



**SUSTAIN SOUTHERN MAINE**

*Partnering to strengthen our economy, environment and community*

## **Sea Level Rise Vulnerability Assessment**

**A Report for Sustain Southern Maine  
Greater Portland Council of Governments**

**December, 2013**

# ***Sustain Southern Maine Sea Level Rise Vulnerability Assessment***

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## **Prepared by:**

Damon Yakovleff, Greater Portland Council of Governments (GPCOG)

## **Special Thanks to:**

Peter Slovinsky, Maine Geological Survey

Matthew Craig, Casco Bay Estuary Partnership

Lee Jay Feldman, Southern Maine Planning and Development Corporation

Rebecca Schaffner, Greater Portland Council of Governments

Stephanie Carver, Greater Portland Council of Governments

Abe Dailey, Greater Portland Council of Governments

Rick Harbison, Greater Portland Council of Governments

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## Disclaimer

Please note that **this is not an exhaustive assessment** of the hazards present in each municipality. It is meant more to highlight the higher profile vulnerabilities **to both locally and regionally important public infrastructure**. This document, by using the same methodology for each coastal municipality between Brunswick and Kittery, seeks to showcase the methodology that could be used to demonstrate the regional threat SLR poses. It is intended that this document be used to set the stage for future SLR vulnerability assessment work.

## I. Introduction

This document presents a compilation of work to assess vulnerability to coastal flooding for the Sustain Southern Maine (SSM) region. The SSM Region (Figure 1) extends from Brunswick to Kittery along the coast, and inland to Raymond, Standish, and Acton. This assessment is based on information provided by organizations including the Maine Geological Survey, Southern Maine Planning and Development Commission (SMPDC), the U.S. Environmental Protection Agency (EPA), Casco Bay Estuary Partnership (CBEP), the Greater Portland Council of Governments (GPCOG), and various other municipal and federal entities.

This assessment was written in consultation with Peter Slovinsky at the Maine Geological Survey (MGS). It builds on the collaborative effort between MGS and SMPDC in developing the Coastal Hazards Resiliency Tools (CHRT) project. This report also references CBEP's recent work assessing marsh migration for 10 of the 14 Casco Bay municipalities. A map showing where the CHRT and CBEP assessments have been employed is shown in Figure 2. Table 1 compares the various SLR assessments and the scenarios they compared. The work is differentiated according to whether it was primarily completed as part of the CHRT project or by CBEP.

As demonstrated by Figure 2 (on the next page), the majority of the SSM region has seen either a CHRT or CBEP assessment, and some municipalities have had both. The difference between these two assessments is the CHRT process assesses a wider range of impacts from SLR (as shown by Table 1) and also includes extensive public outreach. The CBEP assessments are focused on the issue of marsh migration, providing a more comprehensive analysis than had previously been available. The CBEP assessments did not include a comprehensive public outreach process.

Figure 1: Sustain Southern Maine Region



Figure 2: Coastal Flood Vulnerability Assessment Status

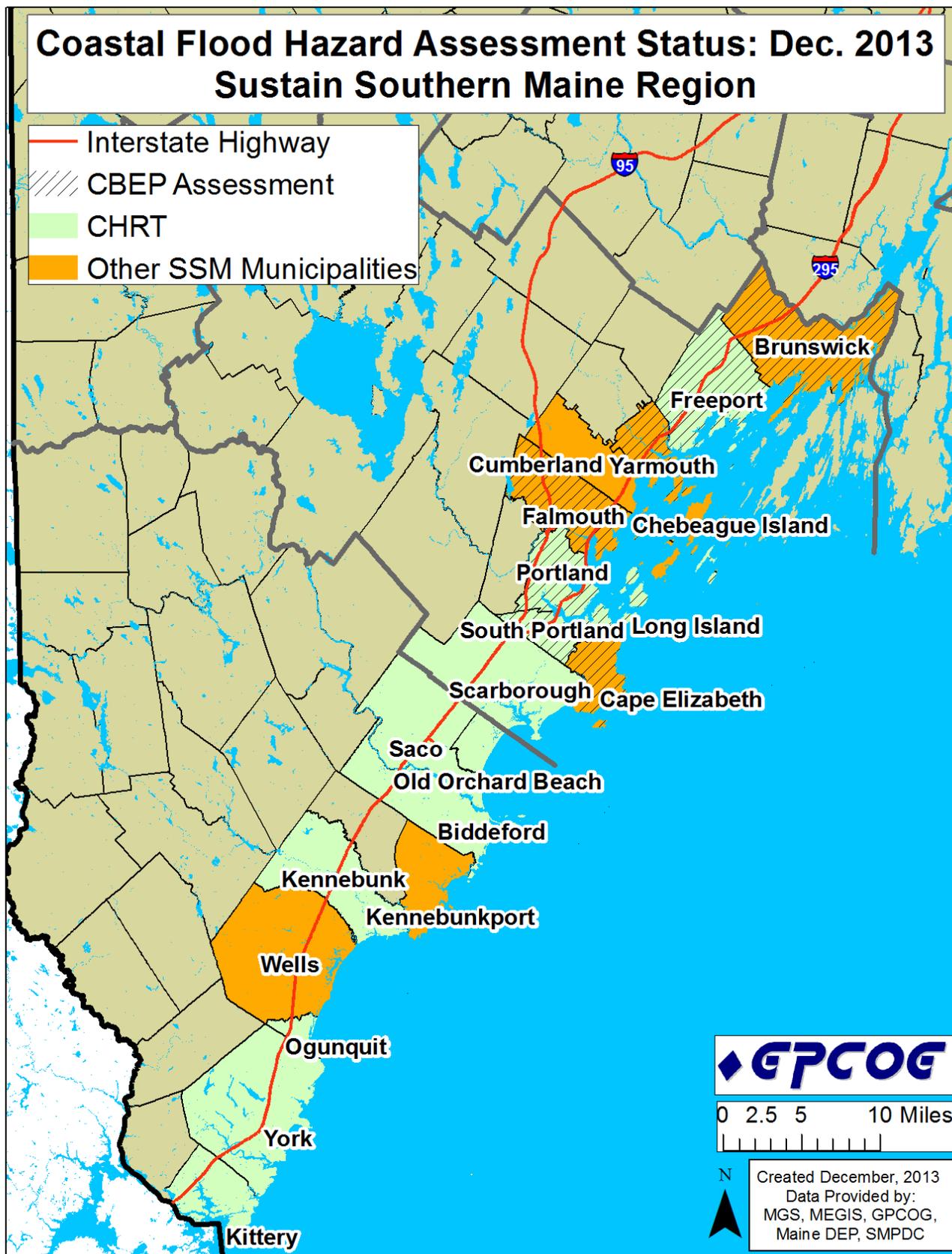


Table 1: Sea Level Rise Scenario Data Availability

Note – Maine Geological Survey work in green, CBEP data in pink

SSM Communities	Sea Level Rise (Coastal Hazards Resilience Tools / Storm Tsunami Mapping -- HAT + 6 ft. only)									Marsh Migration (EPA Data)			Marsh Migration (NOAA Data)				Marsh Migration Mapping (CBEP Data)		Marsh Migration Mapping		Tidal Barrier Mapping	
	HAT +				100-Year Storm +				Outreach	HAT +			HAT +				HAT +		MTL +/-HAT + 1'		MTL +/-HAT +3'	
	1 ft.	2 ft.	3 ft.	6 ft.	1 ft.	2 ft.	3 ft.	6 ft.		1 ft.	2 ft.	3 ft.	1 ft.	2 ft.	3 ft.	6 ft.	1 ft.	3 ft.	1 ft.	3 ft.	1 ft.	3 ft.
Coastal	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X
Biddeford	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X
Brunswick				X						X	X	X					X	X	X	X	X	X
Cape Elizabeth				X						X	X	X					X	X	X	X	X	X
Cumberland				X						X	X	X					X	X	X	X	X	X
Falmouth				X						X	X	X					X	X	X	X	X	X
Freeport	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X
Kennebunk	X	X	X	X	X	X	X	X	X	X	X	X										
Kennebunkport				X						X	X	X										
Kittery	X	X	X	X	X	X	X	X	X	X	X	X										
Ogunquit	X	X	X	X	X	X	X	X	X	X	X	X										
Old Orchard Beach	X	X	X	X	X	X	X	X	X	X	X	X										
Portland	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X
Saco	X	X	X	X	X	X	X	X	X	X	X	X										
Scarborough	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
South Portland	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X
Wells				X						X	X	X										
Yarmouth				X						X	X	X					X	X	X	X	X	X
York	X	X	X	X	X	X	X	X	X	X	X	X										
Non-Coastal																						
Arundel										X?	X?	X?										
Berwick										X	X	X										
Buxton																						
Eliot										X	X	X										
South Berwick										X	X	X										

While much of the northern portion of the SSM Region has not yet seen public outreach about SLR impacts through CHRT or other assessments, other work has been done to assess and communicate sea level rise impacts in this region to the public. For example, Bowdoin College researchers published a paper (Camill et al. 2012) assessing various SLR impacts to Brunswick and Harpswell. This work included a comprehensive public outreach component, bringing together local decision makers, the general public, and research scientists. The work serves as a model for outreach and coordination between the various SLR associated stakeholders for other municipalities in the region.

Other organizations have assessed SLR impacts to various municipalities in the region. For example, several organizations have provided assessments for Scarborough, including MGS as part of the NOAA project of special merit program. Multiple organizations have conducted assessments and outreach work for Wells, including The Wells Reserve, MIT with the Consensus Building Institute, as well as MGS.

Although a significant amount of work has been done to assess SLR impacts in the SSM region, a disparity exists in the level of detail in which each municipality has explored its vulnerability to coastal flooding. This document is intended to provide a consistent evaluation for each municipality. This allows a cross-comparison of vulnerable infrastructure and in some cases regionally applicable actions to protect such infrastructure. Better knowledge of such vulnerabilities on a regional level will facilitate a more cost effective response and help to stimulate mutual aid.

This document is in no way an exhaustive assessment of the risk for each municipality. It is intended to help maintain momentum for those municipalities where a great deal of work to assess SLR risk has already been completed. Where little work has been completed, it is intended to be used as a conversation starter.

### Why are marshes important?

It may be useful for readers to briefly note why CBEP, and others, are interested in the study of marshlands. For the limited area marshlands occupy in the region, they are extremely important. One reason is that marsh lands provide critical wildlife habitat, including for a number of economically important fisheries. In addition, this includes habitat for endangered species, many of which provide economically important tourism revenue. Marshes also provide valuable ecosystem services, including pollution filtering and flood buffering. Not only do they slow and buffer waters during coastal flood events, but they also slow erosion which otherwise might affect developed areas.

Coastal tidal marshes generally form in areas between the line on the shoreline reached by the “highest annual tide” or HAT, and waters to a given depth that depends on local conditions such as underlying geologic and hydrodynamic factors. In general, marshes at higher elevations are referred to as “high marsh”, and lower marshes are “low marsh”. Areas of high marsh, low marsh, and open water vary according to the overall sea level. If sea level falls, marshlands tend to extend further seaward, and if sea levels rise, marshes “transgress” or migrate inland.

### Why be concerned about marsh migration?

Marshlands in Maine are in relatively short supply in comparison to places further south along the U.S. east coast. This supply shortage is largely a product of Maine’s steep coastal topography. Since the marsh migration process in the state is already constrained by topography, if it is further constrained by development, the amount of marshlands available could significantly decline. In order to mitigate the likely future impacts of marshland migration into developed areas, organizations such as the EPA, CBEP, and MGS have dedicated resources to assessing the probable locations of marsh migration so that actions like coastal zoning changes and other protective actions can be taken.

When possible (not constrained by development, steep slopes, etc.) SLR will cause marshlands to migrate to adjacent upland areas. Some areas of “high marsh” would convert to “low marsh”, and some areas of low marsh would convert to open water. All of the conversions have significant ecological effects, which may affect economically important species such as shellfish. Studies have shown that saltwater wetlands may erode or subside at accelerated rates versus freshwater wetlands, which has implications for developed or potentially developable real estate. Revisions to shoreland zoning enacted now in anticipation of marsh migration may ameliorate these negative impacts.

## II. Study Methodology

### Flood Layers

The flood layers used in this assessment have been generated by using the most current and highest resolution LiDAR data available. They were produced by adding the flood elevation for each scenario to the baseline highest annual tide (HAT) elevation. They do not include complex hydrodynamic effects such as waves and strong currents, but rather “stillwater” elevations. This means that they are a conservative estimate and that for a given storm actual damage is more likely to be worse than indicated – extending further inland and with greater destructive force.

This assessment considers three different levels or scenarios of coastal flooding. The first considered is the HAT + 2 feet. Two feet of SLR is a useful figure in Maine because it is the level chosen by the State Legislature for SLR planning for coastal dune lands through 2100. It also represents a good baseline conservative figure based on the latest research on SLR and climate change. According to the National Academy of Sciences (2010), higher levels of SLR are certainly possible, given recently detected rises in ice mass loss in Greenland, Antarctica, and various mountain glaciers. For this reason, higher flood elevations of 1-meter (3.28 ft.) and 2-meter (6.56 ft.) are considered here. All layers were provided by MGS, and were derived from the same LiDAR base data. The 2-foot and 1-meter layers were originally created for an EPA funded project on marsh migration, and the 2-meter layer for emergency management response planning.

It is important to stress that even with no SLR, severe coastal flooding on the order of the highest flood elevation considered here is still possible. This was demonstrated last year by the devastating effects Hurricane Sandy had on coastal New Jersey, New York, and Connecticut. With just a small amount of SLR, the recurrence interval of the more destructive of storm events would likely increase. For example, with just 1 foot of SLR, the 100 year event water elevation would have a recurrence interval of only 10 years. This effect could be exacerbated by the expectation that climate

change may increase the frequency of severe storms in Maine over the course of this century.

### Public Facilities

This report focuses on vulnerabilities of public facilities and infrastructure to coastal flooding. Data on public facilities was provided by the Maine Office of Geographic Information Systems (MEGIS), which also provided data used for basemap layers. Information on sewer and water infrastructure was provided by the Maine Department of Environmental Protection and SMPDC. The public facilities and wastewater data layers were intersected with the different flood polygons to determine possible vulnerability.

### Road Infrastructure

As this assessment (and associated stakeholder outreach process) proceeded, it became increasingly clear that a significant amount of road infrastructure in the SSM is vulnerable to inundation. This could have numerous effects, especially during storm emergencies. In many cases, entire neighborhoods are connected through only one or two road linkages to the rest of the road network. Many of these linkages are vulnerable to inundation.

For the purposes of this assessment, vulnerable road “segments” have been identified. For the most part, “segments” are lengths of roads between intersections with other road segments, as broken down by the state in the creation of the “Next Generation 911” roads dataset. The total number of road segments is provided in order to compare the relative risks in a regional sense. It should be noted that an estimate of the total length of road inundation was not calculated here. Such an estimate would be both inaccurate and of less use, given that if a road is inundated and impassible, a detour to the nearest intersection would likely be required. Responding to impassible roads by segments is an especially useful approach from the perspective of emergency management.

## GIS Methodology

The GIS methodology for generating the regional road network vulnerability analysis proceeded as follows:

- 1) Obtained NG911 Road data from MEGIS
  - a. It should be noted that this is the most up to date and most comprehensive road dataset available for the state
  - b. This dataset includes multiple roughly parallel line features for interstate highways. This was retained as it may prove useful to know which side of the interstate may be impacted. However, if both sides are impacted, it may cause some impacted interstate highway segments to “count double”.
- 2) Removed bridge segments from road data layer using the MEGIS supplied MDOT bridge layer. Segments within 70 meters of a bridge have been removed to account for georeferencing errors and other discrepancies in the dataset.
- 3) Selected road segments from the dataset with bridge segments removed. Selected and created shapefiles for segments where any portion is inundated at 2 feet, 1 meter, and 2 meters.
- 4) Used query tools to ascertain number of affected segments by flood event by municipality.



Figure 3: Salt water follows storm drains and inundates Somerset St. in Portland during the Dec. 4<sup>th</sup>, 2013 “KingTide”.

### III. Summary of Regional Vulnerability

The assessment of street segment vulnerabilities found numerous potentially at-risk street segments. It should be noted that there are several limitations to this analysis. Since the methodology subtracted segments within 70 meters of a bridge (as identified by MEGIS) some at-risk segments may have been undercounted. For example, if a bridge's road surface height is less than the flood water elevation, inundation will occur. It is also possible that some segments are over-counted, for example where bridges were not correctly identified in the data source. In addition, this assessment does not include risks to the regional rail system. Such an assessment is possible, but the additional complexity was outside the scope of this assessment.

Figure 4: Coastal Flooding in Portland's Old Port, January 2<sup>nd</sup>, 2010.



Table 2: Total Number of Street Segments Affected by Given Flood Events

Municipality	2 ft.	1 m	2 m
<b>Brunswick</b>	6	12	20
<b>Freeport</b>	7	10	20
<b>Yarmouth</b>	2	8	17
<b>Cumberland</b>	0	0	0
<b>Falmouth</b>	2	2	5
<b>Portland</b>	58	116	224
<b>South Portland</b>	5	23	109
<b>Cape Elizabeth</b>	5	8	21
<b>Scarborough</b>	54	95	243
<b>Old Orchard Beach</b>	127	154	256
<b>Saco</b>	33	58	98
<b>Biddeford</b>	23	40	82
<b>Kennebunkport</b>	61	115	172
<b>Kennebunk</b>	30	61	106
<b>Wells</b>	121	158	203
<b>Ogunquit</b>	8	14	21
<b>York</b>	48	85	190
<b>Kittery</b>	23	47	84
<b>Total</b>	613	1006	1871

This analysis demonstrates that as coastal flooding increases, the number of impacted road segments also increases. As shown by the maps in the section covering impacts to individual municipalities, it can be seen that some segments are critical linkages, and that large numbers of other road segments area isolated when they become impassible. As previously noted, researchers at Bowdoin College (Camill et al. 2012) used network analysis tools to demonstrate the cascading effects of inundation of critical road linkages.

Table 3: Length of Impacted Road Segments by Scenario

TOWN	2 ft Impact (Mi.)	1m Impact (Mi.)	2m impact (Mi.)
Brunswick	1.89	3.49	7.53
Freeport	3.85	4.40	6.68
Yarmouth	0.50	1.80	3.41
Cumberland	0.00	0.00	0.00
Falmouth	0.14	0.14	0.39
Portland	6.20	11.78	21.60
South Portland	0.45	2.18	9.08
Cape Elizabeth	1.68	2.32	4.62
Scarborough	9.21	15.68	33.28
Old Orchard Beach	8.48	10.52	16.01
Biddeford	4.80	6.52	11.37
Saco	2.44	3.92	5.98
Kennebunkport	8.74	12.97	19.93
Kennebunk	4.56	8.20	12.96
Wells	9.63	12.19	16.23
Ogunquit	0.62	1.12	1.58
York	6.81	11.57	23.25
Kittery	3.04	5.04	10.51
<b>Total</b>	<b>40.64</b>	<b>61.53</b>	<b>101.81</b>

While a full network analysis was outside the scope of this assessment, the Bowdoin College research can serve as a model for how local municipalities could follow-up on these findings. This kind of fine-grained local assessment should be made before any decisions regarding adaptation response are made. Once such an assessment is conducted, several adaptation actions may be considered. One possible action would be to elevate critical roadways. Another is to plan for inundation of certain roadways, and identify detour routes around the break in the road network. This would include access routes by first responders as well as evacuation routing.



Figure 5: Coastal Flooding Affects Jay’s Oyster Bar, Portland’s Old Port. January 2<sup>nd</sup>, 2010.

