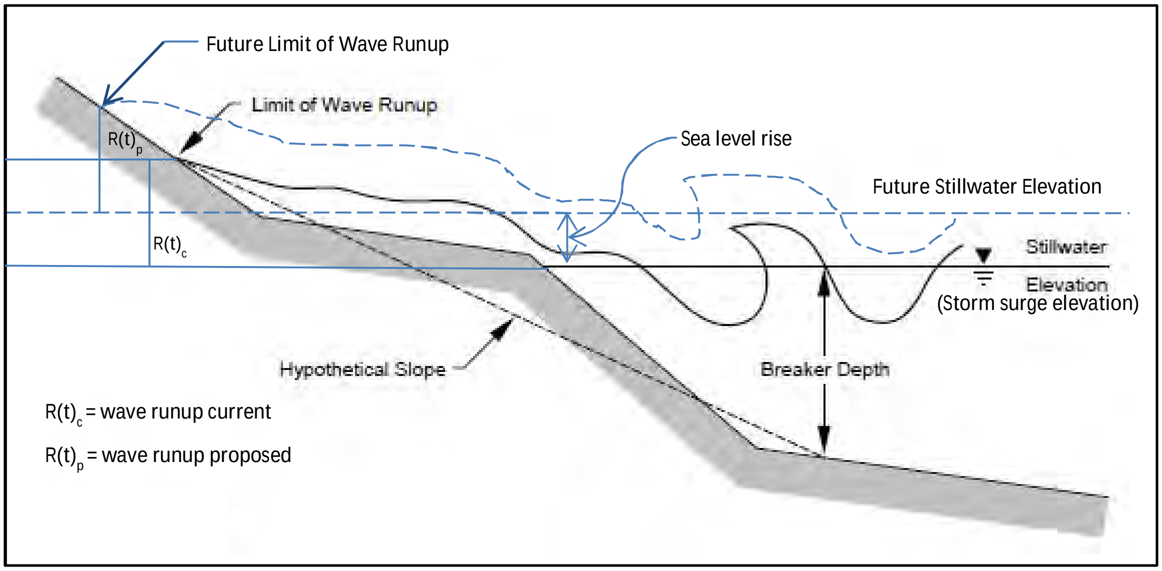


Figure 4: Schematic representation of changes of wave runup elevation and limit of wave runup as a result of sea level rise *(Source: Base figure without SLR effects is from the FEMA report "Guidelines and Specifications for Flood Hazard Mapping Partners, February 2007)*

As noted above, the storm surge results based on the SLOSH modeling do not take into account the effects of wave run-up above the mean level of the storm surge. Actual water surfaces for storm surge will be higher than the results indicate due to the crests of waves being above the mean surge elevation. However, modeling the wave runup/overtopping component of flooding was outside the scope of funding for the current project. We recommend that additional modeling effort be involved in a subsequent study to understand the effects of flooding in the three towns as a result of wave runup, overtopping of coastal barriers from wave action, etc.

The next sections discuss the sea level rise and storm surge impacts for each of the three towns separately.

Sea Level Rise Impacts -Town of Scituate, MA

1. Town-wide inundation maps for 2038 (25 years), 2063 (50 years) and 2088 (75 years) with sea level rise only and sea level rise combined with storm surge

2. Sea Level Rise and Storm Surge Maps for specific areas
   a. Front Street/Scituate Harbor Area
   b. Central Avenue, Humarock
   c. Wastewater Treatment Plant
   d. “Avenues” Area

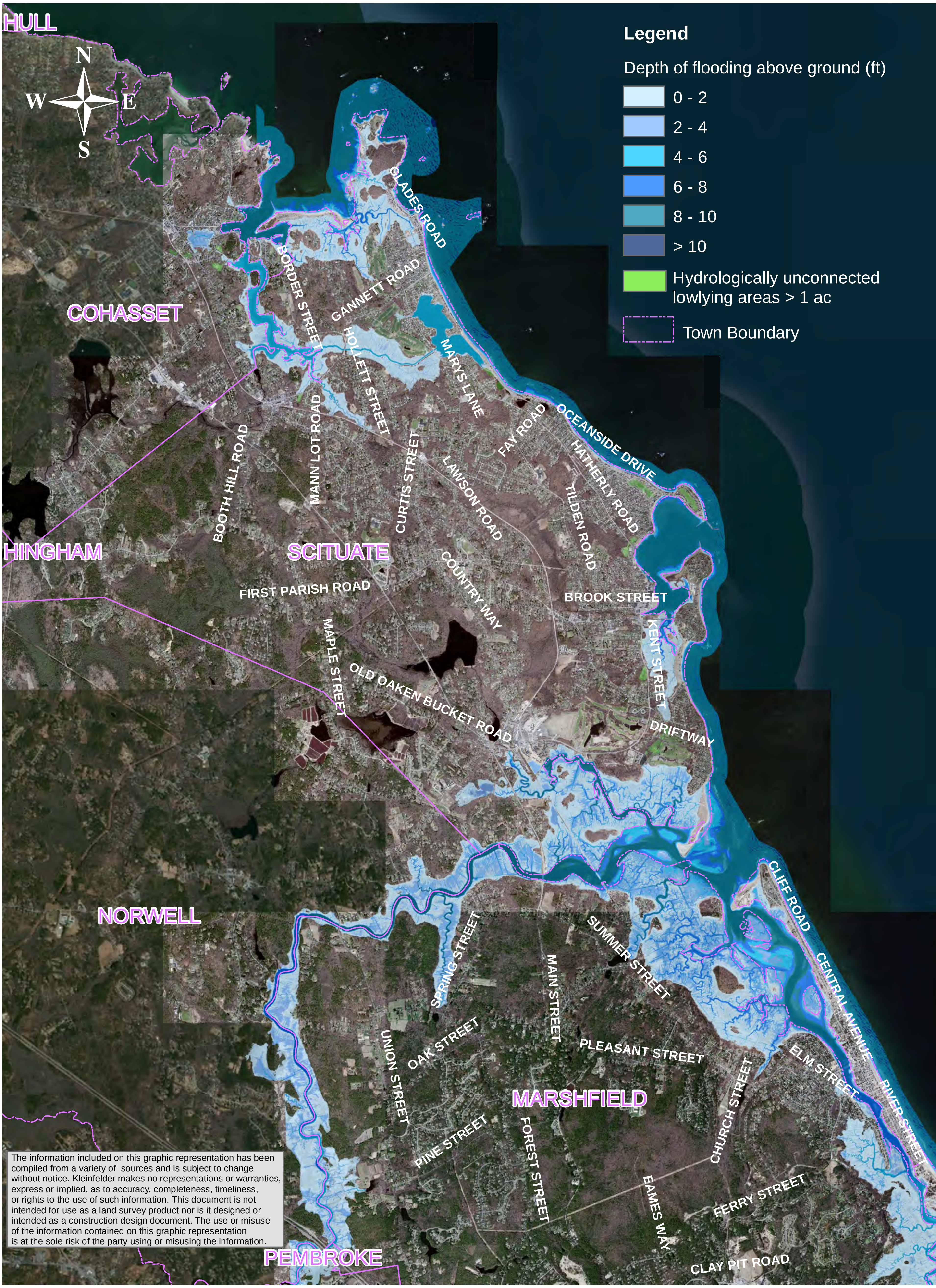
3. 3D renderings of selected areas for 2088 (75 years) with sea level rise and storm surge combined

4. Natural Resource Impacts
   - Tidal Salt Marshes
   - Beaches
   - Wildlife

5. Infrastructure Impacts
   - Roadways and Bridges
   - Coastal Stabilization Structures
   - Wastewater Treatment Plant
   - Underground Infrastructure Systems

6. Transportation Impacts

7. Emergency Access Impacts



SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2038 (25 YEARS)
TOWN OF SCITUATE, MA
JULY 2013

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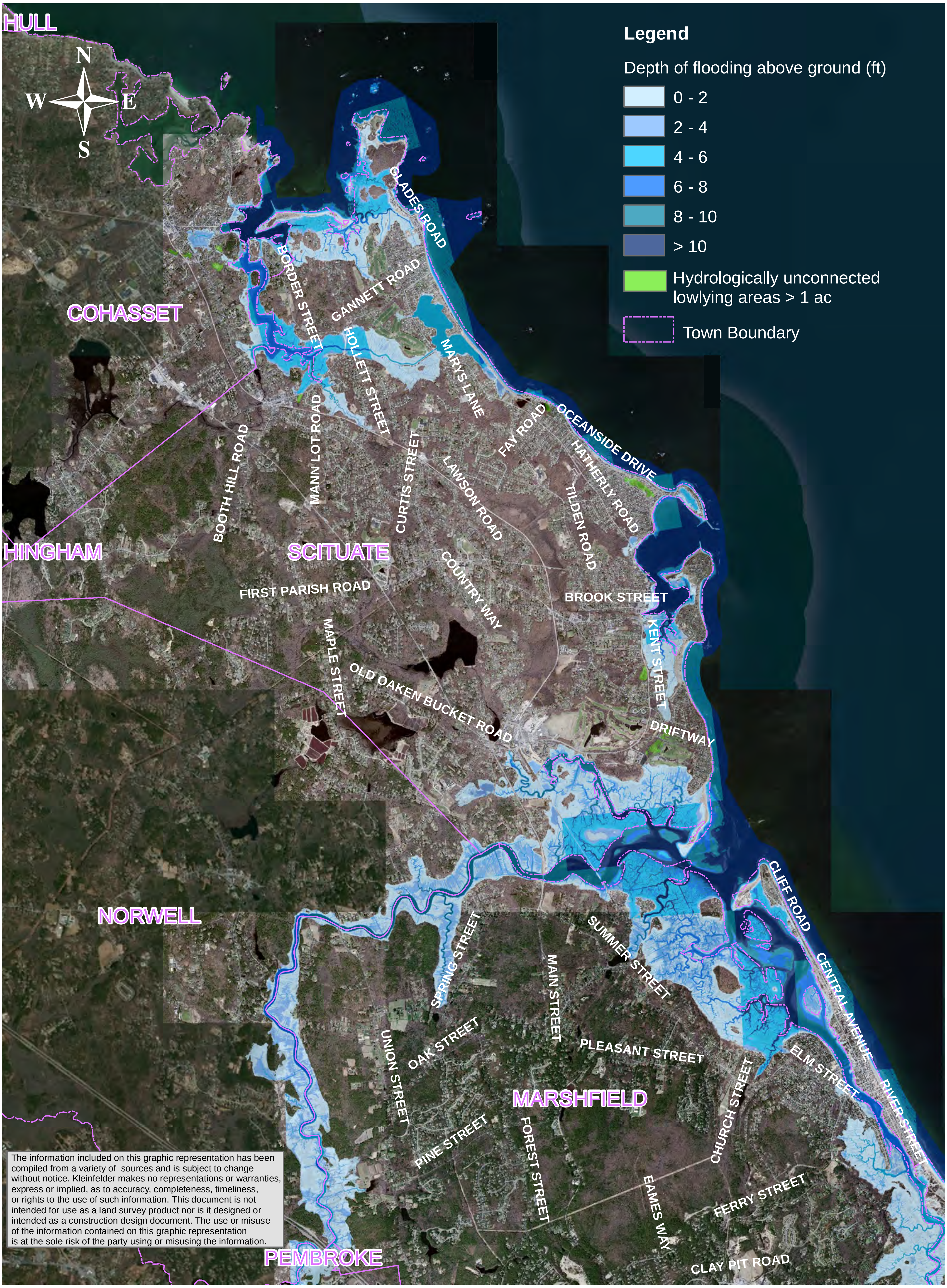

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2038 (25 YEARS)
AND STORM SURGE
TOWN OF SCITUATE, MA
JULY 2013

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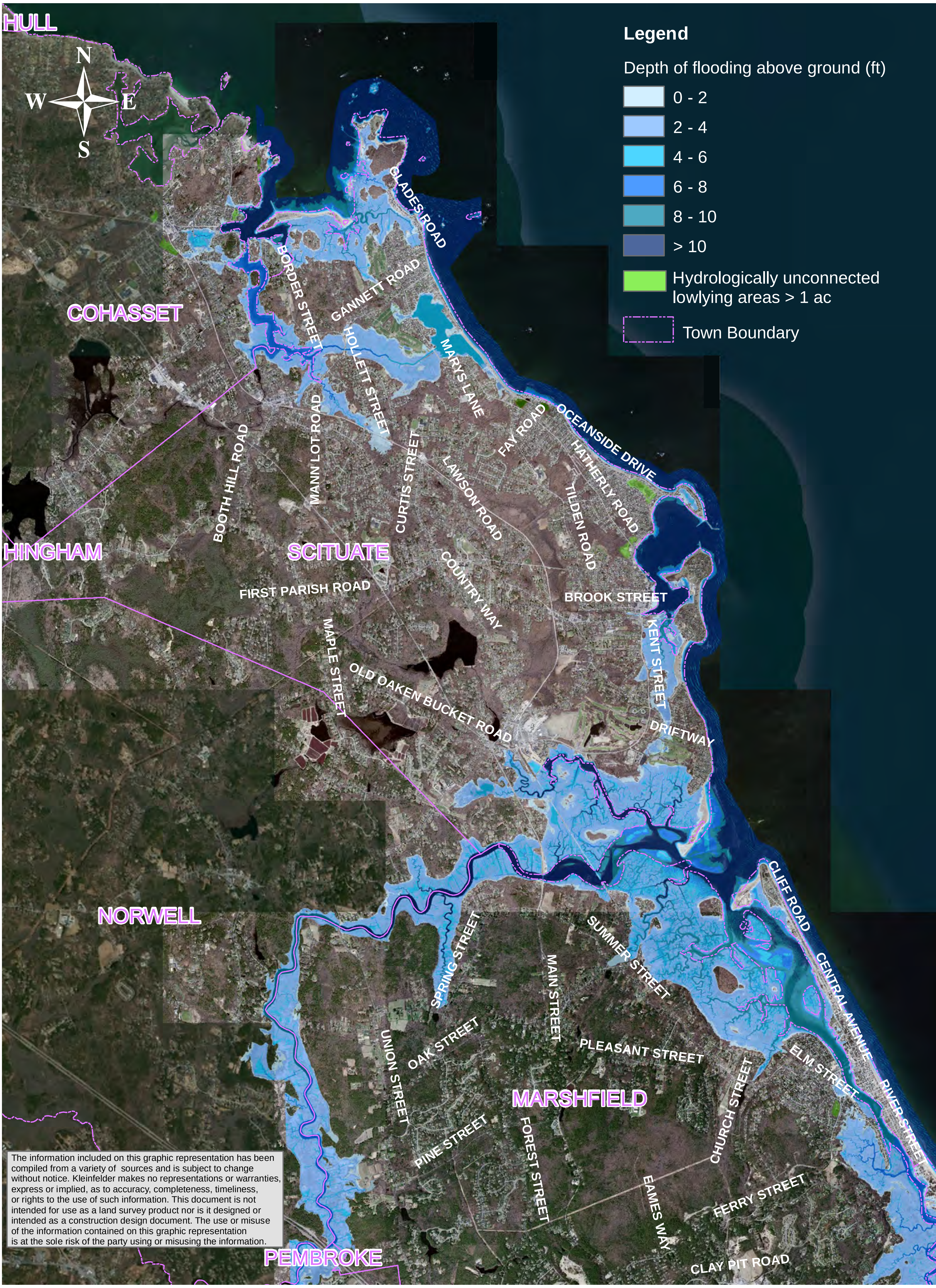

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SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2063 (50 YEARS)
TOWN OF SCITUATE, MA
JULY 2013

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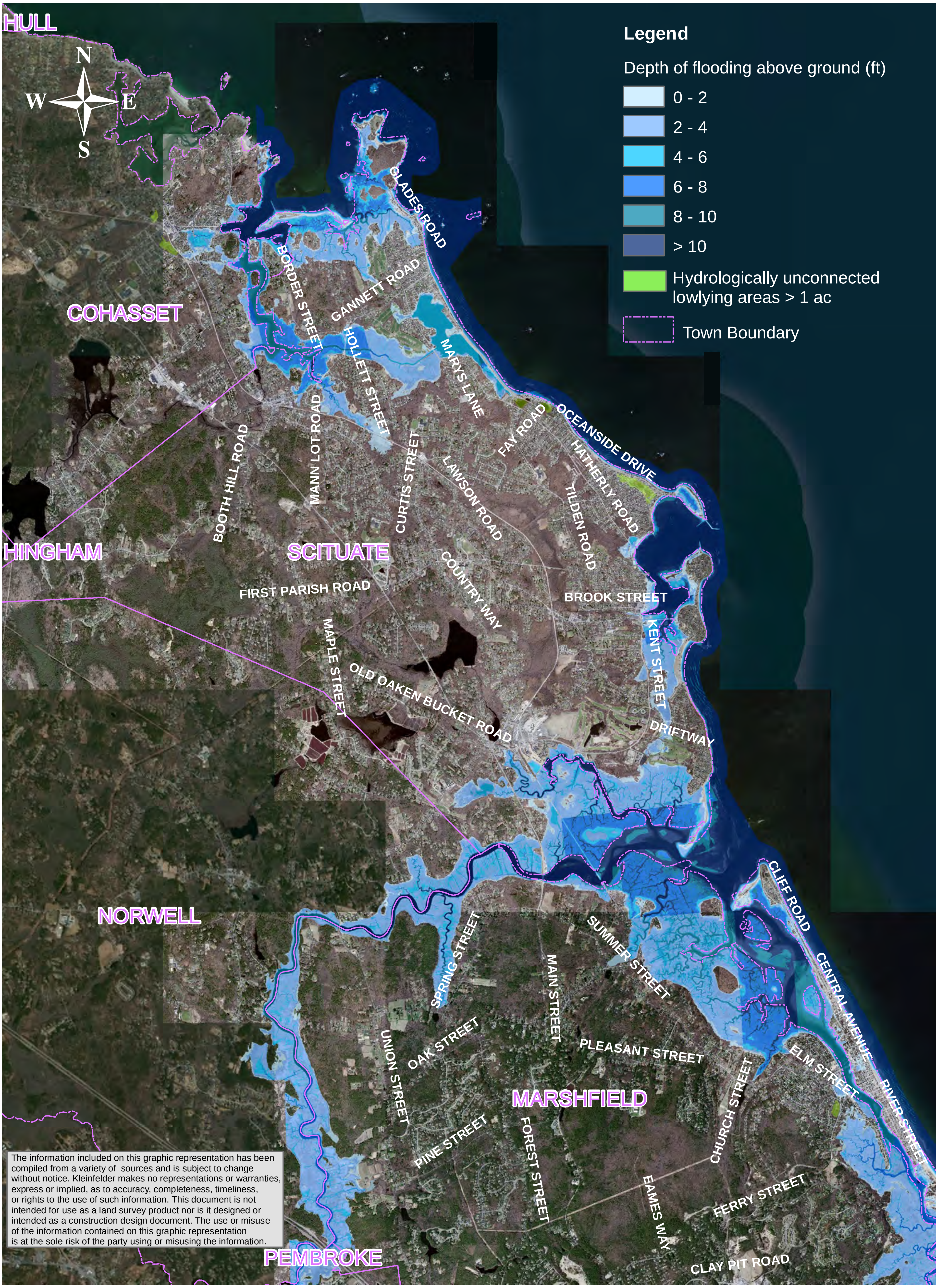

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2063 (50 YEARS)
AND STORM SURGE
TOWN OF SCITUATE, MA
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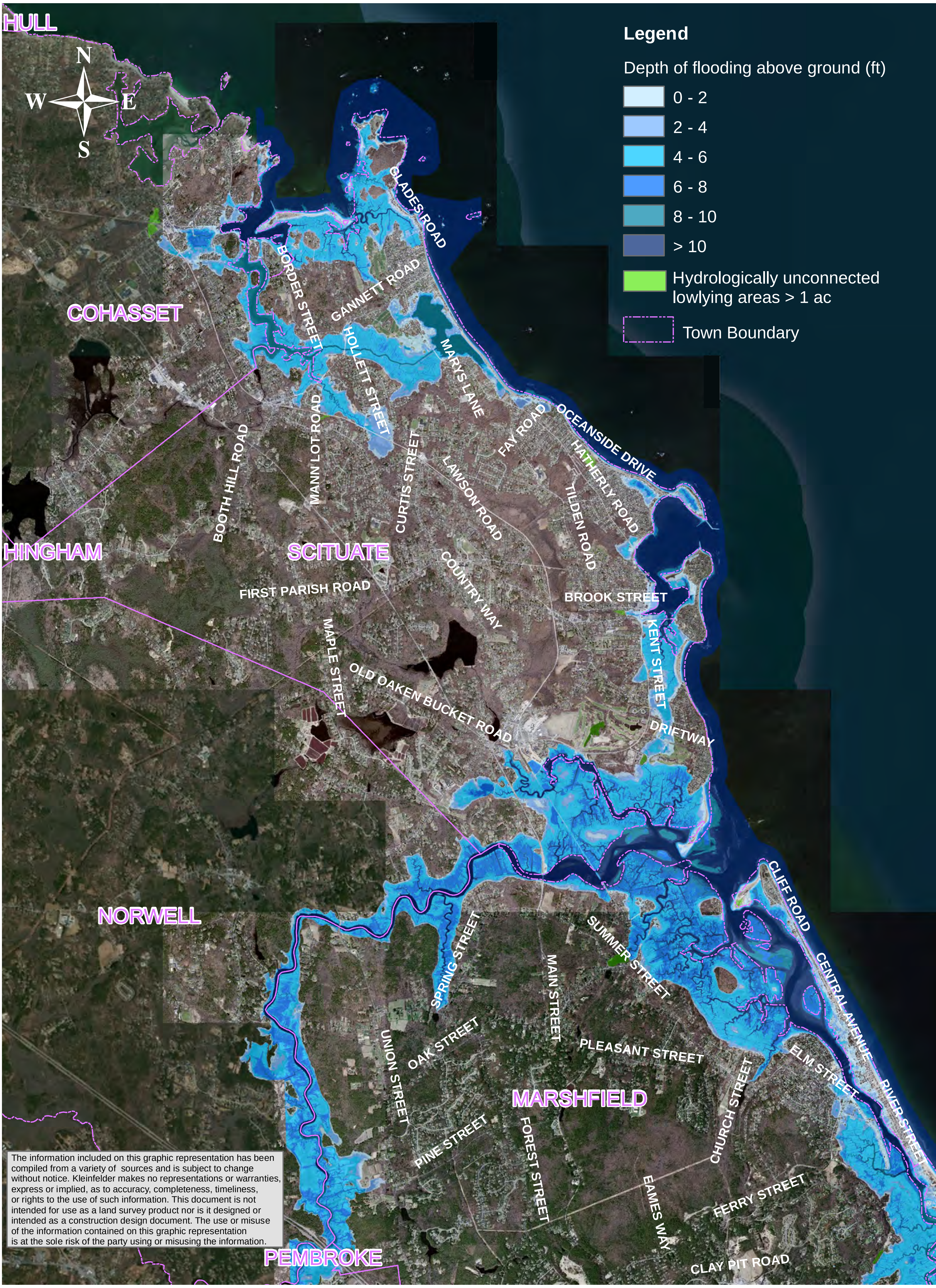

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SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2088 (75 YEARS)
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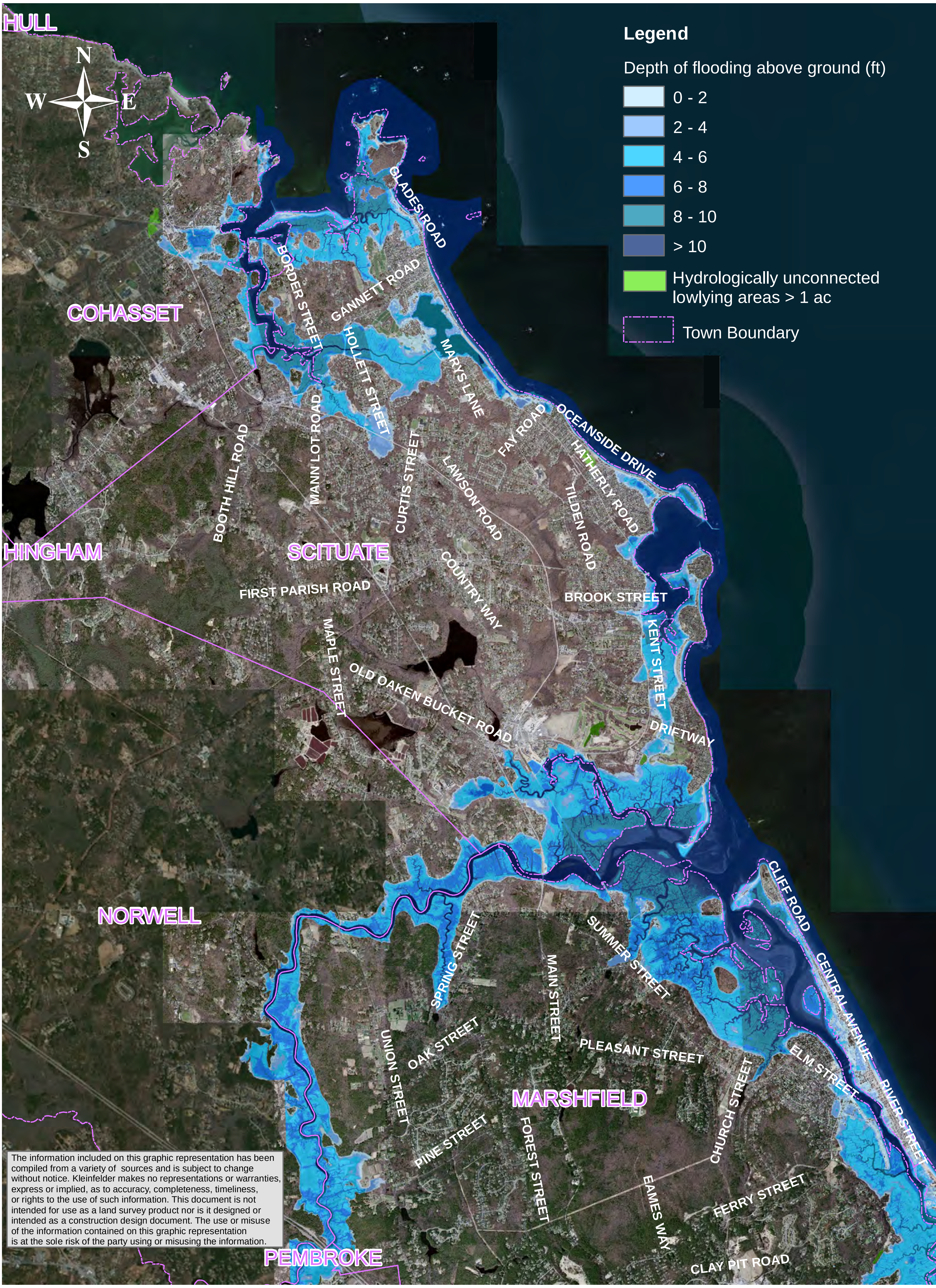

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2088 (75 YEARS)
AND STORM SURGE
TOWN OF SCITUATE, MA
JULY 2013

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Gulf of Maine Council on the Marine Environment

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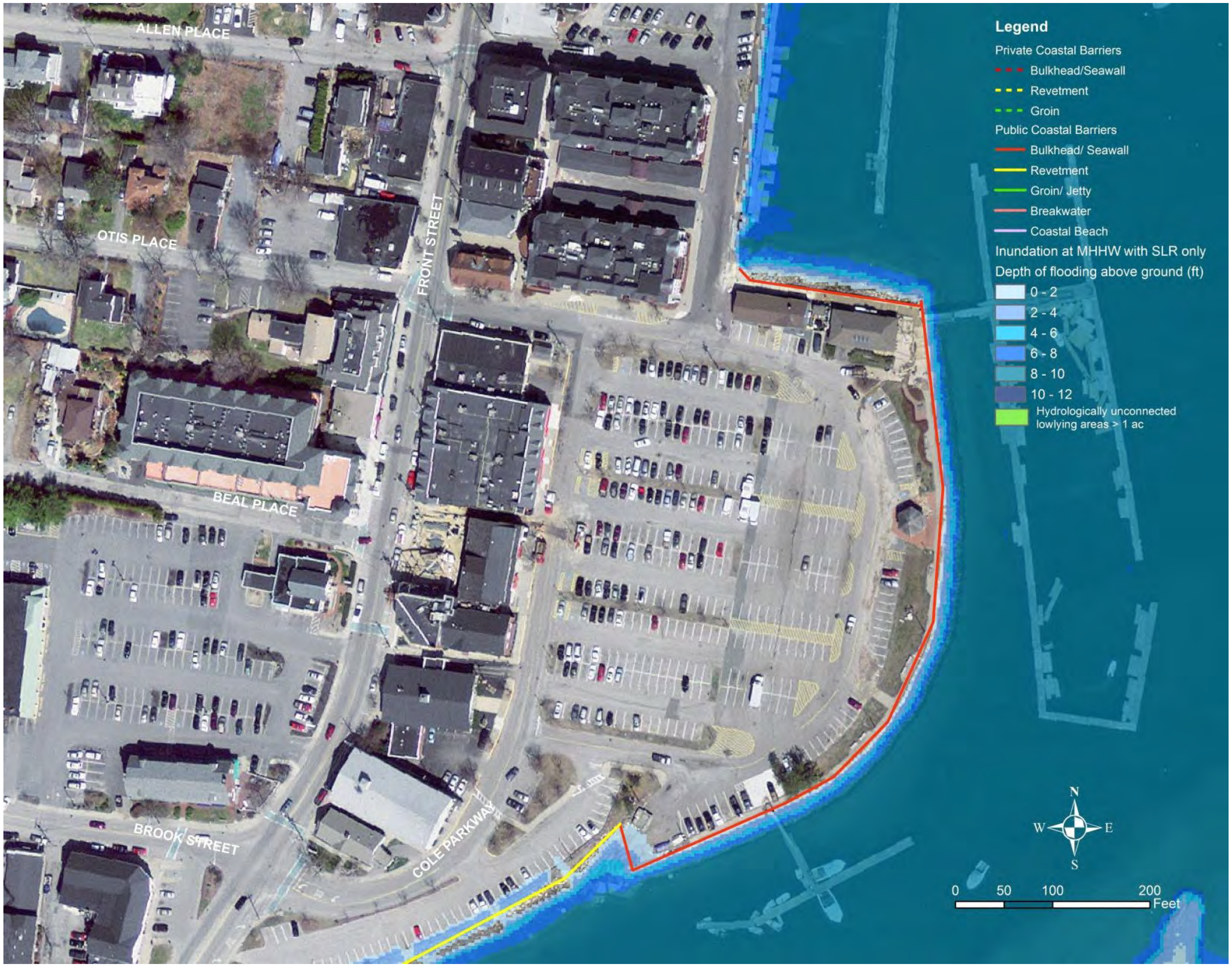
Front Street/Scituate Harbor 2038
25-year Time Horizon

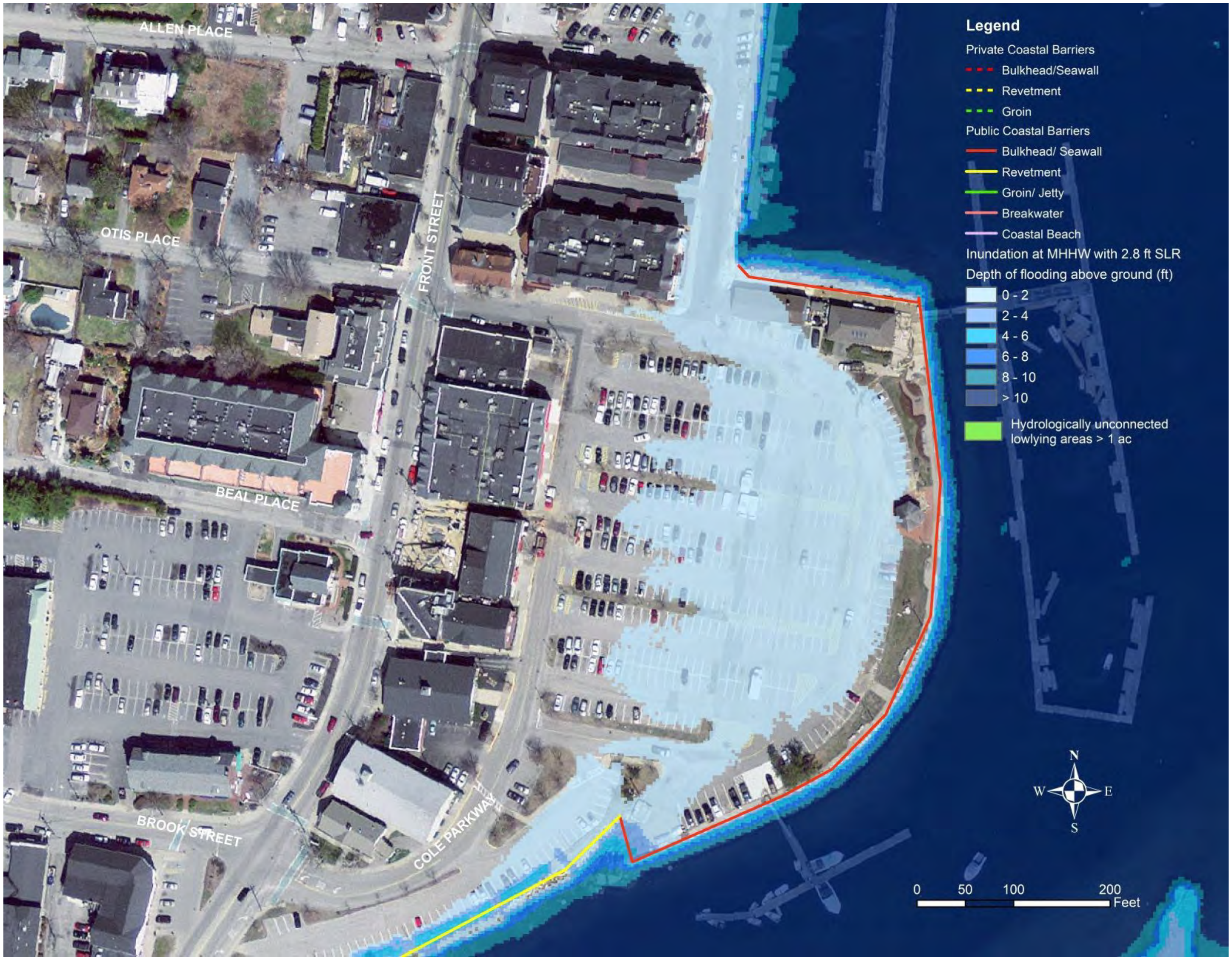


SLR of 1.08 ft. by 2038

Front Street/Scituate Harbor 2038
25-year Time Horizon

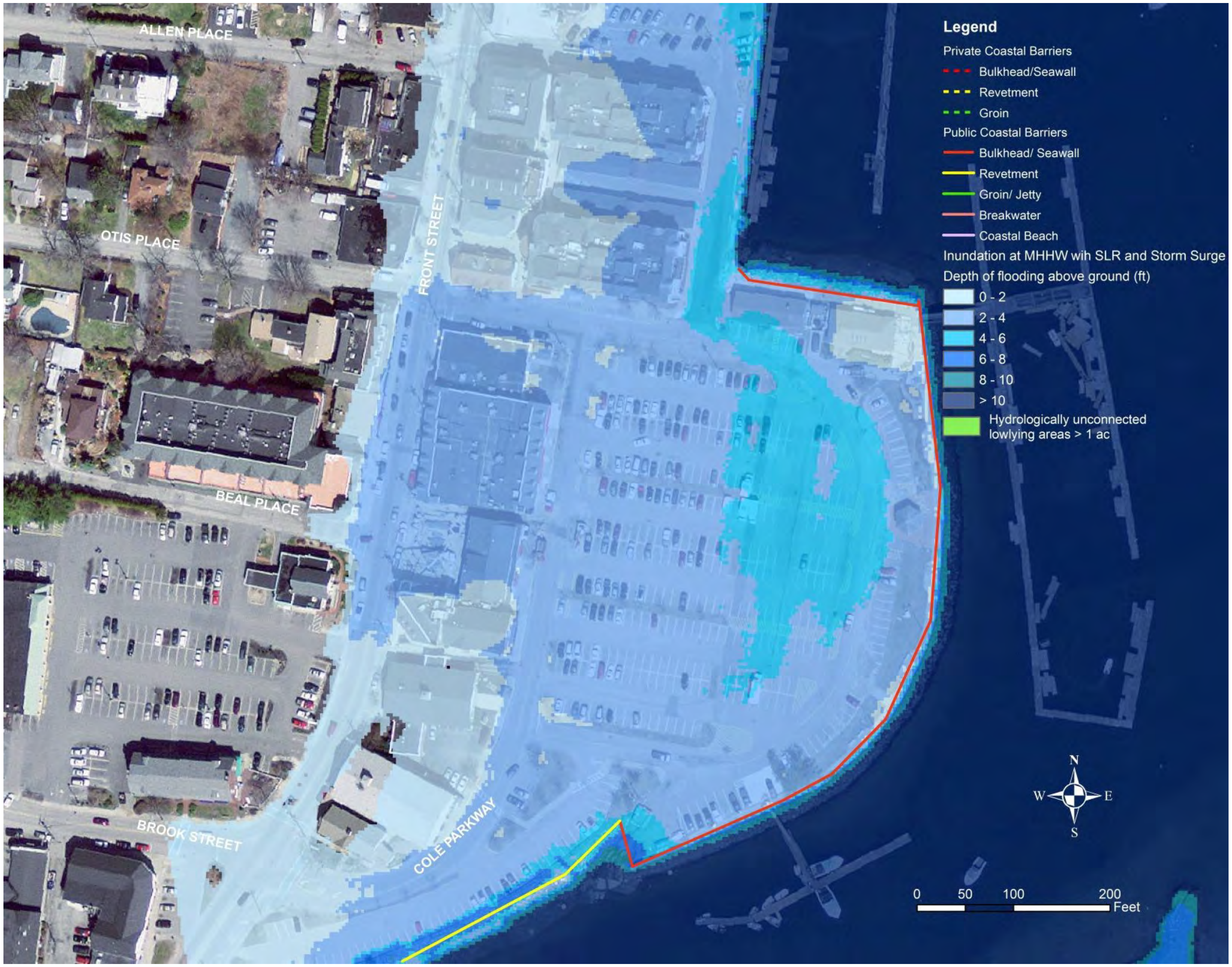
SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Front Street/Scituate Harbor 2063
50-year Time Horizon



SLR of 2.80 ft. by 2063

Front Street/Scituate Harbor 2063
50-year Time Horizon

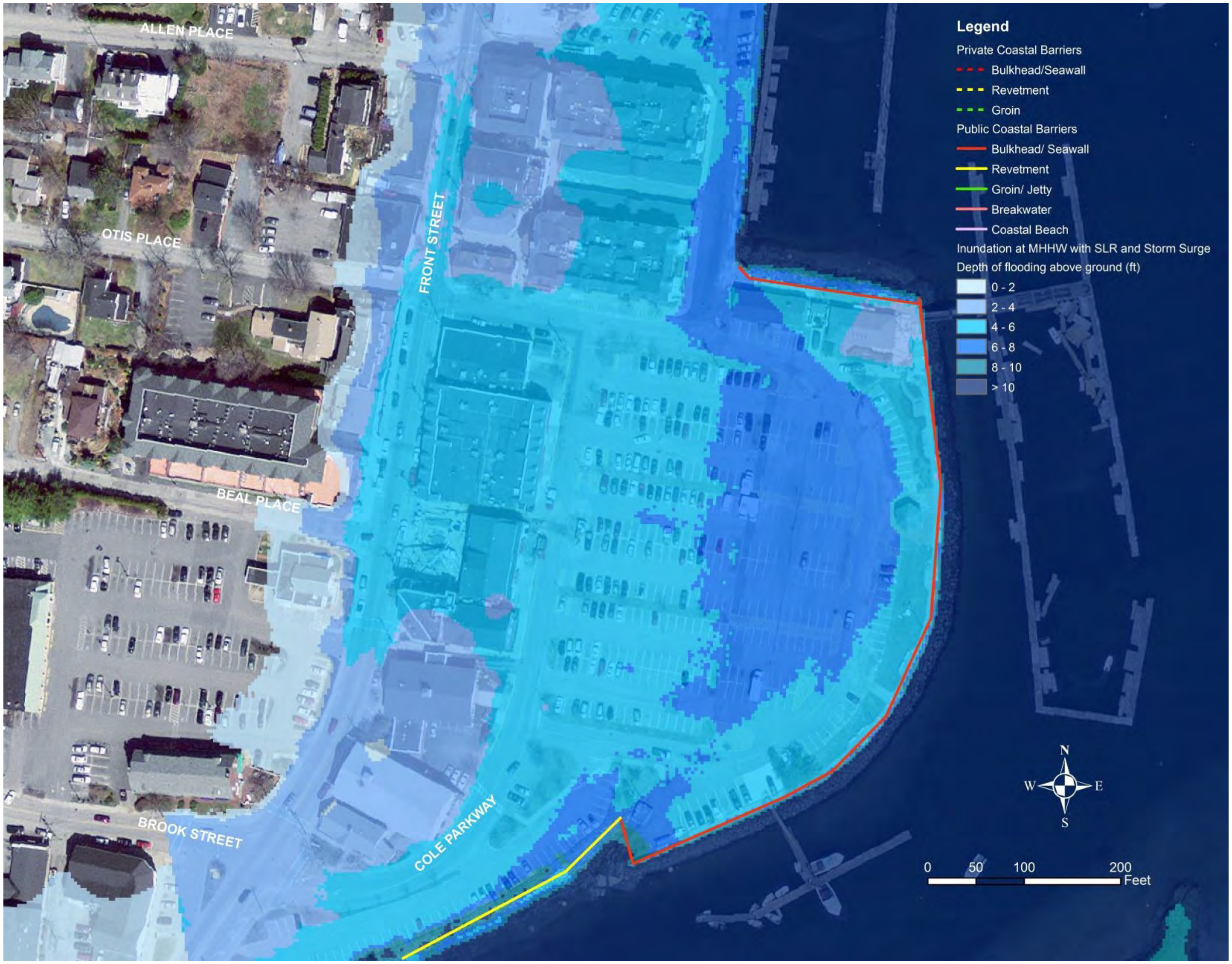


SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Front Street/Scituate Harbor 2088
75-year Time Horizon

SLR of 5.16 ft. by 2088

Front Street/Scituate Harbor 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering
Front Street Looking North, Scituate by 2088 (75-years) with SLR and Storm Surge

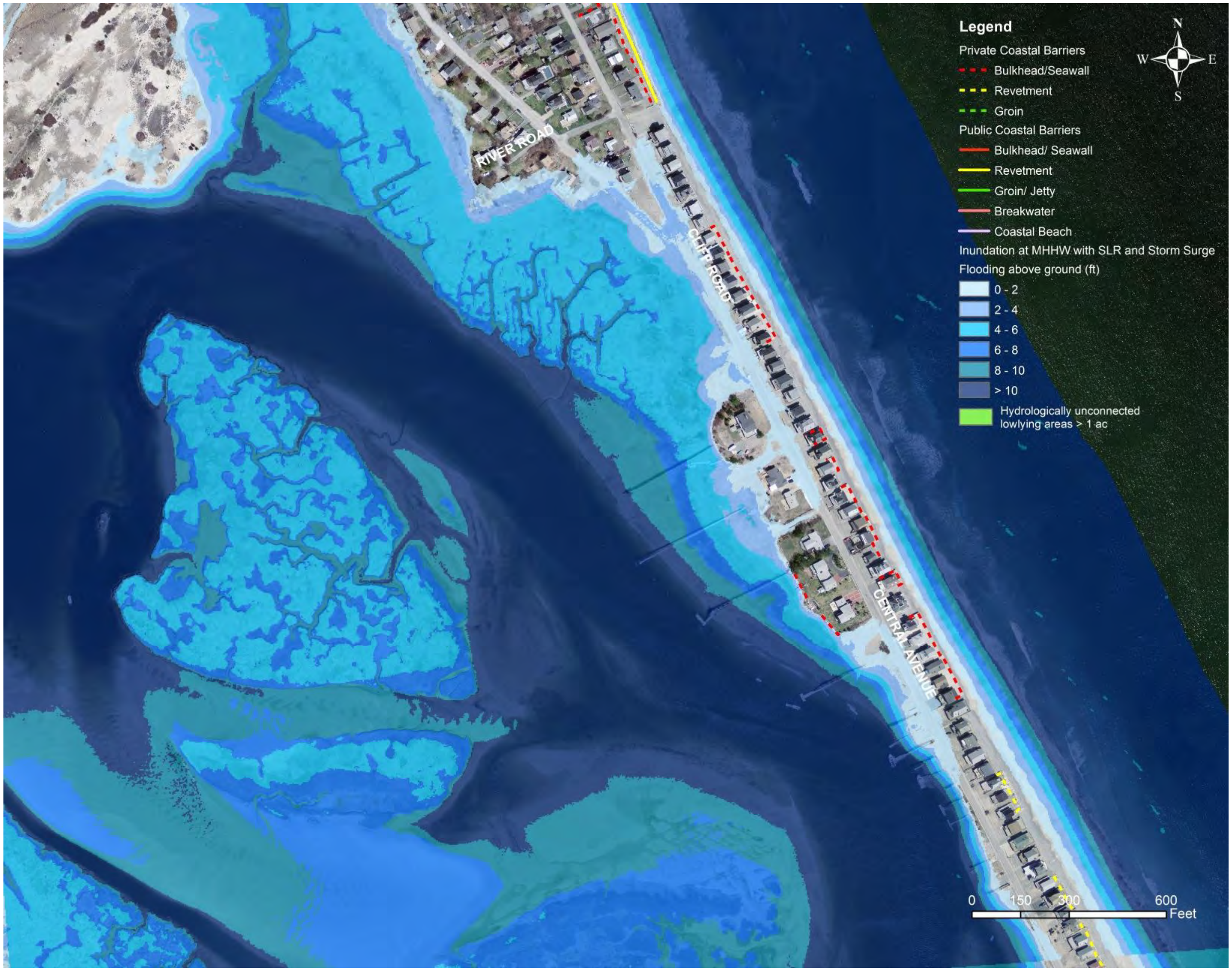
2088

Present

Central Avenue, Humarock, Scituate 2038
25-year Time Horizon

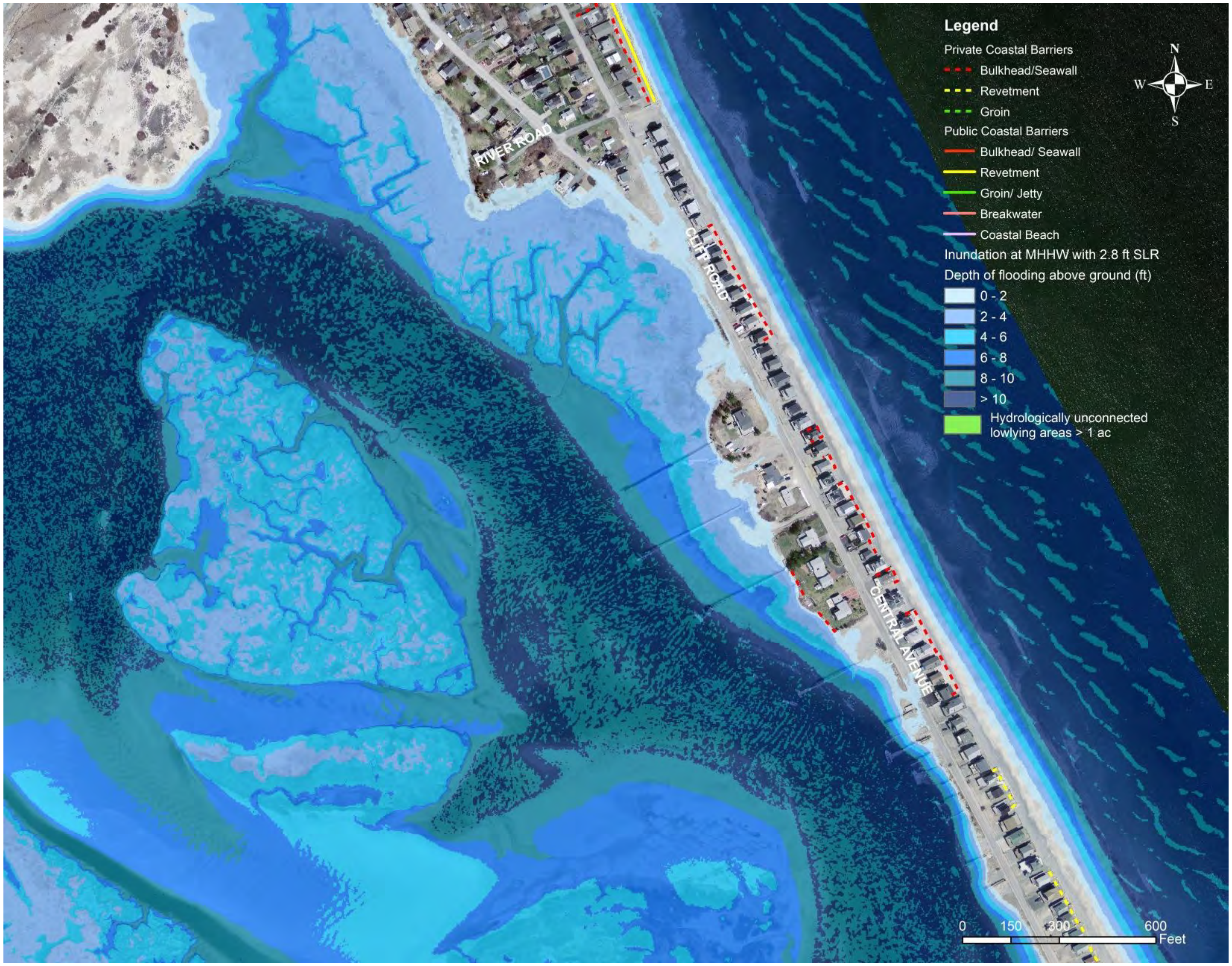
SLR of 1.08 ft. by 2038

Central Avenue, Humarock, Scituate 2038
25-year Time Horizon



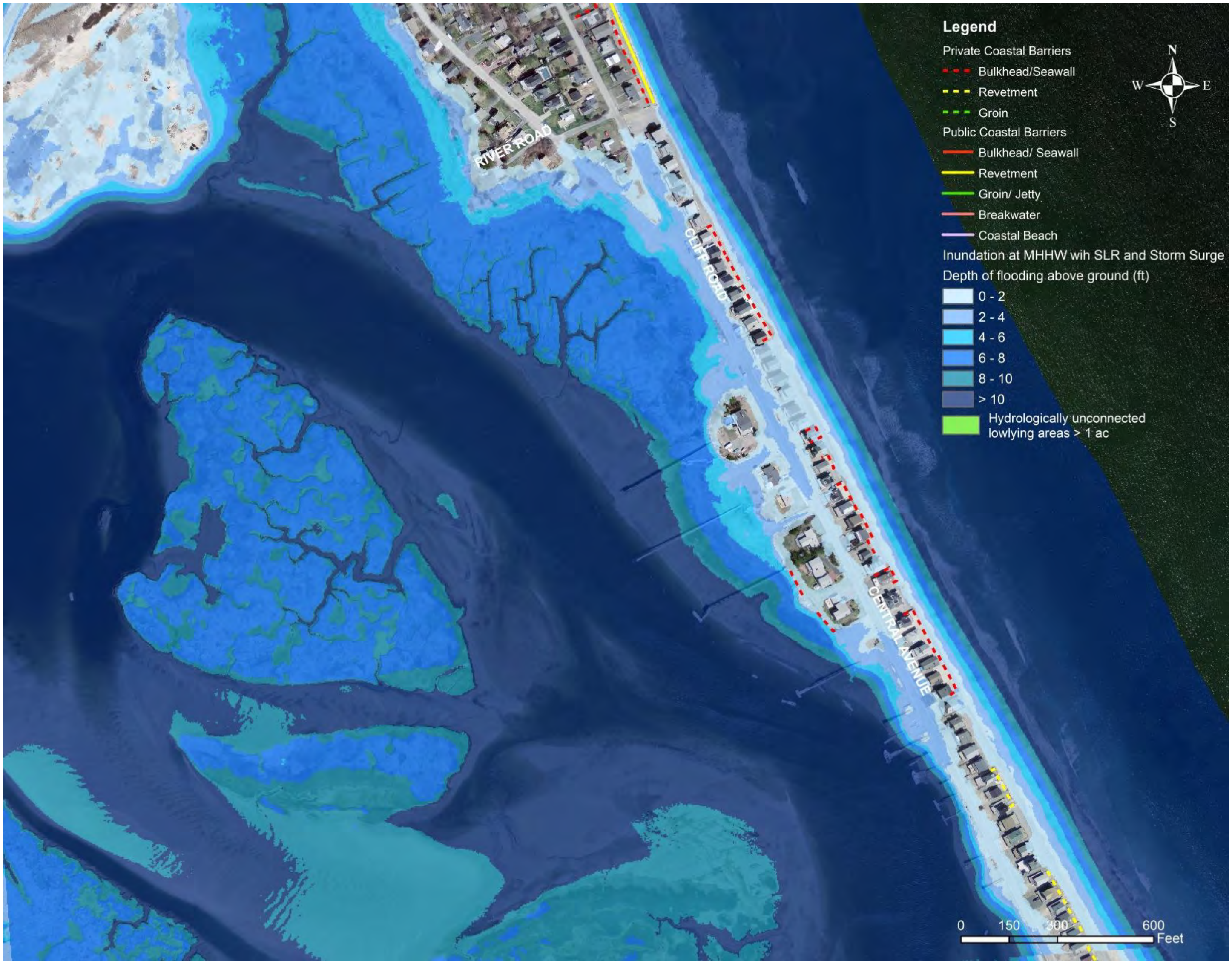
SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Central Avenue, Humarock, Scituate 2063
50-year Time Horizon



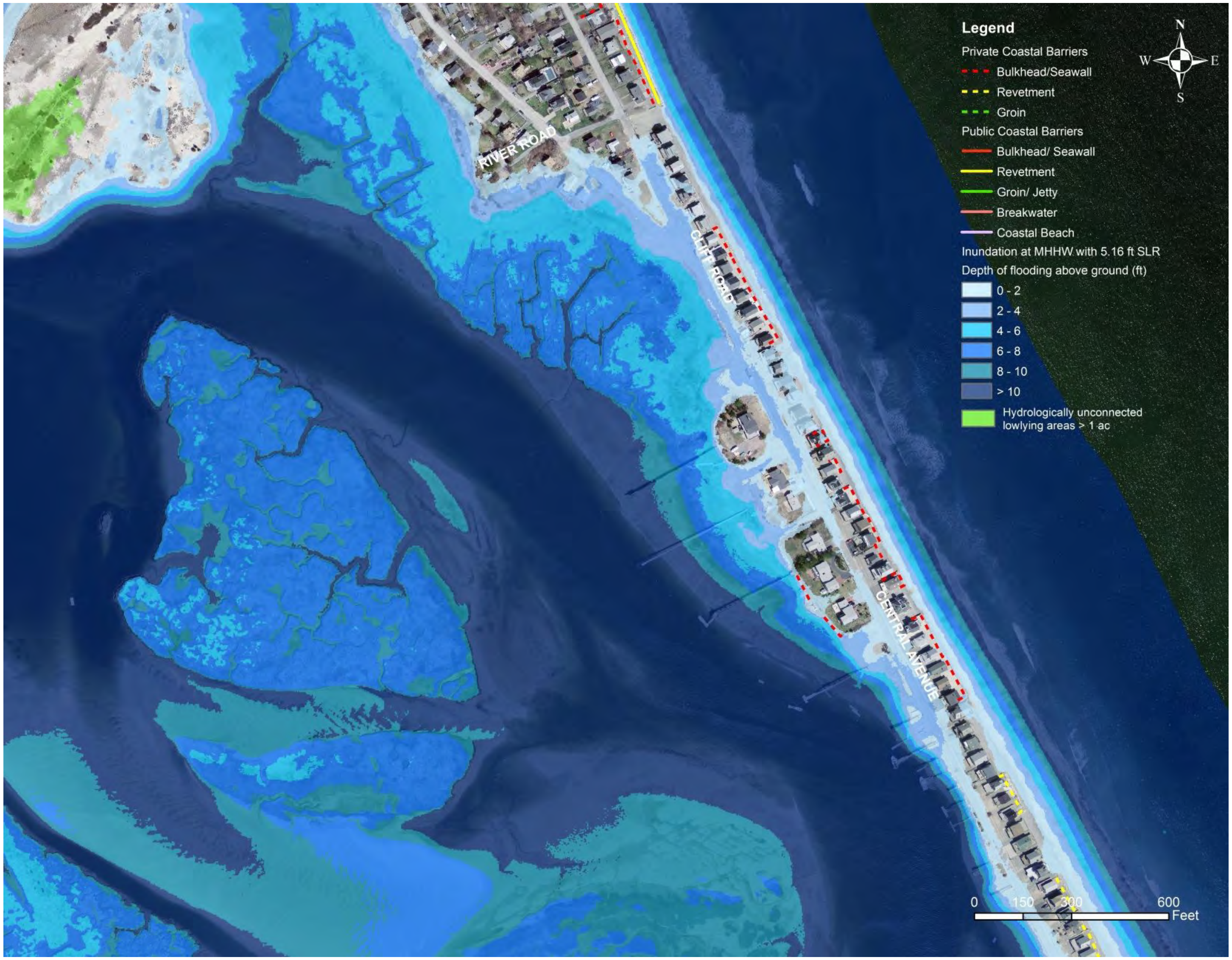
SLR of 2.80 ft. by 2063

Central Avenue, Humarock, Scituate 2063
50-year Time Horizon



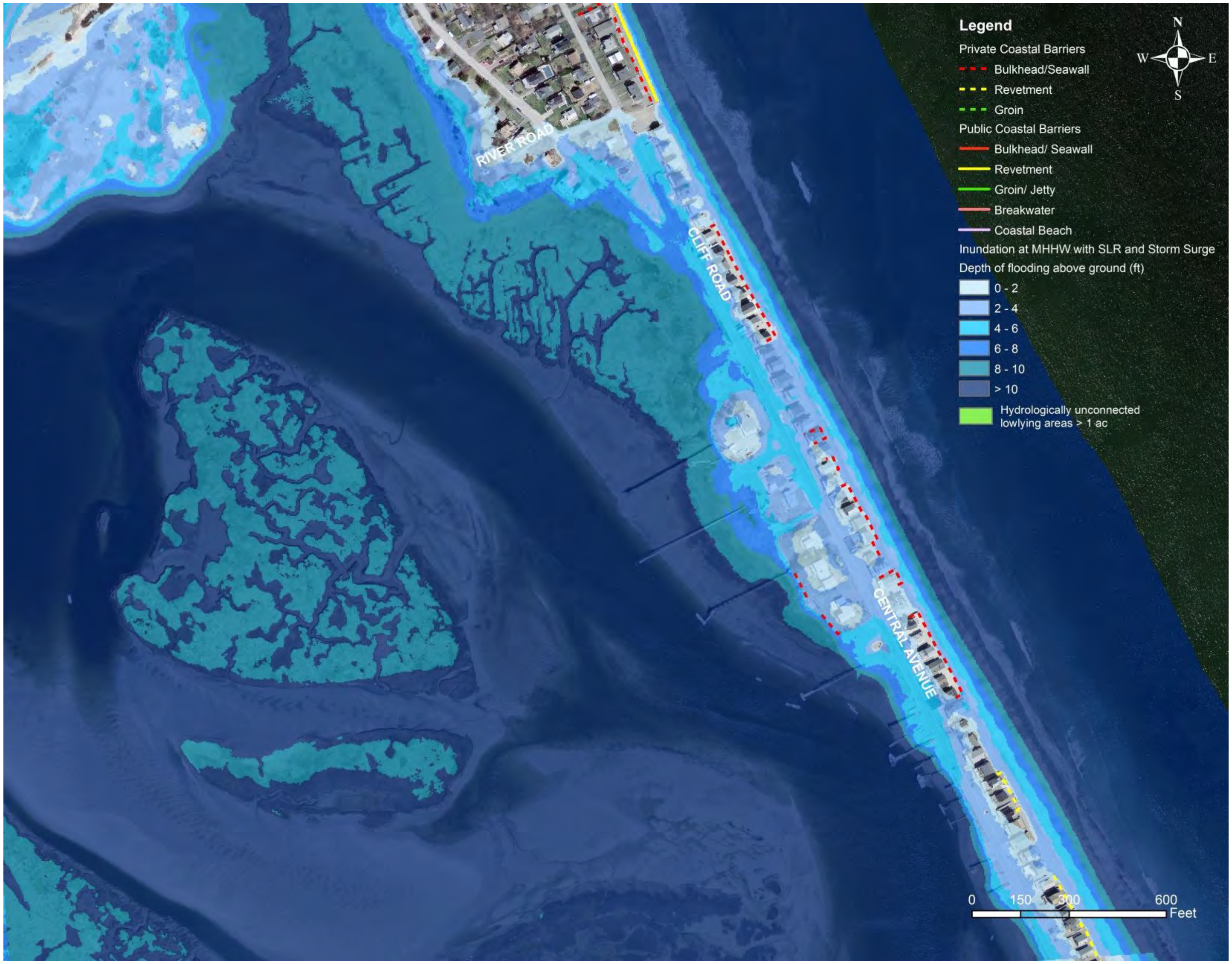
SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Central Avenue, Humarock, Scituate 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088

Central Avenue, Humarock, Scituate 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering
Central Avenue Looking North, Humarock, Scituate by 2088 (75-years) with SLR and Storm Surge

2088

Present

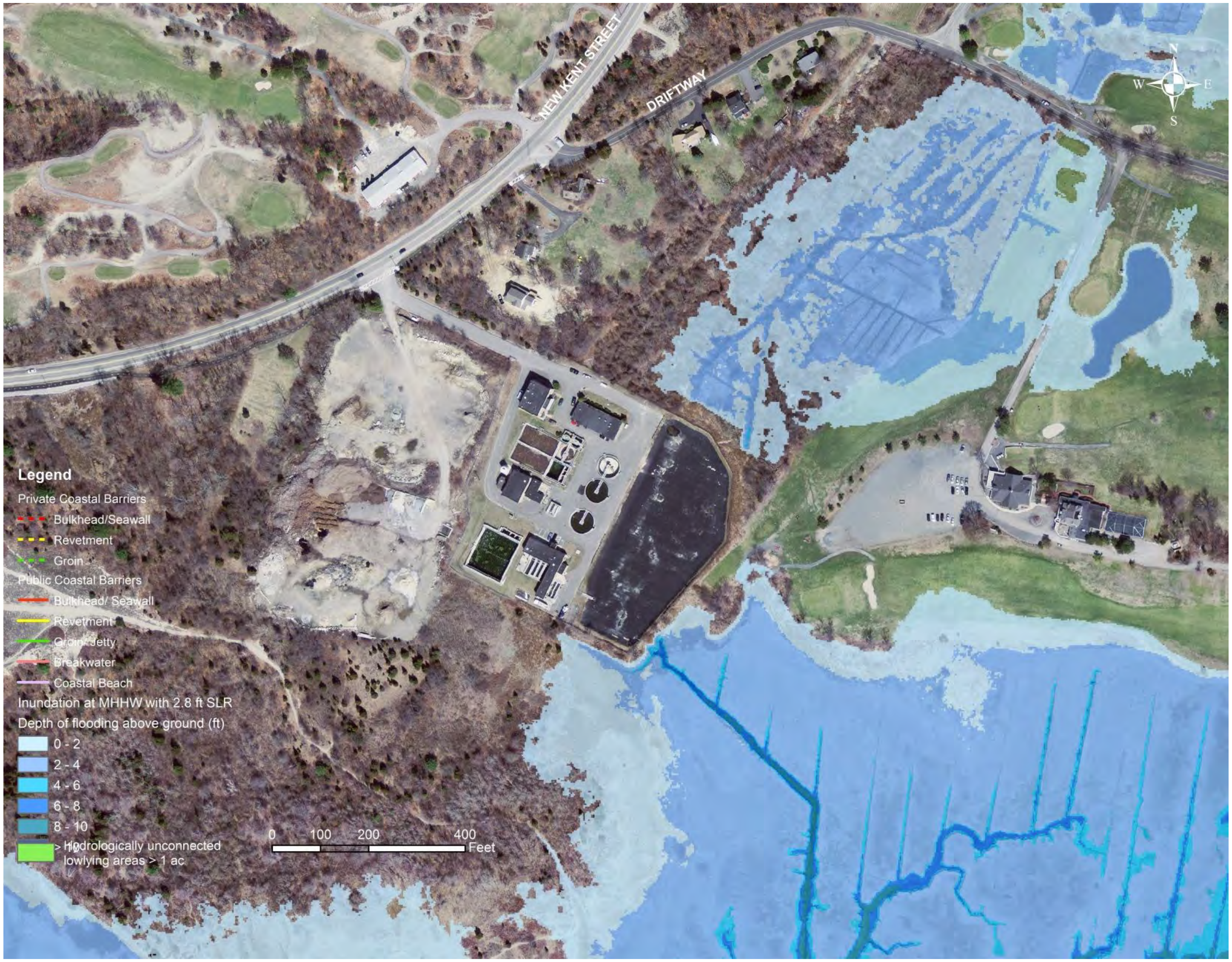
Wastewater Treatment Plant, Scituate
25-year Time Horizon