Table 4: Regional Impacts to Public Facilities

Municipality	2 ft.	1 m	2 m
Brunswick			
Freeport			
Yarmouth			
Cumberland			
Falmouth			
Portland			Nursing Home
South Portland			
Cape Elizabeth			
Scarborough			Fire Station
Old Orchard Beach	Library	Library	Library
Saco			
Biddeford			
Kennebunkport			Library
Kennebunk			
Wells			
Ogunquit			
York			Fire Station
Kittery			

Table 4 shows the public facilities for which statewide location data was available from the Maine Office of GIS. The analysis showed that, for the most part, significant impacts to public facilities are not expected at coastal flooding levels up to HAT +1 meter. However, at HAT + 2 meters, numerous impacts could be expected. It should be stressed that many other facilities not included in the MEGIS dataset are likely at risk. A more fine-grained local assessment of such risks would need to include an expanded inventory. It would likely be desirable for such an inventory to include commercial establishments, such as grocers, hardware stores, and other retailers supplying goods important during emergency situations.

The wastewater dataset from the Maine DEP shows that the vulnerability of this infrastructure to coastal flooding increases sharply as flood levels reach HAT + 2 meters. It should be noted that this dataset includes a mixture of public and private wastewater facilities. However, private facilities are included here because, when impacted, they would have a significant effect on the overall impacts of a flood event. For example many of the private facilities are petrochemical businesses in Portland harbor, the inundation of those wastewater systems would be particularly undesirable.

Table 5: Regional Impacts to Public and Private Wastewater Facilities

Municipality	2 ft.	1 m	2 m
Brunswick			
Freeport			
Yarmouth			
Cumberland			
Falmouth			
Portland	1	2	5
South Portland		2	4
Cape Elizabeth			
Scarborough			2
Old Orchard Beach			
Saco			
Biddeford			2
Kennebunkport			
Kennebunk			1
Wells			
Ogunquit			1
York			2
Kittery			
<b>Total</b>	<b>1</b>	<b>4</b>	<b>17</b>

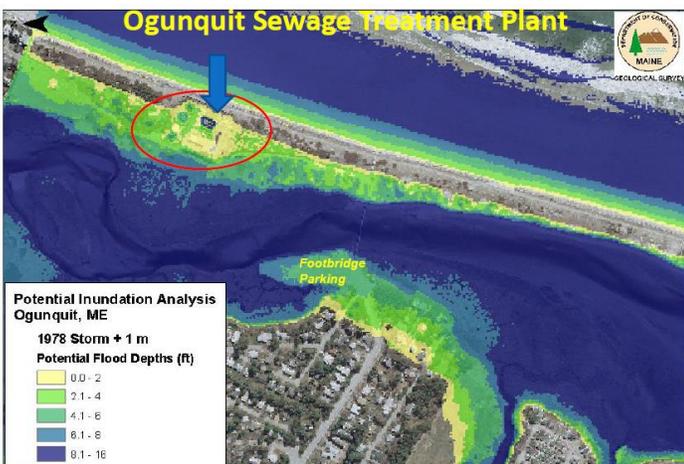


Figure 6: At Risk Wastewater Facility (Source Slovinsky, 2012)

## IV. Assessments of Individual Municipality Vulnerability

The large amount of information now available on sea level rise vulnerability in the Southern Maine region necessitates some guidance for the reader of this section of the report. Previously completed analysis is included for each municipality in the study area. This research has been augmented by the additional analysis conducted for SSM. The regional vulnerability assessment segment of the report includes a summary of the regional impacts found by using SSM's methodology.

Where other organizations, such as CBEP or MGS / SMRPC via the CHRT initiative has already conducted an

analysis, this work serves as a summary and also a corroboration of the existing work with a focus on public facilities. Some additional facilities are considered here that were not included in the CHRT analysis. For each town analyzed here, all known vulnerabilities from this, CHRT, and any other vulnerability assessment have been listed. Maps showing the vulnerable facilities or infrastructure are provided where applicable. When possible, potential vulnerabilities which should be investigated by more advanced (dynamic) modeling are listed as well.

Figure 7: A large number of regionally important retail stores, such as this grocery store in South Portland, are in locations prone to coastal flooding. High Tide, April 27<sup>th</sup> 2013.



# 1. Brunswick

Brunswick’s public facilities do not appear to be significantly vulnerable to coastal flood hazards, at least in comparison to Maine municipalities south of Portland. Much of the coastline is ledge or bluff land, which is far more resilient than sand dunes. This analysis does raise several areas of concern, however.

Several roads may be vulnerable to flooding, for example Adams road near Midcoast Hospital, shown in [Figure 9](#). This road would flood and likely become impassible at HAT + 1 meter of flooding (whether from SLR, storm surge or both). The analysis found that at 2

feet of flooding 6 road segments are vulnerable, at 1 meter of flooding 12 are, and at 2 meters of flooding 20 segments are vulnerable. A more detailed road elevation assessment would be needed to ascertain the full extent of road vulnerability to coastal flooding in the context of SLR. It is possible that a number of the roads which access Brunswick’s many peninsulas may be cut off at low points. This would render these areas islands during high water events, inhibiting emergency access or evacuation. Further analysis, using LiDAR obtained road elevation data, is needed to fully assess risk to road infrastructure.

Figure 8: Brunswick Coastal Flood Hazard

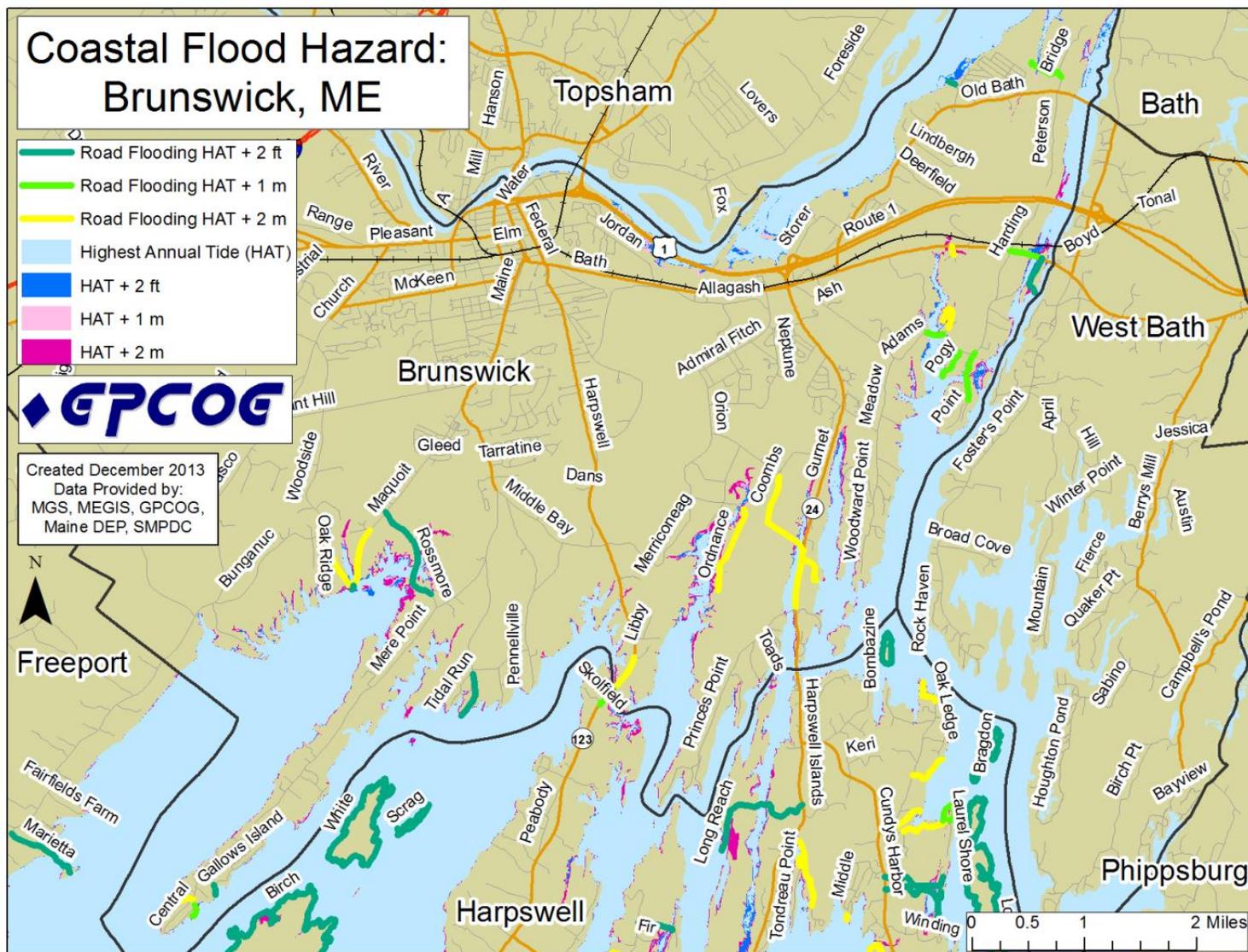
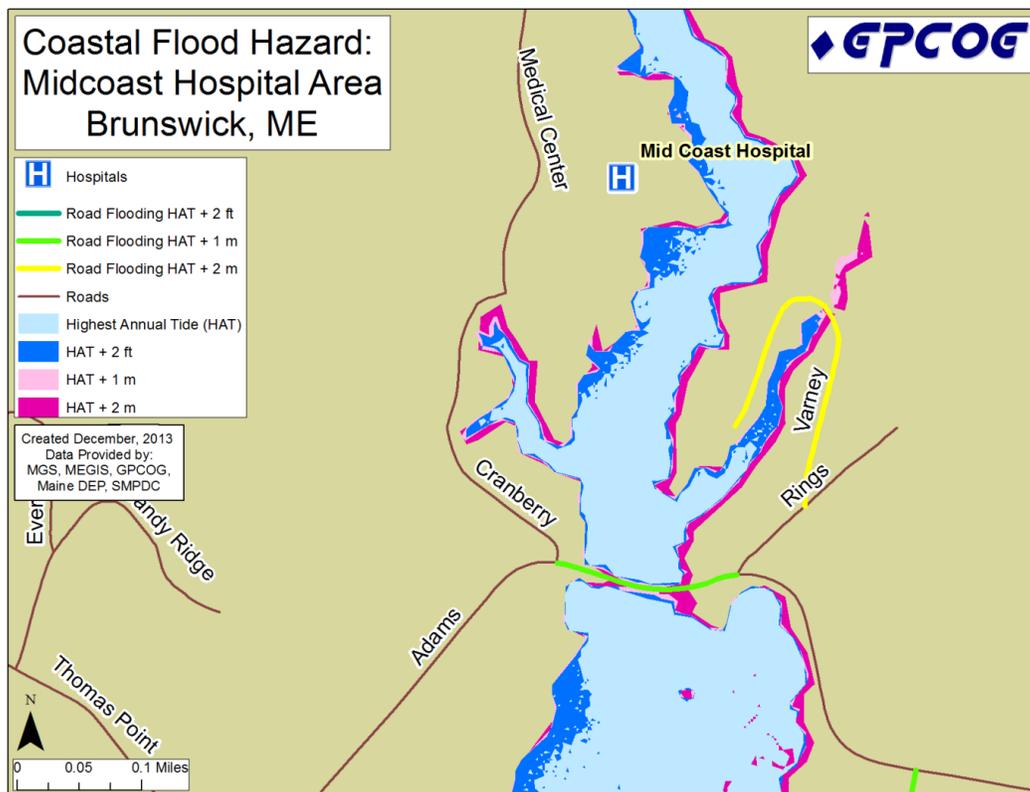


Figure 9: Brunswick Midcoast Hospital Coastal Flood Hazard



Another potential issue in Brunswick is marsh migration. One area identified as being particularly vulnerable to marsh migration is along Brunswick's unique Merrymeeting Bay. While this bay is today largely fresh, increased saltwater intrusion would likely be one of the results of SLR. Increased water levels could cause significant expansion of wetland area around the bay. A study completed by the Kennebec Estuary Land Trust (2010) discusses this possibility in greater detail.

The Casco Bay Estuary Partnership recently completed a thorough analysis of possible SLR induced Marsh Migration effects that included Brunswick, titled "Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts" (CBEP, 2013). The study used SLR levels of 1 foot and 3 feet. A primary focus of the report was the potential effects of tidal restrictions (from roads or dams) on marsh migration as sea levels increase. The report also considers conflicts between

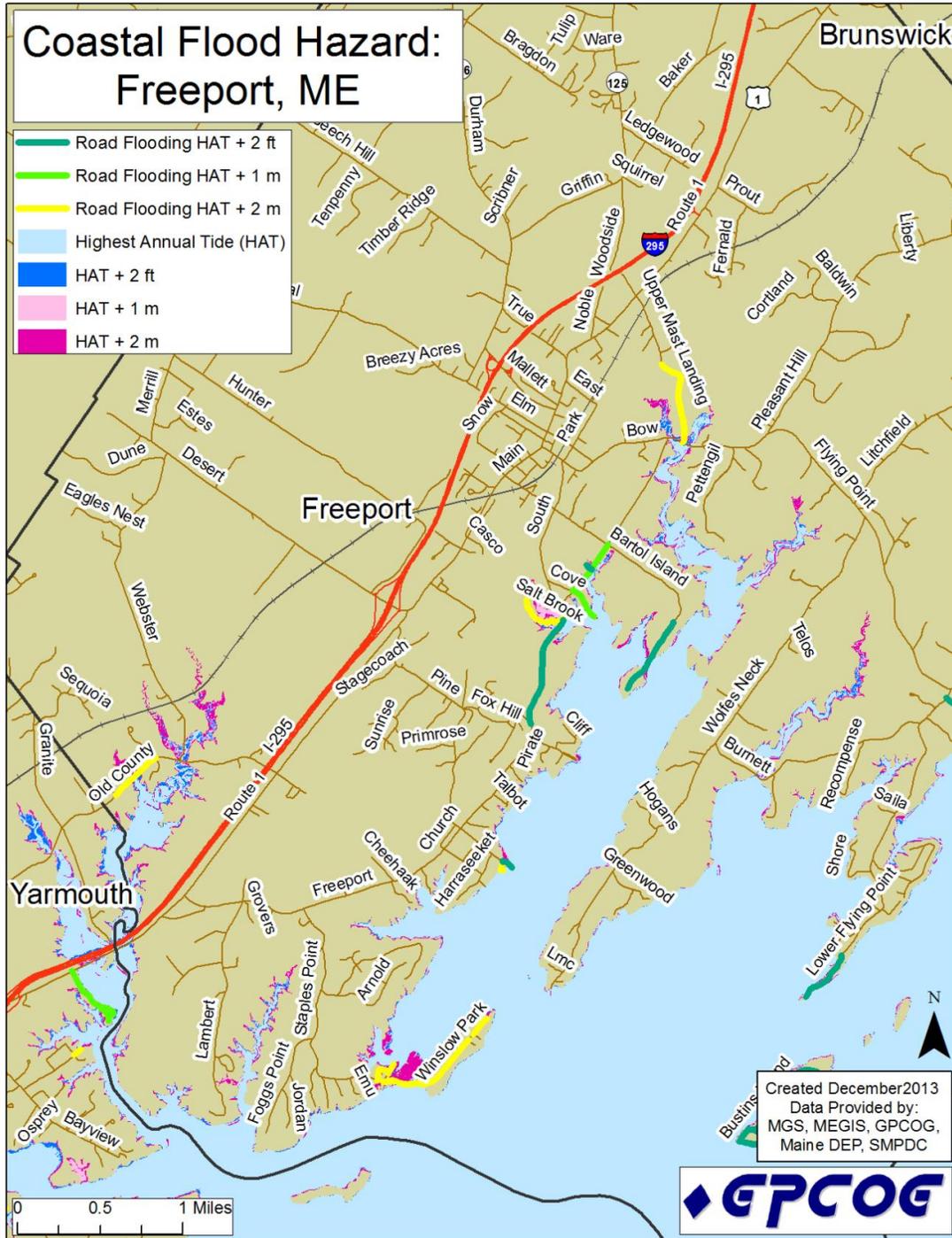
marsh migration and development. Nine of the Town's tidal inlets were discussed in detail, including: Maquoit Bay, Mere Point Bay, Middle Bay, Harpswell Cove, Buttermilk Cove, Woodward Cove, Thomas Bay, Lower New Meadows "Lake", and Upper New Meadows "Lake". See this report for further details.

According to the CBEP study and this analysis, marsh transgression will occur as sea level rises along Brunswick's numerous coves. Heads of coves appear to contain larger areas where transgression is likely, in general. For the most part these areas are not heavily developed. However, future development may occur in areas that eventually convert to marshland given higher SLR scenarios. For example, the Brunswick Naval Air Station site is adjacent to the head of Harpswell Cove, a potential marsh transgression zone. It may be prudent to consider future marsh migrations in shoreland zoning by increasing buffers. Newly available LiDAR data can help ensure accuracy and fairness in this process.

## 2. Freeport

Much of the public facilities and private development in Freeport’s coastal areas is located along ledges or bluffland. As such, the municipality is considerably more resilient to coastal flooding effects than areas further south. It is likely that at least some private development may be vulnerable to coastal flooding, but neighborhood-wide destruction is not likely.

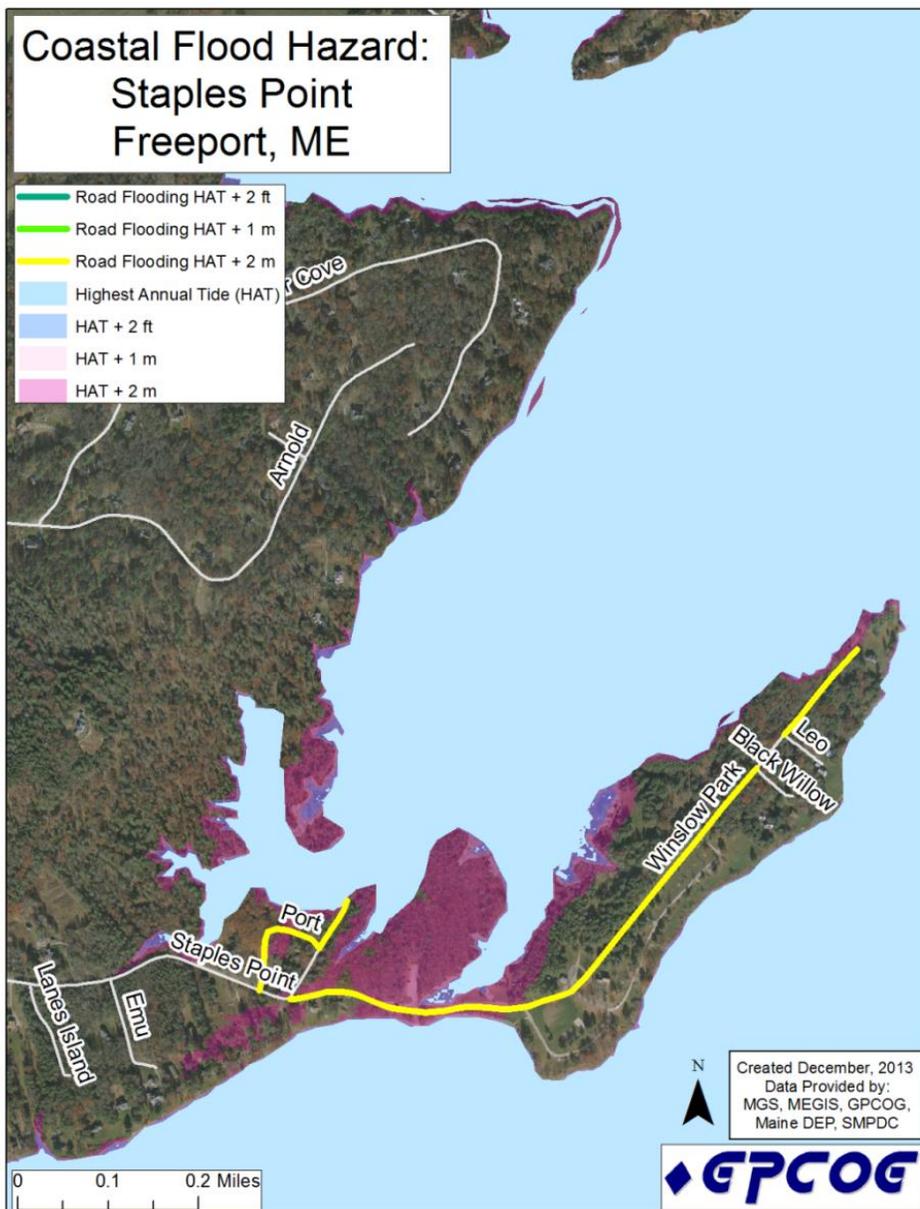
Figure 10: Freeport Coastal Flood Hazard



The primary threat in Freeport from coastal flooding appears to be to critical road linkages. The analysis found that at 2 feet of flooding 7 road segments are vulnerable, at 1 meter of flooding 10 are, and at 2 meters of flooding 20 segments are vulnerable. This is similar to the situation in Brunswick and Yarmouth. Freeport’s coastline is made up of a number of points extending out into Casco Bay. The majority of these points have only one access road, and there often is a low area where the point narrows. During a flood event, the one road could flood, effectively rendering the point an island. This would cut off emergency access, potentially when it would be most needed.