SLR of 1.08 ft. by 2038

Wastewater Treatment Plant, Scituate
25-year Time Horizon

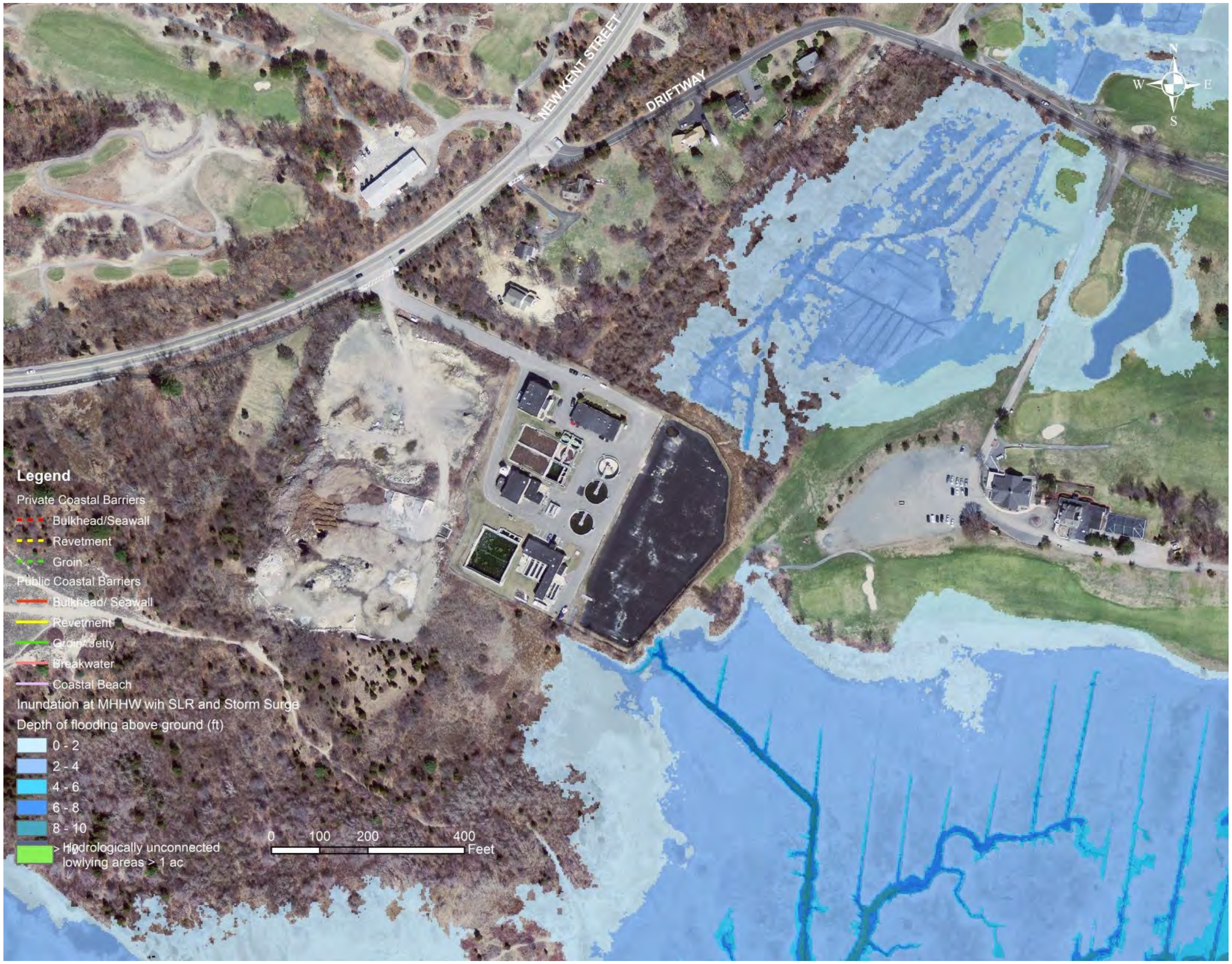
SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Wastewater Treatment Plant, Scituate
50-year Time Horizon



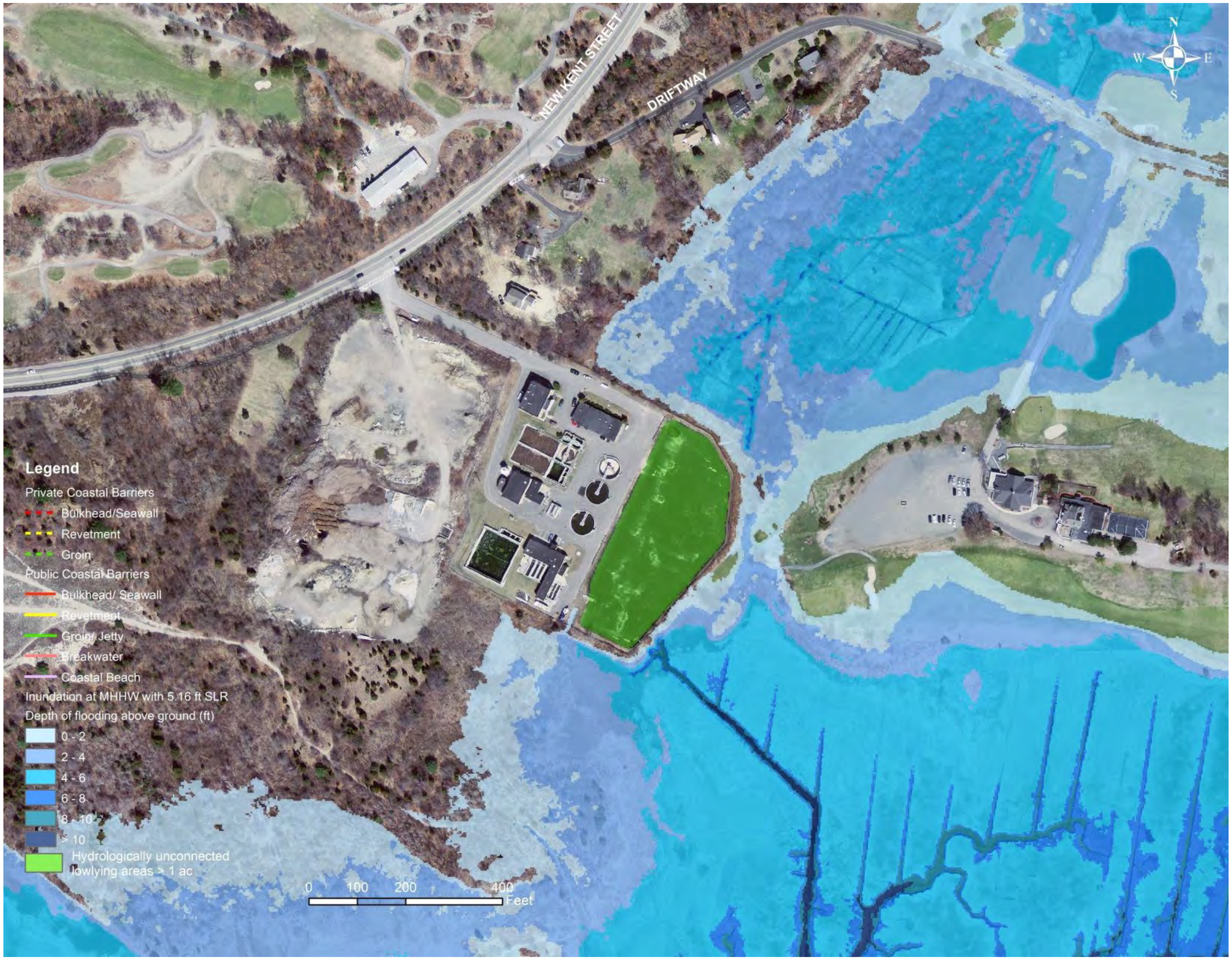
SLR of 2.80 ft. by 2063

Wastewater Treatment Plant, Scituate
50-year Time Horizon



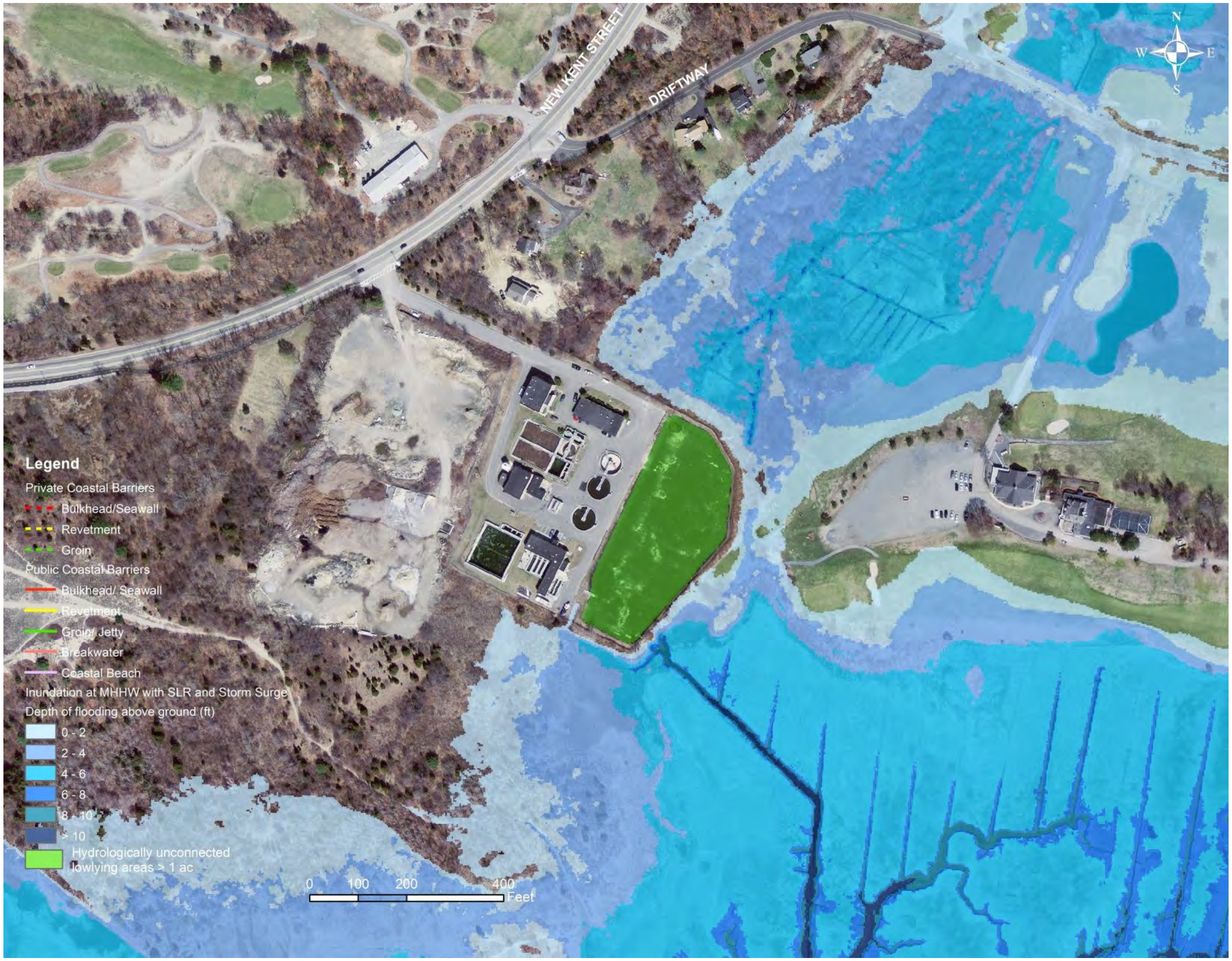
SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Wastewater Treatment Plant, Scituate
75-year Time Horizon



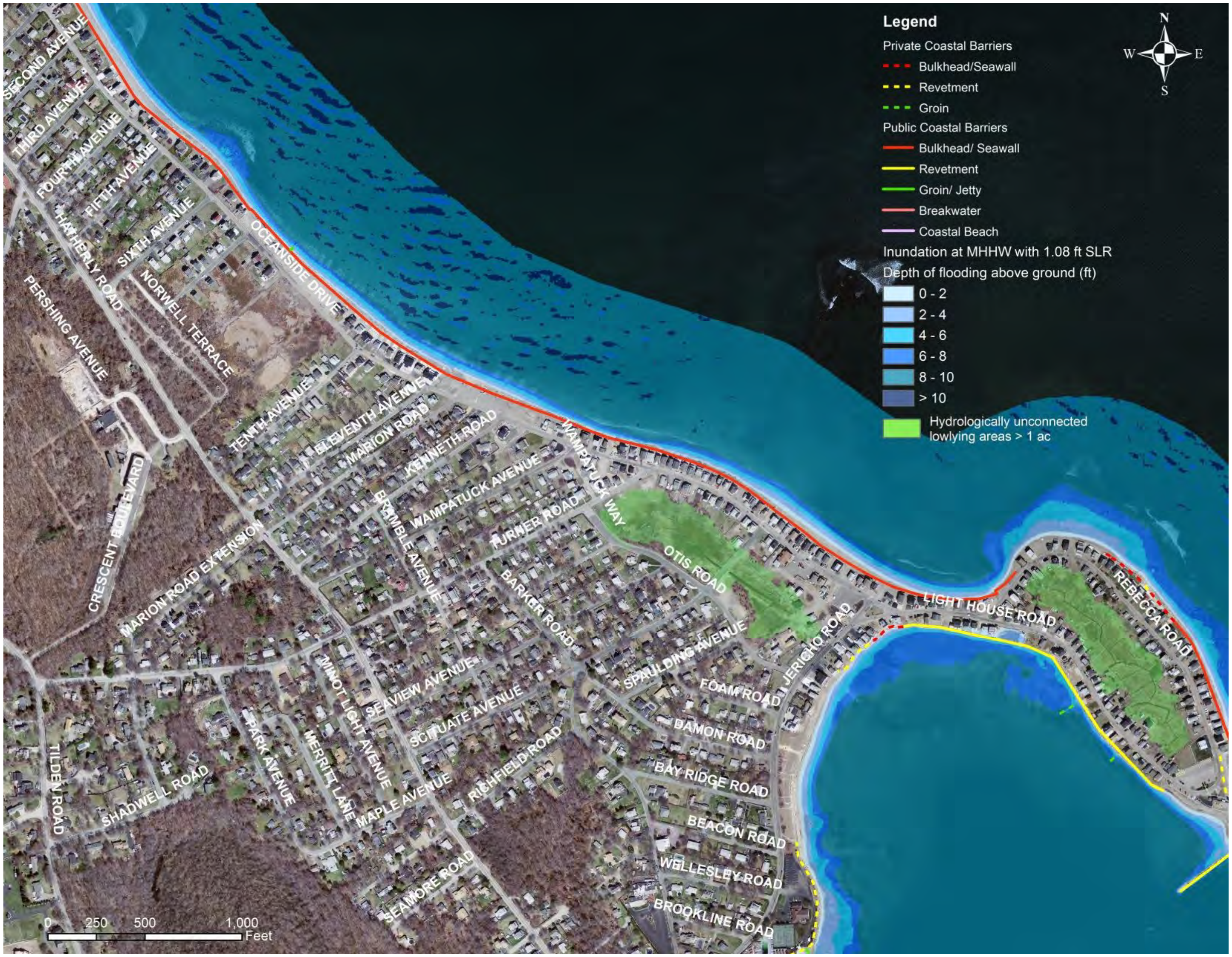
SLR of 5.16 ft. by 2088

Wastewater Treatment Plant, Scituate
75-year Time Horizon



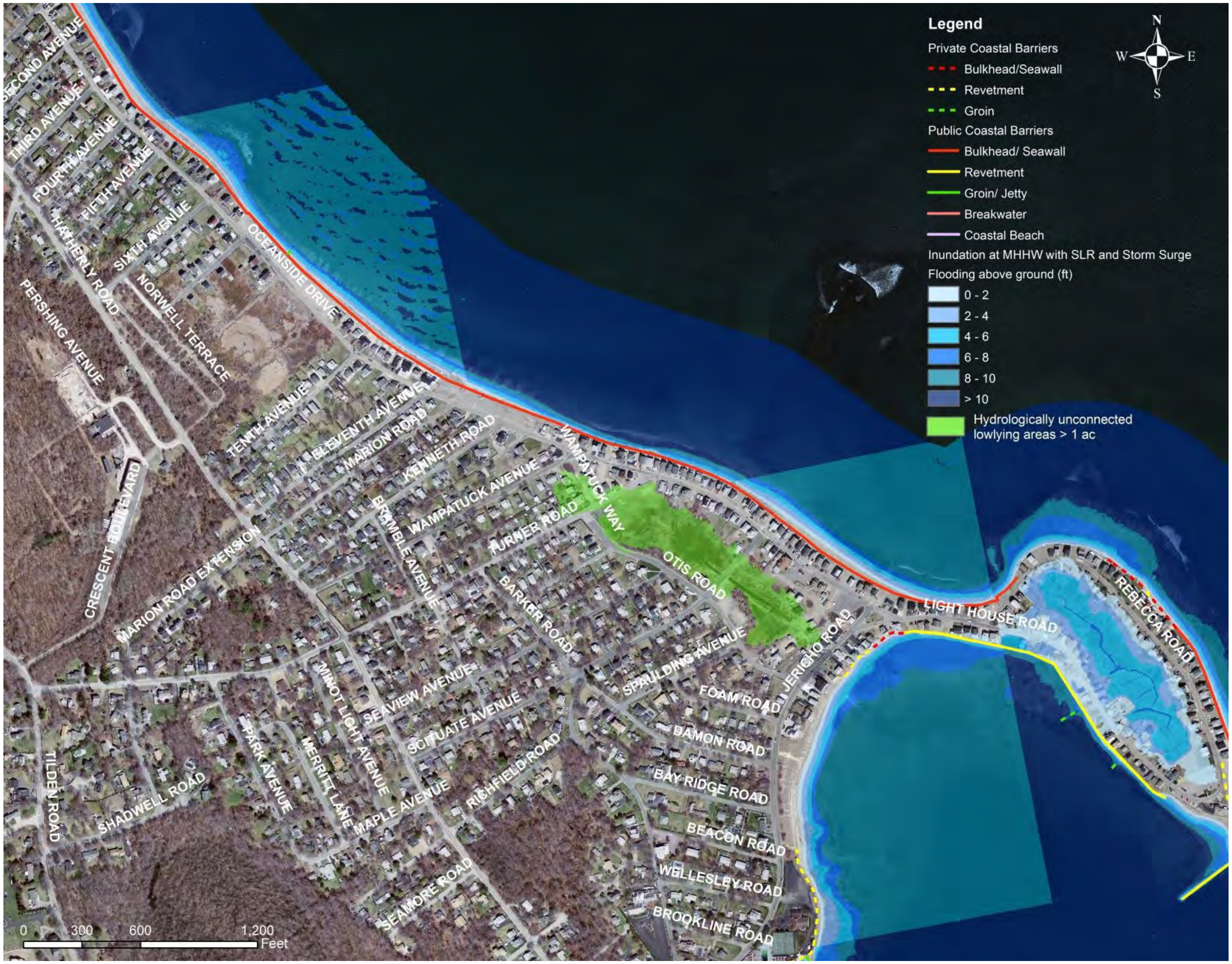
SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

The "Avenues", Scituate
25-year Time Horizon



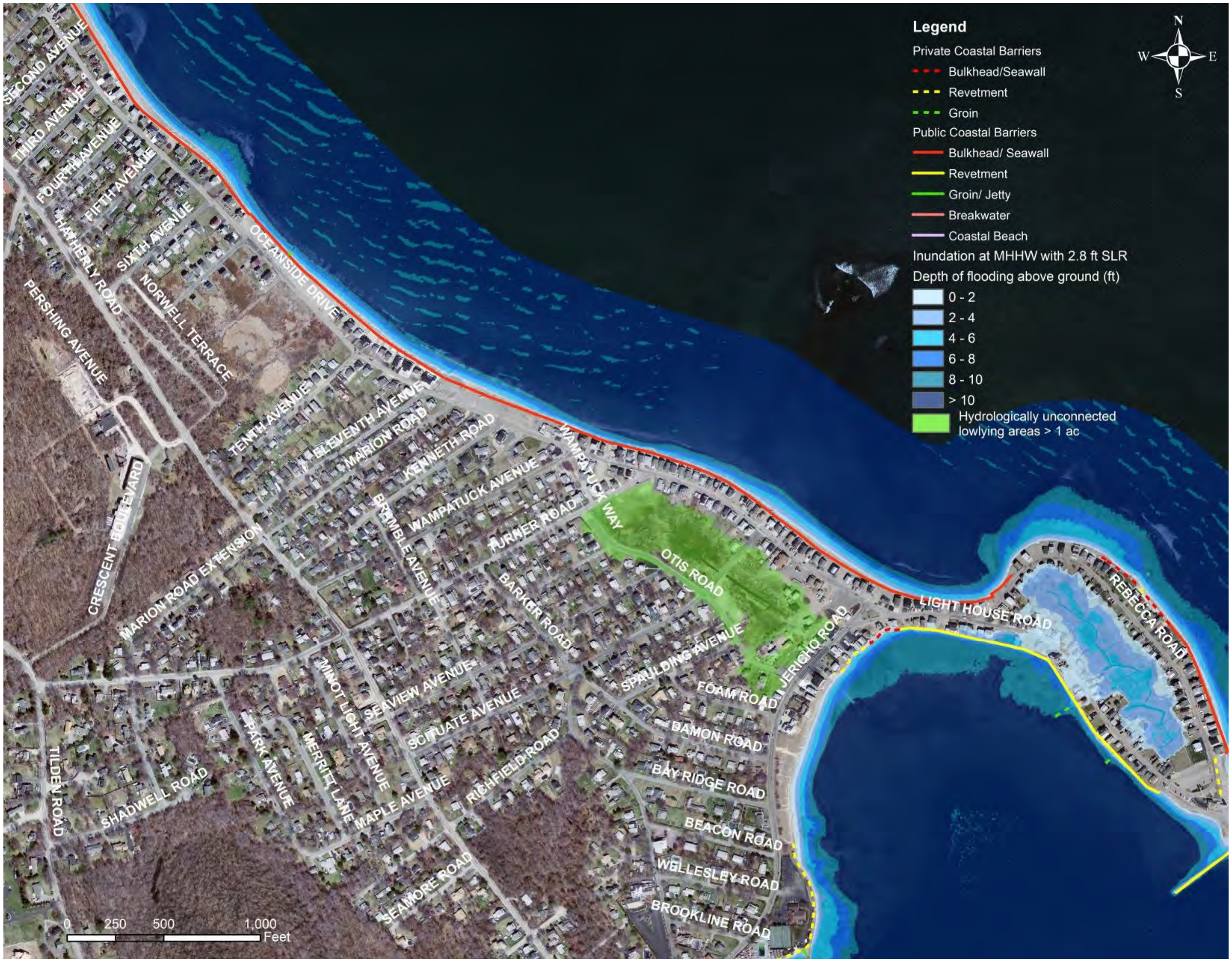
SLR of 1.08 ft. by 2038

The "Avenues", Scituate
25-year Time Horizon



SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

The "Avenues", Scituate
50-year Time Horizon



SLR of 2.80 ft. by 2063

The "Avenues", Scituate
50-year Time Horizon

SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

The "Avenues", Scituate
75-year Time Horizon

SLR of 5.16 ft. by 2088

The "Avenues", Scituate
75-year Time Horizon

SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering
Jericho Road, Scituate (looking West) by 2088 (75-years) with SLR and Storm Surge

2088

Present

3D Rendering
Edward Foster Bridge, Scituate (looking West) by 2088 (75-years) with SLR and Storm Surge

2088

Present

3D Rendering
Scituate Community Center at the Harbor, Scituate (looking East) by 2088 (75-years) with SLR and Storm Surge

2088

Present

Scituate - Natural Resources Impacts

Tidal Salt Marsh

Tidal salt marshes are an important part of the local coastal ecosystem. They are an essential element of the aquatic food web, provide valuable habitat for many birds and other aquatic species, and they also provide protection from the effects of waves and currents. Sea level rise projections for Scituate include potential negative impacts to tidal salt marsh in various areas of town including: salt marsh associated with Musquashcut Pond and its connection to Cohasset Harbor in North Scituate, the salt marshes along Kent Street and Edward Foster Road, the salt marsh system west of Humarock, and the extensive salt marsh system associated with the North River estuary. Each of these tidal salt marsh ecosystems will experience higher daily tidal ranges as sea levels rise.

Survival of the tidal marsh ecosystem depends on a balance between forces creating marsh vertical growth such as organic sediment accumulation and the forces causing deterioration of the marsh such as subsidence, sea level rise, and wave erosion. The impact to the marsh ecosystems in Scituate will be negative if tidal salt marsh elevations cannot keep pace with sea level rise through natural or assisted vertical growth of the marsh platform which includes plant matter accumulation such as root production and decomposition of dead plants. If the vertical growth of tidal salt marsh cannot keep pace with the rising sea levels, the result will be more flooding of the marshes which will cause the plants to die, and marsh ecosystem will eventually convert to intertidal mudflat or subtidal open water. Further study will be required to determine how sea level rise will affect the tidal salt marsh ecosystem.

Beaches

Beaches along the Scituate coast line will be affected by rising sea levels. Tidal elevations will increase on a daily basis. If beaches are not otherwise nourished and raised, there could be partial or complete loss of some ocean front beaches at high tides. In addition, the potential for increased frequency and intensity of storm events can also lead to additional deterioration of ocean front beaches.

Wildlife

If rising sea levels cause a loss of tidal salt marsh and beach habitat, there will likely be a great effect on the habitat for coastal wildlife including birds, and fin fish that utilize the bays and estuaries for spawning. Interruption of spawning ground and resulting decline in shellfish and fin fish could have major economic impact. Impacts to mudflats, which provide key habitat for migratory shorebirds, crabs, mollusks, and fish, may also have significant ecological and economic consequences.

Shellfish and Aquaculture

The mud flats and salt marshes provide prime habitat for a thriving shellfish industry serving both commercial and recreational interests. Major shellfish species include softshell clams, mussels, razor clams and quahogs. The impacts to shellfish due to rising sea levels and water temperatures are not well understood at this time. Some effects that could negatively affect the shellfish population and industry include:

- Deeper waters will reduce time available to access and work shellfish beds.
- Deeper waters may alter patterns of predation and exposure.
- Rising water temperatures could affect shellfish growth patterns and timing.
- Rising water temperatures could increase potential for disease.

- Changes to existing tidal salt marshes could change nutrient levels in the water which could affect shellfish growth.

It should be noted that changes in sea level and water temperature are occurring at a slow rate, so there is potential for shellfish to evolve and adapt to meet the changing conditions.

Scituate – Infrastructure Impacts

Roadways and Bridges
The inundation maps for Scituate for the various sea level rise and storm surge projections indicate that a number of roads along the coast will be affected by higher tides and storm events, especially at the 75 year scenario. Some of the roads which will be greatly affected by rising sea levels alone in 75 years (excluding the effects of storm surge) include:

- Front Street commercial area at Scituate Harbor
- Cole Parkway and parking lots at Scituate Harbor
- Central Avenue and other roads on Humarock
- Bayberry Road
- Edward Foster Road
- Jericho Road
- Turner Road
- Egypt Avenue
- Surfside Road

Major bridges such as the Route 3A Bridge over the North River and the Edward Foster Road Bridge do not appear to get flooded, even at the 75 year projection with storm surge. However, the approach roads to the Edward Foster Road Bridge do get flooded.

In the “Avenues” section of Shore Acres, as well as other areas behind ocean-front seawalls, the inundation maps do not show the effect of wave action during the storm surge event. The storm surge is based on the mean level of surge, not the highest wave heights. With no changes to the top of sea wall elevations, the higher wave heights will overtop the existing sea walls and cause flooding and road damage behind the wall, much as it does today, but worse.

Travel on flooded roadways is generally not possible. Closed roads greatly impact emergency access during storms due to the need to deal with flooding, downed wires, house fires and other related events. Much like what happens today, road traffic will have to be curtailed during storm events. However, some of these roads will also be affected in the future during normal daily high tide cycles which will not be acceptable for the town’s normal operations. In addition, increase flooding of roads will lead to significant increases in the rate of deterioration of the road structure itself.

Coastal Stabilization Structures
There are numerous coastal stabilization structures along the Scituate coastline, including concrete sea walls, stone revetments, groins, and breakwaters. Rising sea levels, combined with the effects of the projected higher frequency and intensity of coastal storms, will result in more damage to coastal stabilization structures and more over-topping of the structures due to storm wave action. Many of the existing sea walls experience over-topping today during major

storms. Over-topping, and the associated damage of structures and public infrastructure located behind sea walls, will only increase as sea levels rise in the future.

Higher tidal elevations will result in deeper water depths in front of coastal stabilization structures during high tides, which will result in larger ocean waves hitting the structures, which will in turn accelerate structural damage of the structures and increase the rate of erosion in front of the structures. Deeper water will increase not only the force of wave impacts, but also the frequency of interaction between the wave energy and the structure, further eroding the beach fronting the seawall. This self-reinforcing cycle (eroding beach creates deeper water creates more wave interaction creates eroding beach) ultimately leaves the seawall/structure without adequate coastal beach to provide stability or protection during a storm. Currently, due to coastal erosion and sea level rise, many areas have little or no beach in front of structures constructed in the 1930s through 1950s which can absorb wave energy. In these areas, the structures are the first and only lines of coastal defense. Where this is the case, increasing the height of seawalls may not be the best solution. A better solution is to raise structures while recreating landform in front of the structures to help absorb wave energy and to stabilize the structures.

Wastewater Treatment Plant

The Scituate Wastewater Treatment Plant located on the Driftway does not appear to be affected by rising sea levels. Even at the 75 year projection with storm surge, the plant and access road are not inundated. Note that the storm surge projections do not include the effect of wave action above the mean storm surge level. However, given that the location of the plant is protected from direct wave action, the effects of wave action will be minimal or non-existent.

Underground Infrastructure Systems

There are many buried piping systems and utilities in the roads including sanitary sewer, storm sewer, water and gas. Electrical, telephone and cable television systems appear to be pole-mounted in all of the coastal roadways that are affected by flooding. All of the roadways that are shown to be impacted by rising sea levels and storm surge are currently susceptible to flooding and damage during storm events. Increased flooding during high tides and storm events will increase the rate of deterioration of any underground infrastructure and increase the possibility of wash outs that could cause unsafe conditions and service interruptions.

In the “Avenues” of Shore Acres, there is a sewer pump station that could be affected by rising sea levels if the pump electrical systems are inundated. Further study is required to determine what the impact of rising sea levels will be to the pump station.