An example is included below of Staples Point, where the popular Winslow Park beach is located. As flooding approaches HAT +2 meters, it is likely that the park will be completely inundated and that the end of the point would become an island, inaccessible by road. It is likely that other roads in Freeport are vulnerable to coastal flooding. A more detailed survey, using latest LiDAR obtained road and bridge surface elevations, would determine these vulnerabilities more specifically.

Figure 11: Staples Point, Freeport Coastal Flood Hazard



Like Brunswick and many other communities in the region, Freeport also needs to consider the issue of marsh migration. In Freeport, marsh migration appears to be most likely to occur along coastal inlets, especially at the heads of bays or rivers. The CBEP study of marsh migration in Freeport identified three areas where SLR may initiate marsh migration in the town. These areas include the Cousins River area, the Spar and Staples Cove areas, and the Lower Mast Landing Road area. The study identified the potential for significant marsh migration in all three areas with 3 ft of SLR, as well as significant conflict with existing development. However, it also showed that, at least in the Spar and Staples Cove areas, zero net loss of marsh may result if development conflicts with marsh migration are mitigated. See the study for more details.

### 3. Yarmouth

At SLR up to 2 meters above HAT, public facilities in Yarmouth do not appear to be particularly vulnerable. However, several vulnerabilities were found in road infrastructure. In addition, Yarmouth will likely see marsh transgression in some areas, which may have significant ecological impacts. Some private real estate is likely at risk in Yarmouth, although specific information about what private development is at risk is not the focus of this study.

Yarmouth has several of the same “point” land forms as Brunswick or Freeport. In Yarmouth, they were found to be less vulnerable to floodwaters cutting off road access than areas further north. However, some weak points in terms of coastal flood vulnerability were found in the town’s road infrastructure. The analysis found that at 2 feet of flooding 2 road segments are vulnerable, at 1 meter of flooding 8 are, and at 2 meters of flooding 17 segments are vulnerable.

For example, it is likely that Prince’s Point Road would begin to flood at HAT + 1 meter. The causeway between Little John and Cousins Island would likely flood at HAT +1

meter as well. While these vulnerabilities are immediately apparent, a further study of Yarmouth’s road network, using elevation data obtained by the latest LiDAR methods, would help to establish detailed flood hazard to the town’s road system. For example, further analysis could incorporate bridge elevation data and network analysis, which this study does not do. This would all have implications for rerouting emergency services and prioritization of adaptation actions.

Marsh transgression in Yarmouth can be expected in the low areas adjacent to inlets or estuaries, according to this study as well as work done by the CBEP (note that CBEP used 1 foot and 3 feet of SLR for its analysis). CBEP found that three areas would see especially pronounced marsh migration: this includes the heads of the inlets along the Royal River, the Pratt Brook area, and the Broad Cove area. The analysis found that in the Broad Cove area few changes would occur at 1 foot of SLR, but significant migration at 3 feet. Significant migration and conflict with development would occur in the other two areas at both 1 foot and 3 feet of SLR. See the study for maps and further details.

Figure 12: Yarmouth Coastal Flood Hazard

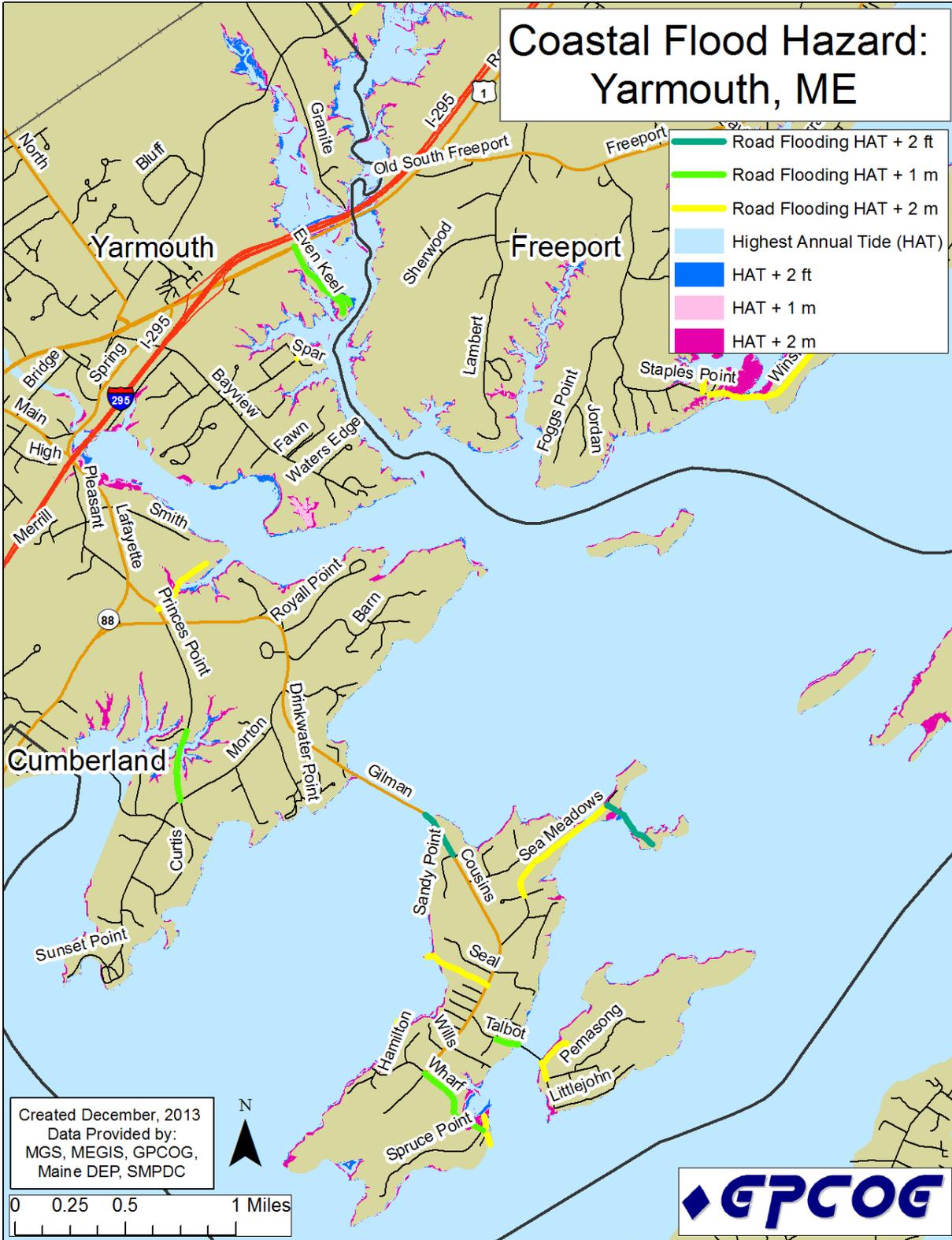
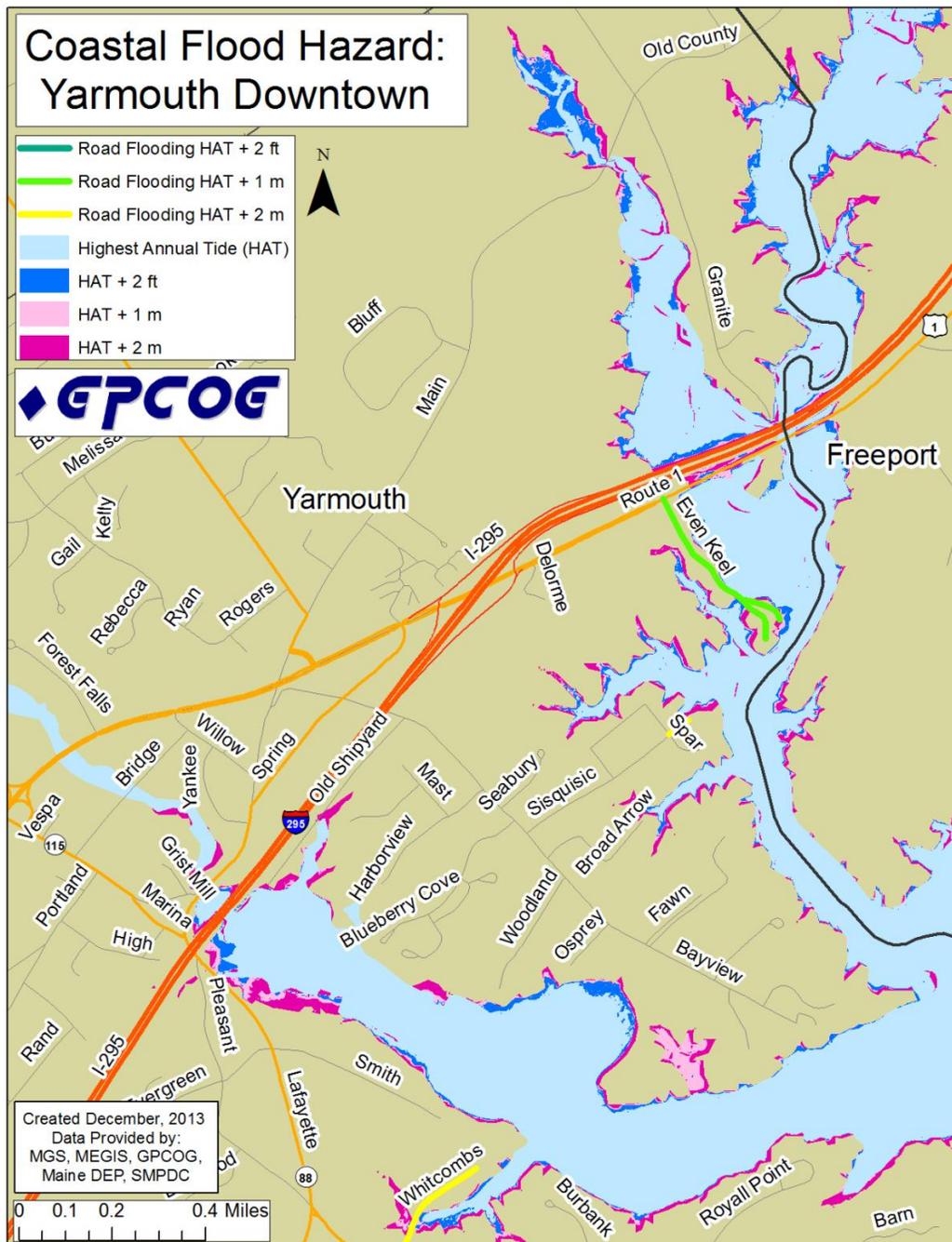


Figure 13: Downtown Yarmouth Coastal Flood Hazard



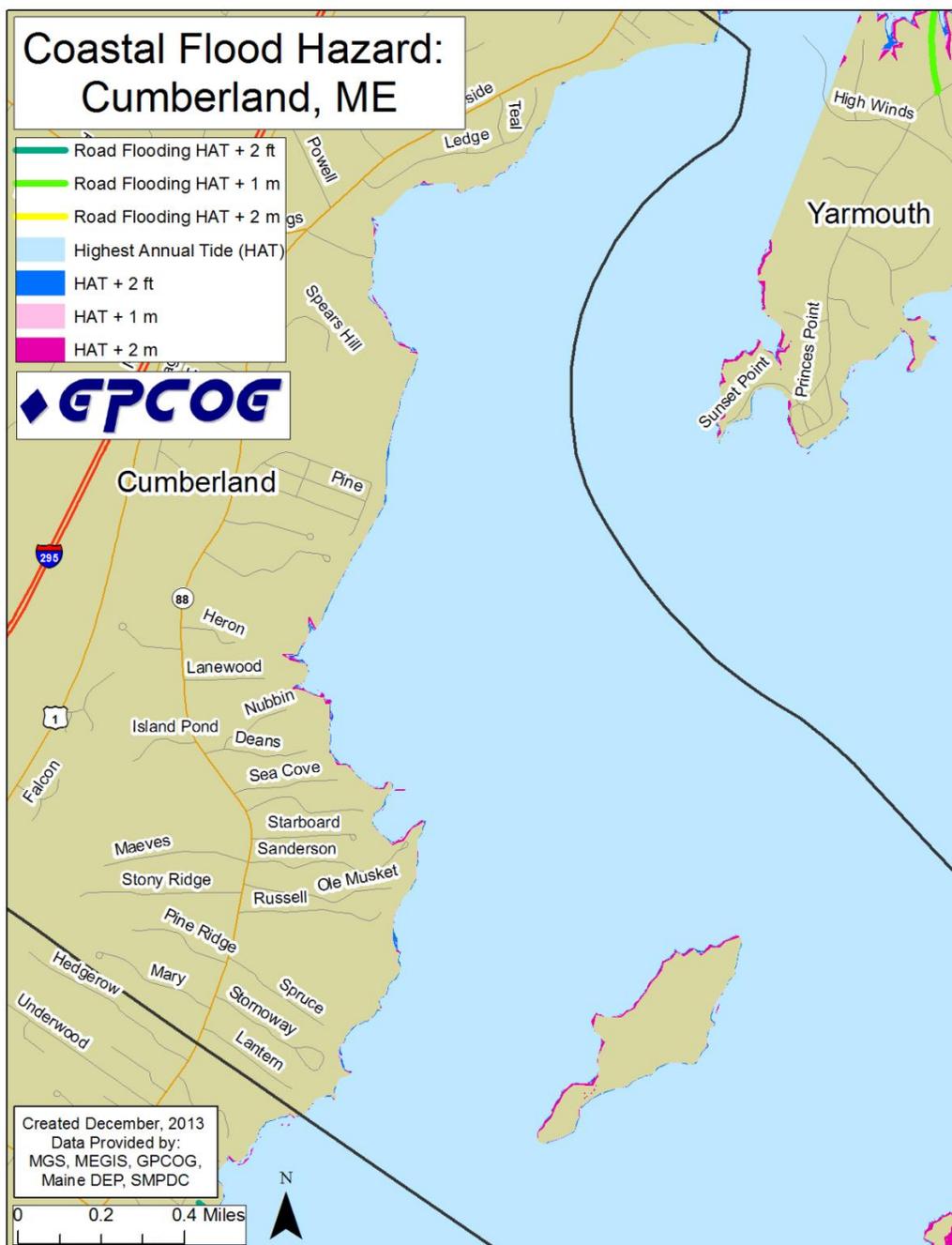
#### 4. Chebeague Island / Long Island

An assessment of the coastal flood hazard for both Chebeague and Long Islands is not available at this time due to unavailability of LiDAR derived flood elevation data. Data for these municipalities may be available in the future. When the data does become available, the vulnerability of these towns should be assessed.

## 5. Cumberland

This assessment found that Cumberland is less vulnerable to SLR and coastal flooding than other municipalities included in this analysis. It does not have any significant vulnerability to its public facilities or infrastructure, based on the scenarios assessed. At levels of inundation analyzed here 0 road segments were found to be vulnerable. It may only have slight private real estate vulnerabilities, although this is complicated by the uncertainties in bluffland erosion and landslide risk. Some slight revisions to shoreland zoning may be necessary as a result of SLR induced marsh transgression, although the area involved is not significant.

Figure 14: Cumberland Coastal Flood Hazard



## 6. Falmouth

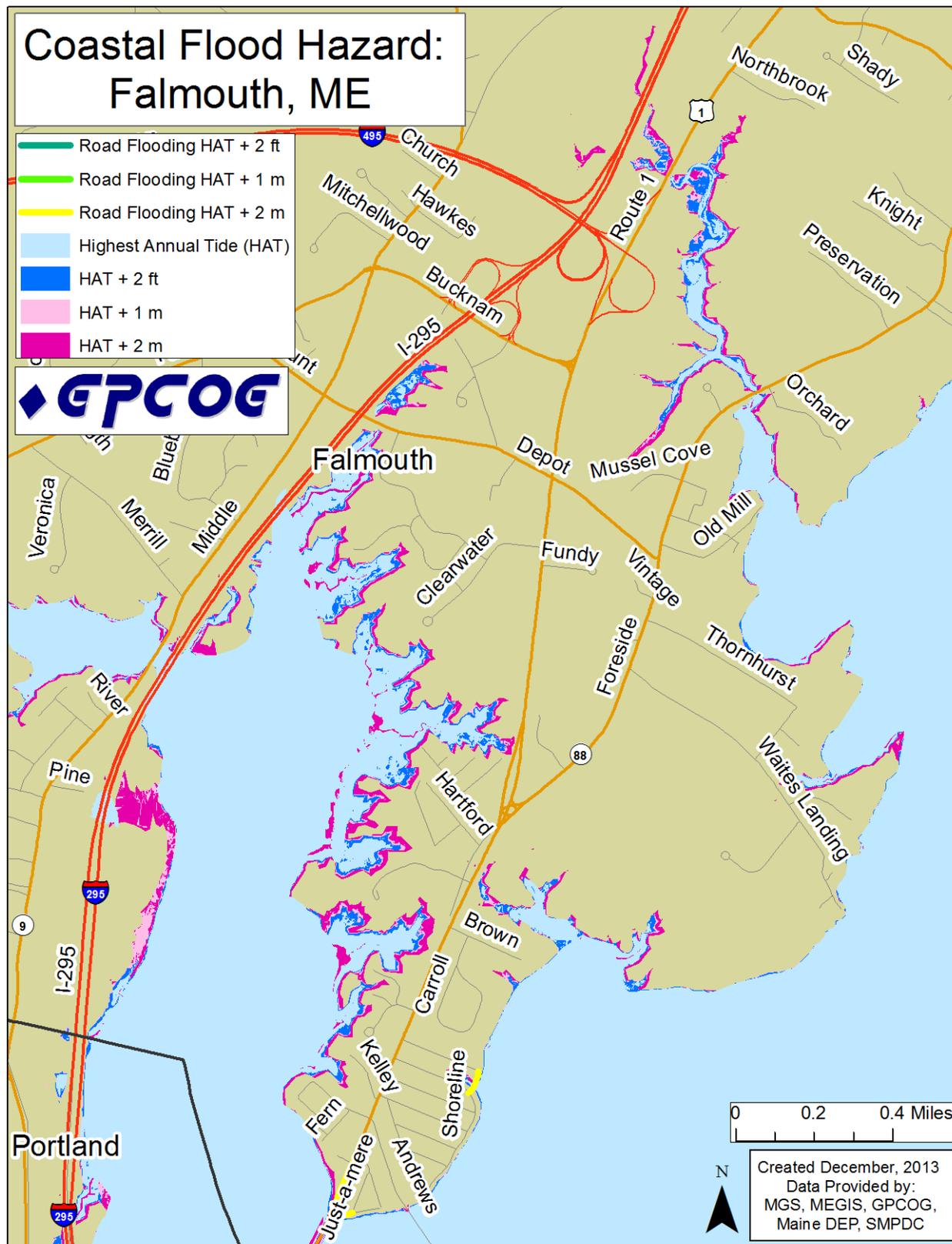
Falmouth's public facilities do not appear to be vulnerable to coastal flooding at levels of up to HAT + 2 meters. Its road facilities also appear to be relatively resilient, however a detailed study using LiDAR road and bridge elevation data would help to clarify that this is indeed the case. The analysis found that at 2 feet of flooding 2 road segments are vulnerable, at 1 meter of flooding 2 are, and at 2 meters of flooding 5 segments are vulnerable. The one exception to this is the causeway to Mackworth Island, the vulnerability of which is unclear from this analysis. Private real estate does not appear to be a particular issue in Falmouth at flooding up to HAT + 2 meters, although further analysis would be needed to confirm this.

The primary coastal flood issue in Falmouth which is likely to be affected by SLR is the issue of marsh migration. The EPA and CBEP assessment of marsh migration shows significant marsh changes may occur in the town. Even modest amounts of SLR could cause extensive changes to marshland in Falmouth. When

possible (not constrained by development, steep slopes, etc.) SLR will cause marshlands to migrate to adjacent upland areas. Some areas of "high marsh" would convert to "low marsh", and some areas of low marsh would convert to open water.

The CBEP study (note that this study used 1 foot and 3 feet for SLR scenarios) identified four areas with potentially significant marsh migration in Falmouth, including: The Upper and Lower Presumpscot Estuaries, Mussel Cove, and the Falmouth Foreside area. The study showed that marsh migration will likely conflict with development along the Presumpscot, however there may be a no net loss of total marshland if development is well-regulated. According to the study, "substantial" new wetlands may form in the Mussel Cove area with 3 feet of SLR. The report also found that marsh migration would be restricted by development in Falmouth Foreside, and that some waterfront infrastructure was vulnerable to SLR at 3 feet. See the CBEP study for more details and maps.

Figure 15: Falmouth Coastal Flood Hazard



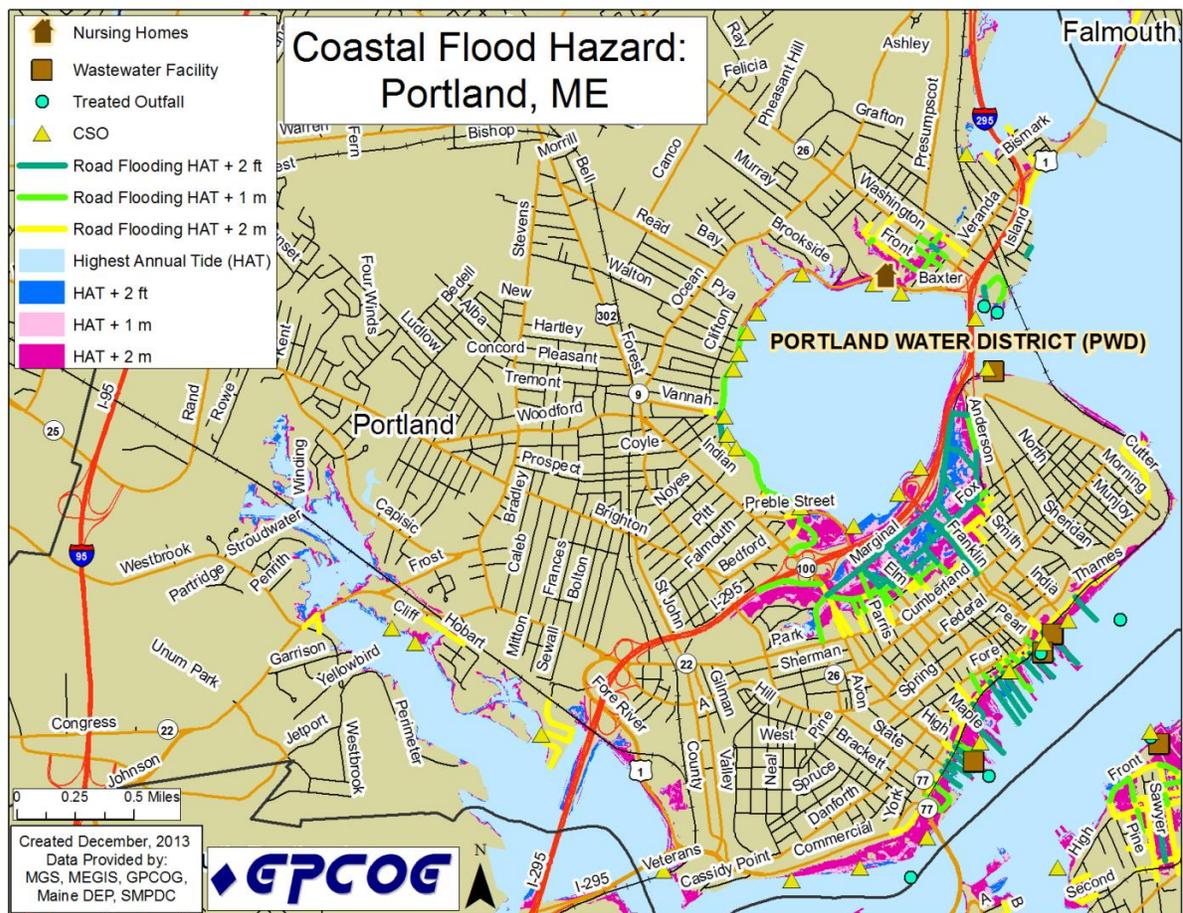
## 7. Portland

Portland’s vulnerability to coastal flooding has been well studied, particularly in the Back Cove area. These studies have found a large amount of at-risk public facilities and infrastructure in the city. In addition, a great deal of private real estate is likely at-risk, although that is not the focus of this assessment. In general, Portland faces coastal flood issues of the backwater, low velocity type. Its islands, while exposed to the open ocean and its wave effects, have ledges or bluffland coasts that are more resistant to flood effects, and likely will continue to be so even as SLR occurs. Public facilities found to be at risk by this and other analysis includes wastewater treatment infrastructure, road and rail systems, a nursing facility, the ferry terminal, and the many wharves. A large amount of private real estate in Portland is also likely at risk.

Of the municipalities studied here, Portland has the greatest number of combined sewerage overflow’s (CSOs). During flood events it is likely that high amounts of precipitation will cause a release of untreated sewage at the noted CSO locations. (Note that ongoing progress to remove CSOs, such as those on Baxter Blvd., will significantly reduce this impact). Inundation adjacent to these locations would likely be a degree more hazardous as a result of the sewage content. Portland has other vulnerable wastewater infrastructure, such as the pumping station at India Street and given enough flooding possibly even the main treatment plant on the East End.

A public discussion of flooding in the Back Cove area was facilitated by the New England Environmental Finance Center at the University of Southern Maine in

Figure 16: Portland Flood Coastal Hazard



conjunction with MGS and the City of Portland in February, 2012. The presentation is available at <http://www.ci.portland.me.us/sustainableportland/pdf/presentationslovinsky02312sealevel.pdf>. The public process discussed flood effects for different SLR and storm surge scenarios. In concert with this public process, MGS' Peter Slovinsky made a presentation to the Portland City Council. This presentation built on the methodology used in earlier assessments done as part of CHRT.

The MGS assessment described the likely effects of SLR for different scenarios of SLR, SLR + storm flooding, or storm flooding alone. The first effect discussed was the impact on Portland's marshlands. The analysis focused on marshes along the Fore River, although the effects discussed likely apply to Portland's other saltwater marshes.

The analysis noted a dramatic change in marshlands as sea levels increase, which has also been confirmed by a CBEP analysis. When possible (not constrained by development, steep slopes, etc.) marshlands would

migrate to adjacent upland areas. Some areas of "high marsh" convert to "low marsh", and some areas of low marsh convert to open water. All of the conversions have significant ecological effects, which may affect economically important species such as shellfish.

The CBEP assessment of marsh migration (using 1 foot and 3 feet for SLR scenarios) identified 4 key at-risk areas: the Upper Fore River, the Back Cove, Commercial Street, and East Deering. In both the Fore River and Back Cove areas, 1 foot of SLR would cause some conflicts between marsh migration and development and 3 feet of SLR would result in much more. Along the waterfront on Commercial Street, some impacts to wharves were found to be at risk at 1 foot, but at 3 feet nearly every wharf was vulnerable to inundation. East Deering was not found to have significant marsh migration issues until SLR approaches 3 feet.

The slide below shows the incongruity between existing shoreland zones and LiDAR derived shoreland zones along a section of the Fore River:

**Figure 17: Using LiDAR for Shoreland Zoning Mapping**

Source: Preparing Portland for the Potential Impacts of Sea Level Rise (Slovinsky, 2012)

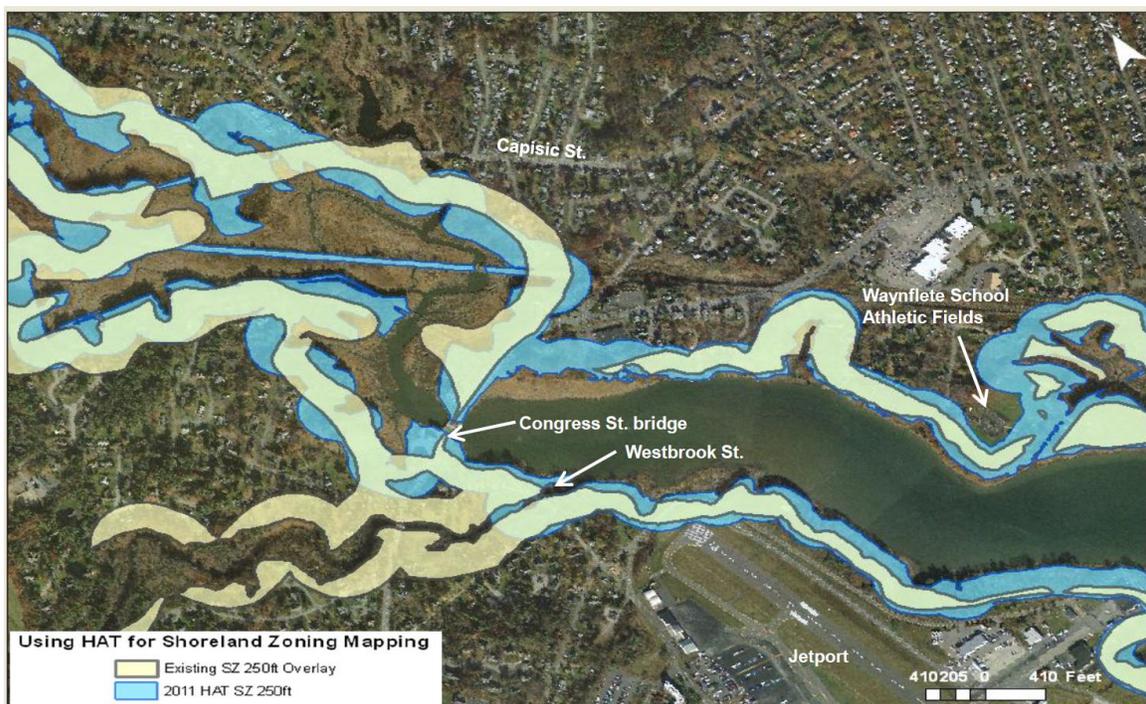
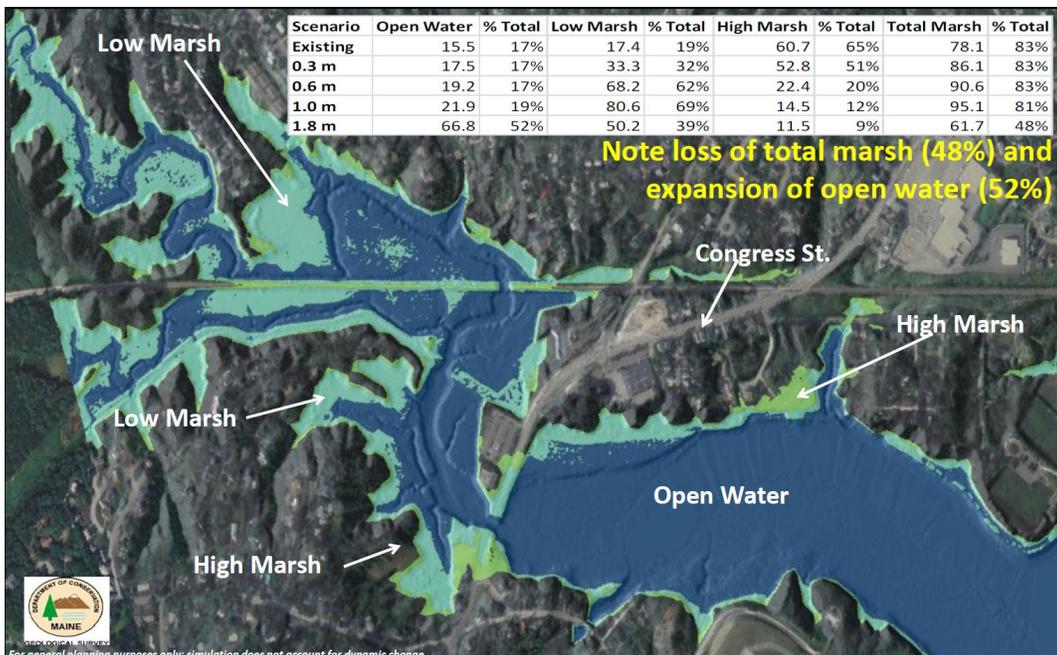


Figure 18: LiDAR Used for Marsh Migration Estimate for Fore River

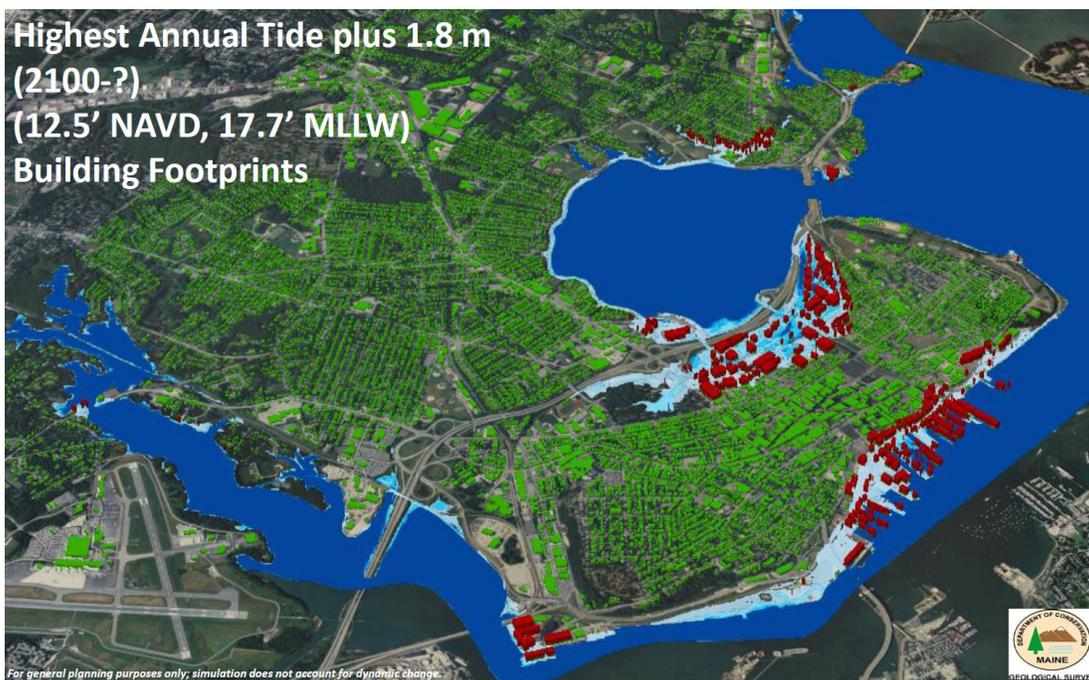
Source: Preparing Portland for the Potential Impacts of Sea Level Rise (Slovinsky, 2012)



The MGS analysis also considered effects on public facilities and private real estate by using a LiDAR based analysis of building footprint inundations by different heights of storm surge and / or SLR. Under the HAT + 1.8 meter scenario, large areas of real estate and infrastructure in Bayside and the Old Port would be affected. The following two slides show the impacts to buildings and roads respectively. Note that many other scenarios combining SLR and storm surge were explored and are available in the presentation.

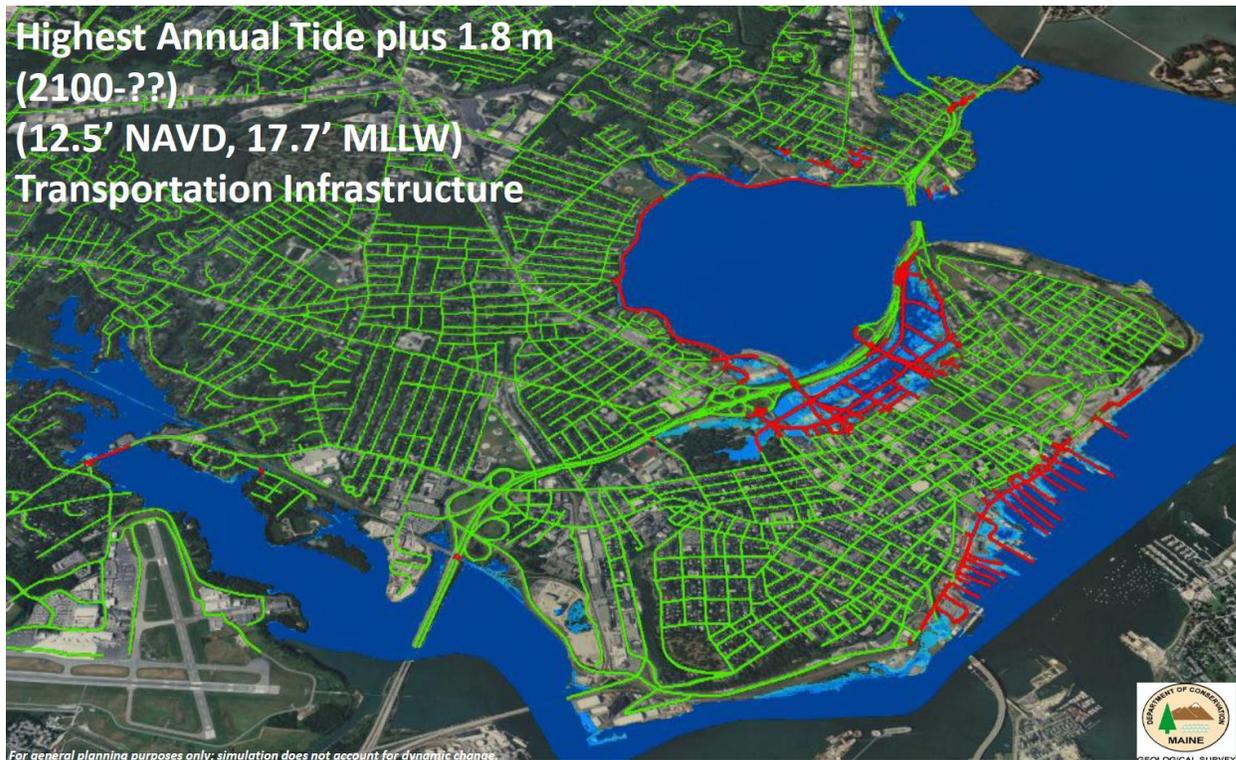
Figure 19: Using LiDAR to Estimate Building Inundation in Portland

Source: Preparing Portland for the Potential Impacts of Sea Level Rise (Slovinsky, 2012)



**Figure 20: Using LiDAR to Assess Transportation Infrastructure Impacts in Portland**

Source: Preparing Portland for the Potential Impacts of Sea Level Rise (Slovinsky, 2012)



As shown in the SSM generated map, as well as in Figure 18 above, a significant number of roads in the City of Portland may be vulnerable to inundation. The SSM analysis found that at 2 feet of flooding 58 road segments are vulnerable, at 1 meter of flooding 116 are, and at 2 meters of flooding 224 segments are vulnerable. A large number of the segments are found on the areas filled in along the Commercial Street waterfront and along the Back Cove's Bayside, East Bayside, and Oakdale neighborhoods. Other vulnerable areas include the neighborhoods along the Presumpscot and Fore Rivers.