There are some remaining private septic systems near the coast, particularly in Humarock, not connected to the town’s wastewater treatment plant. Rising sea levels could affect septic systems if ground water elevations near the coast rise due to rising sea levels. The higher ground water levels could make septic systems adjacent to the coast line noncompliant, even potentially causing breakout and contamination.

In the village of Scituate Harbor, there is an underground drainage system which is likely to be affected by sea level rise. It is not within the scope of this project to determine which culverts or underground drainage systems, if any, could be affected by rising sea levels.

Scituate – Transportation Impacts

The MBTA Greenbush and North Scituate commuter rail stations do not appear to be affected by rising sea levels. The MBTA track passes through a low lying marshy area near where it crosses Hollett Street. However, it appears that the track bed is constructed high enough that it may not be subject to flooding. Public school and transit bus routes utilizing roads subject to flooding from sea level rise and storm surge will be affected and may need to be temporarily or permanently re-routed.

Scituate - Emergency Access Impacts

The inundation maps for Scituate for the various sea level rise and storm surge projections indicate that flooding and closure of Edward Foster Road and Central Avenue on Humarock will affect emergency access to residents of the First, Second and Fourth Cliff sections of Scituate. If access roads to these areas are blocked off, then there is no other emergency egress route to these sections of town. It should be noted, that these roads currently do get flooded and closed during astronomical tidal and storm events, so the town already does have a system to deal with emergency access in these locations. However, if nothing is done to change the roads, the frequency and duration of flooding and closures can be expected to increase, putting more strain on the Police, Fire, and Public Works Departments.

Sea Level Rise Impacts -Town of Marshfield, MA

1. Town-wide inundation maps for 2038 (25 years), 2063 (50 years) and 2088 (75 years) with sea level rise only and sea level rise combined with storm surge

2. Sea Level Rise and Storm Surge Maps for specific areas
    a. Wastewater Treatment Plant/Dyke Rd Area
    b. Brant Rock Area
    c. Ocean Street and Winslow Street Area
    d. Rexhame Beach Area

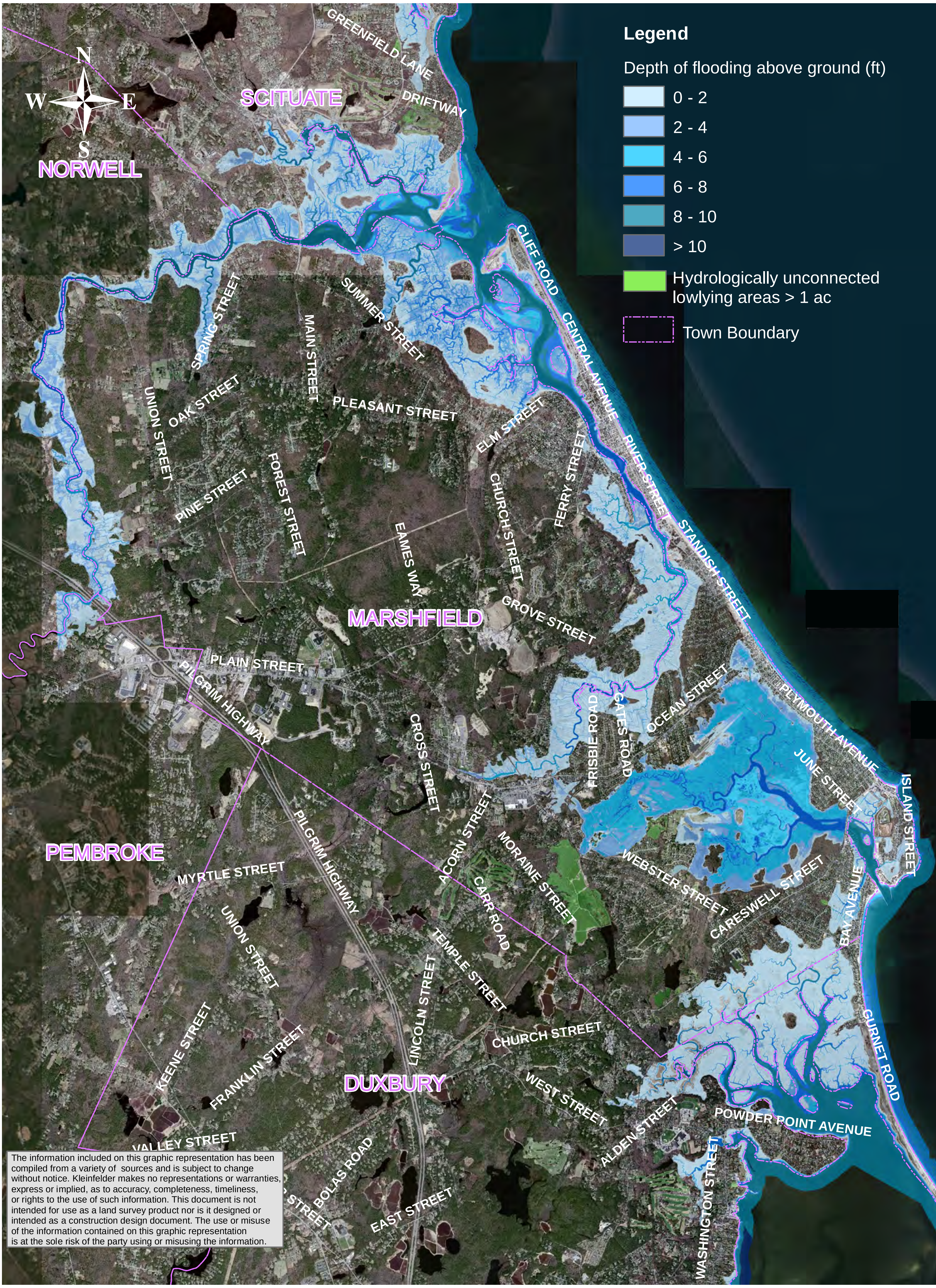
3. 3D renderings of selected areas for 2088 (75 years) with sea level rise and storm surge combined

4. Natural Resource Impacts
    - Tidal Salt Marshes
    - Beaches
    - Wildlife

5. Infrastructure Impacts
    - Roadways and Bridges
    - Coastal Stabilization Structures
    - Wastewater Treatment Plant
    - Underground Infrastructure Systems

6. Transportation Impacts

7. Emergency Access Impacts



SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2038 (25 YEARS)
TOWN OF MARSHFIELD, MA
JULY 2013

Miles
0 0.25 0.5 1

Gulf of Maine Council on the Marine Environment

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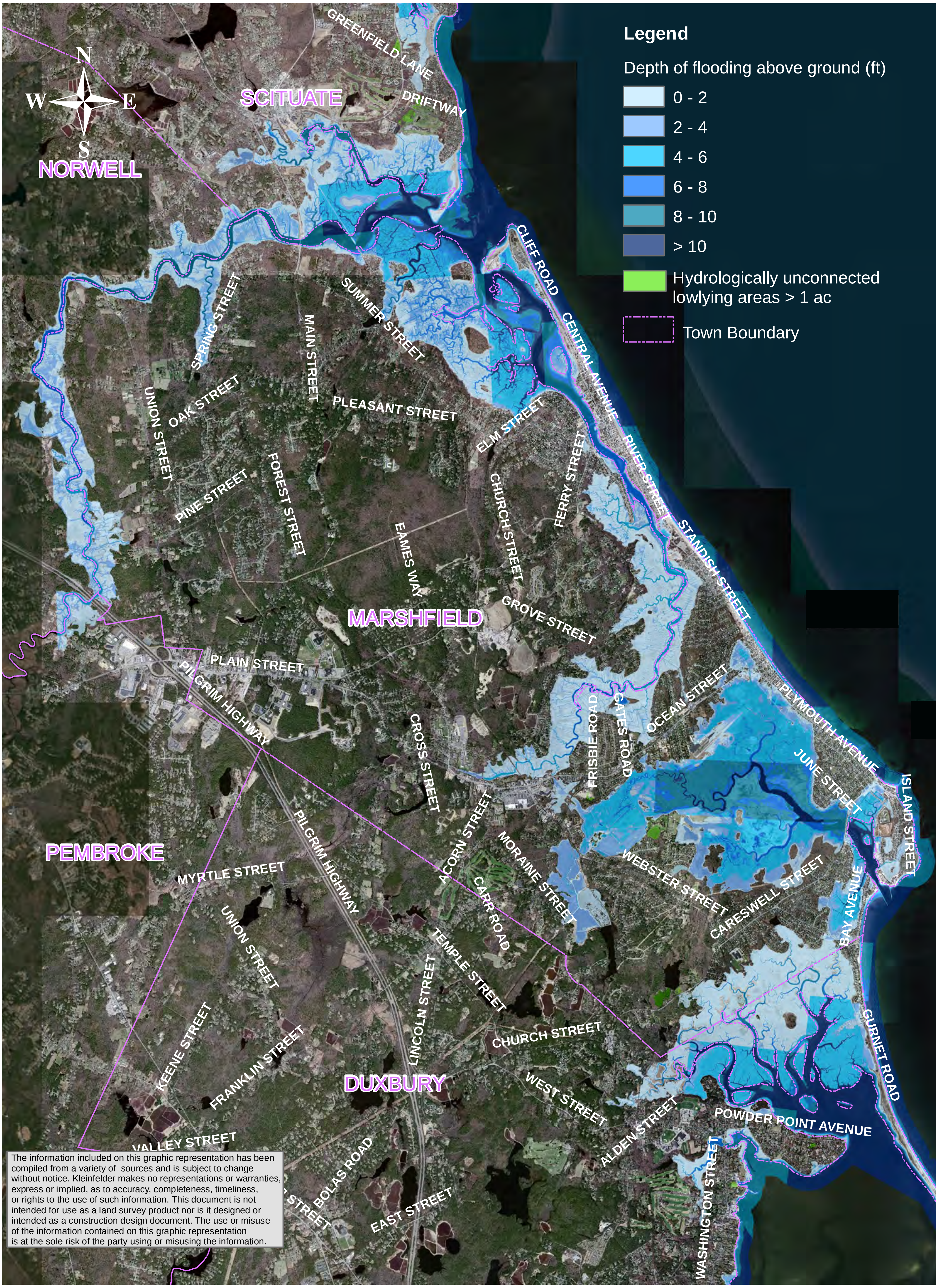

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SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2038 (25 YEARS)
AND STORM SURGE
TOWN OF MARSHFIELD, MA
JULY 2013

Miles
0 0.25 0.5 1

Gulf of Maine Council on the Marine Environment

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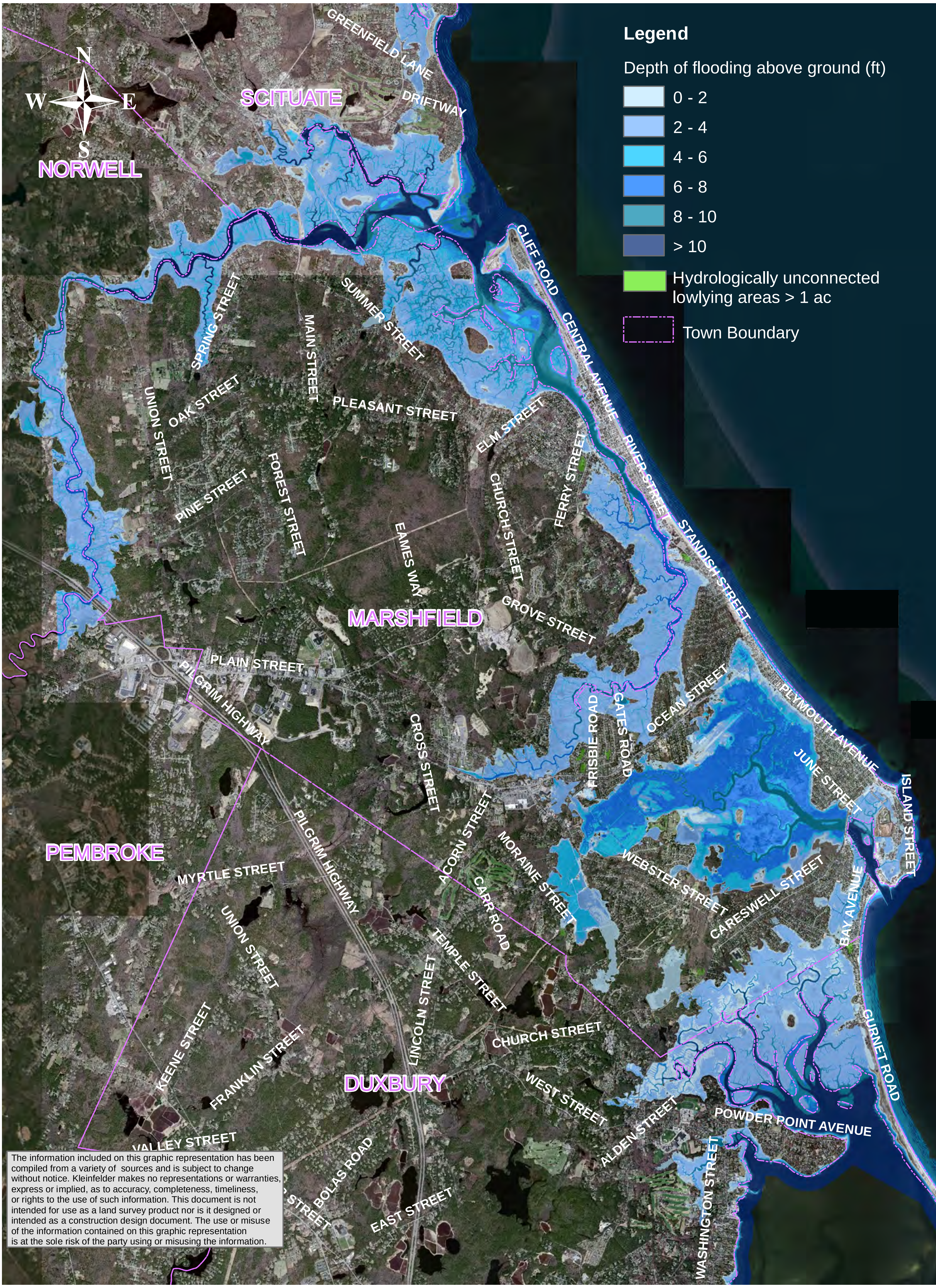

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2063 (50 YEARS)
TOWN OF MARSHFIELD, MA
JULY 2013

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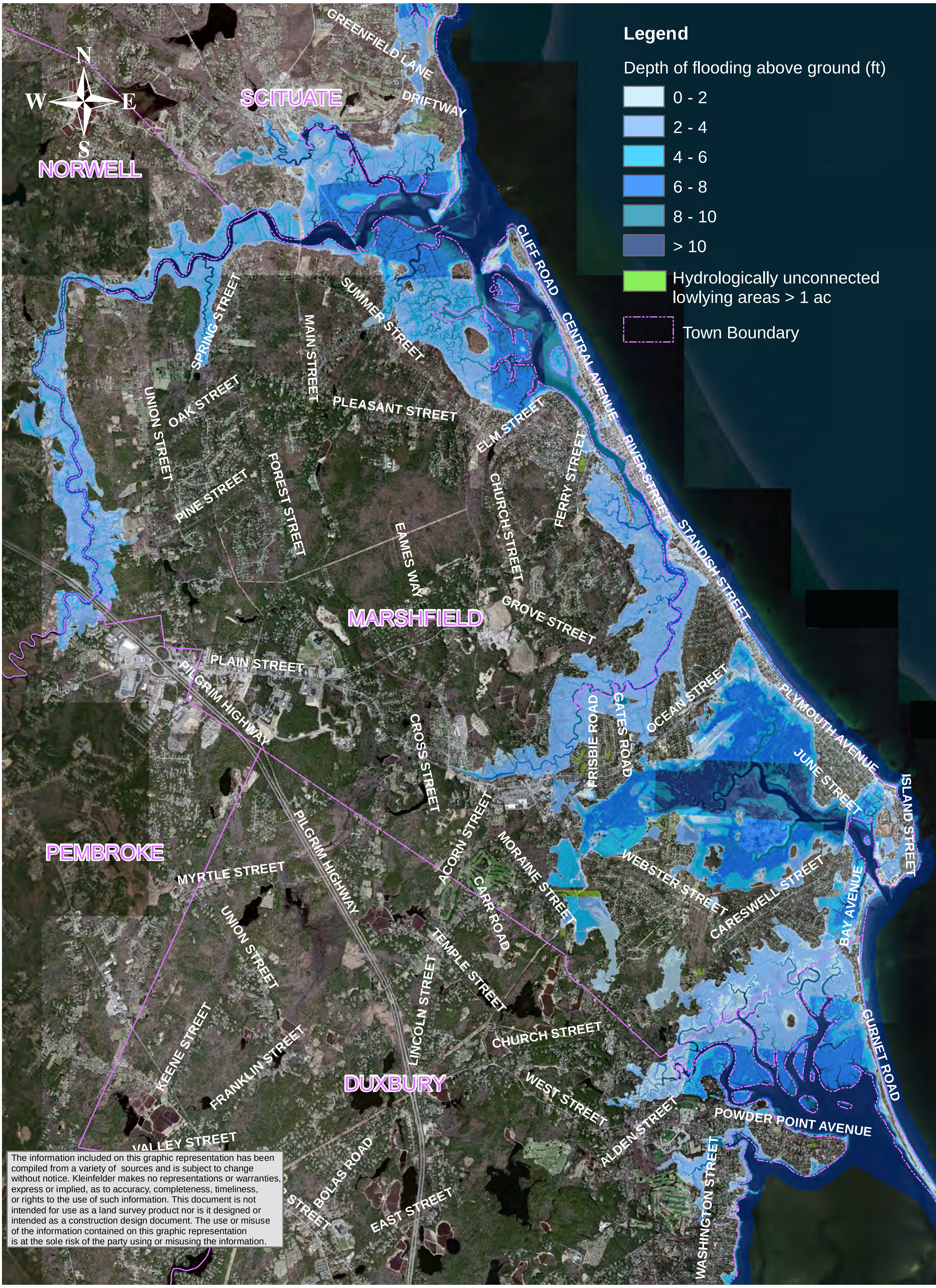

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2063 (50 YEARS)
AND STORM SURGE
TOWN OF MARSHFIELD, MA
JULY 2013

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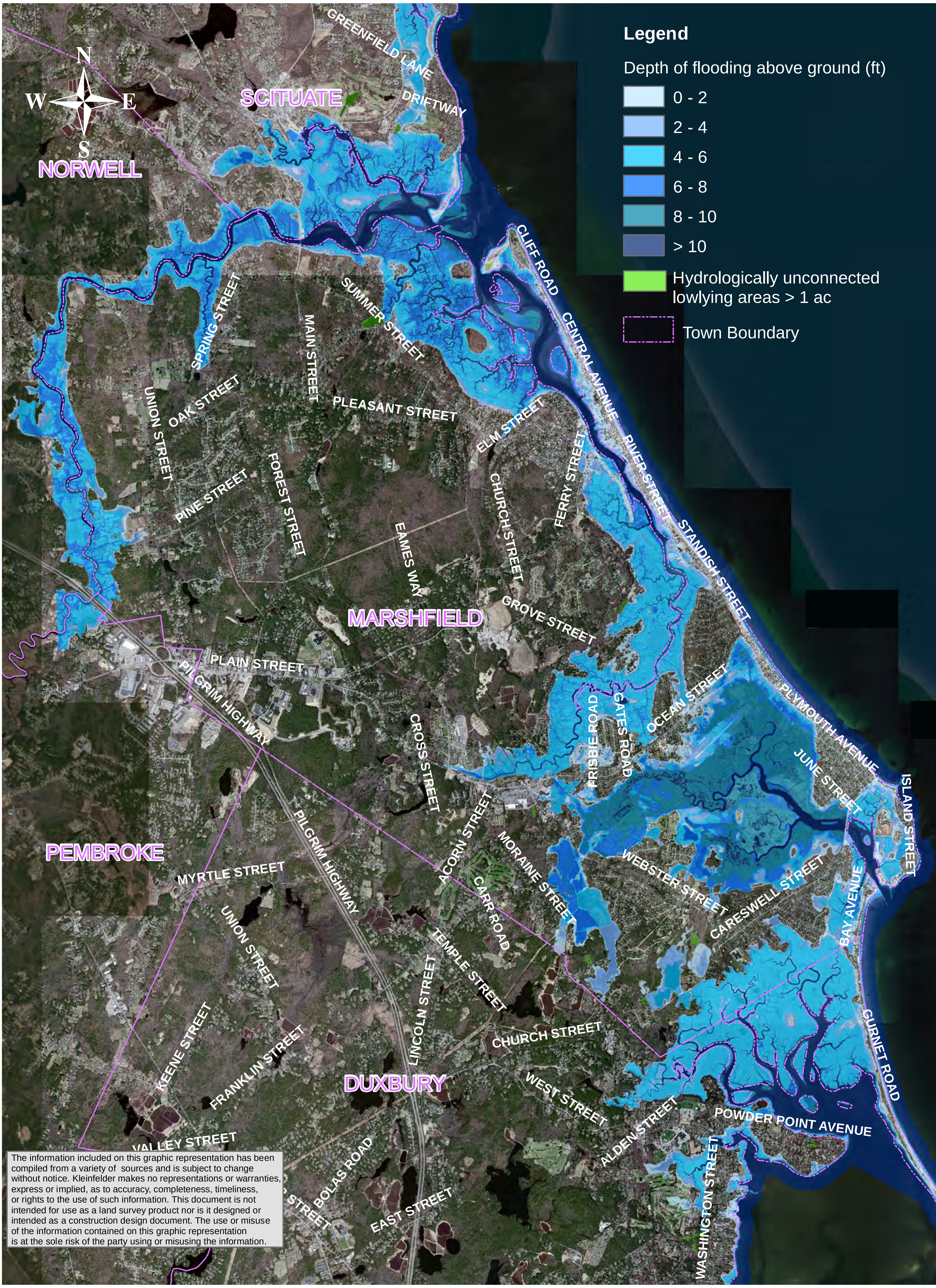

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2088 (75 YEARS)
TOWN OF MARSHFIELD, MA
JULY 2013

Miles
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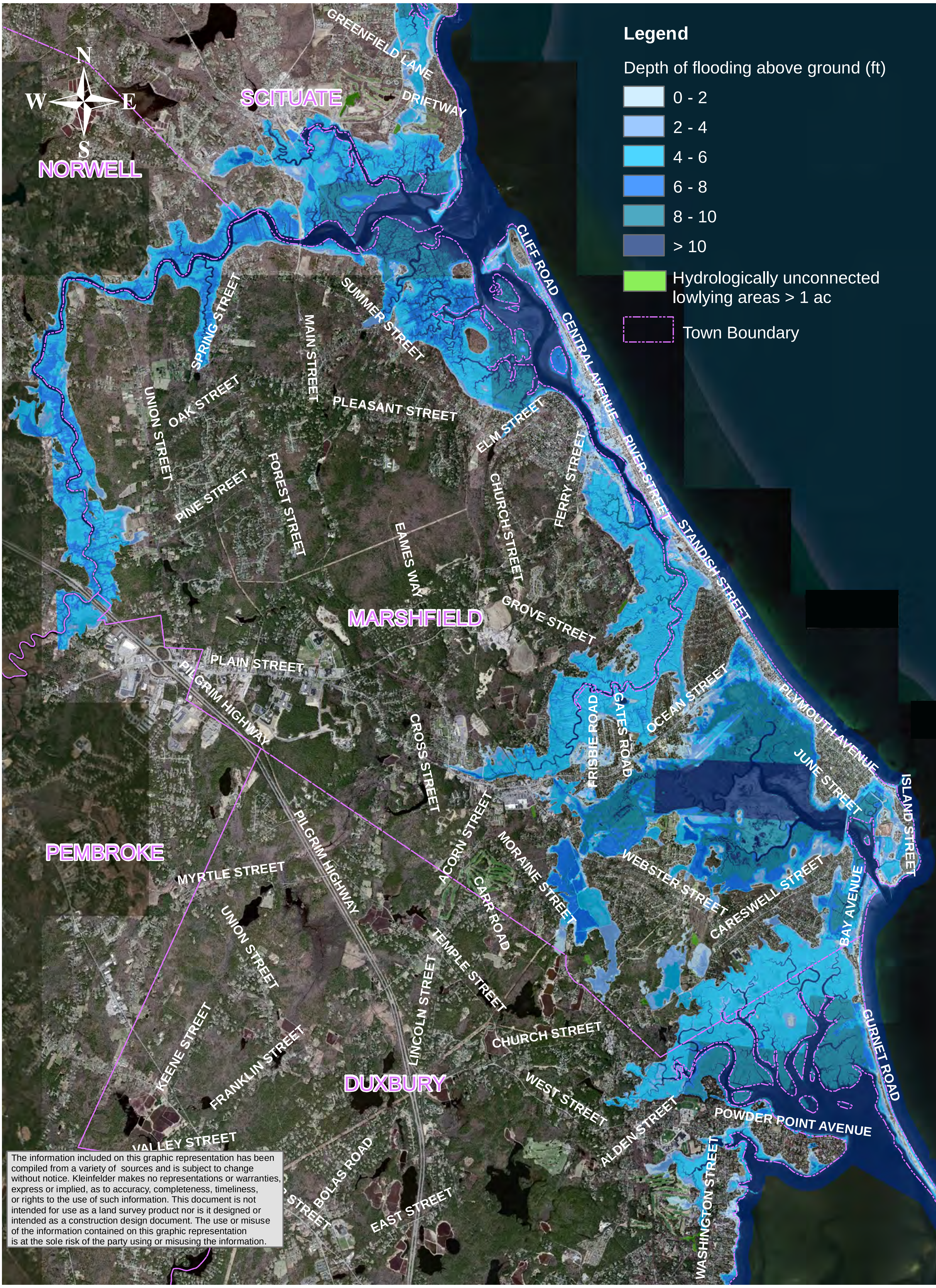

SOUTH SHORE SEA LEVEL RISE STUDY

Miles
0 0.25 0.5 1

SEA LEVEL RISE BY 2088 (75 YEARS)
AND STORM SURGE
TOWN OF MARSHFIELD, MA
JULY 2013

Gulf of Maine Council on the Marine Environment

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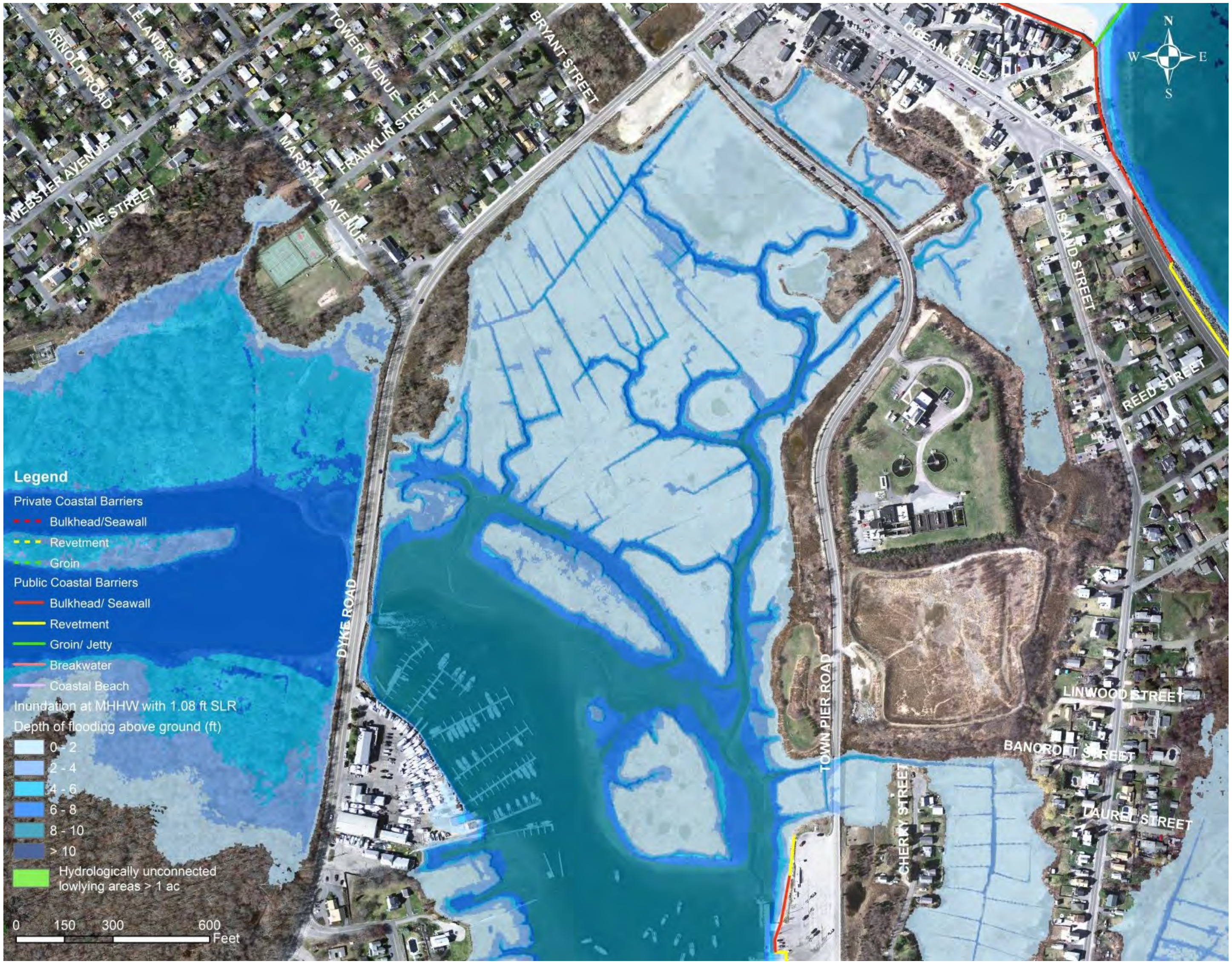
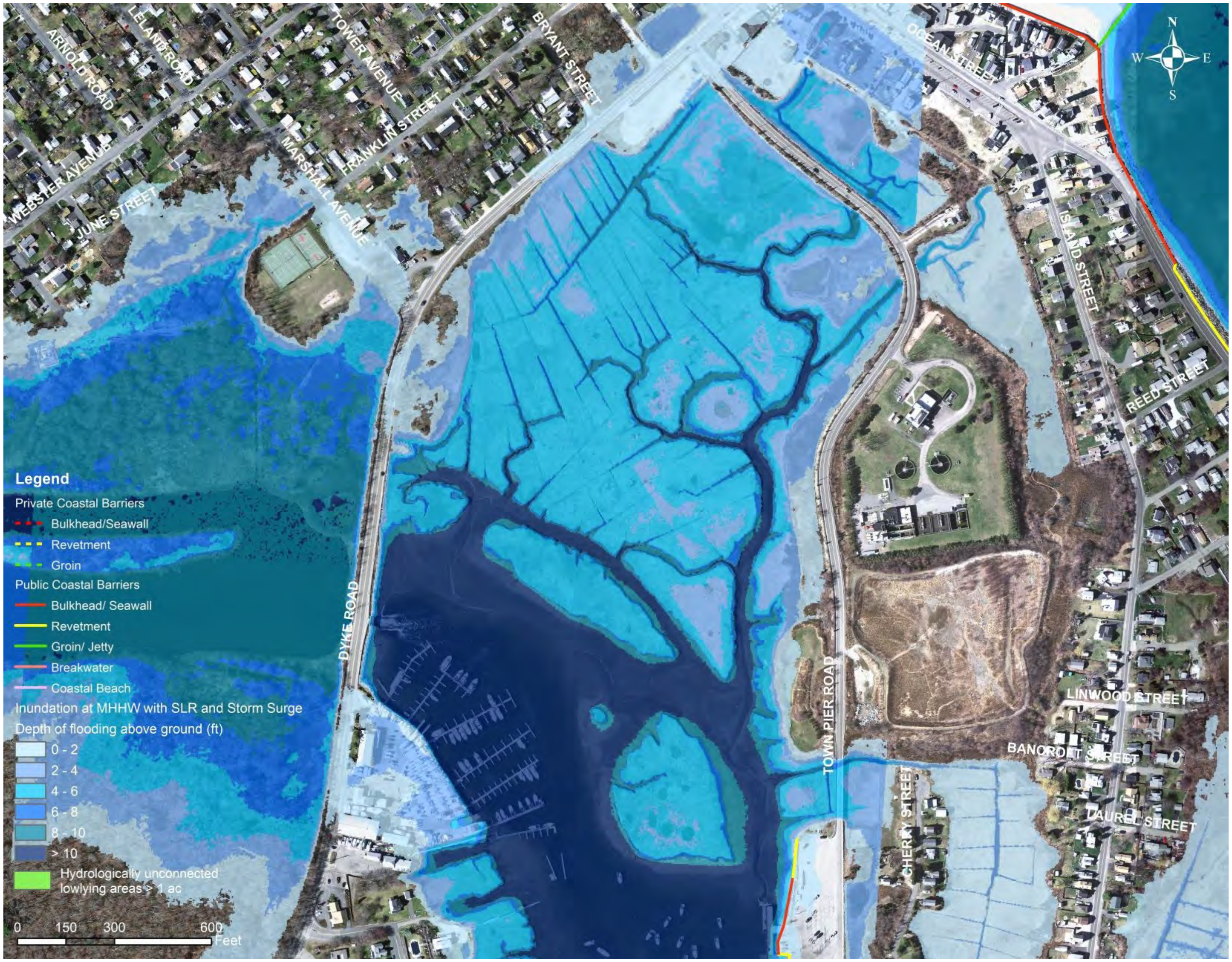
Wastewater Treatment Plant/Dyke Road Area, Marshfield 2038
25-year Time Horizon