This analysis suggests various larger infrastructure type adaptation actions may be appropriate in Portland. Unlike less developed areas, retreat from vulnerable areas may be less of an option. For example, given the potential loss of the use of key road segments, emergency access rerouting is highly recommended. This could be implemented relatively easily, by routing to less vulnerable streets. Where this is not possible,

another option might be elevating roadways. The scenario based approach used by MGS could help to prioritize this investment: more vulnerable or critical at-risk roads should be upgraded first.

Other larger adaptation actions might be advisable in Portland. Given the topography of the city, it may be cost effective to construct a surge barrier at Tukey's Bridge, protecting all of the Back Cove and Bayside areas. Such an investment was discussed in detail at the public presentation, and was compared with the less effective but less expensive option of protecting the Back Cove with a smaller berm. Other suggestions include retrofitting storm drains with tidal restrictions, increasing elevations of building and vulnerable infrastructure, and even considering retreat from some areas. A detailed discussion of these actions, and the public's initial reactions, can be found in the write-up of the event by the New England Environmental Finance Center (Merrill et al, 2012).

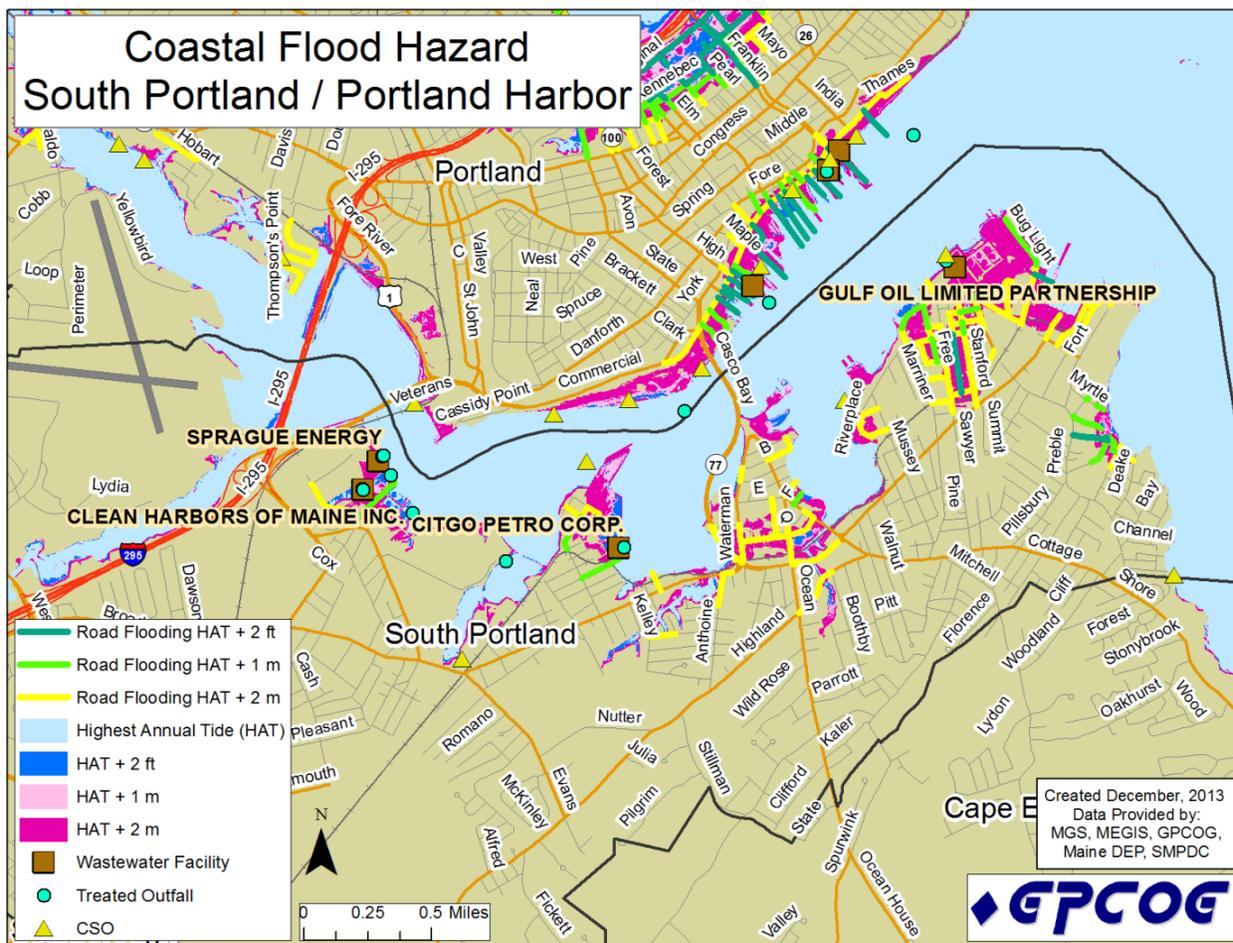
## 8. South Portland

A significant amount of facilities, infrastructure, and real estate is at-risk to coastal flooding in South Portland. This risk is likely to increase substantially with SLR. Particularly severe effects appear likely as flood elevations due to storm surge, SLR, or some combination exceed 2 meters above HAT. According to this analysis and others, areas along the Fore River and its inlets are particularly vulnerable. From Spring Point to the Cape Elizabeth border less inundation can be expected, with a few exceptions.

A detailed write-up of the South Portland’s coastal flooding vulnerabilities was prepared by GPCOG in cooperation with MGS in April, 2012 titled “Adapting to Sea Level Rise in South Portland”. It is highly recommended that this document be referenced by any agencies or individuals concerned with planning for SLR in the city. The findings in this document, and a review of vulnerabilities found through the methods discussed in the rest of this document, will only be briefly summarized here.

Because the 2012 South Portland assessment used detailed building footprint data it reveals vulnerabilities with a great deal of clarity. For example, it can detect if just a portion of a public facility may be inundated. It also clearly shows private facility vulnerabilities. For example, it shows many commercial buildings to be at-risk in the Mill Creek shopping area. It also shows that a portion of the city’s primary wastewater treatment plant may be vulnerable, but the remainder

Figure 21: South Portland Coastal Flood Hazard



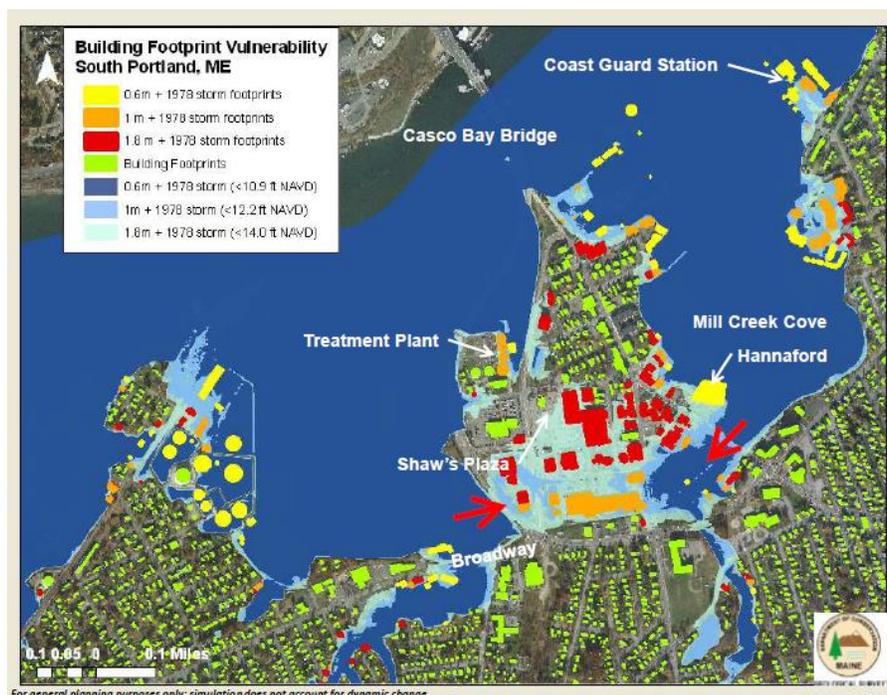
may be at sufficient elevation to be resilient. Besides the treatment plant itself, it appears through this analysis that a pump station in the Willard Beach area may also be vulnerable. Other at risk public facilities include the Coast Guard Station, portions of the Greenbelt Walkway, and boat launch facilities at Bug Light.

South Portland also has a number of CSO sites. These are shown on the map by the dark-yellow triangles. It is likely that during some coastal flood events enough precipitation will occur to trigger a CSO. Inundation in areas adjacent to the CSO point would likely be of increased hazard as a result of the sewage content.

A great deal of road infrastructure is at risk in South Portland. The analysis found that at 2 feet of flooding 5 road segments are vulnerable, at 1 meter of flooding 23 are, and at 2 meters of flooding 109 segments are vulnerable. A more detailed assessment using LiDAR elevation data, as well as a network analysis, would more fully measure the extent of this risk. Such an analysis would be useful because of the major implications for ensuring the integrity of emergency access and evacuation routes. The assessment would help to prioritize such adaptations as elevating roadways by showing which roads are likely to flood first under SLR scenarios of increasing severity.

Although this document is not intended to be a detailed analysis of at risk private real estate, in South Portland it is worth noting that a large amount of private petroleum storage facilities appear to be at risk to SLR. This risk is notable because of the consequences of these facilities' failure, as was seen during hurricane Katrina where a large amount of petroleum products leaked following inundation, significantly worsening water pollution resulting from the disaster. Many other private real estate is also at risk in South Portland, including homes and businesses. The full magnitude of this threat would best be assessed with a tool such as COAST, developed and released by the New England Environmental Finance Center at the University of Southern Maine in Portland<sup>1</sup>.

**Figure 22: South Portland Knightville Building Footprint Vulnerability**  
 Source: Adapting to Sea Level Rise in South Portland (GPCOG, 2012)



<sup>1</sup> Newer versions of COAST are available through Catalysis Adaptation Partners, LLC; <http://www.catalysisadaptationpartners.com/>

Figure 23: South Portland Willard Beach Building Footprint Vulnerability

Source: Adapting to Sea Level Rise in South Portland (GPCOG, 2012)

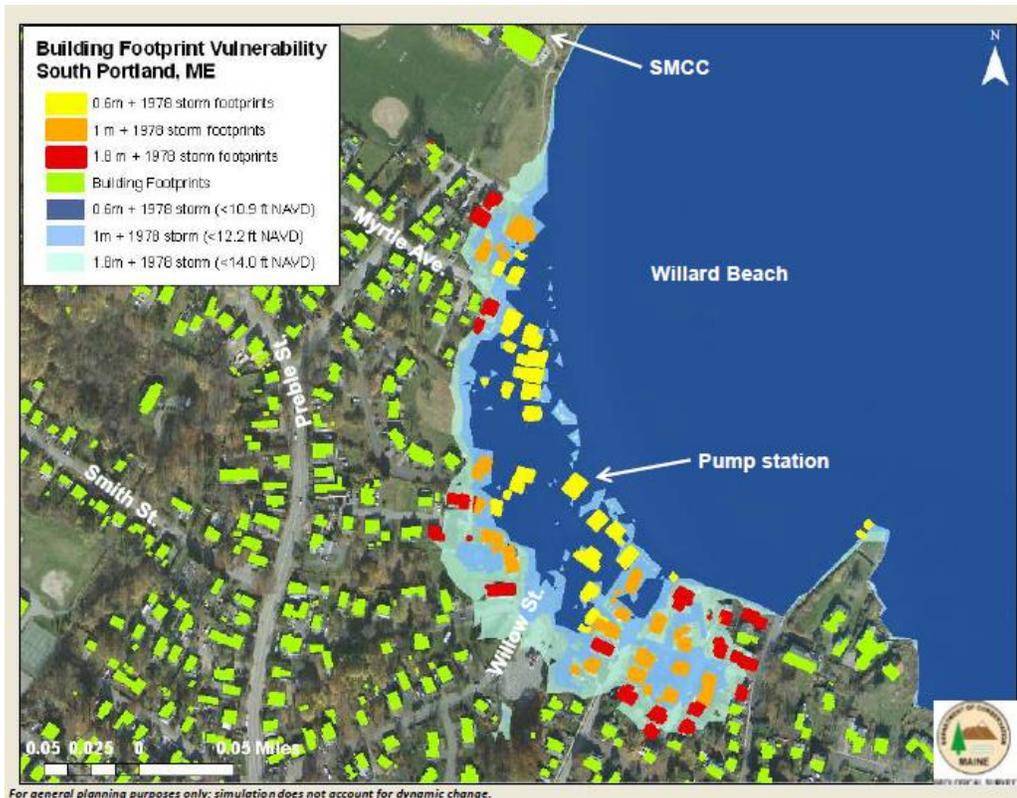
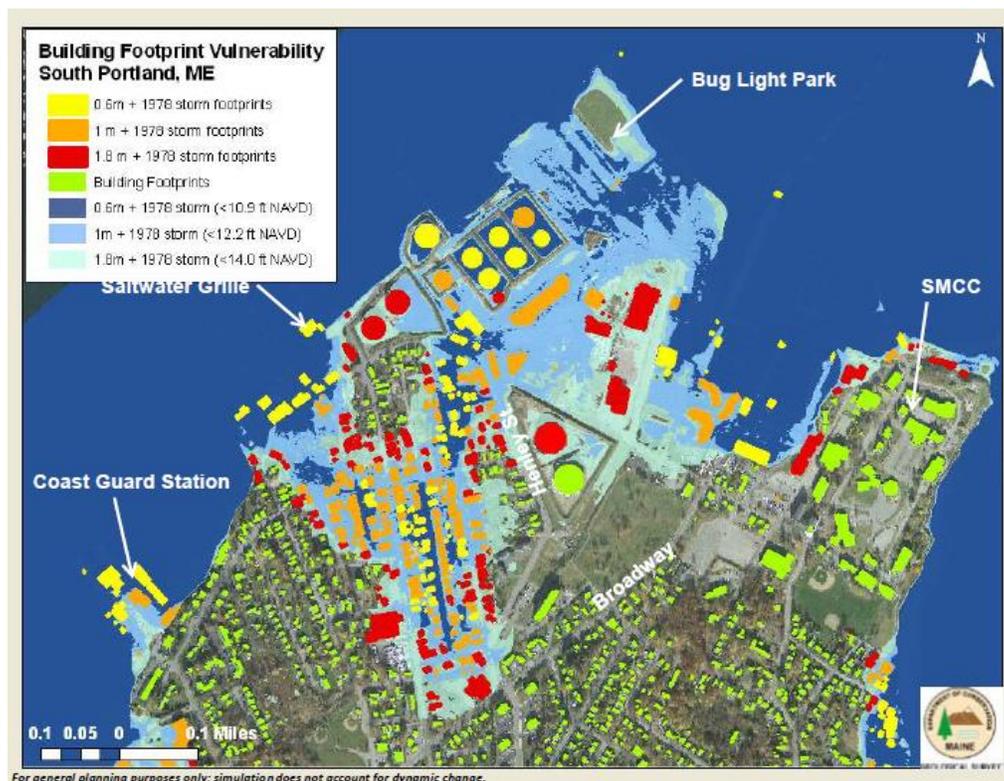


Figure 24: South Portland Bug Light Building Footprint Vulnerability

Source: Adapting to Sea Level Rise in South Portland (GPCOG, 2012)



SLR induced marsh transgression (inland migration) may also be an issue in South Portland, as highlighted by the recent CBEP report on marsh migration in Casco Bay. Migration can be expected in particular in the areas of Bug Light and Southern Maine Community College, Mill Creek and Turner Island, and in the Forest City Cemetery area. The study found slight risks to these areas at 1 foot of flooding, and moderate risks at 3 feet. It noted that the large amount of industrial development on South Portland's waterfront was likely to restrict marsh migration. It also recommended a study to further assess the risk of petroleum products leaking during inundation events.

## 9. Cape Elizabeth

Much of Cape Elizabeth's coastline is of the bluff land ledge type, and so is more resilient to coastal flood hazards than areas further south where sand dunes are more common. However, that is not to say that Cape Elizabeth is immune to coastal flood hazards. This is particularly true of the southern portions of the town.

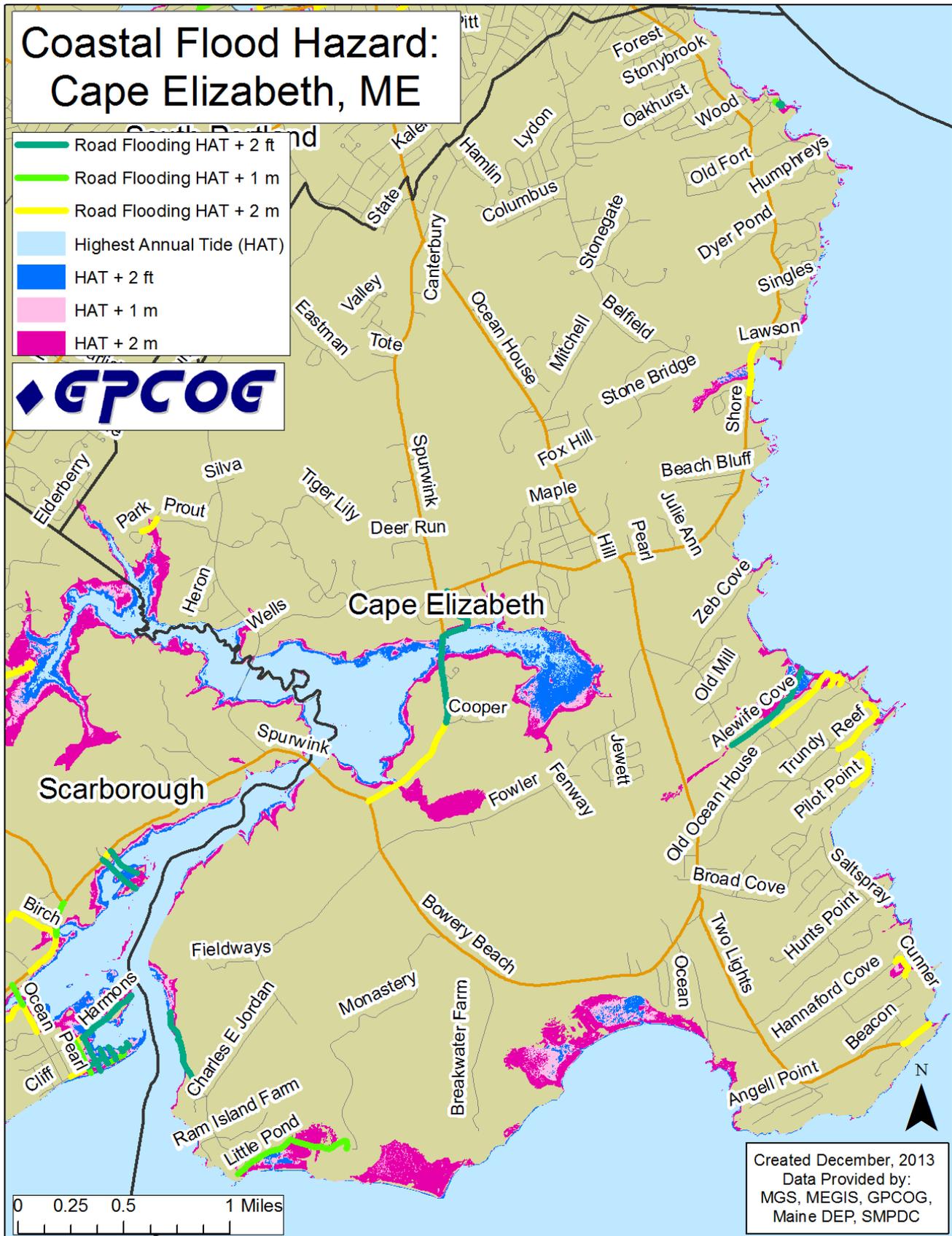
Figure 25, on the next page, shows the coastal flood hazard for the southern portions of Cape Elizabeth. According to this analysis, there are no at-risk *public* facilities in Cape Elizabeth. However, it appears that the road infrastructure in the town is possibly vulnerable. The analysis found that at 2 feet of flooding 5 road segments are vulnerable, at 1 meter of flooding 8 are, and at 2 meters of flooding 21 segments are vulnerable. This should be studied in more detail using LiDAR obtained road elevation data, as recommended for other area municipalities. This initial assessment indicates that Old Ocean House, Shore, and Spurwink Roads may be vulnerable. Some smaller dead-end coastal access roads may also be at-risk. Cape Elizabeth may also have at-risk private real estate, although the magnitude of this risk bears further study.

The risk to private property, and to an extent road infrastructure, is complicated by the process of marsh transgression, or the process of salt water marshes migrating inland as a result of SLR. The CBEP report on marsh migration (using 1 foot and 3 feet as scenarios) showed the SLR induced marsh transgression in Cape Elizabeth is likely to occur in the areas along Pond Cove and Alewife Cove.

Other smaller pockets of marshland in the town may experience some transgression. Compared to other areas studied, CBEP found lower levels of marsh migration are likely in Cape Elizabeth than elsewhere on Casco Bay. However, at 3 feet of SLR, more tidal wetlands would likely form in both areas identified. In addition, some conflicts with development are also likely if SLR exceeds 3 feet.

It should be noted that Cape Elizabeth is currently in the process of addressing coastal flood hazards by adjusting its Shoreland Zoning language to account for Highest Astronomical Tide plus 3 feet of SLR.

Figure 25: Cape Elizabeth Coastal Flood Hazard



## 10. Scarborough

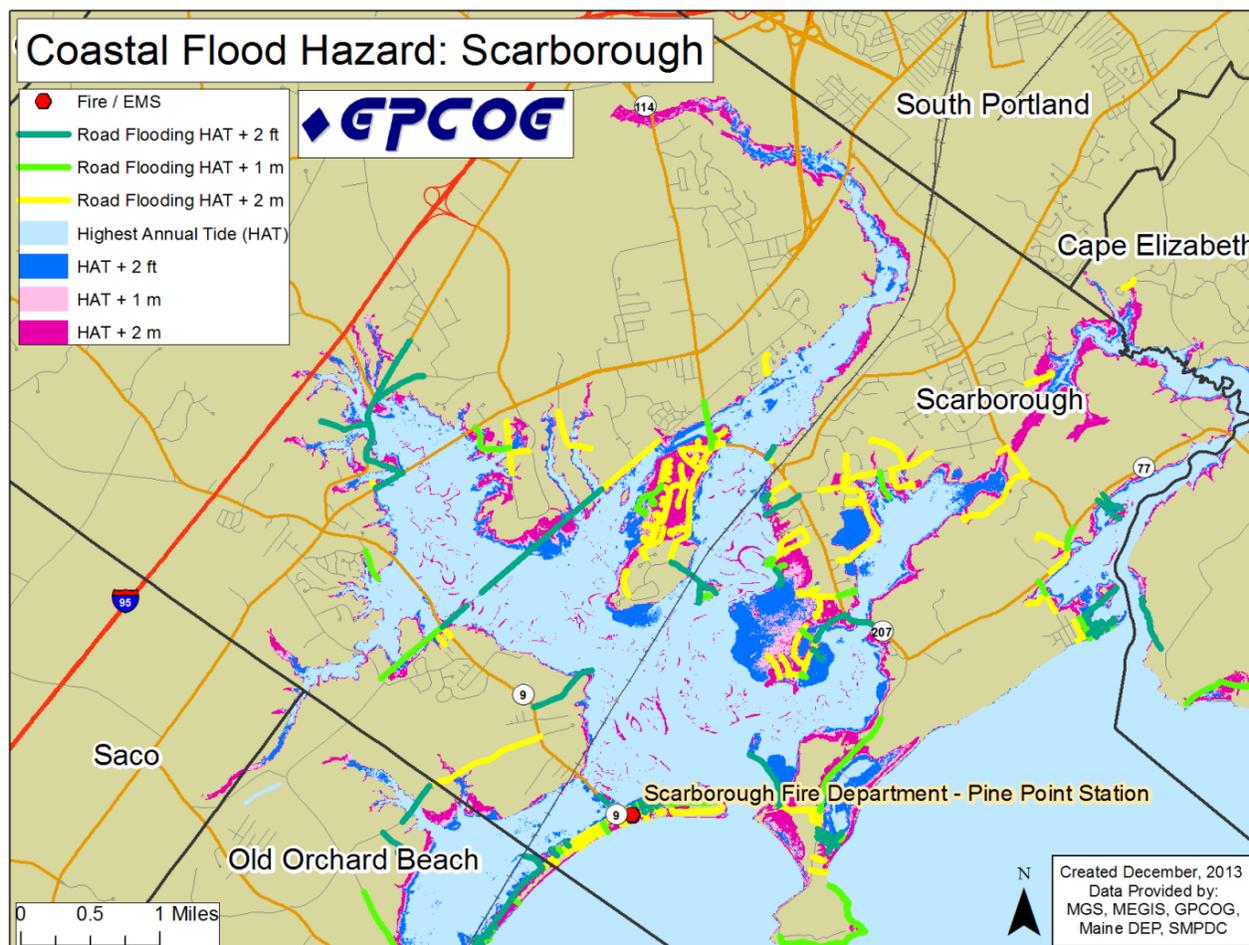
Scarborough, Old Orchard Beach, Saco, and Biddeford are all part of the Saco Bay Sea Level Adaptation Working Group (SLAWG). This work was done in concert with other planning work for SLR by MGS, with a focus on Saco Bay as a region. A key point of the SLAWG process has been that issues of SLR flooding involve complex geological processes that do not stop at political boundaries. This is particularly true in Saco Bay, where rates of sediment transportation greatly affect outcomes for coastal erosion rates in the context of increased storms and SLR.

In Scarborough, several areas of concern have been raised. Large areas of the town far inland could be inundated in future flood events, extending as far as the Maine turnpike. Fortunately, the turnpike is likely at a high enough elevation to safeguard it against even the 2 meters flood event. However, an extremely large number of other roads may be more vulnerable. The analysis found that at 2 feet of flooding 54 road segments are vulnerable, at 1 meter of flooding 95 are, and at 2 meters of flooding 243 segments are vulnerable.

Under the most extreme flood event analyzed here, Scarborough would be cut off into at least 3 different islands. Much of the inundated areas are undeveloped, being found in the Scarborough Marsh. However, given even small amounts of SLR, extensive geomorphological changes could occur, pushing the boundaries of the marsh closer or even into developed areas. Studies of marsh transgression by MGS and others have suggested that as marshes transition from fresh to saltwater, rates of subsistence may increase. As a result, large areas of Scarborough may face issues with increased flooding, saltwater intrusion into freshwater resources, and increased erosion.

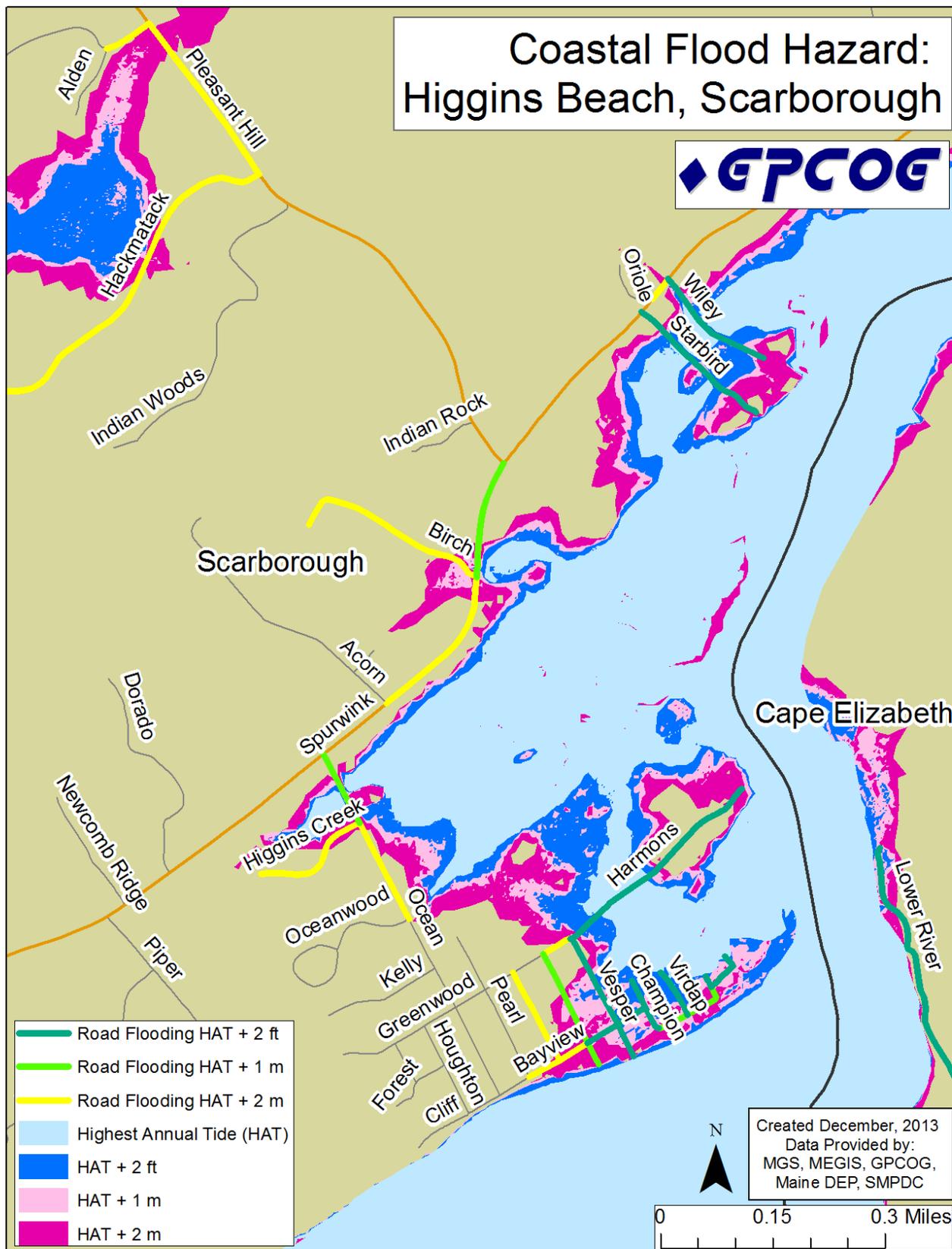
The transition of current low marsh to open water, high marsh into low marsh, and uplands into wetlands will have profound ecological effects. Development in upland areas that blocks transition to wetlands will increase the negative ecological effects and will result in considerable real estate and infrastructure losses. Furthermore, evacuation routes and emergency access during flood events in some areas could be completely cut off, resulting in potential loss of human life in the most extreme cases.

Figure 26: Scarborough Coastal Flood Hazard



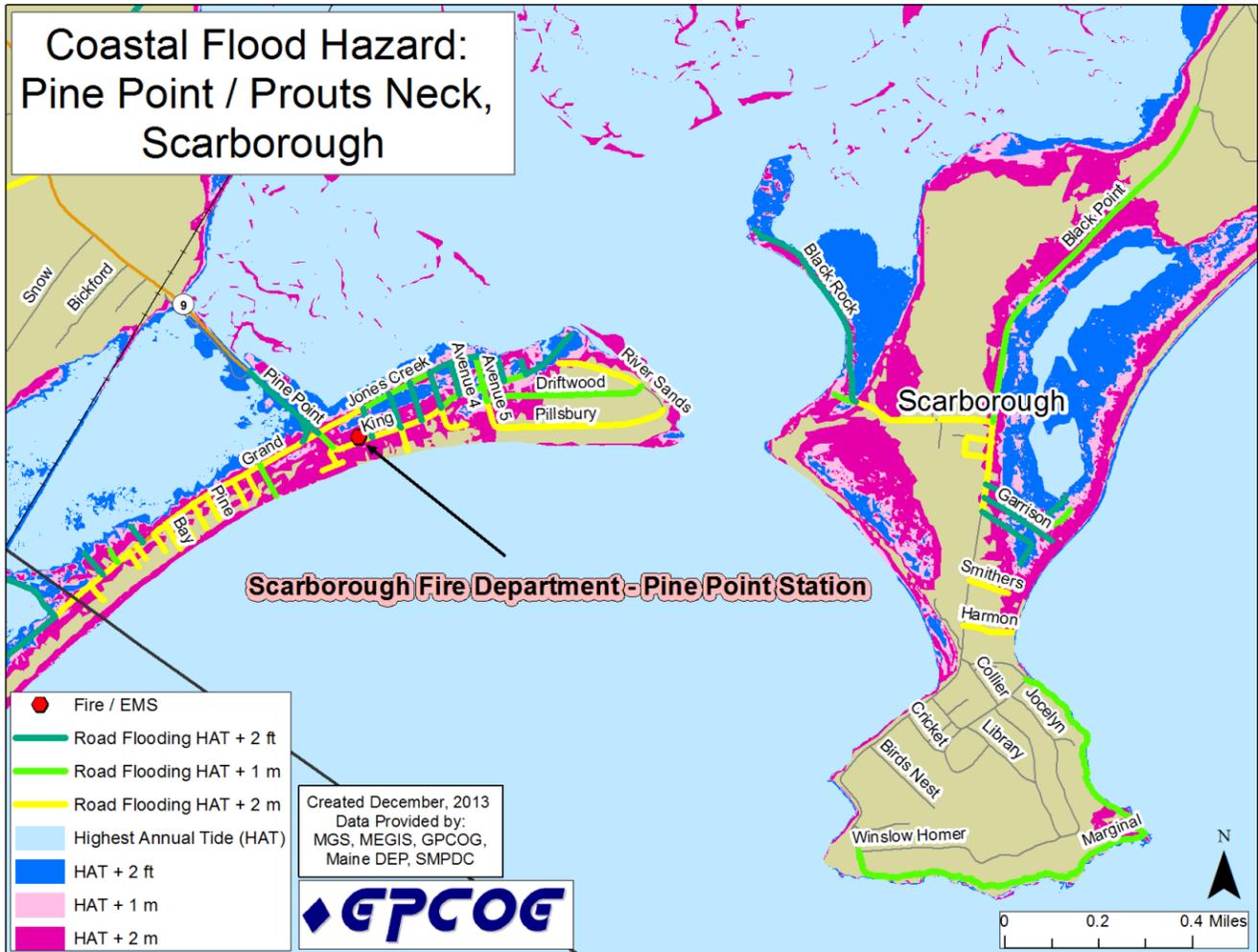
The Scarborough neighborhood of Higgins Beach has frequently been highlighted as vulnerable to SLR and coastal flooding. While this analysis did not find vulnerable public facilities in this neighborhood, it did reveal a significant portion of road infrastructure appears to be at risk, even with a modest 2 foot of flooding above HAT. By the time flooding reaches 1 meter above HAT, the only road to and from Higgins beach will be cut off. This strongly suggests that this community should consider actions such as rerouting or road elevation for this vital link. This analysis also suggests that Higgins Beach likely contains a large amount of at risk private real estate, particularly in the neighborhood's coastal eastern section.

Figure 27: Higgins Beach, Scarborough Coastal Flood Hazard



The MGS CHRT and this analysis both also revealed significant flood vulnerability in Scarborough’s Pine Point and Prouts Neck neighborhoods. The most significant at-risk public facility was found to be the Scarborough Fire Department’s Pine Point Station, which is vulnerable at flood elevations of HAT + 2 meters. Road infrastructure is also vulnerable, even at HAT + 2 feet of inundation, when the critical link along Pine Point Road would be flooded. As with Higgins beach, a significant amount of private real estate is at-risk according to this analysis.

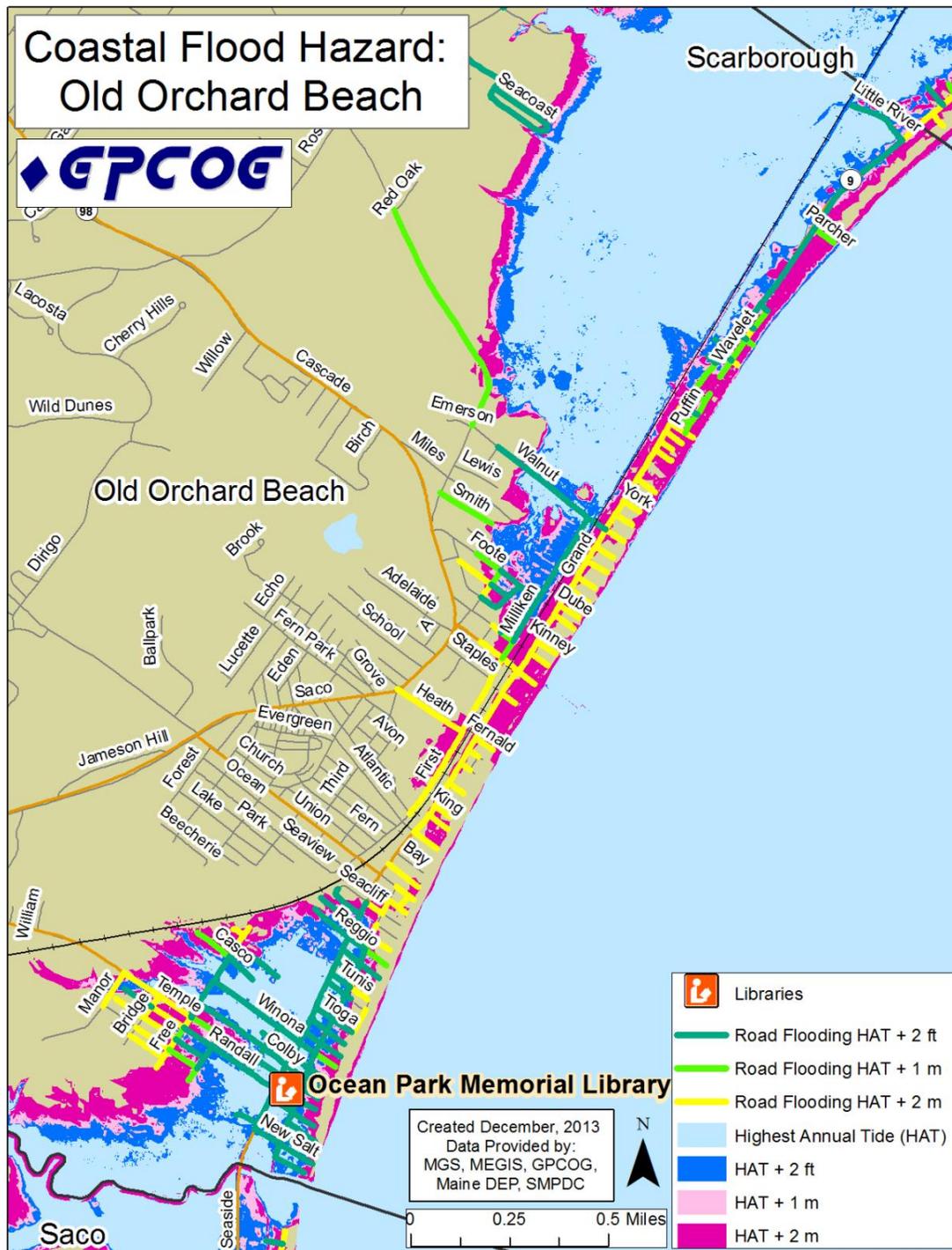
Figure 28: Pine Point / Prouts Neck, Scarborough Coastal Flood Hazard



## 11. Old Orchard Beach

Old Orchard Beach’s vulnerability to coastal flooding has been well studied. This analysis shows that, fortunately, OOB’s primary wastewater treatment plant is not especially vulnerable. However, as noted by MGS analysis, the pump station in Ocean Park is quite vulnerable. The primary public facility found to be vulnerable is the public library, which is projected to flood at HAT + 2 feet of inundation. Indeed, this facility was recently flooded during the Patriot’s Day storm in 2007.