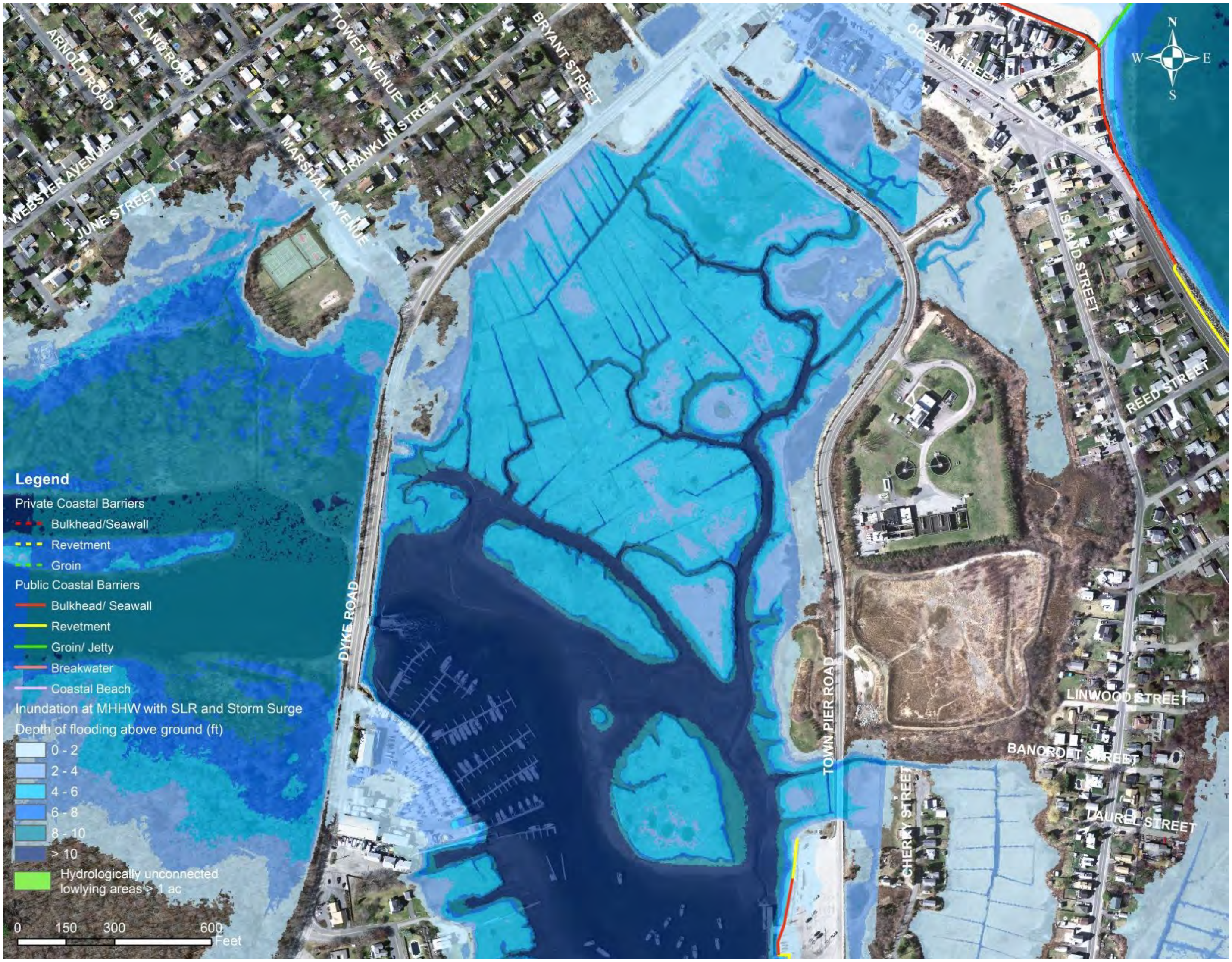
SLR of 1.08 ft by 2088

Wastewater Treatment Plant/Dyke Road Area, Marshfield 2038
25-year Time Horizon



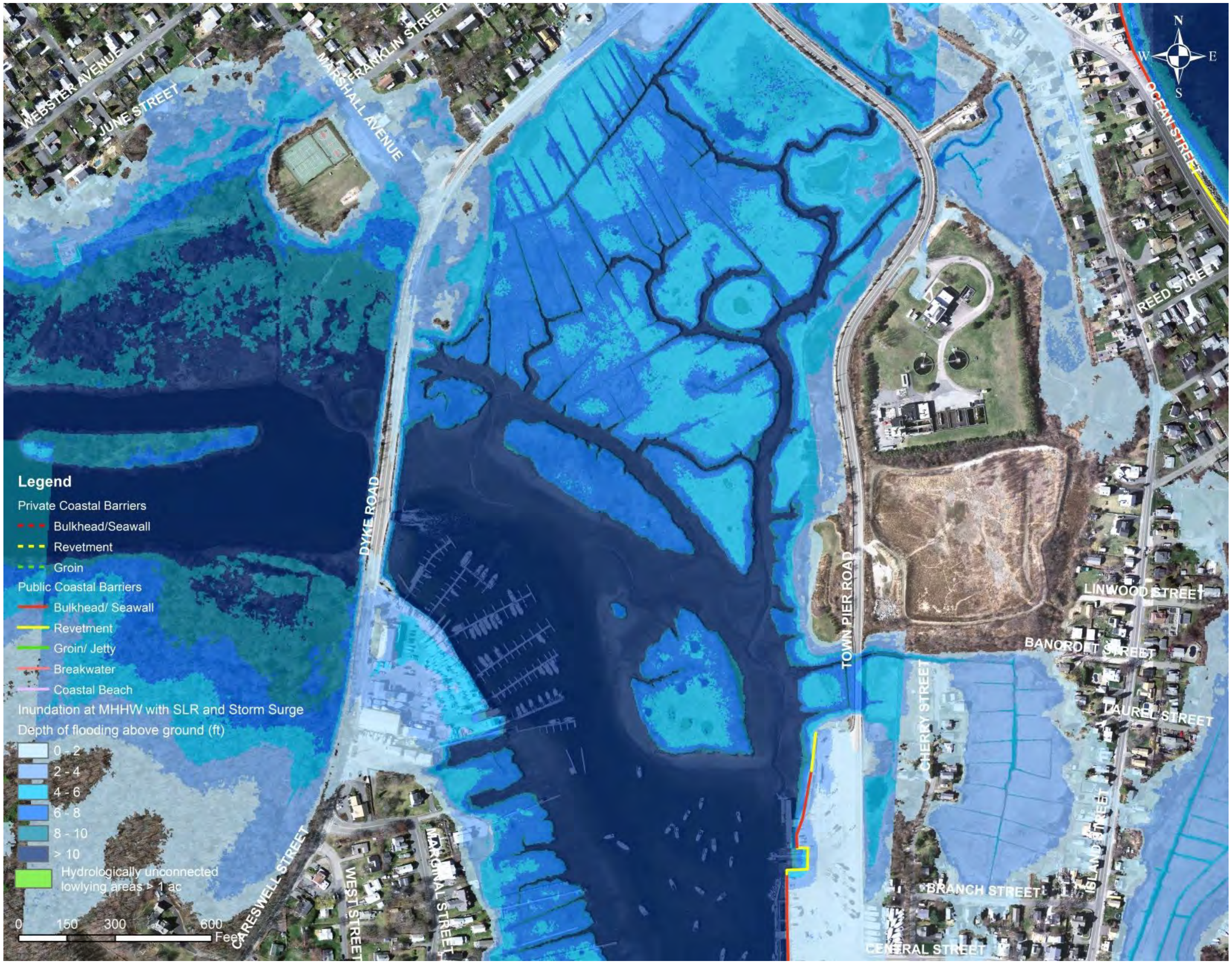
SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Wastewater Treatment Plant/Dyke Road Area, Marshfield 2063
50-year Time Horizon



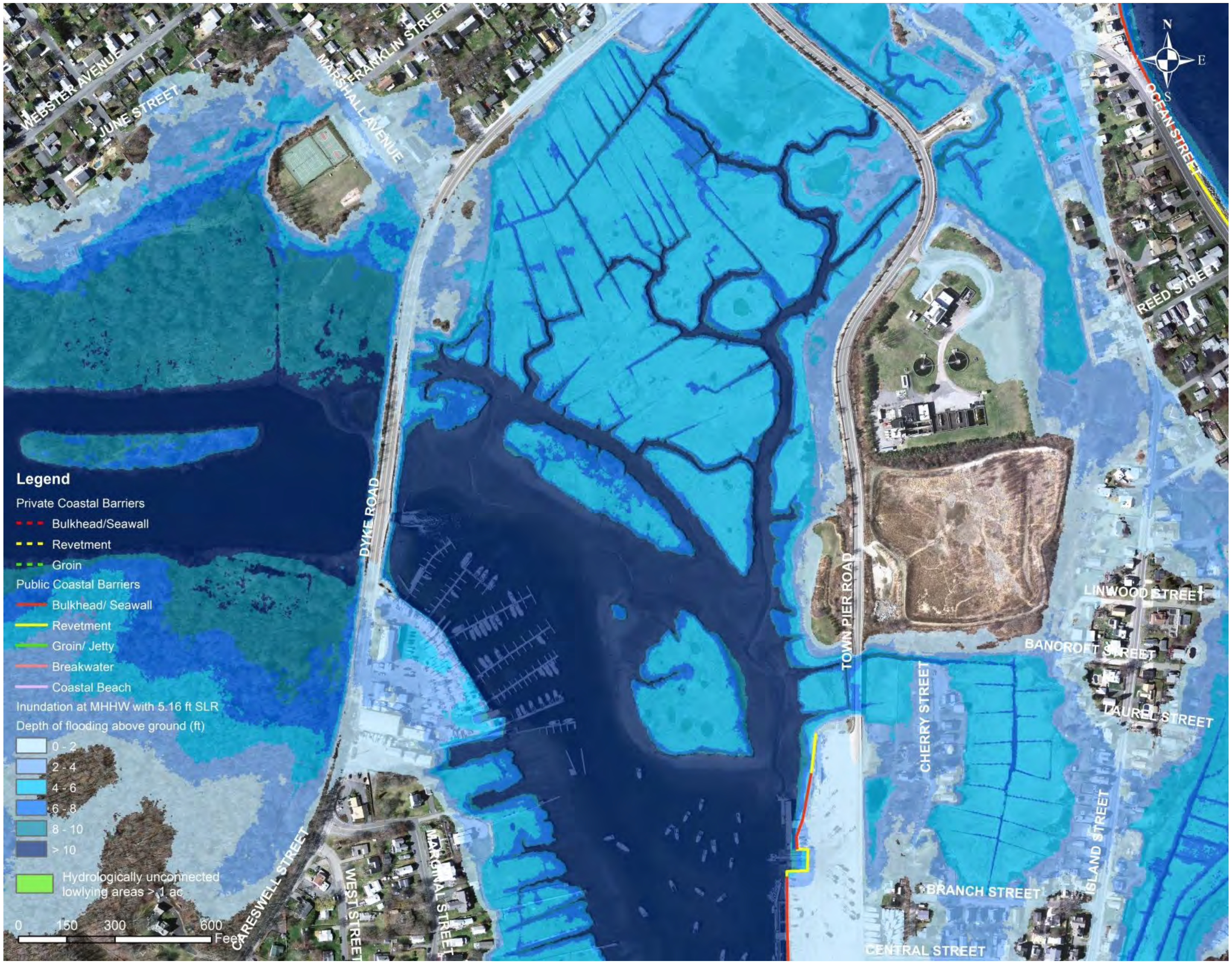
SLR of 2.80 ft. by 2063

Wastewater Treatment Plant/Dyke Road Area, Marshfield 2063
50-year Time Horizon



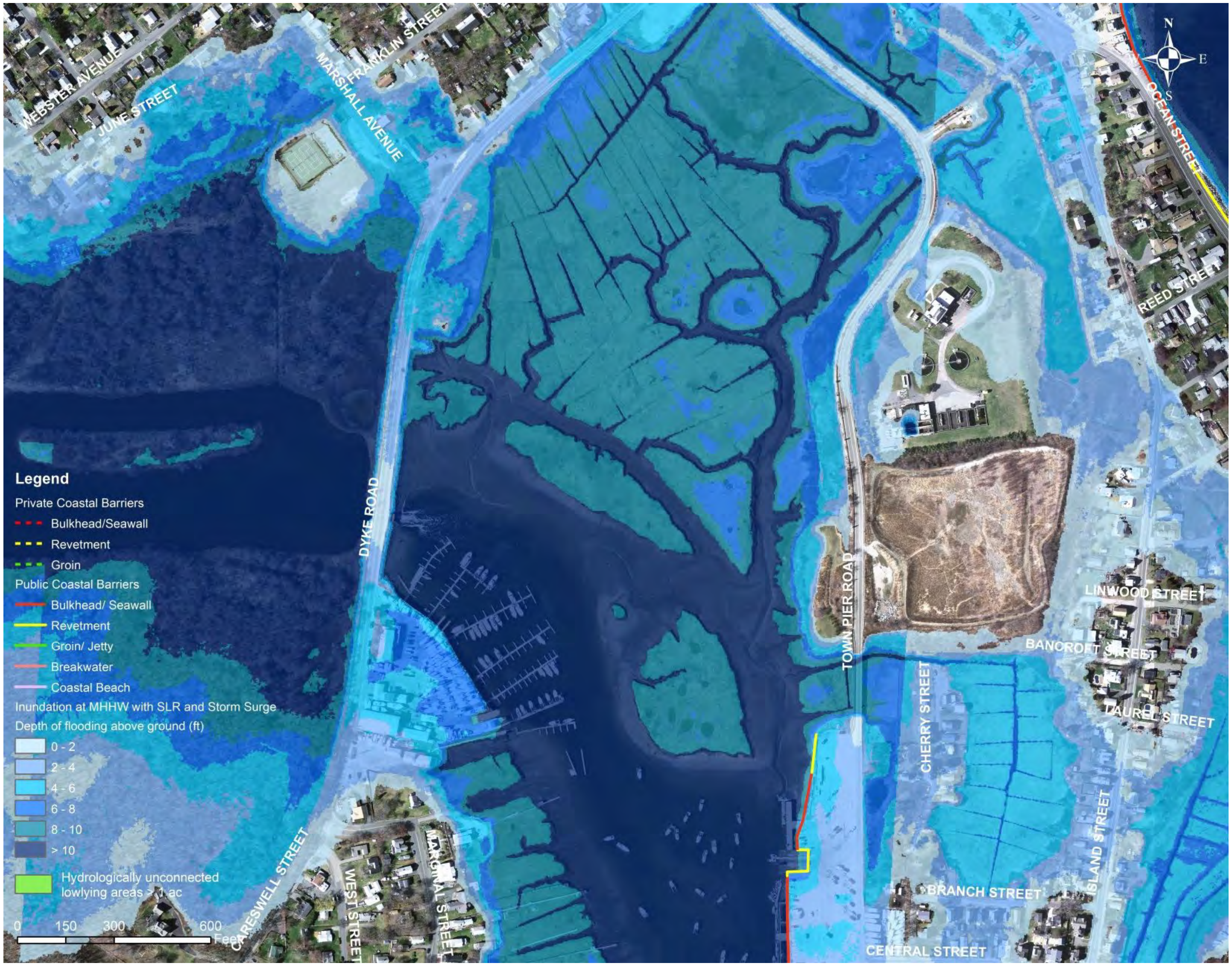
SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Wastewater Treatment Plant/Dyke Road Area, Marshfield 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088

Wastewater Treatment Plant/Dyke Road Area, Marshfield 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering

Outlet Control Structure on Dyke Road at Green Harbor, Marshfield by 2088 (75-years) with SLR and Storm Surge

2088

Present

3D Rendering
Wastewater Treatment Plant, Marshfield by 2088 (75-years) with SLR and Storm Surge

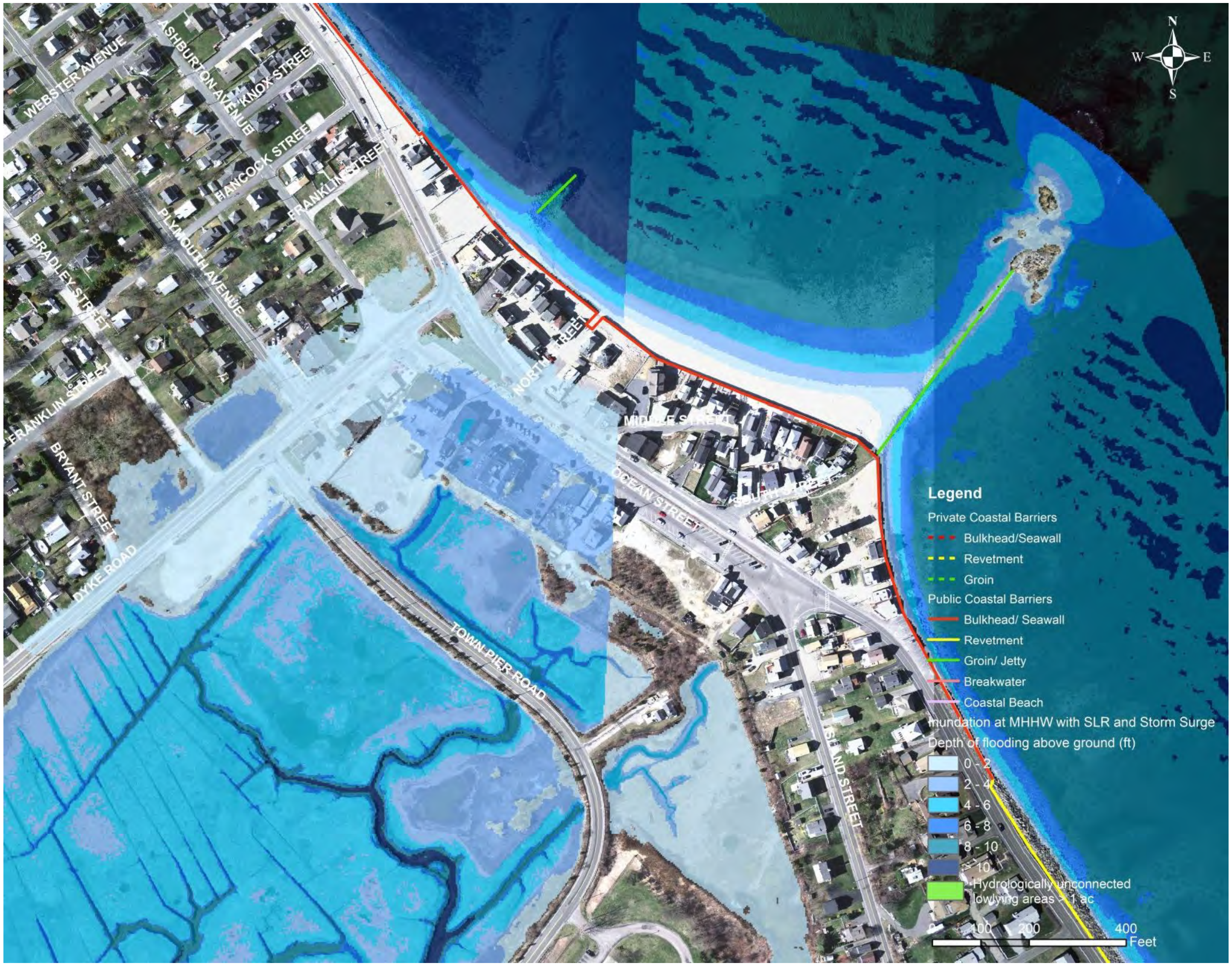
2088

Present

Brank Rock Area, Marshfield 2038
25-year Time Horizon

SLR of 1.08 ft. by 2038

Brank Rock Area, Marshfield 2038
25-year Time Horizon

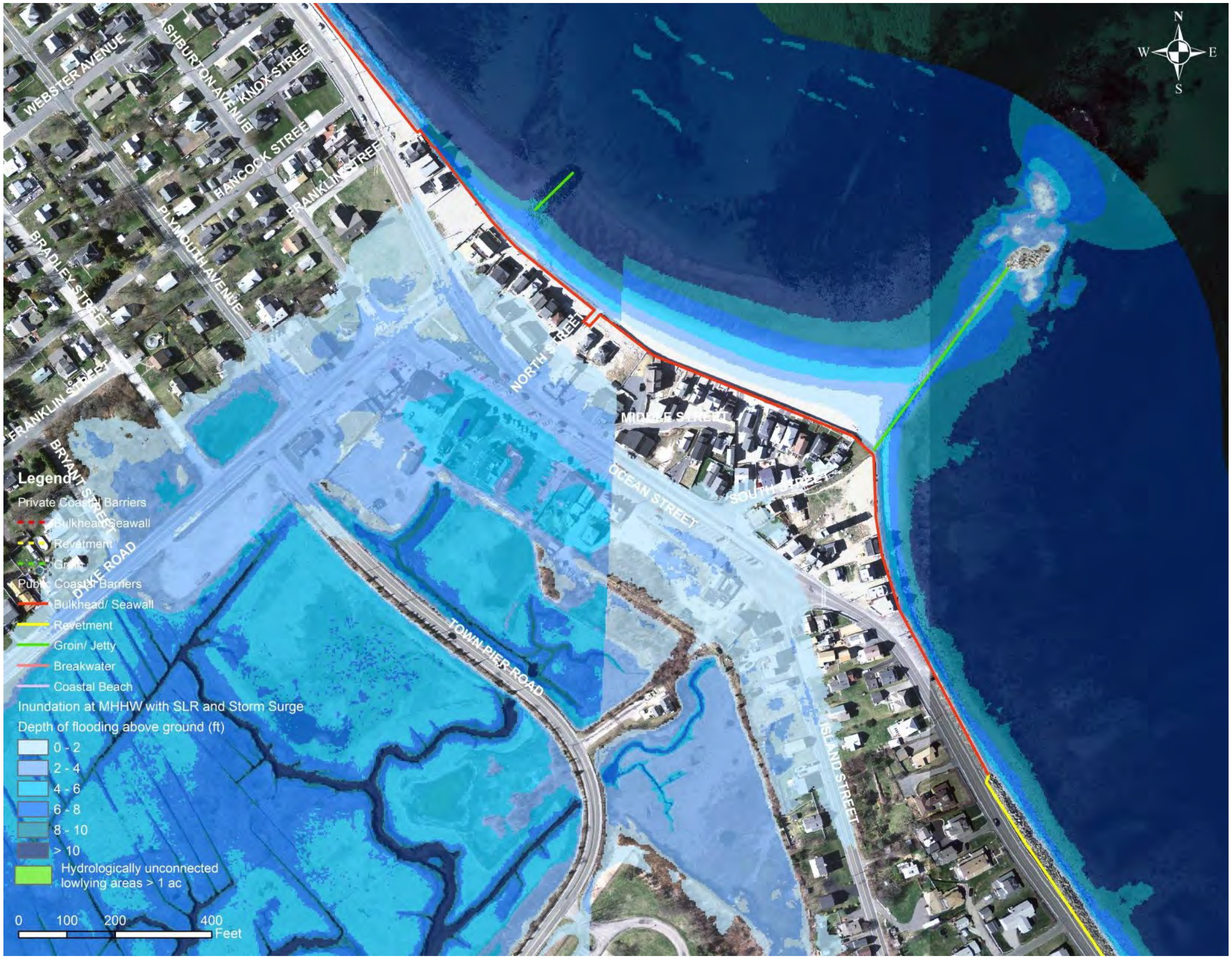


SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Brank Rock Area, Marshfield 2063
50-year Time Horizon

SLR of 2.80 ft. by 2063

Brank Rock Area, Marshfield 2063
50-year Time Horizon



SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

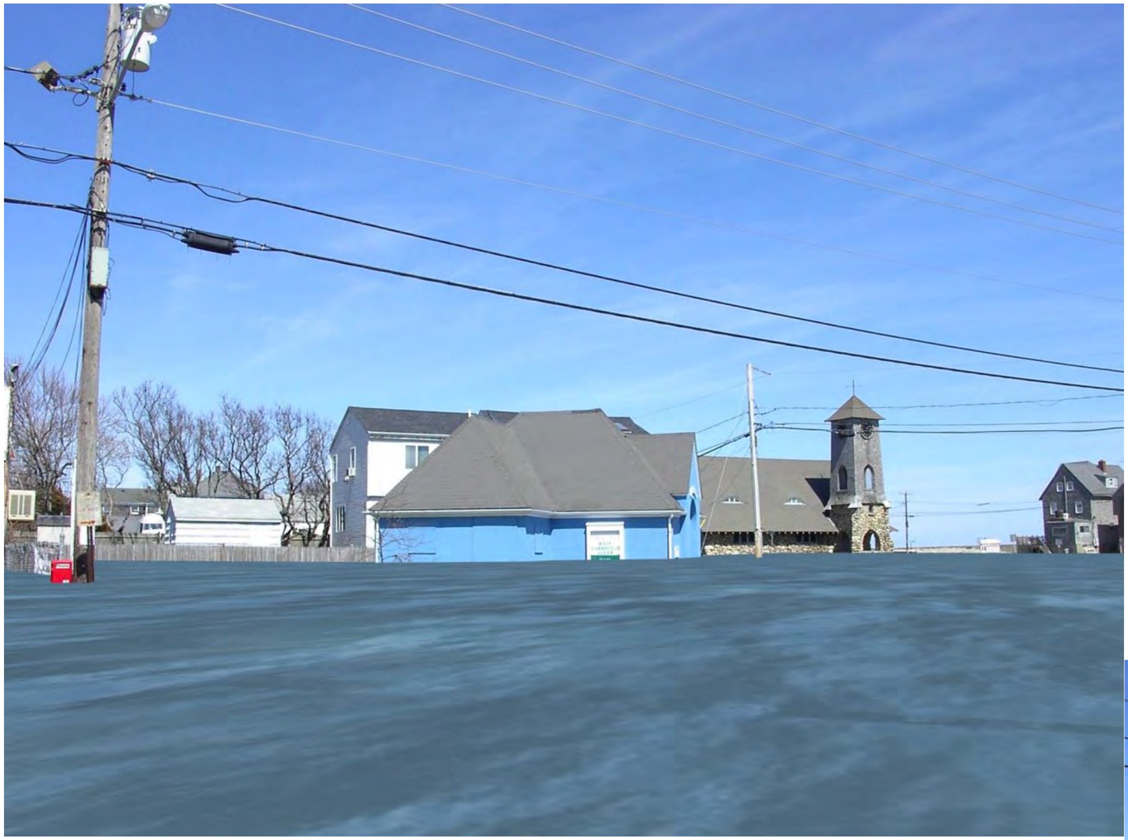
Brank Rock Area, Marshfield 2088
75-year Time Horizon

SLR of 5.16 ft. by 2088

Brank Rock Area, Marshfield 2088
75-year Time Horizon

SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering
Comfort Station at Brant Rock, Marshfield by 2088 (75-years) with SLR and Storm Surge



2088

Present

Ocean Street and Winslow Street Area, Marshfield 2038
25-year Time Horizon

SLR of 1.08 ft. by 2038

Ocean Street and Winslow Street Area, Marshfield 2038
25-year Time Horizon

SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

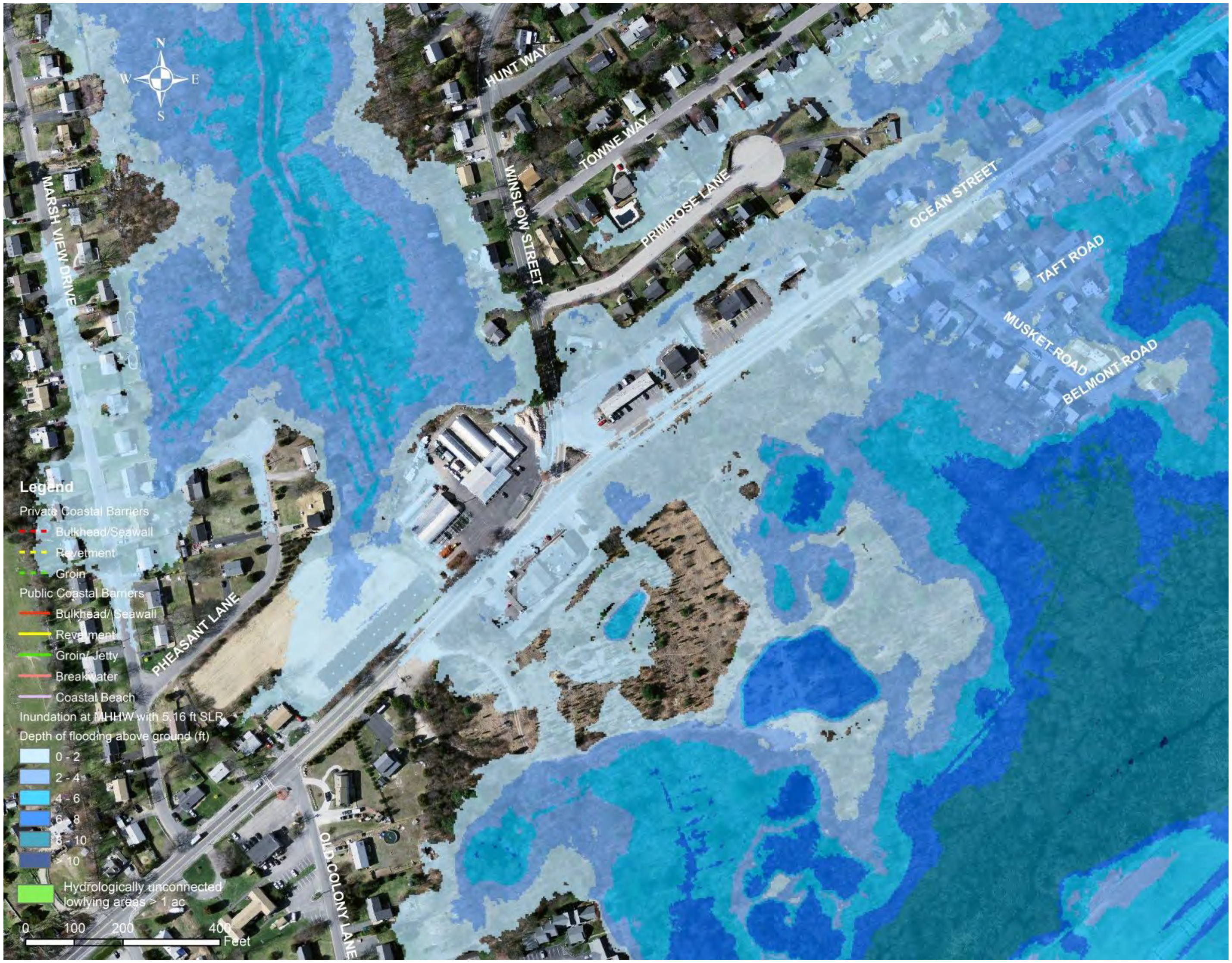
Ocean Street and Winslow Street Area, Marshfield 2063
50-year Time Horizon