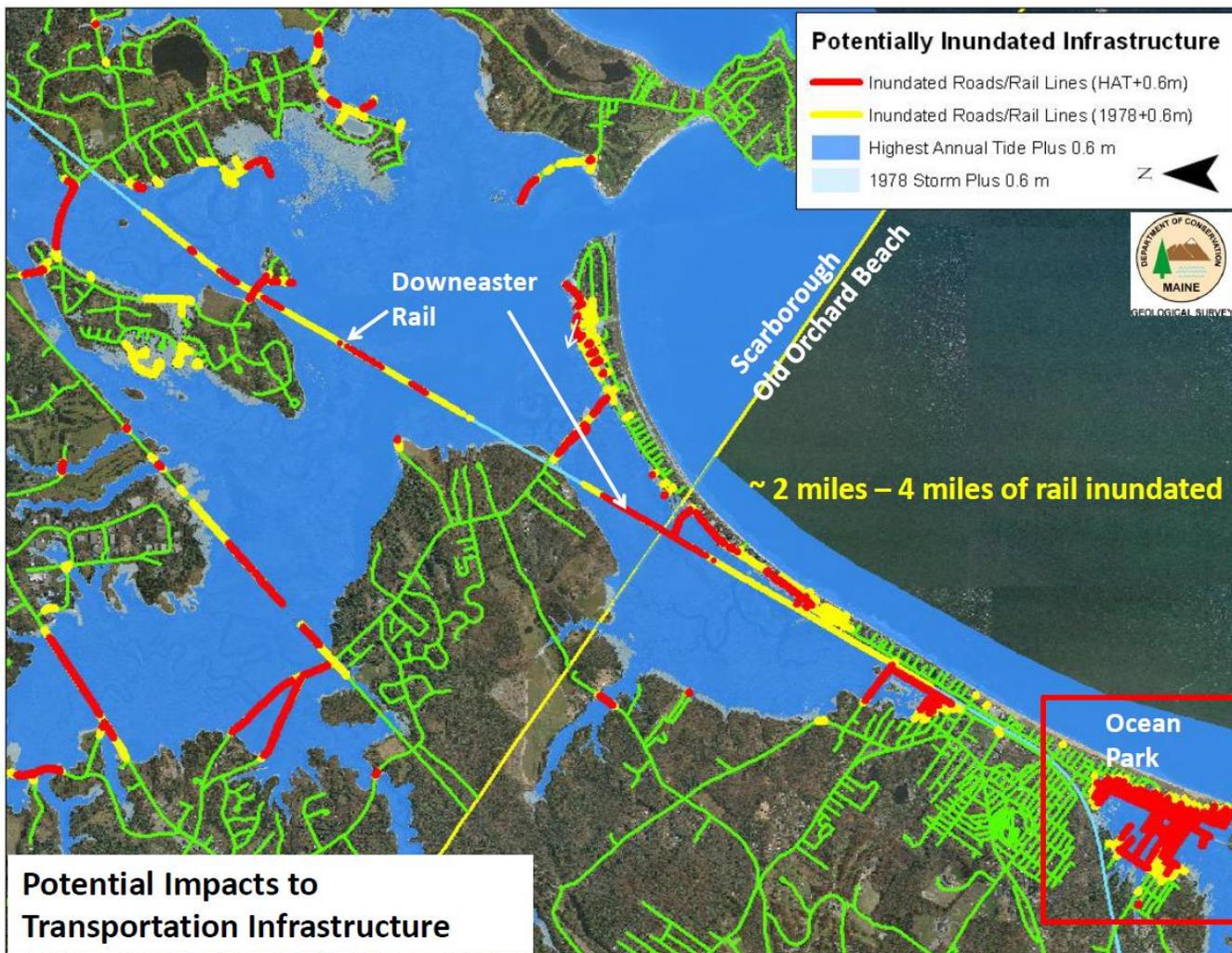
Figure 29: Old Orchard Beach Coastal Flood Hazard



Road infrastructure is also vulnerable in OOB. The analysis found that at 2 feet of flooding 127 road segments are vulnerable, at 1 meter of flooding 154 are, and at 2 meters of flooding 256 segments are vulnerable. As in several other southwestern Maine coastal communities a detailed road elevation study is warranted by this preliminary analysis. Such a study can help to ensure routes for evacuation and emergency responder access are open during flood events. A network based analysis would help to prioritize hardening of the most critical routes over time as SLR increases. Analysis by Peter Slovinsky at MGS showed which roads may be vulnerable, and also that 2 to 4 miles of rail infrastructure may be at-risk even with 2 feet of SLR over HAT.

**Figure 30: Old Orchard Beach Transportation Infrastructure Impacts**

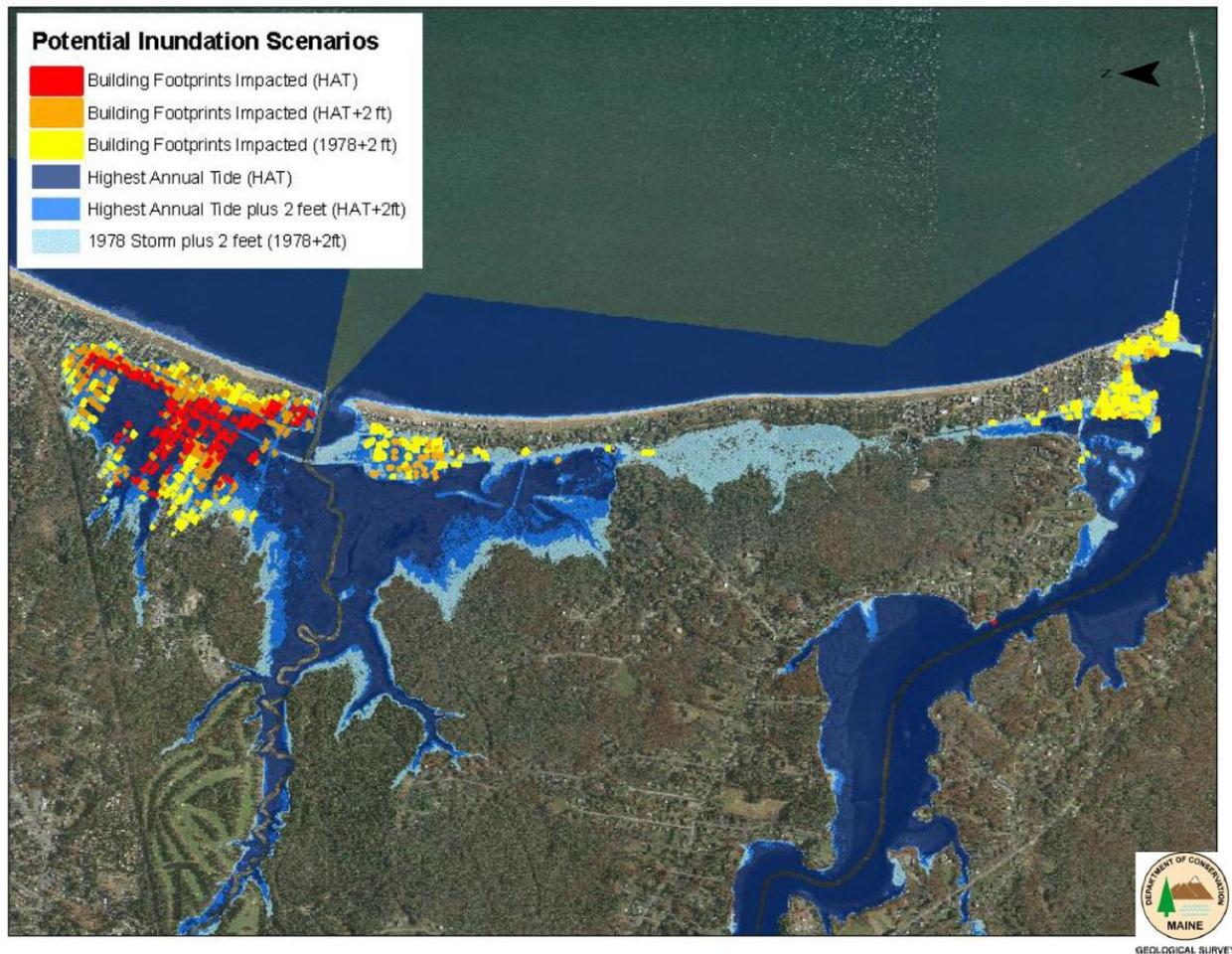
Source: Presentation to Maine Emergency Management Agency (Slovinsky, 2013)



Besides public road infrastructure, a great deal of private real estate is at-risk in OOB. This analysis, and work done by the Maine Geological Survey, has shown that even given no SLR this area is currently at-risk to erosion and inundation due to present storm flooding periods. The slide below shows how impacts to building footprints may increase with 2 feet of SLR during the “100 Year” storm at HAT, which for this area most recently experienced during the blizzard of 1978.

**Figure 31: Old Orchard Beach Building Inundation by Scenario**

Source: Presentation to Maine Emergency Management Agency (Slovinsky, 2013)



MGS has developed an updated beach scoring system to help prioritize any adaptation actions to address the issue. This has been applied in OOB and other communities in Saco Bay to help assess the short and long term changes likely to take place with sand beaches and associated dune systems in Maine. The system can help to determine adaptation actions, such as beach nourishment, dune restoration, or more substantial measures such as development retreat.

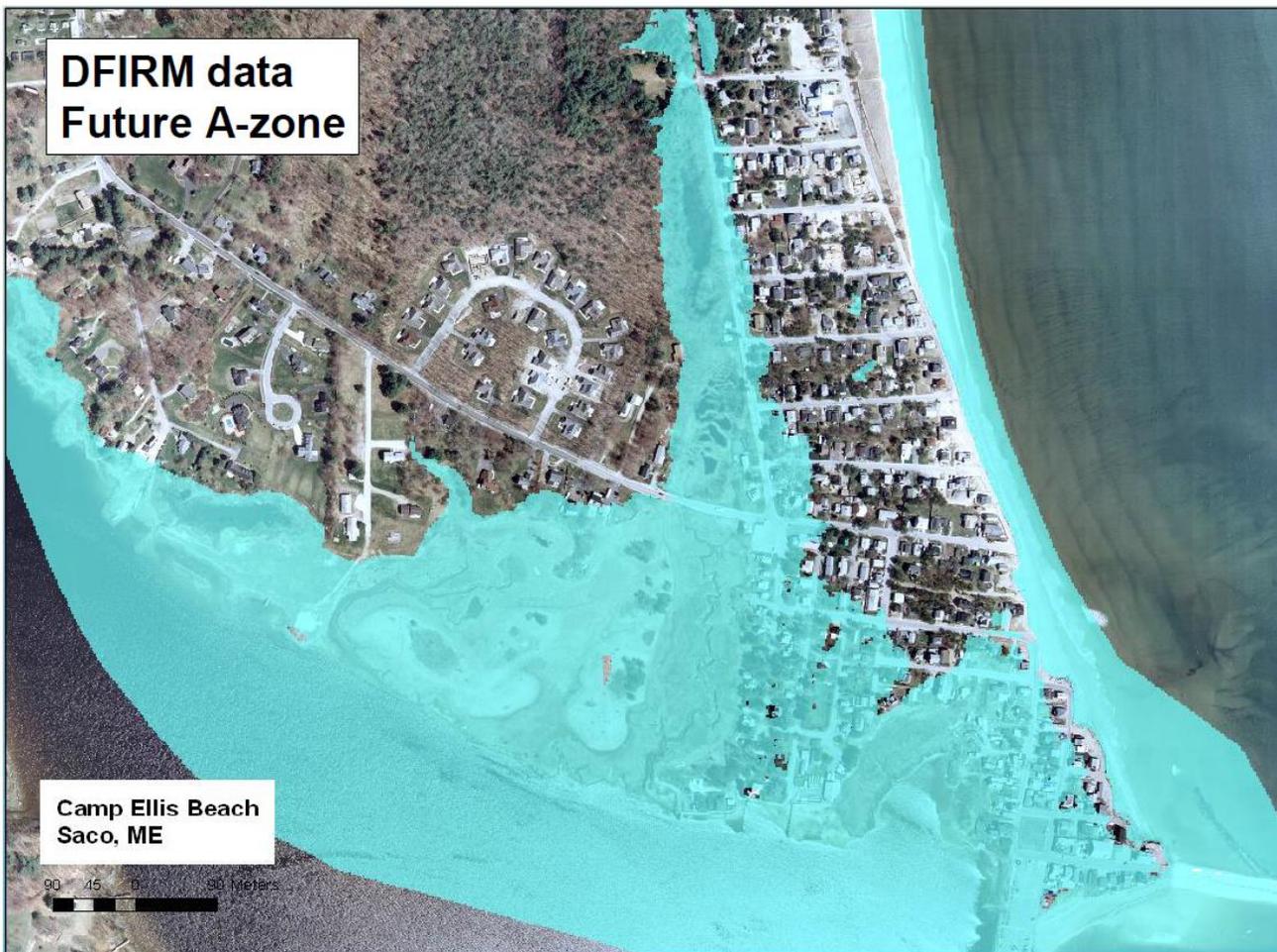
Like other coastal Maine communities, OOB is likely to see a dramatic change in marshlands as sea levels increase. Fortunately, OOB has recently adjusted its shoreland zoning using the new LiDAR data, becoming the first municipality in Maine to do so. This change will help to better accommodate the marsh transgression process as it affects OOB. Effects will be seen both along inlets and along the coastal strip through backwater flooding. OOB’s proactive shoreland zoning adjustment will help ameliorate these effects, and should be closely studied by other communities.

## 12. Saco

This analysis, and the work done as part of the CHRT process, shows that Saco does not have a large number of public facilities at risk due to coastal flooding. However, like many other municipalities in this area it does contain a large amount of at-risk road infrastructure and private real estate. Particularly concerning is a dramatic expansion of flood zones in the Camp Ellis Beach area, even with a relatively modest 2 feet of SLR, as shown in the image below from the CHRT process.

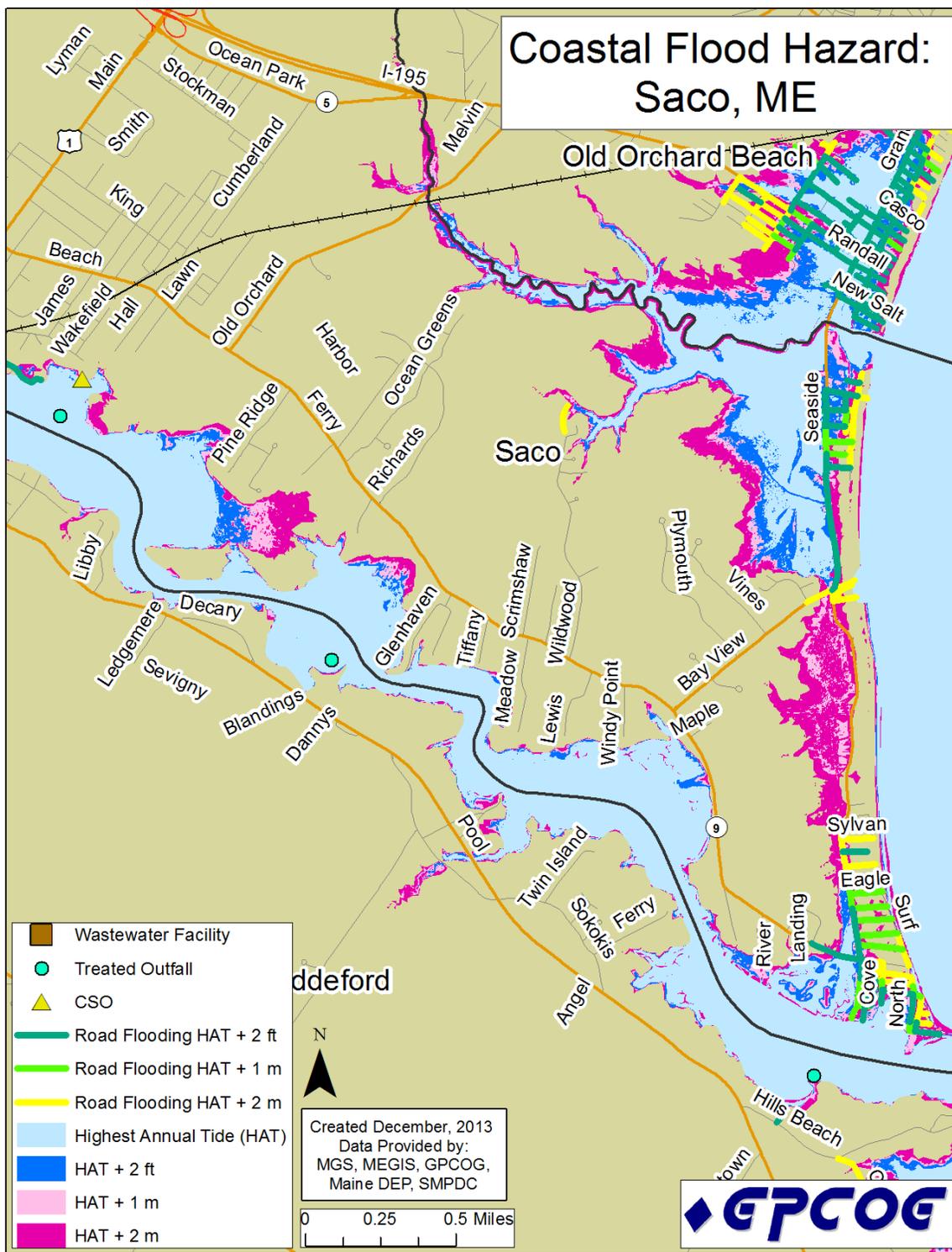
As with other municipalities in coastal Maine, there are areas of Saco that may be cut off from emergency responder access during even relatively modest flood events. In addition, evacuation routes could be cut off during the initial phases of a flood event. It is plausible that these residents could be stranded. The SSM analysis found that at 2 feet of flooding 33 road segments are vulnerable, at 1 meter of flooding 58 are, and at 2 meters of flooding 98 segments are vulnerable; because of this, a more detailed follow-up road network vulnerability analysis would likely be of use to Saco.

Figure 32: Using LiDAR to Adjust Flood Zones, Saco



This map shows potential future static flood zones after 2 feet of SLR on top of the effective 2009 FEMA DFIRM A zone elevations. Source: Improving Storm Hazard Resiliency (Slovinsky, 2008)

Figure 33: Saco Coastal Flood Hazard



Saco has begun to implement the shoreland zoning changes needed to address SLR effects. The City was the first community in the State to pass an increased floodplain management ordinance which included 3 feet of freeboard above the base flood elevation. “Freeboard” refers to the elevation of the lowest inhabitable floor elevation above projected flood heights.

### 13. Biddeford

Biddeford faces significant vulnerabilities to coastal flooding. Wastewater treatment facilities in both downtown Biddeford and in Biddeford pool are vulnerable to flooding of 2 meters. Flooding also occurs at Biddeford’s combined sewer overflows along the Saco, which could lead to untreated sewage back flowing into homes and businesses, or mixing with flood waters and inundating structures. Significant road infrastructure is also vulnerable, including the only route to and from Biddeford Pool, which floods at only 2 feet above HAT. This section, along Fortune Rocks Beach, also includes a large amount of vulnerable private real estate.

Biddeford also has a large amount of vulnerable road infrastructure. This analysis found that at 2 feet of flooding 23 road segments are vulnerable, at 1 meter of flooding 40 are, and at 2 meters of flooding 82 segments are vulnerable. Most of the road flooding vulnerability was in highly developed residential areas along the coast. In some cases whole neighborhoods are found to be at-risk of being cut off from the mainland road networks during even modest storm events. This has large implications for emergency access and evacuation routing.