SLR of 2.80 ft. by 2063

Ocean Street and Winslow Street Area, Marshfield 2063
50-year Time Horizon

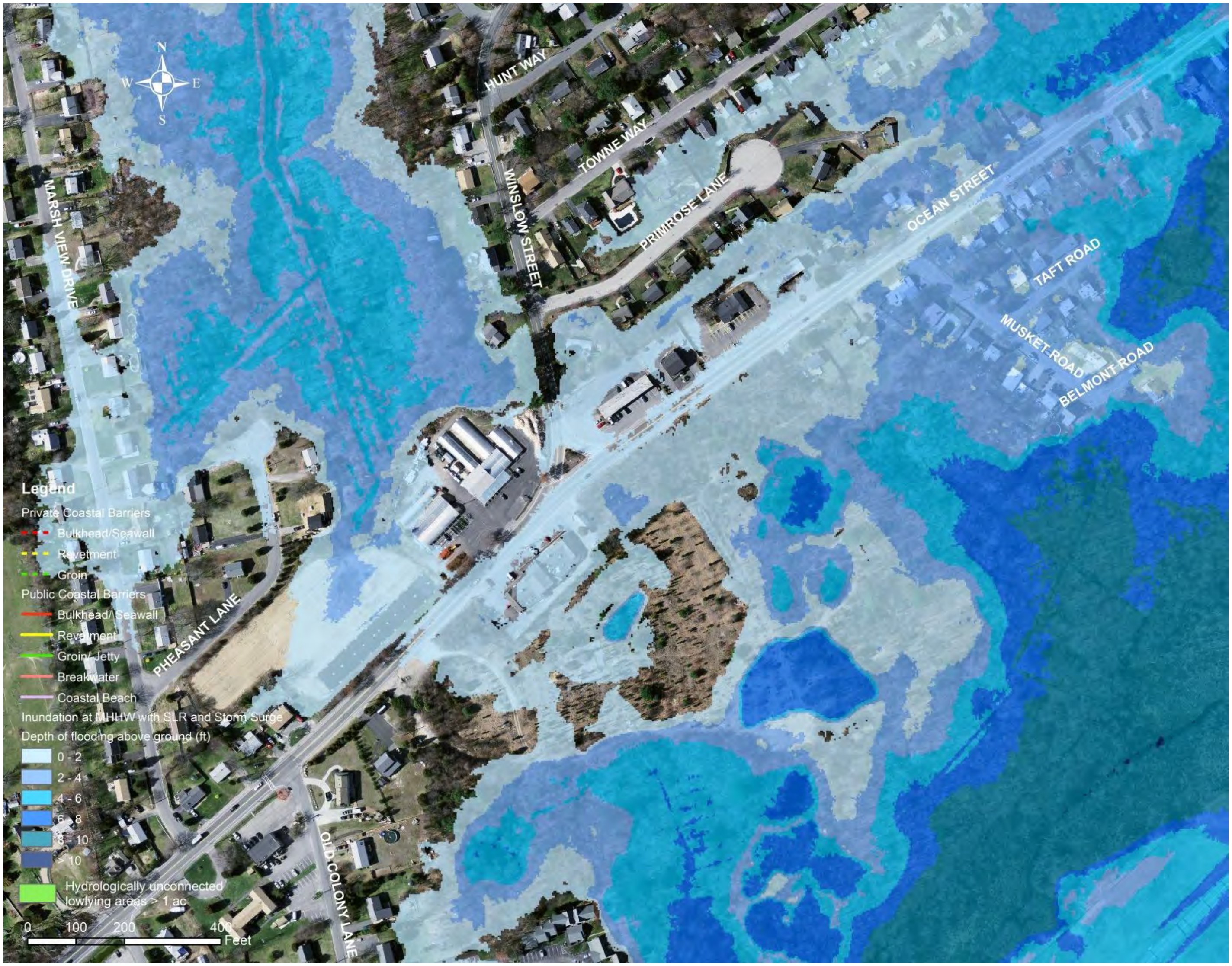
SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Ocean Street and Winslow Street Area, Marshfield 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088

Ocean Street and Winslow Street Area, Marshfield 2088
75-year Time Horizon



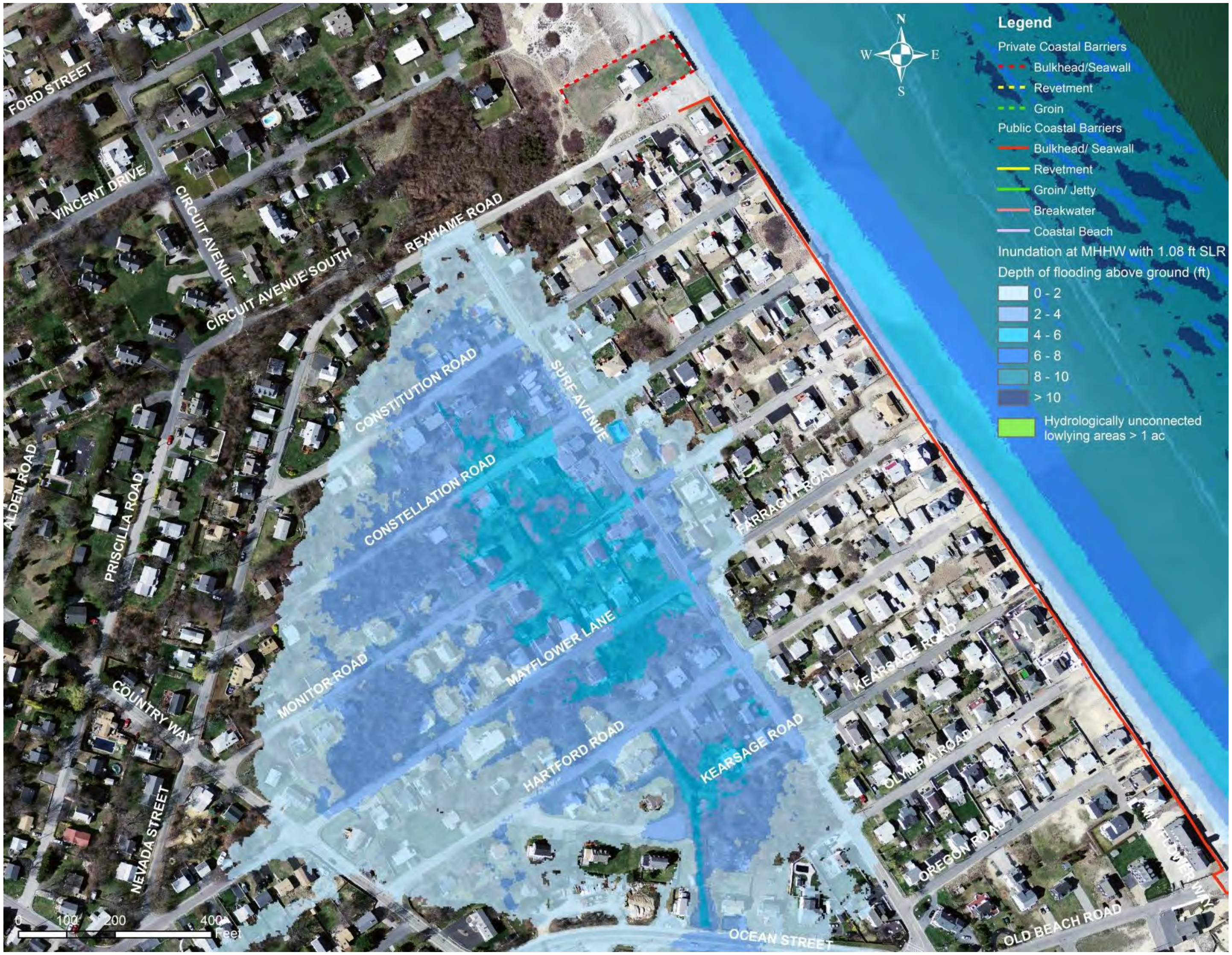
SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering
Ocean Street and Winslow Street, Marshfield by 2088 (75-years) with SLR and Storm Surge

2088

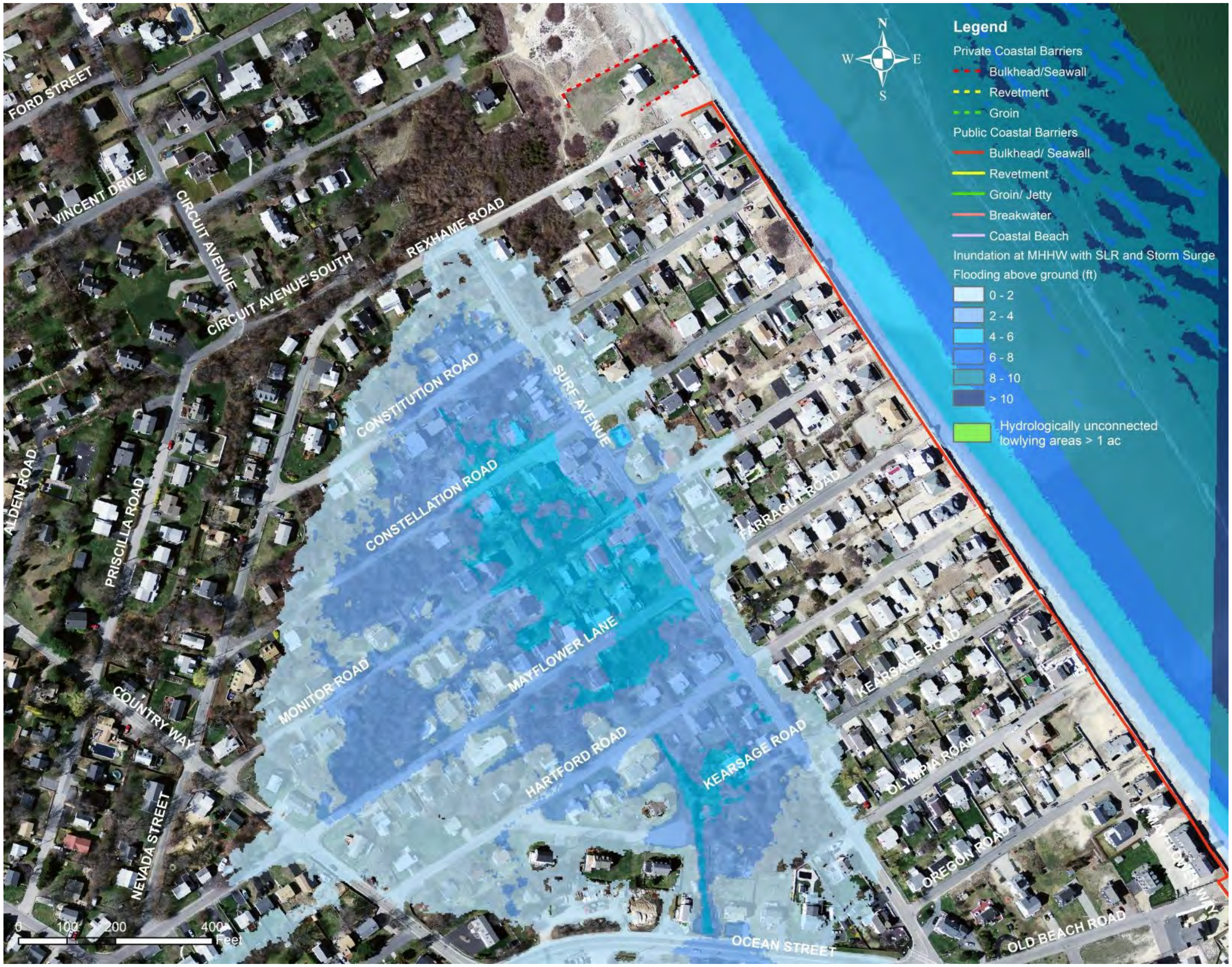
Present

Rexhame Beach Area, Marshfield 2038
25-year Time Horizon



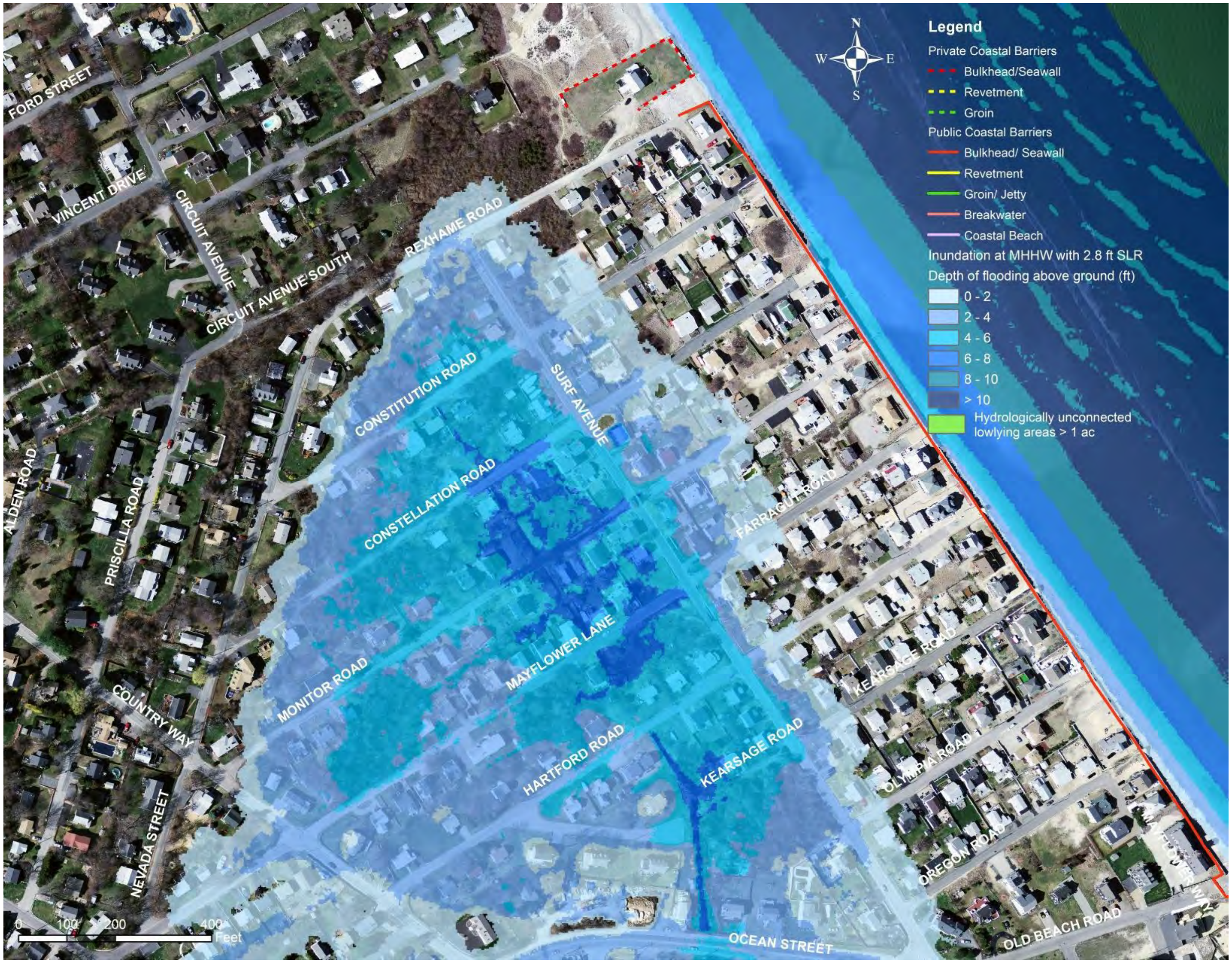
SLR of 1.08 ft. by 2038

Rexhame Beach Area, Marshfield 2038
25-year Time Horizon



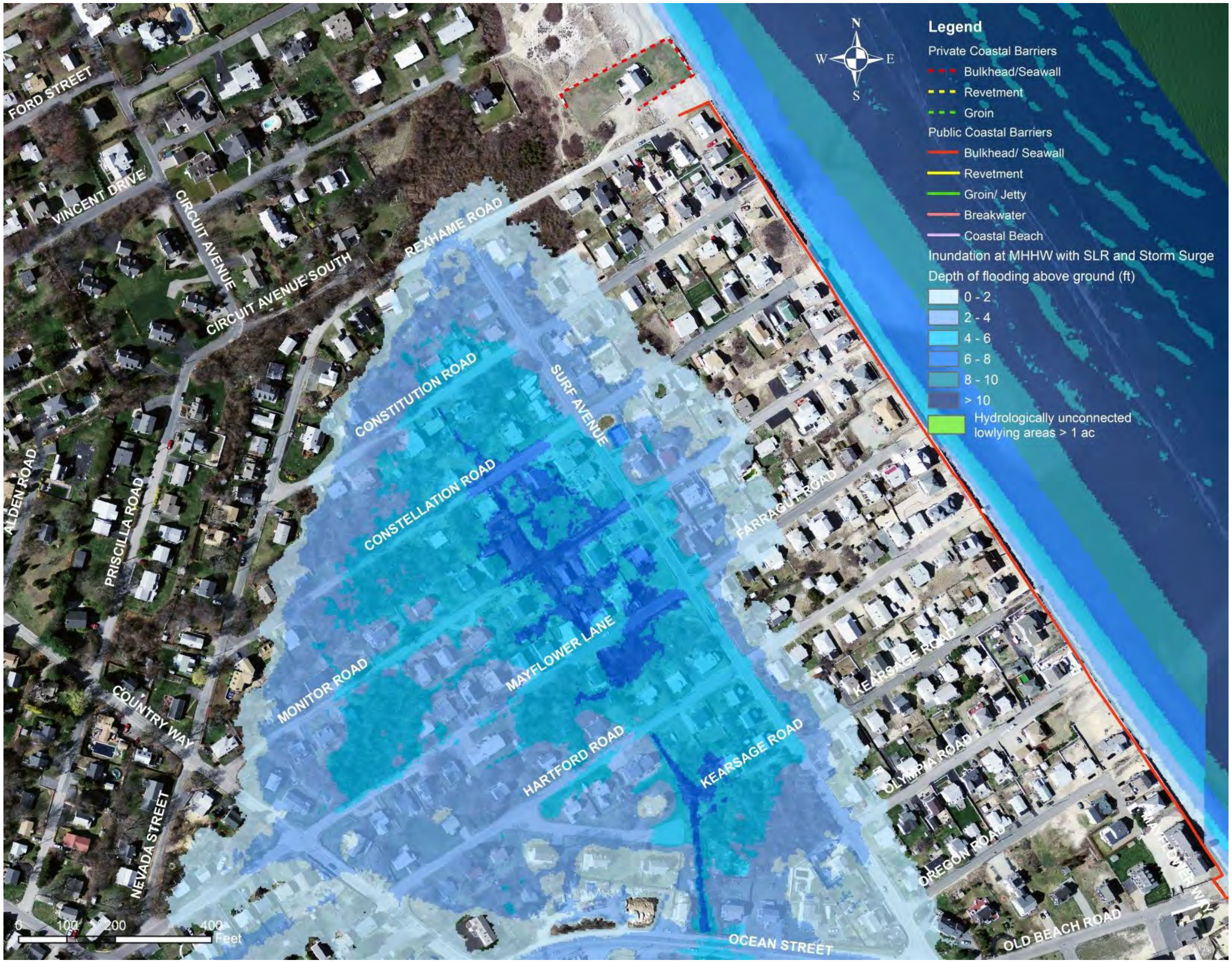
SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Rexhame Beach Area,, Marshfield 2063
50-year Time Horizon



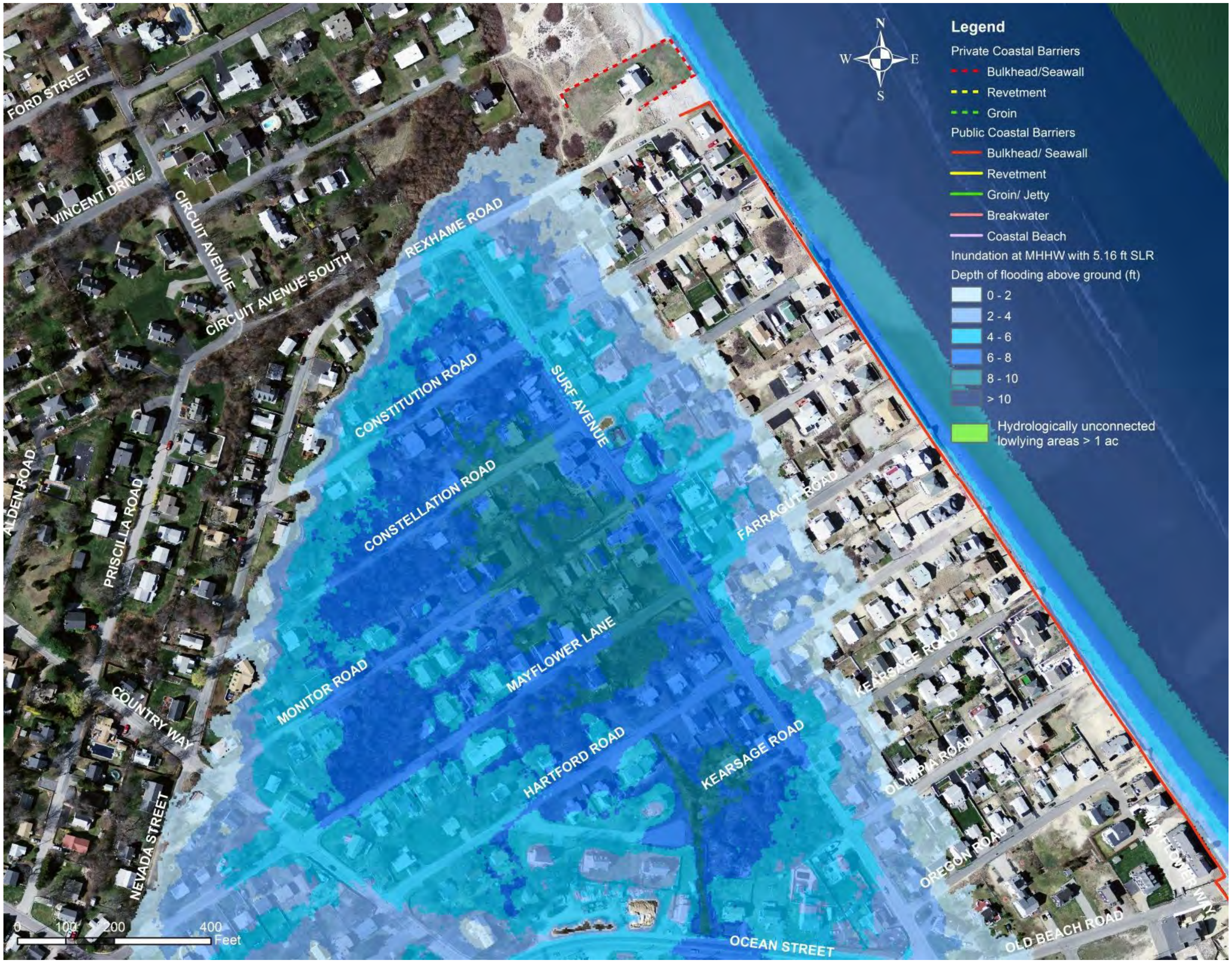
SLR of 2.80 ft. by 2063

Rexhame Beach Area,, Marshfield 2063
50-year Time Horizon



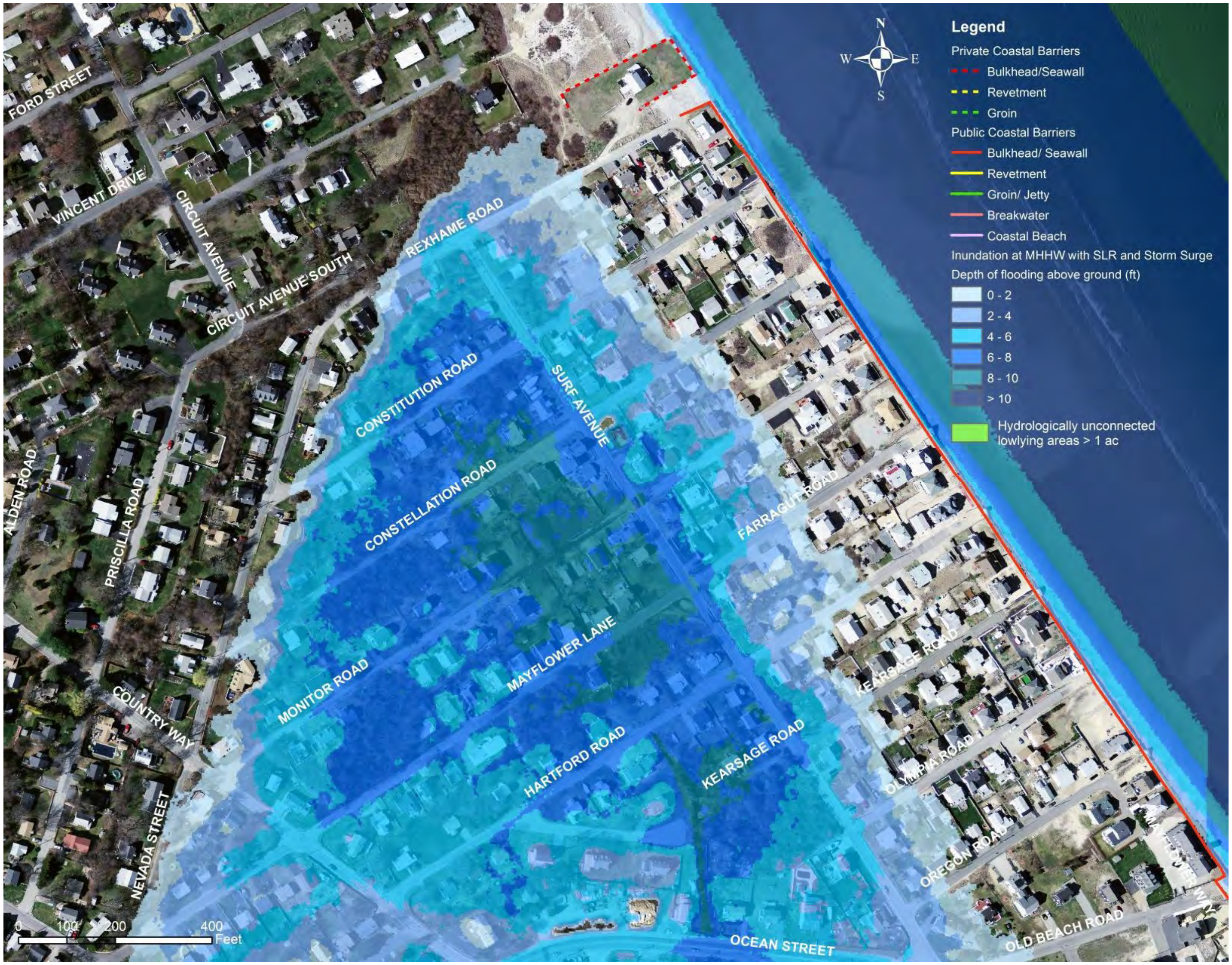
SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Rexhame Beach Area, Marshfield 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088

Rexhame Beach Area, Marshfield 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering
Sea Wall at Rexhame Beach, Marshfield by 2088 (75-years) with SLR and Storm Surge

2088

Present

Marshfield - Natural Resources Impacts

Tidal Salt Marsh

Tidal salt marshes are an important part of the local coastal ecosystem. They are an essential element of the aquatic food web, provide valuable habitat for many birds and other aquatic species, and they also provide protection from the effects of waves and currents. Sea level rise projections for Marshfield include potential negative impacts to tidal salt marsh in various areas of town including the extensive salt marshes associated with the North River, South River, and Green Harbor River estuaries, and marshes which connect to Duxbury Bay. Each of these tidal salt marsh ecosystems will experience higher daily tidal ranges as sea levels rise.

Survival of the tidal marsh ecosystem depends on a balance between forces creating marsh vertical growth such as organic sediment accumulation and the forces causing deterioration of the marsh such as subsidence, sea level rise and wave erosion. The impact to the marsh ecosystems in Marshfield will be negative if tidal salt marsh elevations cannot keep pace with sea level rise through natural or assisted vertical growth of the marsh platform which includes plant matter accumulation such as root production and decomposition of dead plants. If the vertical growth of tidal salt marsh cannot keep pace with the rising sea levels, the result will be more flooding of the marshes which will cause the plants to die, and marsh ecosystem will eventually convert to intertidal mudflat or subtidal open water. Further study will be required to determine more specifically how sea level rise will affect the tidal salt marsh ecosystem.

Beaches

Beaches along the Marshfield coast line, including Rexhame Beach and Green Harbor Beach, will be affected by rising sea levels. Tidal elevations will increase on a daily basis. If beaches are not otherwise nourished and raised, there could be partial or complete loss of some ocean front beaches at high tides. In addition, the potential for increased frequency and intensity of storm events can also lead to additional deterioration of ocean front beaches.

Wildlife

If rising sea levels cause a loss of tidal salt marsh and beach habitat, there will likely be a great effect on the habitat for coastal wildlife including birds and fin fish that utilize the marsh and estuaries for spawning and habitat. Interruption of spawning grounds and habitat could result in the declines of shellfish and fin fish populations which could have economic impacts. Impacts to mudflats, which provide key habitat for migratory shorebirds, crabs, mollusks, and fish, may also have significant ecological and economic consequences.

Shellfish

The North and South rivers as well as other tidal marsh areas provide prime habitat for shellfish which are harvested commercially and recreationally. Important shellfish species include softshell clams, mussels, razor clams and quahogs. The impacts to shellfish due to rising sea levels and water temperatures are not well understood at this time. Some effects that could negatively affect the shellfish population and industry include:

- Deeper waters will reduce time available to access and work shellfish beds.
- Deeper waters may alter patterns of predation and exposure.
- Rising water temperatures could affect shellfish growth patterns and timing.
- Rising water temperatures could increase potential for disease.
- Changes to existing tidal salt marshes could change nutrient levels in the water which could affect shellfish growth.

It should be noted that changes in sea level and water temperature are occurring at a slow rate, so there is potential for shellfish to evolve and adapt to meet the changing conditions.

Marshfield – Infrastructure Impacts

Roadways and Bridges
The inundation maps for Marshfield for the various sea level rise and storm surge projections indicate that a number of roads along the coast will be affected by higher tides and storm events, especially at the 75 year scenario. Some of the roads which will be greatly affected by rising sea levels alone in 75 years (excluding the effects of storm surge) include:

- Sections of Gurnet Road and Bay Avenue
- Dyke Road (Route 139)
- Ocean Street, Island Street and Cove Street in the Brant Rock area
- Town Pier Road and the Parking area at the Town Pier
- Plymouth Avenue
- Numerous streets in the Rexhame Beach Area
- Revere Street
- Macombers Ridge and Macombers Way
- Bartletts Isle Way

The Route 3A Bridge over the North River does not appear to get flooded, even at the 75 year projection with storm surge. The Dyke Road (outlet structure at the Green Harbor River does not flood at the 25 and 50 year scenarios and the 75 year projection for sea level rise alone, but the approach roads do flood. However, the Dyke Road outlet structure is over-topped for the scenario of the 75 year projection for sea level rise plus storm surge.

The inundation maps do not show the effect of wave action during the storm surge event. The storm surge is based on the mean level of surge, not the highest wave heights. With no changes to the top of sea wall elevations, the higher wave heights will overtop the existing sea walls and cause flooding and road damage behind the walls more often than it does today.

The obvious effect of flooded roadways is that travel on the roads will be greatly affected during storm events. Much like what happens today, road traffic will have to be curtailed during storm events. However, some of these roads will also be affected during normal daily high tide cycles which will not be acceptable for the town’s normal operations. In addition, increase flooding of roads will lead to significant increases in the rate of deterioration of the road structure itself.

Coastal Stabilization Structures
There are numerous coastal stabilization structures along the Marshfield coastline, including concrete sea walls, stone revetments, groins, and breakwaters. Rising sea levels, combined with the effects of the projected higher frequency and intensity of coastal storms, will result in more damage to coastal stabilization structures and more over-topping of the structures due to storm wave action. Many of the existing sea walls experience over-topping today during major storms. Over-topping, and the associated damage of structures and public infrastructure located behind sea walls, will only increase as sea levels rise in the future.

Higher tidal elevations will result in deeper water depths in front of coastal stabilization structures during high tides, which will result in larger ocean waves hitting the structures, which will in turn accelerate structural damage of the structures and increase the rate of erosion in front of the structures. Deeper water will increase not only the force of wave impacts, but also the frequency of interaction between the wave energy and the structure, further eroding the beach fronting the seawall. This self-reinforcing cycle (eroding beach creates deeper water creates more wave interaction creates eroding beach) ultimately leaves the seawall/structure without adequate coastal beach to provide stability or protection during a storm. Currently, due to coastal erosion and sea level rise, many areas have little or no beach in front of structures constructed in the 1930s through 1950s which can absorb wave energy. In these areas, the structures are the first and only lines of coastal defense. Where this is the case, increasing the height of seawalls may not be the best solution. A better solution is to raise structures while recreating landform in front of the structures to help absorb wave energy and to stabilize the structures.

There are several openings in the existing sea walls and revetments in the Rexhame beach area that allow water to pass through the structures and flood neighborhoods behind the structures during storm events. The inundation map for the 75 year sea level rise and storm surge does not indicate water flooding through the wall openings, because the storm surge used does not take into account wave heights above the mean surge level. Based on discussions with Town staff, water is known to pass through these openings today under the right tidal and storm conditions.

Wastewater Treatment Plant

The 25 year and 50 year sea level projections combined with storm surge do not appear to result in flooding at the Marshfield Wastewater Treatment Plant located on Joseph Driebeck Way. However, for the 75 year projections, it does appear that there will be some minor flooding of the access road for the projected sea level rise of 5.16 feet alone, and additional flooding of the site when storm surge is added. It appears that the majority of the plant itself will experience little to no flooding during the storm event. Note that the storm surge projections do not include the effect of wave action above the mean storm surge level. Given that the location of the plant is protected from direct wave action, the effects of wave action will be minimal or non-existent.

Underground Infrastructure Systems

There are many buried piping systems and utilities in the roads including sanitary sewer, storm sewer, water and gas. Electrical, telephone, and cable television systems appear to be pole-mounted in all of the coastal roadways that are affected by flooding. All of the roadways that are shown to be impacted by rising sea levels and storm surge are currently susceptible to flooding and damage during storm events. Increased flooding during high tides and storm events will increase the rate of deterioration of any underground infrastructure and increase the possibility of wash outs that could cause unsafe conditions and service interruptions.

There also may be some private septic systems along the coast for any homes or businesses not connected to the town’s wastewater treatment plant. Rising sea levels could affect septic systems if ground water elevations near the coast rise due to rising sea levels. The higher ground water levels could make septic systems adjacent to the coast line noncompliant, even potentially causing breakout and contamination.

There are also numerous drainage culverts under roadways that connect drainage areas from one side of the road to the other. It is not within the scope of this project to determine which culverts, if any, could be affected by rising sea levels.

Marshfield – Transportation Impacts

There are no MBTA commuter rail facilities located in Marshfield. Public school and transit bus routes utilizing roads subject to flooding from sea level rise and storm surge will be affected and may need to be temporarily or permanently re-routed.

Marshfield - Emergency Access Impacts

The inundation maps for Marshfield for the various sea level rise and storm surge projections indicate that flooding and closure of Ocean Street, Island Street and Cove Street in the Brant Rock area; Ocean Street in the Rexhame Beach area; Macombers Ridge and Macomber Way; and Bartletts Isle Way will affect emergency access to residents served by these roads. If access roads to these areas are blocked off, then there is either no other emergency egress route to these sections of town or emergency access could be slowed down significantly. It should be noted, that most of these roads currently do get flooded and are sometimes closed during astronomical tidal and storm events, so the town already does have a system to deal with emergency access in these locations. However, if nothing is done to change the roads, the frequency and duration of flooding and closures can be expected to increase, putting more strain on the Police, Fire and Public Works Departments.

Sea Level Rise Impacts – Town of Duxbury, MA

1. Town-wide inundation maps for 2038 (25 years), 2063 (50 years) and 2088 (75 years) with sea level rise only and sea level rise combined with storm surge

2. Sea Level Rise and Storm Surge Maps for specific areas
    a. Blue Fish River and School Complex
    b. Duxbury Beach/Blakeman's Area
    c. Washington Street/Snug Harbor Area

3. 3D renderings of selected areas for 2088 (75 years) with sea level rise and storm surge combined

4. Natural Resource Impacts
    - Tidal salt Marshes
    - Beaches
    - Wildlife
    - Shellfish and Aquaculture

5. Infrastructure Impacts
    - Roadways and Bridges
    - Coastal Stabilization Structures
    - Duxbury Beach
    - Underground Infrastructure Systems

6. Transportation Impacts

7. Emergency Access Impacts

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2038 (25 YEARS)
TOWN OF DUXBURY, MA
JULY 2013

Miles
0 0.25 0.5 1

Gulf of Maine Council on the Marine Environment

KLEINFELDER
Bright People. Right Solutions.

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2038 (25 YEARS)
AND STORM SURGE
TOWN OF DUXBURY, MA
JULY 2013

Miles
0 0.25 0.5 1

NOAA
Gulf of Maine Council on the Marine Environment

KLEINFELDER
Bright People. Right Solutions.

SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2063 (50 YEARS)
TOWN OF DUXBURY, MA
JULY 2013

Miles
0 0.25 0.5 1

KLEINFELDER
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SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2063 (50 YEARS)
AND STORM SURGE
TOWN OF DUXBURY, MA
JULY 2013

Miles
0 0.25 0.5 1

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SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2088 (75 YEARS)
TOWN OF DUXBURY, MA
JULY 2013

Miles
0 0.25 0.5 1

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SOUTH SHORE SEA LEVEL RISE STUDY

SEA LEVEL RISE BY 2088 (75 YEARS)
AND STORM SURGE
TOWN OF DUXBURY, MA
JULY 2013

Miles
0 0.25 0.5 1

Gulf of Maine Council on the Marine Environment

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Blue Fish River and School Complex, Duxbury 2038
25-year Time Horizon

SLR of 1.08 ft. by 2038

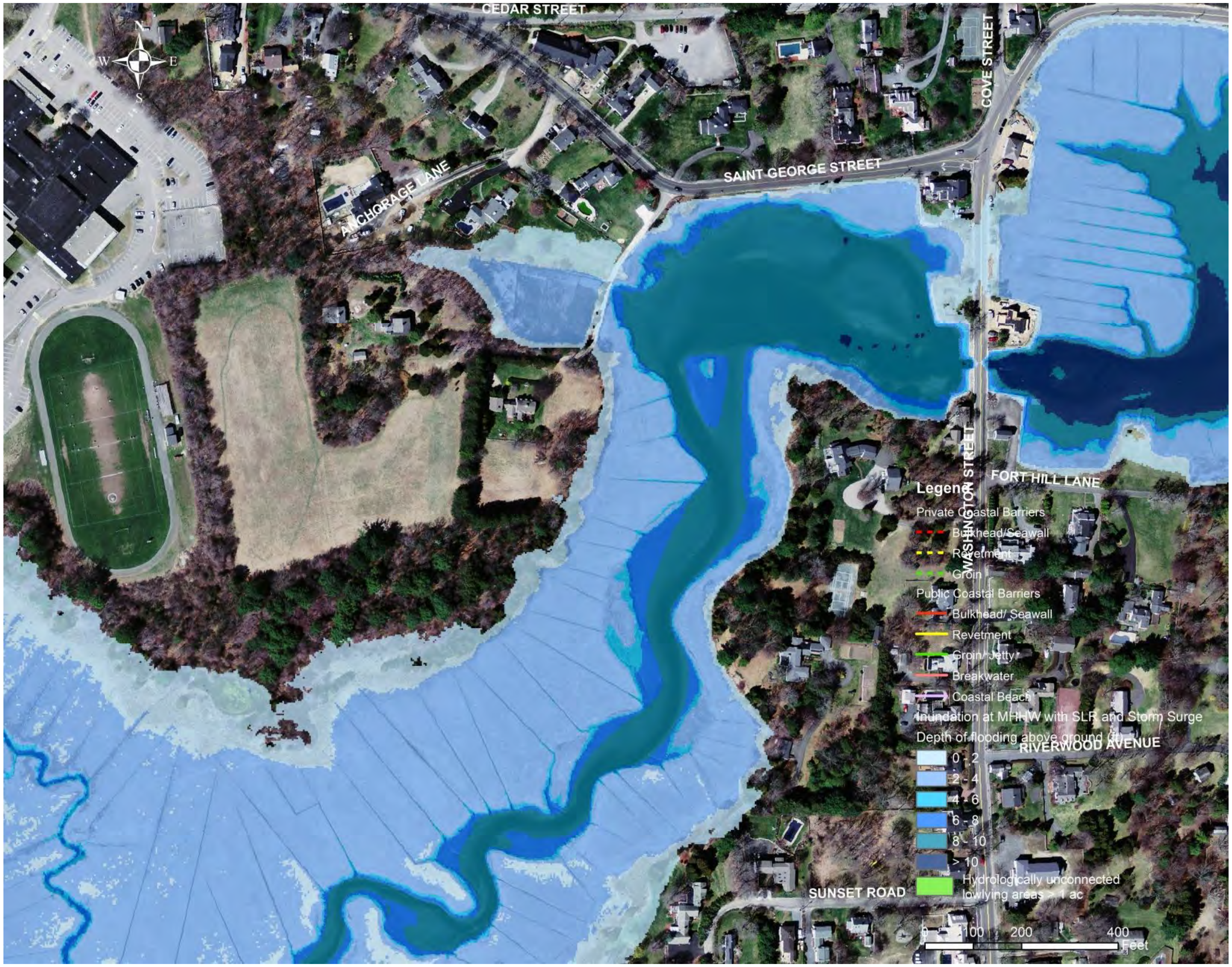
Blue Fish River and School Complex, Duxbury 2038
25-year Time Horizon

SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Blue Fish River and School Complex, Duxbury 2063
50-year Time Horizon

SLR of 2.80 ft. by 2063

Blue Fish River and School Complex, Duxbury 2063
50-year Time Horizon

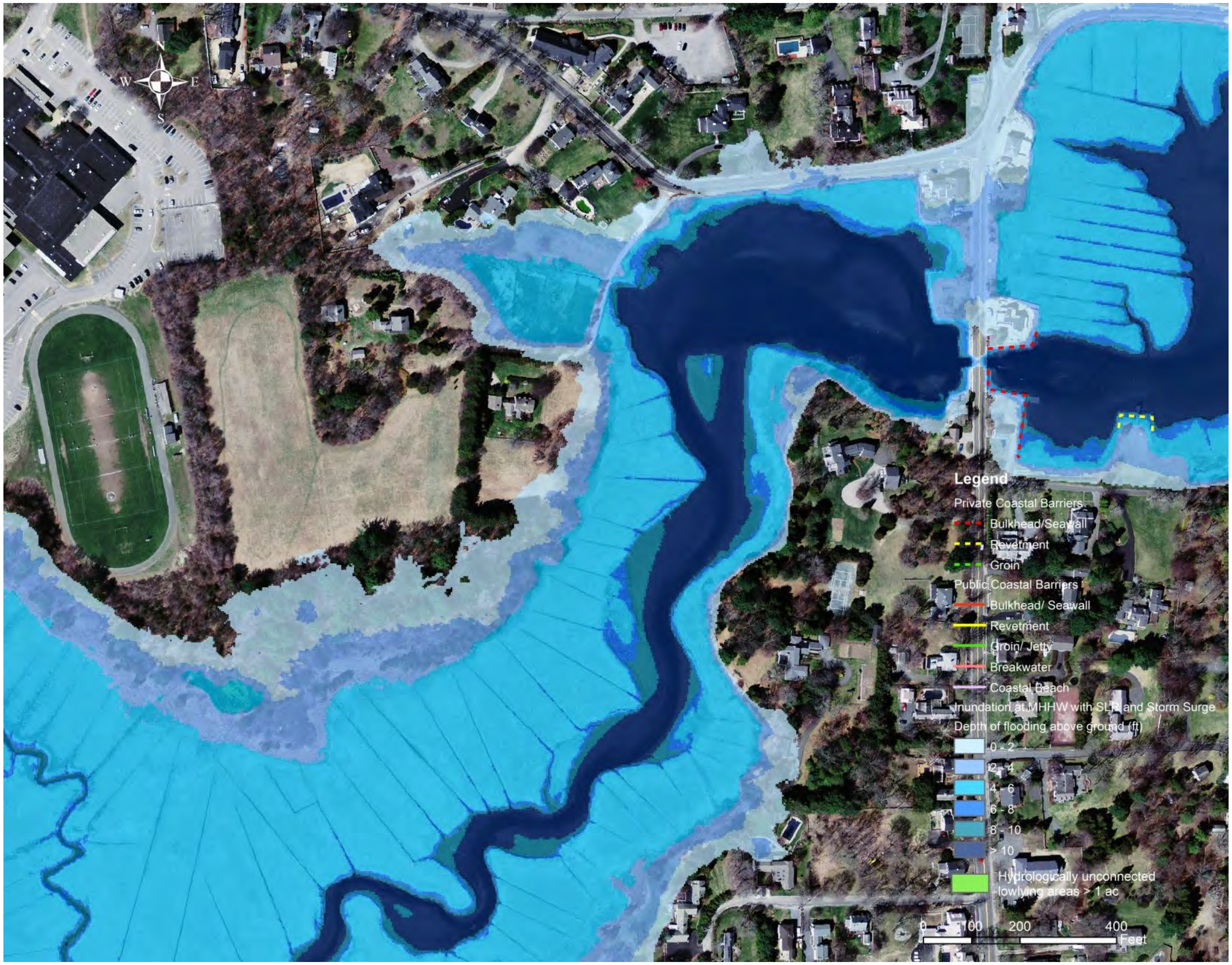


SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Blue Fish River and School Complex, Duxbury 2088
75-year Time Horizon

SLR of 5.16 ft. by 2088

Blue Fish River and School Complex, Duxbury 2088
75-year Time Horizon



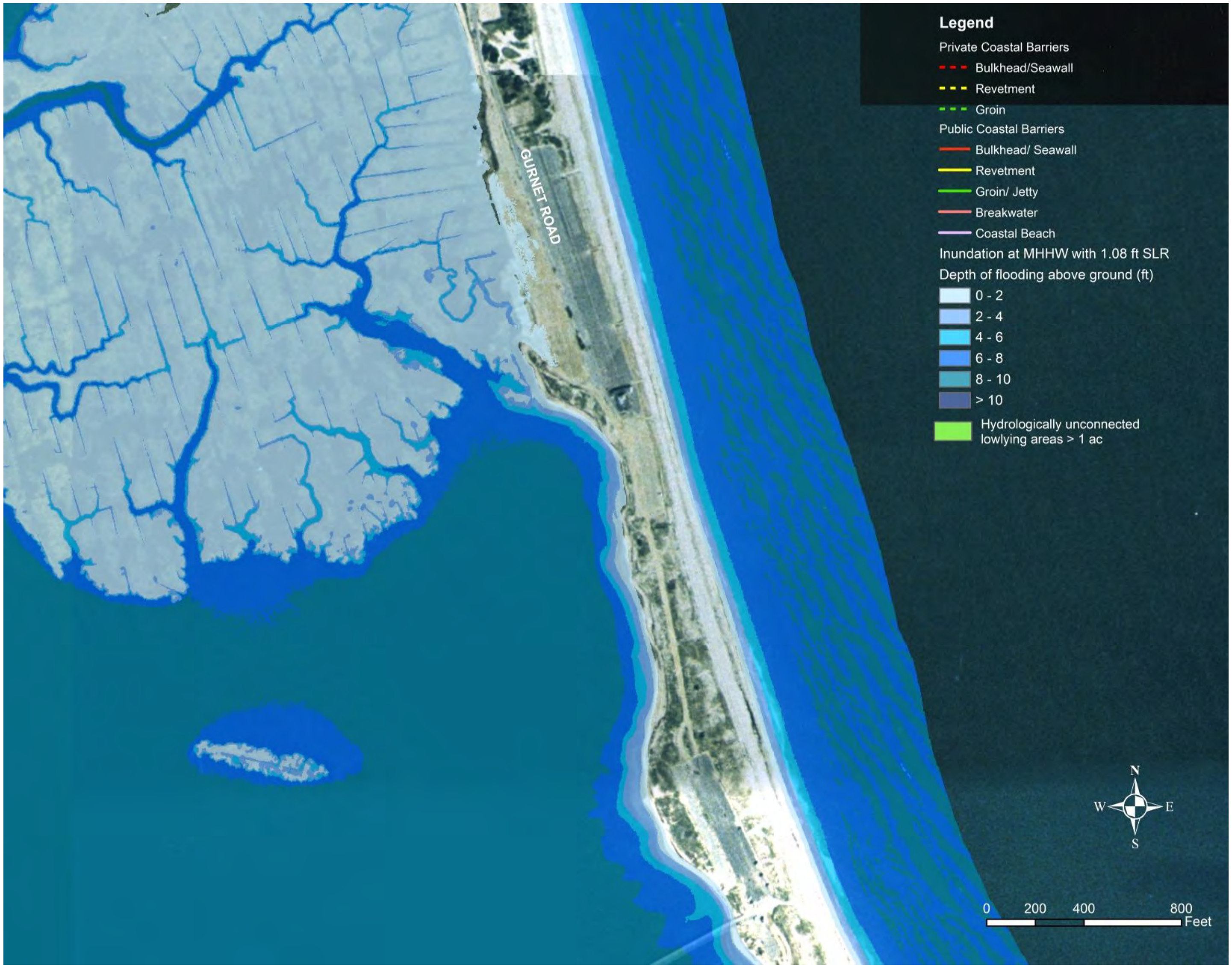
SLR of 5.16 ft by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering
Blue Fish River Bridge, Duxbury by 2088 (75-years) with SLR and Storm Surge

2088

Present

Duxbury Beach/Blakeman's Area 2038
25-year Time Horizon

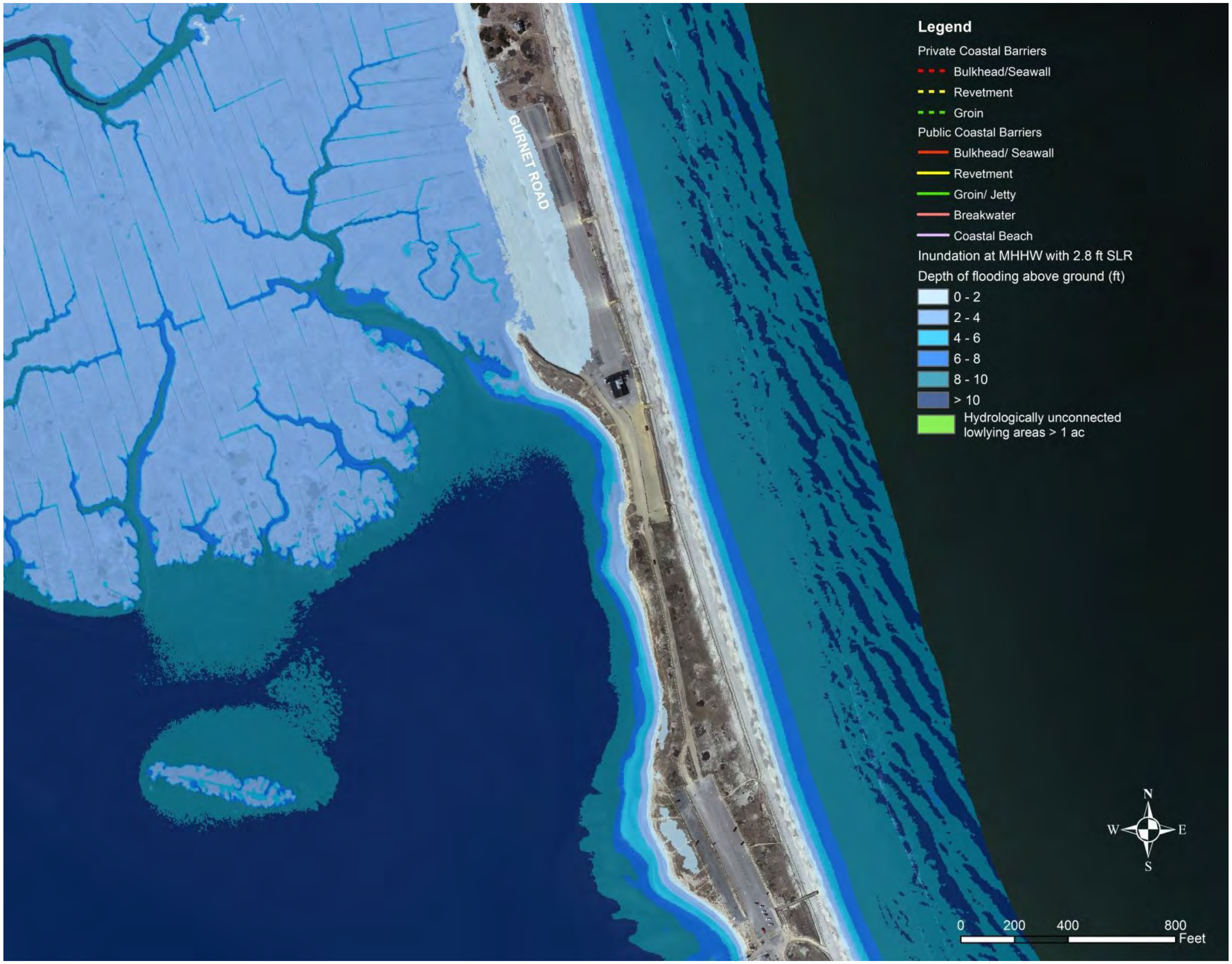


SLR of 1.08 ft. by 2038

Duxbury Beach/Blakeman's Area 2038
25-year Time Horizon

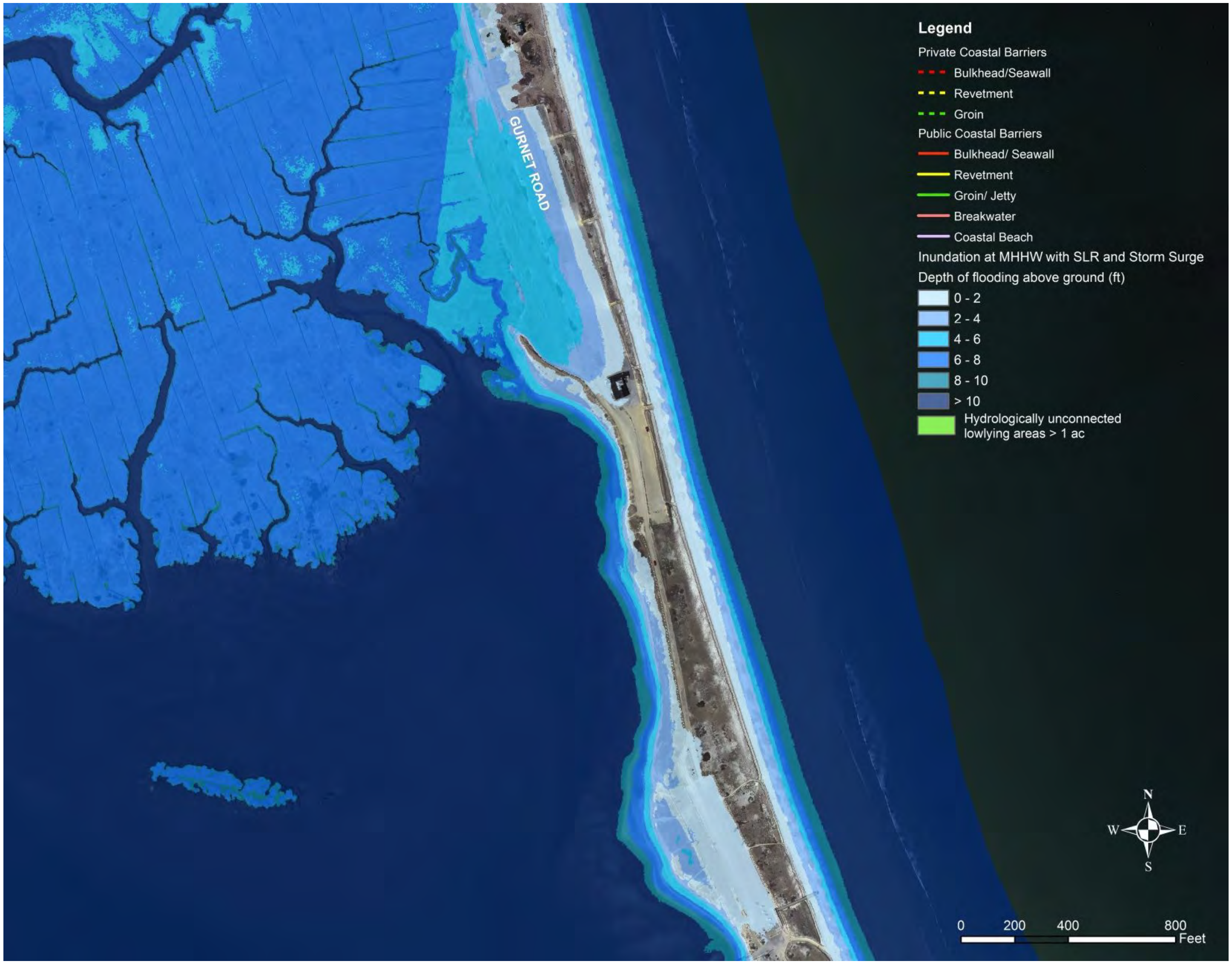
SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Duxbury Beach/Blakeman's Area 2063
50-year Time Horizon



SLR of 2.80 ft. by 2063

Duxbury Beach/Blakeman's Area 2063
50-year Time Horizon

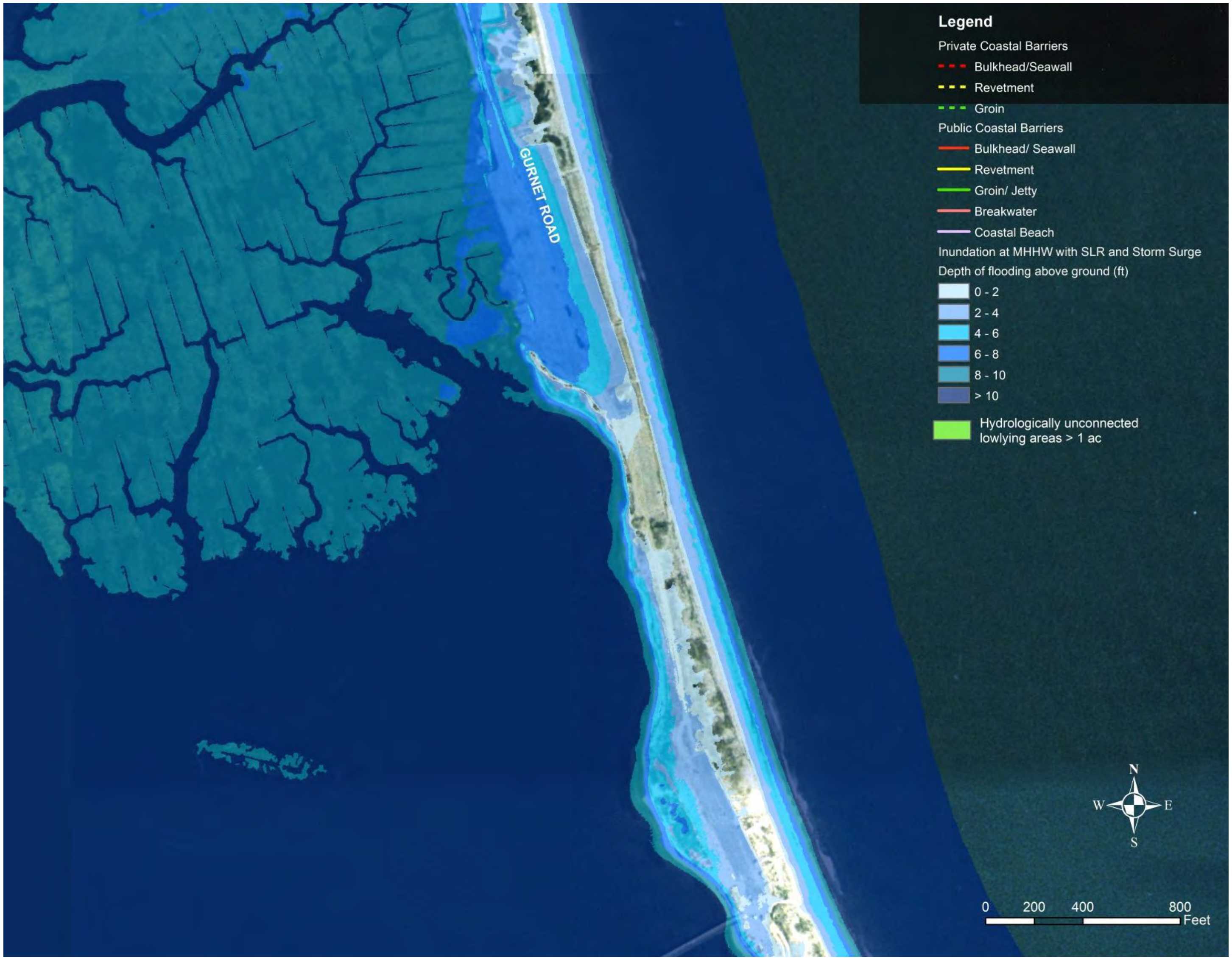


SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Duxbury Beach/Blakeman's Area 2088
75-year Time Horizon

SLR of 5.16 ft. by 2088

Duxbury Beach/Blakeman's Area 2088
75-year Time Horizon



SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

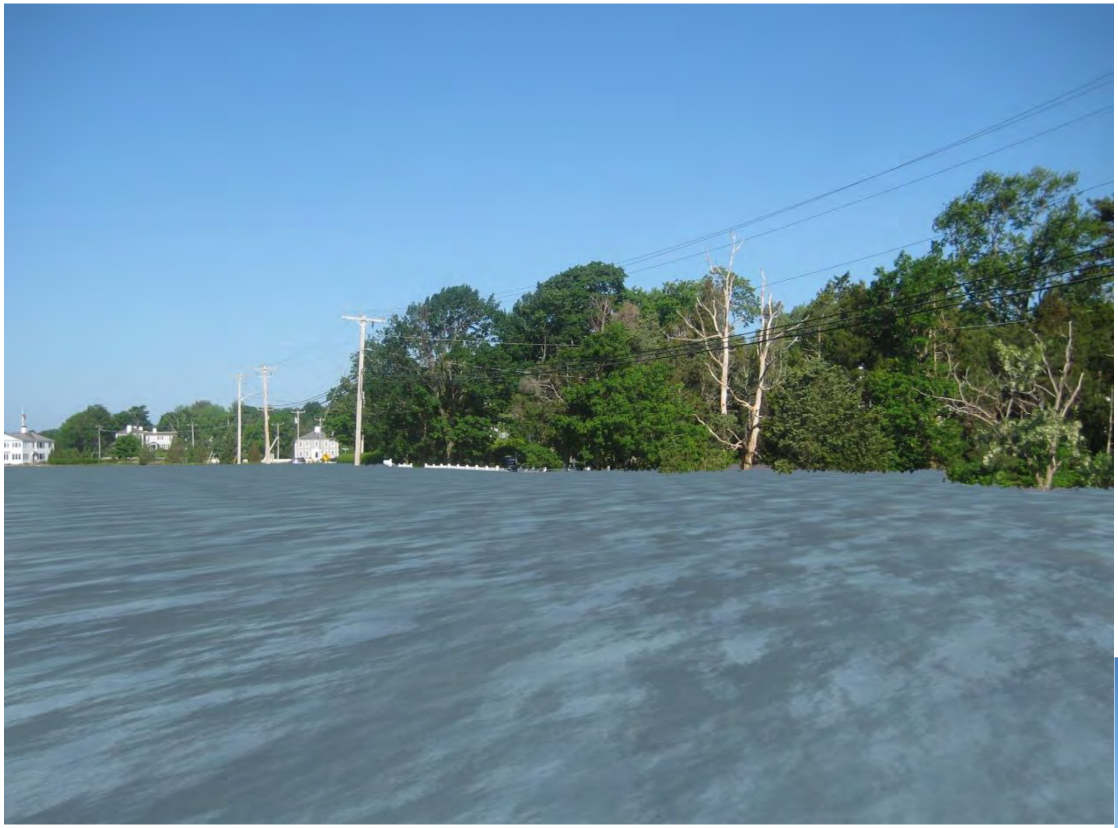
3D Rendering
Duxbury Beach by 2088 (75-years) with SLR and Storm Surge

2088

Present

3D Rendering

Powder Point Avenue at King Caesar Road, Duxbury by 2088 (75-years) with SLR and Storm Surge



2088

Present

Washington Street/Snug Harbor Area, Duxbury 2038
25-year Time Horizon

SLR of 1.08 ft. by 2038

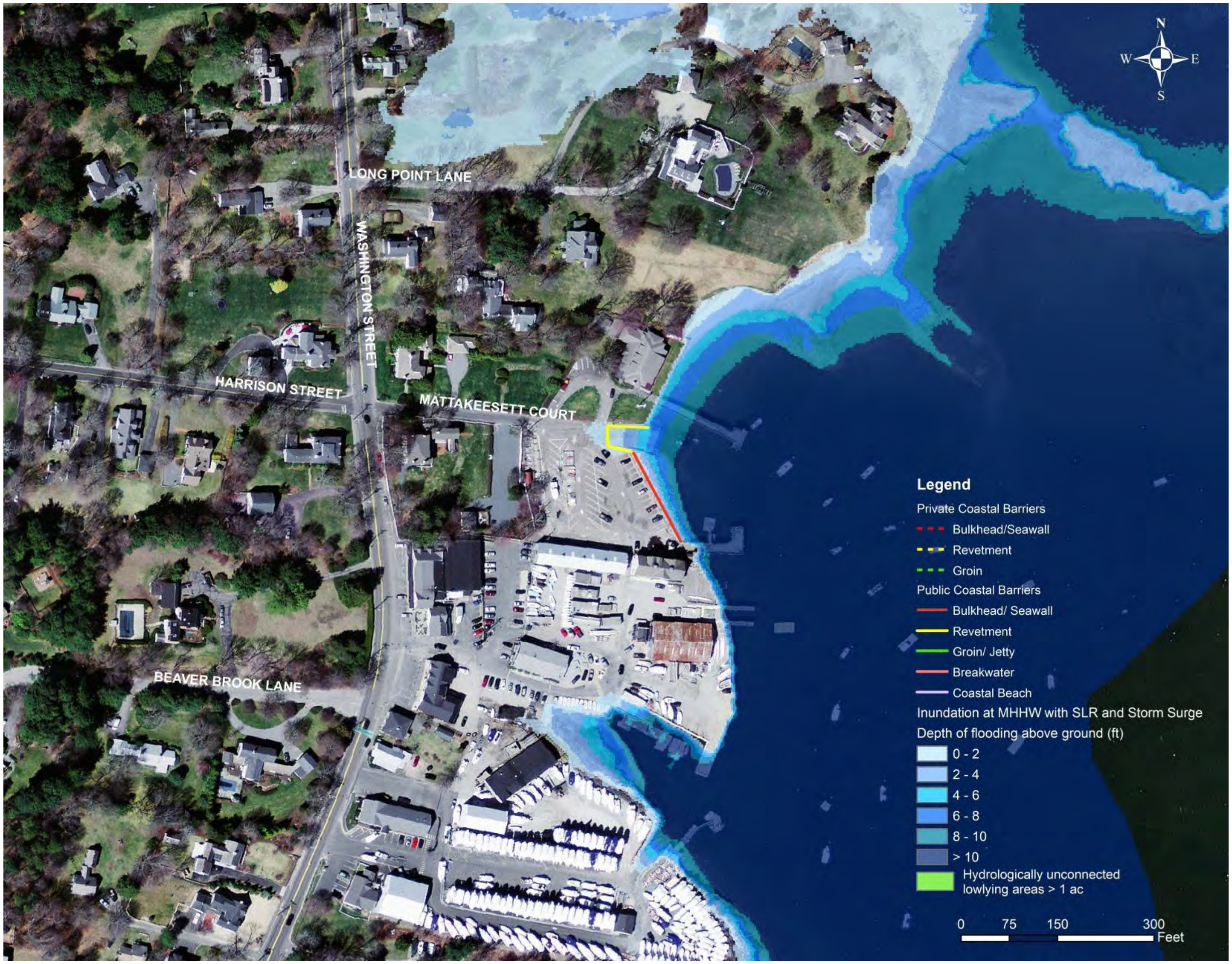
Washington Street/Snug Harbor Area, Duxbury 2038
25-year Time Horizon

SLR of 1.08 ft. by 2038 and Storm Surge from Category 1 Hurricane

Washington Street/Snug Harbor Area, Duxbury 2063
50-year Time Horizon

SLR of 2.80 ft. by 2063

Washington Street/Snug Harbor Area, Duxbury 2063
50-year Time Horizon



SLR of 2.80 ft. by 2063 and Storm Surge from Category 1 Hurricane

Washington Street/Snug Harbor Area, Duxbury 2088
75-year Time Horizon

SLR of 5.16 ft. by 2088

Washington Street/Snug Harbor Area, Duxbury 2088
75-year Time Horizon

SLR of 5.16 ft. by 2088 and Storm Surge from Category 1 Hurricane

3D Rendering

Washington Street looking North at Snug Harbor, Duxbury by 2088 (75-years) with SLR and Storm Surge

2088

Present

Duxbury - Natural Resources Impacts

Tidal Salt Marsh

Tidal salt marshes are an important part of the local coastal ecosystem. They are an essential element of the aquatic food web, provide valuable habitat for many birds and other aquatic species, and they also provide protection from the effects of waves and currents. Sea level rise projections for Duxbury include potential negative impacts to tidal salt marsh in various areas of town including marshes associated with the Pine Point River, Little Wood River and Back River, at the north end of Duxbury Bay, marshes associated with the Bluefish River, marshes associated with Duxbury, Kingston and Eagles Nest Bays and marshes in the Nook. Each of these tidal salt marsh ecosystems will experience higher daily tidal ranges as sea levels rise.

Survival of the tidal marsh ecosystem depends on a balance between forces creating marsh vertical growth such as organic sediment accumulation and the forces causing deterioration of the marsh such as subsidence, sea level rise and wave erosion. The impact to the marsh ecosystems in Duxbury will be negative if tidal salt marsh elevations cannot keep pace with sea level rise through natural or assisted vertical growth of the marsh platform which includes plant matter accumulation such as root production and decomposition of dead plants. If the vertical growth of tidal salt marsh cannot keep pace with the rising sea levels, the result will be more flooding of the marshes which will cause the plants to die, and marsh ecosystem will eventually convert to intertidal mudflat or subtidal open water. Further study will be required to determine how sea level rise will affect the tidal salt marsh ecosystem.

Beaches

Beaches along the Duxbury coast line, including Duxbury Beach, Ship Yard Lane Beach, and various smaller beaches and landings, will be affected by rising sea levels. Tidal elevations will increase on a daily basis. If beaches are not otherwise nourished and raised, there could be partial or complete loss of some ocean front beaches at high tides. In addition, the potential for increased frequency and intensity of storm events can also lead to additional deterioration of ocean front beaches.

Wildlife

Duxbury Beach is an important nesting habitat for Piping Plovers and Least Terns, both of which are listed as “Threatened” under the federal Endangered Species Act. Rising sea levels and potential destruction of nesting habitat on Duxbury Beach due to dune erosion would result in dramatic decreases in the fledge rates of Piping Plovers and Least Terns. Also, potential loss of tidal salt marsh wetlands would also affect habitat of many other coastal birds and other coastal aquatic wildlife.

Shellfish and Aquaculture

Duxbury Bay is prime habitat for a thriving shellfish industry serving both commercial and recreational interests. Major shellfish species include oysters, softshell clams, mussels, razor clams, and quahogs. There is an important commercial aquaculture industry focused on growing oysters. The impacts to shellfish due to rising sea levels and water temperatures are not well understood at this time. Some effects that could negatively affect the shellfish population and industry include:

- Deeper waters will reduce time available to access and work shellfish beds.
- Deeper waters may reduce optimal growing areas on current aquaculture leases, even potentially shifting optimal areas off of leases.

- Deeper waters may alter patterns of predation and exposure.
- Rising water temperatures could affect shellfish growth patterns and timing.
- Rising water temperatures could increase potential for disease.
- Changes to existing tidal salt marshes could change nutrient levels in the water which could affect shellfish growth.

It should be noted that changes in sea level and water temperature are occurring at a slow rate, so there is potential for shellfish to evolve and adapt to meet the changing conditions.

Duxbury – Infrastructure Impacts

Roadways and Bridges
The inundation maps for Duxbury for the various sea level rise and storm surge projections indicate that a number of roads along the coast will be affected by higher tides and storm events, especially at the 75 year scenario. Some of the roads which will be greatly affected by rising sea levels alone in 75 years (excluding the effects of storm surge) include:

- Washington Street in the Snug Harbor area
- Powder Point Avenue and King Caesar Road leading to Powder Point
- Sections of Bay Road
- Pine Point Road
- Marginal Road
- Gurnet Road
- Duxbury Beach Access Road providing access to Gurnet and Saquish areas located at the South end of Duxbury Beach in the Town of Plymouth

The deck of the Powder Point Bridge going to Duxbury Beach appears to be above the flood and storm surge levels at the 75 year scenario. Similarly, the Eagles Nest (Marshall Street) and Bluefish River (Washington Street) Bridges appear to be above the 75 year flood and storm surge levels, however the approach roads to both bridges will be inundated and likely impassable.

The obvious effect of flooded roadways is that travel on the roads will be greatly affected during storm events. Much like what happens today, road traffic will have to be curtailed during storm events. However, some of these roads will also be affected during normal daily high tide cycles which will not be acceptable for normal town operations. In addition, increase flooding of roads will lead to significant increases in the rate of deterioration of the road structure itself.

Coastal Stabilization Structures
There are numerous coastal stabilization structures along the Duxbury coastline, including concrete sea walls, stone revetments, groins, and breakwaters. Rising sea levels, combined with the effects of the projected higher frequency and intensity of coastal storms, will result in more damage to coastal stabilization structures and more over-topping of the structures due to storm wave action. Many of the existing sea walls experience over-topping today during major storms. Over-topping, and the associated damage of structures and public infrastructure located behind sea walls, will only increase as sea levels rise in the future.

Higher tidal elevations will result in deeper water depths in front of coastal stabilization structures during high tides, which will result in larger ocean waves hitting the structures, which will in turn accelerate structural damage of the structures and increase the rate of erosion in front of the structures. Deeper water will increase not only the force of wave impacts, but also the frequency of interaction between the wave energy and the structure, further eroding the beach fronting the seawall. This self-reinforcing cycle (eroding beach creates deeper water creates more wave interaction creates eroding beach) ultimately leaves the seawall/structure without adequate coastal beach to provide stability or protection during a storm. Currently, due to coastal erosion and sea level rise, many areas have little or no beach in front of structures constructed in the 1930s through 1950s which can absorb wave energy. In these areas, the structures are the first and only lines of coastal defense. Where this is the case, increasing the height of seawalls may not be the best solution. A better solution is to raise structures while recreating landform in front of the structures to help absorb wave energy and to stabilize the structures.

Duxbury Beach

Duxbury Beach serves as a major storm control structure for the Town of Duxbury as well as an important recreational facility. It is a 4.5 mile sand/cobble barrier beach that acts as a natural breakwater to prevent ocean waves from crossing Duxbury Bay and reaching the mainland. The Duxbury Beach Reservation, Inc., a private non-profit corporation that owns the beach and leases it to the Town of Duxbury, maintains an engineered “sacrificial” dune along the entire length of the beach to protect the beach and longitudinal roadway from extreme erosion from ocean waves. As sea levels rise and ocean storms become more frequent and intense, the existing dune is proving to be insufficiently high to prevent over-topping of waves. Two recent winter Nor’easters in 2013 caused major damage to the beach, parking lots and roadway which required approximately $800,000 of repairs to restore the sacrificial dune to its current approved elevation.

Underground Infrastructure Systems

There are many buried piping systems and utilities in the roads including sanitary sewer, storm sewer, water and gas. Electrical, telephone, and cable television systems appear to be pole-mounted in all of the coastal roadways that are affected by flooding. All of the roadways that are shown to be impacted by rising sea levels and storm surge are currently susceptible to flooding and damage during storm events. Increased flooding during high tides and storm events will increase the rate of deterioration of the underground infrastructure and increase the possibility of wash outs that could cause unsafe conditions and service interruptions.

The Town of Duxbury does not operate a Wastewater Treatment Plant. All residences and businesses in town utilize septic systems to dispose of sanitary waste. Rising sea levels could affect septic systems if ground water elevations near the coast rise due to rising sea levels. The higher ground water levels could make septic systems adjacent to the coast line non-compliant, even potentially causing breakout and contamination.

A number of homes and businesses in Duxbury utilize shared septic systems which collect sanitary waste from individual home and businesses into a shared collection tank at the low point of the system. The waste is then pumped uphill to leaching fields away from the coastline. There are three such shared septic systems in Duxbury that will be subject to additional flooding due to sea level rise. Pump systems and collection chambers are located on Washington Street at the Bluefish River, in Mattakeeset Court parking lot at Snug Harbor, and on Bay Road. Each of these systems currently operates in areas subject to flooding, but the flood levels will increase which may affect the electrical power supplies and power panels for the pumps. The underground chambers themselves should not be affected by rising sea levels.

There are also numerous drainage culverts under roadways that connect drainage areas from one side of the road to the other. It is not within the scope of this project to determine which culverts, if any, could be affected by rising sea levels.

Duxbury – Transportation Impacts

There are no MBTA commuter rail facilities located in Duxbury. Public school and transit bus routes utilizing roads subject to flooding from sea level rise and storm surge will be affected and may need to be temporarily or permanently re-routed.

Duxbury - Emergency Access Impacts

The inundation maps for Duxbury for the various sea level rise and storm surge projections indicate that flooding will result in closure of Powder Point Avenue which serves as the only point of access to residences on Powder Point and the Duxbury Beach Access Road which serves as the only point of access to the residences on Gurnet Point and Saquish Beach in Plymouth. If these access roads to these areas are blocked off, then there is no other emergency egress route to these residential sections. These roads also serve as part of the emergency evacuation plan for the Pilgrim Nuclear Power Plant for the Towns of Duxbury and Plymouth, and must be open for the plant to continue operation. It should be noted that these roads currently do get flooded and closed during astronomical tidal and storm events, so the town already does have a system to deal with emergency access in these locations. However, if nothing is done to change the roads, the frequency and duration of flooding and closures can be expected to increase, putting more strain on the Police, Fire and Public Works Departments.

POTENTIAL ADAPTATION STRATEGIES

There are four general approaches to mitigating the long-term effects of sea level rise:

- Do Nothing
- Protection
- Accommodation
- Retreat

Do Nothing – "Do Nothing" is not really a strategy, but rather the lack of a strategy. Although many communities do nothing to deal with long-term issues such as sea level rise, it is not a wise course of action because eventually the problem will need to be dealt with one way or another. Therefore, we will not be making any "do nothing" recommendations as part of this study.

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

Accommodation - Accommodation adaptation strategies allow flood waters to reach a developed area or essential infrastructure, but damage to the development or infrastructure is minimized and controlled. Accommodation strategies acknowledge that structures and infrastructure will be exposed to the rising sea levels and storm surges and get wet, but actions are taken to minimize potential damage. Examples of accommodation adaptation strategies include raising structures above flood elevations, constructing sacrificial dunes and structures that are designed to absorb the impact of large storms to prevent major damage to infrastructure behind them with the understanding that they will need repair or replacement if destroyed, protecting utilities in waterproof enclosures; flood-proofing structures, instituting new building codes and zoning, such as increased setbacks, that require accommodation strategies to be implemented for all new construction and major renovation projects.

Retreat - Retreat adaptation strategies recognize the fact that in some areas it may be too costly, technically not feasible, or politically unrealistic to prevent damage from rising sea levels and storm surge, and that the best strategy is to remove the structures and infrastructure from harm's way. Retreat strategies relocate affected infrastructure away from the ocean to higher ground and to transform the affected areas back to natural barriers which can migrate landward naturally. Examples of retreat adaptation strategies include property buyouts, relocation of roads, buildings and infrastructure, and implementation of new zoning or other regulations limiting new construction, reconstruction, or expansion of existing structures.

The following tables identify a range of recommended adaptation strategies for each town which include a mix of accommodation, fortification and retreat strategies. Strategies are limited to municipal infrastructure only. Adaptation strategies are not provided for private residences or businesses. Each strategy is rated on the basis of relative cost, regulatory constraints, impacts to the tax base, political impacts and environmental impacts. Impacts are rated on a scale of high, medium, low.

Town of Scituate – Potential Adaptation Strategies

(H = High; M = Medium; L = Low)

No.	Scituate - Potential Adaptation Strategy	Strategy Type	Relative Cost	Regulatory Constraints	Impacts: Tax Base	Impacts: Political	Impacts: Environment
1	**Raise Front Street, Cole Parkway, harbor parking lot, and associated underground utilities.** Pros – Solves flooding problem. Cons – Businesses along road also need to be raised.	Accommodation	H	H	H	H	L
2	**Raise Central Avenue and other impacted streets on Humarock and associated underground utilities.** Pros – Solves flooding problem and provides emergency access to 4th Cliff. Cons – Unless sea walls raised, road will still be subject to over-topping debris and resulting closures.	Accommodation	H	H	L	H	H
3	**Raise Edward Foster Road and associated utilities.** Pros – Solves flooding problem and maintains emergency access to 1st and 2nd Cliffs. Cons – Difficult to permit.	Accommodation	H	H	L	M	H
4	**Raise Jericho Road and associated utilities.** Pros – Solves flooding problems. Cons – Some adjacent low homes will need to be raised to street level.	Accommodation	H	H	L	H	M
5	**Raise Bayberry Road and associated utilities**. Pros – Solves flooding problem. Cons – some houses may need to be raised to meet the new street level.	Accommodation	M	H	L	H	M
6	**Raise affected sections of Turner Road, Egypt Avenue and Surfside Road and associated utilities**. Pros – Solves flooding problem. Cons – some houses may need to be raised to meet the new street level.	Accommodation	M	H	L	H	M
7	**Rebuild Existing Sea Walls at least 2 ft. higher to accommodate rising sea levels over next 25 years.** Pros – Helps protect existing Infrastructure. Cons – Walls will need to be raised again. Eventually wall height will become objectionable to neighbors.	Protection	H	H	H	H	H
8	**Investigate constructing offshore floating breakwaters or other wave attenuation devices to absorb wave energy so that existing sea walls do not need to be raised too high.** Pros – Minimizes future sea wall construction. Cons – Could affect beach sediment migration onto adjacent beaches and beaches north and south of Scituate.	Protection	H	H	L	H	H
9	**Investigate possibility of constructing a hurricane barrier across Scituate Harbor to protect Front Street commercial district from effects of storm surge.** Pros – Would minimize how much St. needs to be raised. Cons – Front St. still needs to be raised to prevent flooding from high tides due to sea level rise.	Protection	H	H	M	H	H

No.	Scituate - Potential Adaptation Strategy	Strategy Type	Relative Cost	Regulatory Constraints	Impacts: Tax Base	Impacts: Political	Impacts: Environment
10	**Perform a study of the "Avenues" sewer pumping station to ensure that the electrical systems powering the pump are above future flood levels, and raise electrical systems if necessary**. Pros – Ensures that pump station will remain operational during higher flood events. Cons – None.	Accommodation	L	L	L	L	L
11	**Investigate possibility of instituting a home buy-back plan on Humarock and other vulnerable areas and prohibiting future construction to minimize need for reconstruction of sea walls in the future.** Pros - Long term costs could be minimized if need for sea walls is eliminated. Cons – Cost to buyout properties would be high; Would likely still need to maintain an access road to 4th Cliff and other areas so a sacrificial dune or similar stabilization structure would likely be required.	Retreat	H	H	H	H	L
12	**Conduct a study to assess the health of tidal salt marshes to determine salt marsh restoration strategies to maintain vital tidal salt marshes.** Pros – A study will determine the vertical growth characteristics of the existing tidal salt marshes and can estimate how sea level rise will affect the health of the salt marshes. Cons – None.	Accommodation	L	L	L	L	H
13	**Raise the Scituate Community Center onto pilings so that the first floor is above the 75 year flood elevation.** Pros – Community Center will be raised above flood elevation. Cons – Building may not be worth saving due to its age, condition and use	Accommodation	M	H	L	M	L
14	**Plan to demolish the Scituate Community Center within the next 25 years and rebuild it in a new location.** Pros – Avoid the need to raise the Community Center and make it ADA accessible. Cons – Lose a beautiful location for the Community Center.	Retreat	H	L	L	M	L
15	**Investigate the possibility of implementing Rolling Easements in flood prone sections of town which the town can purchase from a landowner today in exchange for a promise to turn over the property to the town once it is inundated by a storm.** Pros – Rolling easements are a way to provide cash to an owner today with the understanding that when the home is damaged beyond repair in a storm it will not be rebuilt and will be turned over to the town. Cons – Program can be expensive and there is uncertainty as to when transactions will actually take place which makes planning somewhat difficult; properties are taken off the tax rolls.	Retreat	H	L	H	M	L

No.	Scituate - Potential Adaptation Strategy	Strategy Type	Relative Cost	Regulatory Constraints	Impacts: Tax Base	Impacts: Political	Impacts: Environment
16	**Conduct a beach nourishment study to develop a long-term beach nourishment plan, focusing on beaches with public access.** Pros – A well designed and maintained beach helps to absorb wave energy, especially in front of coastal stabilization structures and provides an important recreation asset for the public. Cons – Beach nourishment and on-going maintenance is expensive and can be difficult to permit.	Accommodation	H	H	H	H	H

Town of Marshfield – Potential Adaptation Strategies

(H = High; M = Medium; L = Low)

No.	Marshfield - Potential Adaptation Strategy	Strategy Type	Relative Cost	Regulatory Constraints	Impacts: Tax Base	Impacts: Political	Impacts: Environment
1	**Raise sections of Bay Avenue and associated underground utilities.** Pros – Solves flooding problem. Cons – Some houses along road may also need to be raised.	Accommodation	H	H	H	H	M
2	**Raise sections of Dyke Road (Route 139), and the Dyke Road outlet structure and associated underground utilities.** Pros – Solves flooding problem on a main road. Cons – None	Accommodation	H	H	L	M	H
3	**Raise Ocean Street, Island Street and Cove Street in the Brant Rock area and associated utilities.** Pros – Solves flooding problem and maintains emergency access to the Brant Rock area. Cons – Unless sea walls in the area are raised, some sections of these streets will still be subject to debris and closure due to over-topping during storm events; some area businesses and homes may have to be raised to meet the higher road elevations.	Accommodation	H	H	H	H	L
4	**Raise Town Pier Road and the parking area at the Town Pier and associated utilities.** Pros – Solves flooding problems. Cons – None.	Accommodation	H	M	L	M	M
5	**Raise several roadways in the Rexhame Beach area and associated utilities**. Pros – Solves flooding problems. Cons – Unless sea walls in the area are raised, some sections of these streets may still be subject to debris and closure due to over-topping during storm events; some area homes may have to be raised to meet the higher road elevations.	Accommodation	H	M	L	M	M
6	**Raise Macombers Ridge, Macombers Way and Bartletts Isle Way and associated utilities.** Pros – Solves flooding problems and maintains emergency access to neighborhoods. Cons – None.	Accommodation	M	M	L	L	M
7	**Rebuild Existing Sea Walls at least 2 ft. higher to accommodate rising sea levels over next 25 years.** Pros – Helps protect existing Infrastructure. Cons – Walls will need to be raised again. Eventually wall height may become objectionable to neighbors.	Protection	H	H	H	H	H
8	**Investigate constructing offshore floating breakwaters or other wave attenuation devices to absorb wave energy so that existing sea walls do not need to be raised too high.** Pros – Minimizes future sea wall construction. Cons – Could affect beach sediment migration onto adjacent beaches and beaches north and south of Marshfield.	Protection	H	H	L	H	H

No.	Marshfield - Potential Adaptation Strategy	Strategy Type	Relative Cost	Regulatory Constraints	Impacts: Tax Base	Impacts: Political	Impacts: Environment
9	**Investigate possibility of instituting a home buy-back plan in areas vulnerable to sea level rise and storm damage and prohibiting future construction to minimize need for reconstruction of sea walls in the future.** Pros - Long term costs could be minimized if need for sea walls is eliminated. Cons – Cost to buyout properties would be high.	Retreat	H	H	H	H	L
10	**Conduct a study to assess the health of tidal salt marshes to determine salt marsh restoration strategies to maintain vital tidal salt marshes.** Pros – A study will determine the vertical growth characteristics of the existing tidal salt marshes and can estimate how sea level rise will affect the health of the salt marshes. Cons - None	Accommodation	L	L	L	L	H
11	**Construct storm closure panels at openings in sea walls that can be closed in advance of a storm to ensure that water does not pass through openings during storm events.** Pros – Minimizes penetrations in sea walls. Cons – Devices need to be maintained so that they can be closed in advance of a storm.	Accommodation	M	H	L	L	L
12	**Construct a berm around the wastewater treatment plant to prevent flooding of the treatment plant. The entrance road should be designed to go over the berm, eliminating the need for a closure structure.** Pros – Relatively easy to construct a perimeter berm to ensure plant does not get flooded. Cons - None	Fortification	M	L	L	L	L
13	**Investigate the possibility of implementing Rolling Easements in flood prone sections of town which the town can purchase from a landowner today in exchange for a promise to turn over the property to the town once it is inundated by a storm.** Pros – Rolling easements are a way to provide cash to an owner today with the understanding that when the home is damaged beyond repair in a storm it will not be rebuilt and will be turned over to the town. Cons – Program can be expensive and there is uncertainty as to when transactions will actually take place which makes planning somewhat difficult; properties are taken off the tax rolls.	Retreat	H	L	H	M	L
14	**Conduct a beach nourishment study to develop a long-term beach nourishment plan, focusing on beaches with public access.** Pros – A well designed and maintained beach helps to absorb wave energy, especially in front of coastal stabilization structures, and provides an important recreation asset for the public. Cons – Beach nourishment and on-going maintenance is expensive and can be difficult to permit.	Accommodation	H	H	H	H	H

Town of Duxbury – Potential Adaptation Strategies

(H = High; M = Medium; L = Low)

No.	Duxbury - Potential Adaptation Strategy	Strategy Type	Relative Cost	Regulatory Constraints	Impacts: Tax Base	Impacts: Political	Impacts: Environment
1	**Raise sections of Washington Street in the Snug Harbor area and Bluefish River area and the Mattakeeset Court parking lot at the harbor and associated underground utilities.** Pros – Solves flooding problem. Cons – Some businesses along Washington Street may also need to be raised.	Accommodation	H	H	H	H	M
2	**Raise sections of Powder Point Avenue and King Caesar Road and associated underground utilities.** Pros – Solves flooding problem and maintains emergency access to the Powder Point residential area, Duxbury Beach, and the Gurnet and Saquish neighborhoods in Plymouth. Cons – None	Accommodation	H	H	L	M	H
3	**Raise sections of Bay Road and associated utilities.** Pros – Solves flooding problems. Cons – None.	Accommodation	M	H	M	M	M
4	**Raise Pine Point Road, Marginal Road and Gurnet Road and associated utilities.** Pros – Solves flooding problems. Cons – None.	Accommodation	M	H	M	M	M
5	**Raise the Duxbury beach access road from the Powder Point Bridge to the Gurnet and Saquish neighborhoods in Plymouth at the south end of Duxbury beach**. Pros – Solves flooding problems and maintains emergency access to the Gurnet and Saquish neighborhoods in Plymouth. Cons – Road needs to be an unpaved road which requires annual maintenance; unless dunes along Duxbury beach are raised, road will continue to suffer erosion and breaches during significant storm events.	Accommodation	H	H	L	M	H
6	**Rebuild Existing Sea Walls at least 2 ft. higher to accommodate rising sea levels over next 25 years.** Pros – Helps protect existing Infrastructure. Cons – Walls will need to be raised again. Eventually wall height may become objectionable to neighbors.	Protection	H	H	M	H	H
7	**Investigate constructing offshore floating breakwaters or other wave attenuation devices to absorb wave energy so that existing sea walls do not need to be raised too high.** Pros – Minimizes future sea wall construction. Cons – Could affect beach sediment migration onto adjacent beaches and beaches north and south of Duxbury.	Protection	H	H	L	H	H
8	**Investigate possibility of instituting a home buy-back plan in areas vulnerable to sea level rise and storm damage and prohibiting future construction to minimize need for reconstruction of sea walls in the future.** Pros - Long term costs could be minimized if need for sea walls is eliminated. Cons – Cost to buyout properties would be high.	Retreat	H	H	H	H	L

No.	Duxbury - Potential Adaptation Strategy	Strategy Type	Relative Cost	Regulatory Constraints	Impacts: Tax Base	Impacts: Political	Impacts: Environment
9	**Conduct a study to assess the health of tidal salt marshes to determine salt marsh restoration strategies to maintain vital tidal salt marshes.** Pros – A study will determine the vertical growth characteristics of the existing tidal salt marshes and can estimate how sea level rise will affect the health of the salt marshes. Cons - None	Accommodation	L	L	L	L	H
10	**Raise the parking lots on Duxbury Beach at Blakeman's and at the east end of the Powder Point Bridge. Also raise Blakeman's bath house.** Pros – Solves flooding problems; may not have to be funded by the Town as the owner of the property is the Duxbury Beach Reservation. Cons – May not be cost effective to raise Blakeman's bath house due to its age and condition.	Accommodation	M	H	L	L	H
11	**Raise all electrical power service associated with the three shared septic pump systems to ensure that power service will not be affected by rising sea levels.** Pros – Ensures that shared septic system pumps keep operating, even during flood events. Cons – None.	Accommodation	L	L	M	L	L
12	**Investigate the possibility of implementing Rolling Easements in flood prone sections of town which the town can purchase from a landowner today in exchange for a promise to turn over the property to the town once it is inundated by a storm.** Pros – Rolling easements are a way to provide cash to an owner today with the understanding that when the home is damaged beyond repair in a storm it will not be rebuilt and will be turned over to the town. Cons – Program can be expensive and there is uncertainty as to when transactions will actually take place which makes planning somewhat difficult; properties are taken off the tax rolls.	Retreat	H	L	H	M	L
13	**Conduct a beach nourishment study for Duxbury Beach to develop a long-term beach nourishment plan and raise the sacrificial dune elevation by at least 2 feet to provide further protection of the beach and beach access road.** Pros – A well designed and maintained sacrificial dune helps to absorb wave energy and provides an important recreation asset for the public; the beach and dunes provide important nesting habitat for threatened birds such as Piping Plovers and Least Terns. Cons – Beach nourishment and on-going maintenance of sacrificial dunes is expensive and can be difficult to permit.	Accommodation	H	H	L	H	H

SUGGESTED NEXT STEPS

This report represents the second step undertaken by the Towns of Marshfield, Duxbury and Scituate to proactively start to address the future impacts of sea level rise. Some future steps that should be considered include:

- Pursue funding for a follow-up analysis of the effects of wave-runup and overtopping of coastal stabilization structures. This will further define the potential impacts related to sea level rise and storm surge.

- Formalize inter/intra-municipal working groups to facilitate and advance further studies related to sea level rise studies and to further study potential adaptation strategies.