Figure 34: Biddeford Pool Coastal Flood Hazard

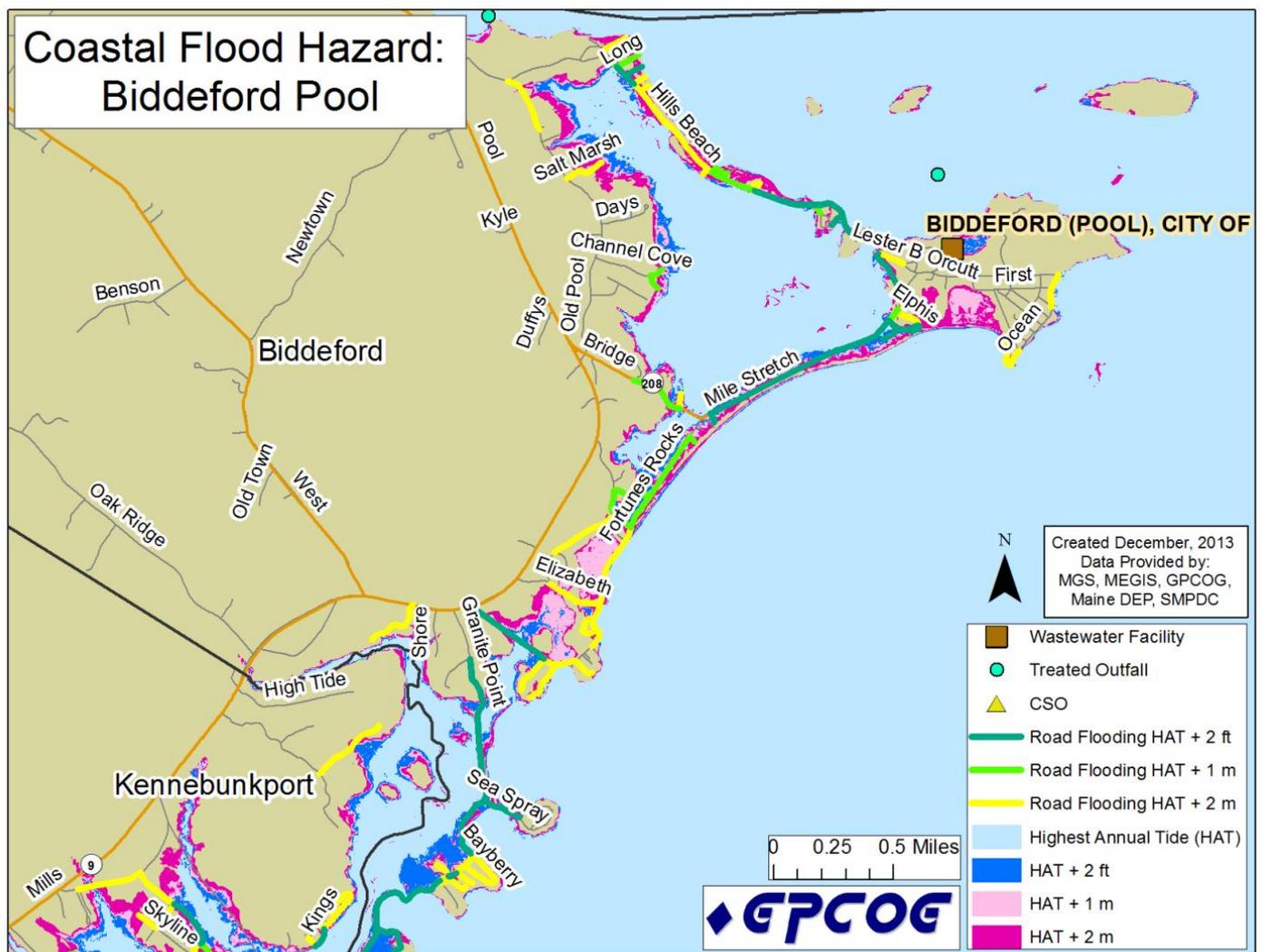
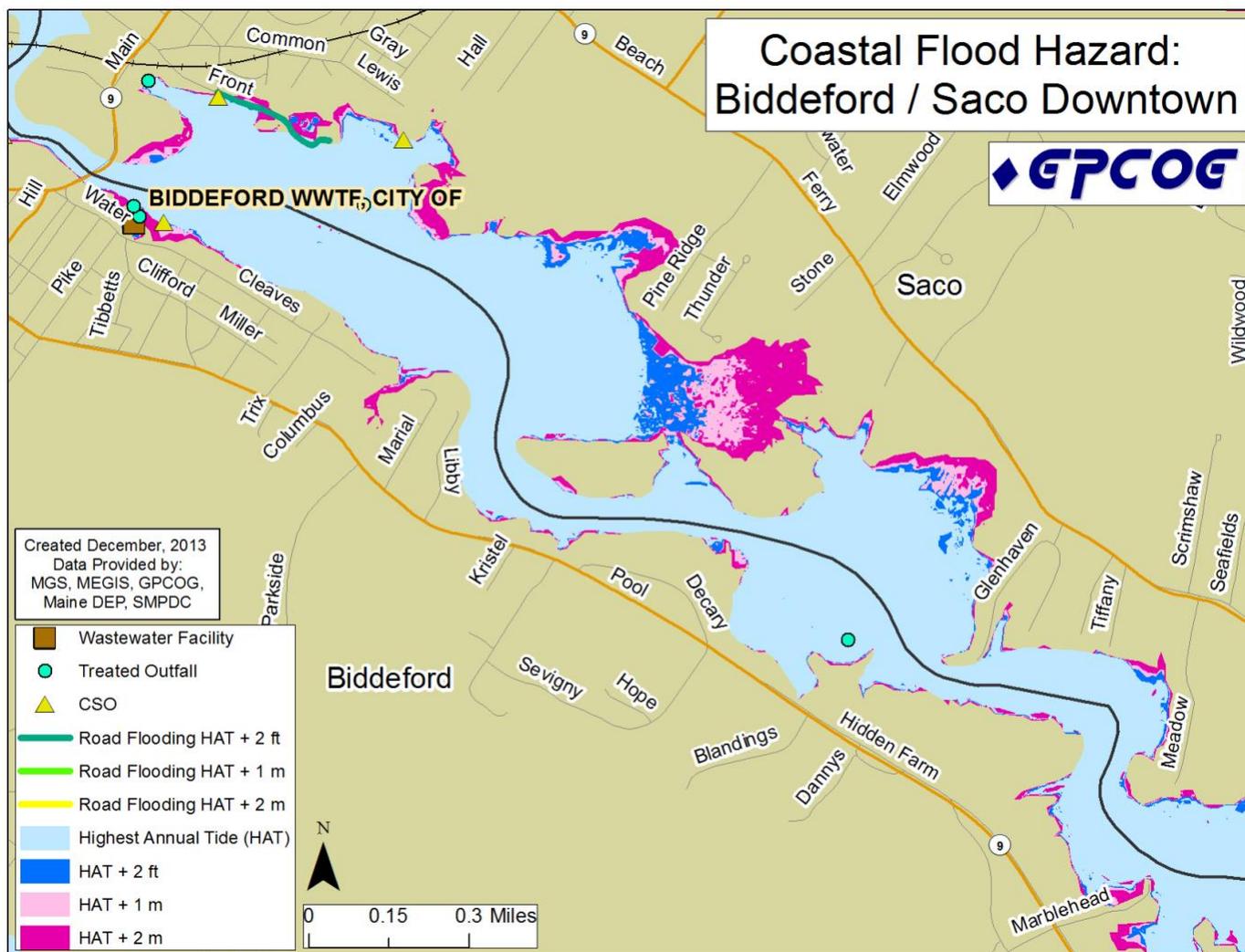


Figure 35: Biddeford / Saco Downtown Coastal Flood Hazard

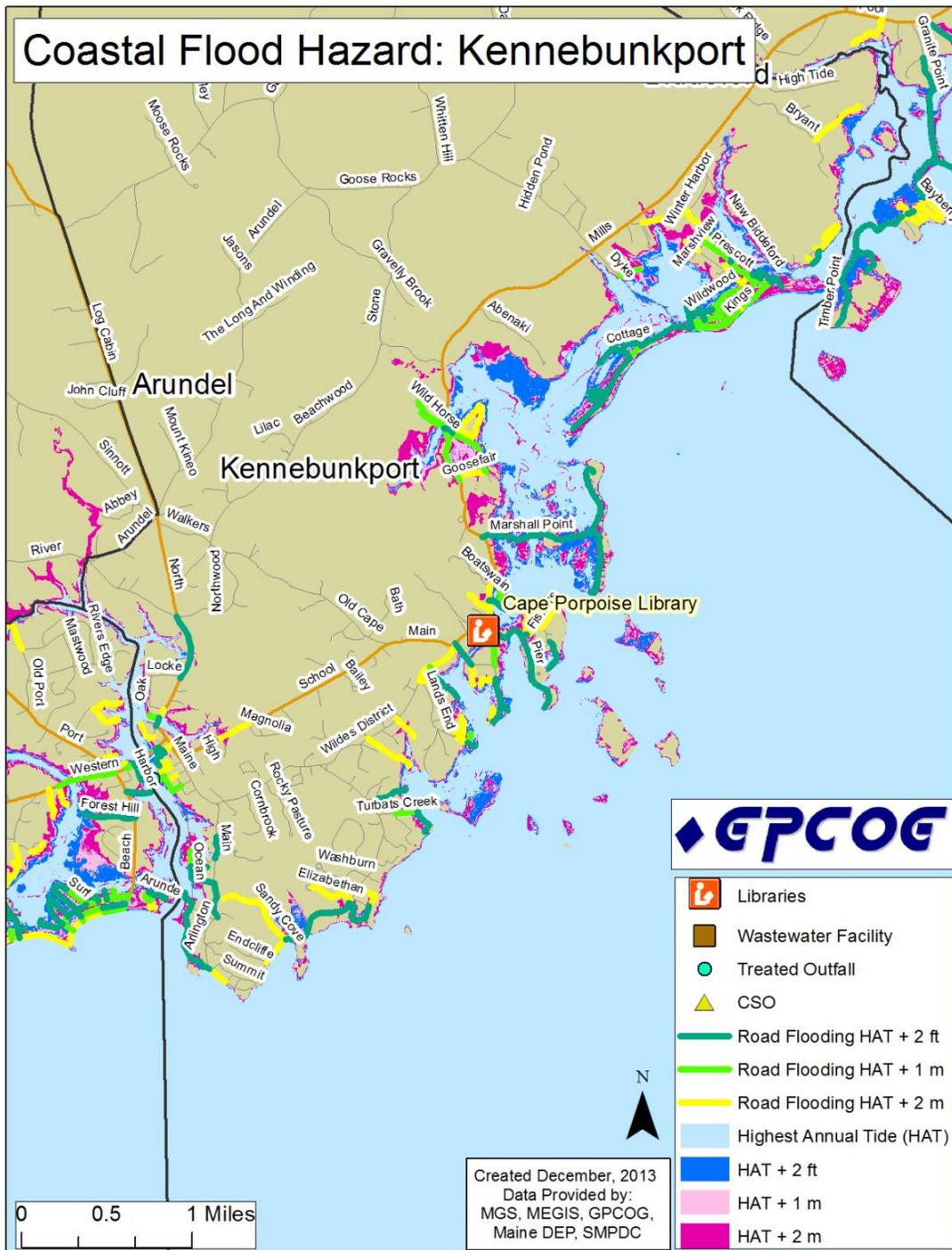


The CHRT analysis for Biddeford also recognized these problems. Furthermore, it discussed adaptation actions in the context of an updated scoring system for shoreline erosion rates along exposed beaches. The analysis also discussed future marsh migration rates under different SLR conditions. Adaptation actions discussed included beach nourishment, wetland restoration, tidal flow control, elevation, utility relocation, and emergency access rerouting.

## 14. Kennebunkport

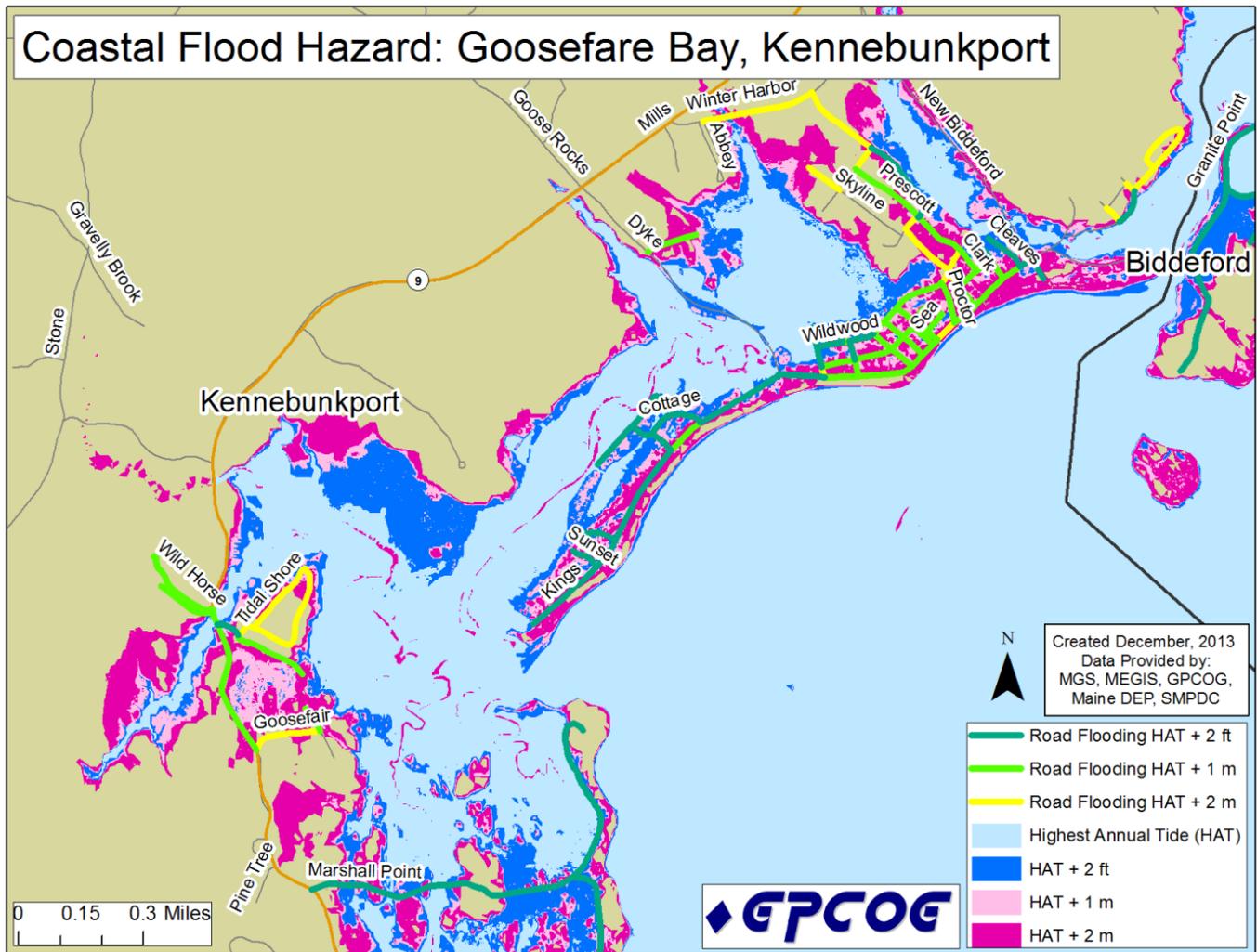
This analysis suggests that the Cape Porpoise Library in Kennebunkport would be vulnerable to coastal flooding of 2 meters or more. Other public facilities were not found to be vulnerable by this analysis. Public road infrastructure, however, may experience flooding effects with flooding as low as HAT + 2 feet. The analysis found that at 2 feet of flooding 61 road segments are vulnerable, at 1 meter of flooding 115 are, and at 2 meters of flooding 172 segments are vulnerable. As a result, further analysis of road elevations is needed to ensure integrity of evacuation routes.

Figure 36: Kennebunkport Coastal Flood Hazard



Significant private infrastructure is likely at-risk in Kennebunkport. This is particularly true in the Goosefare Bay area. In addition, given even small amounts of SLR significant marsh transgression can be expected along tidal inlets.

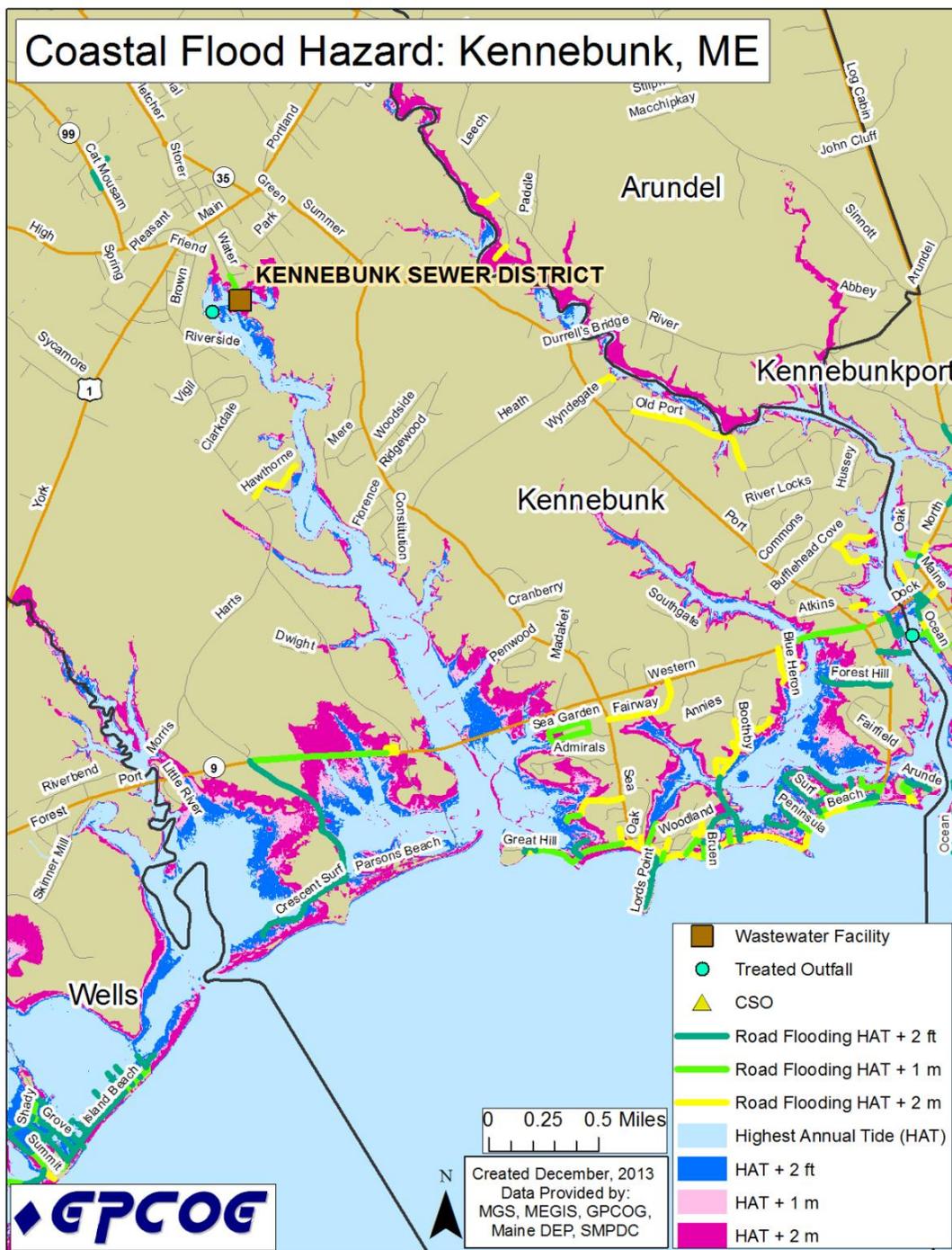
Figure 37: Goosefare Bay, Kennebunkport Coastal Flood Hazard



## 15. Kennebunk

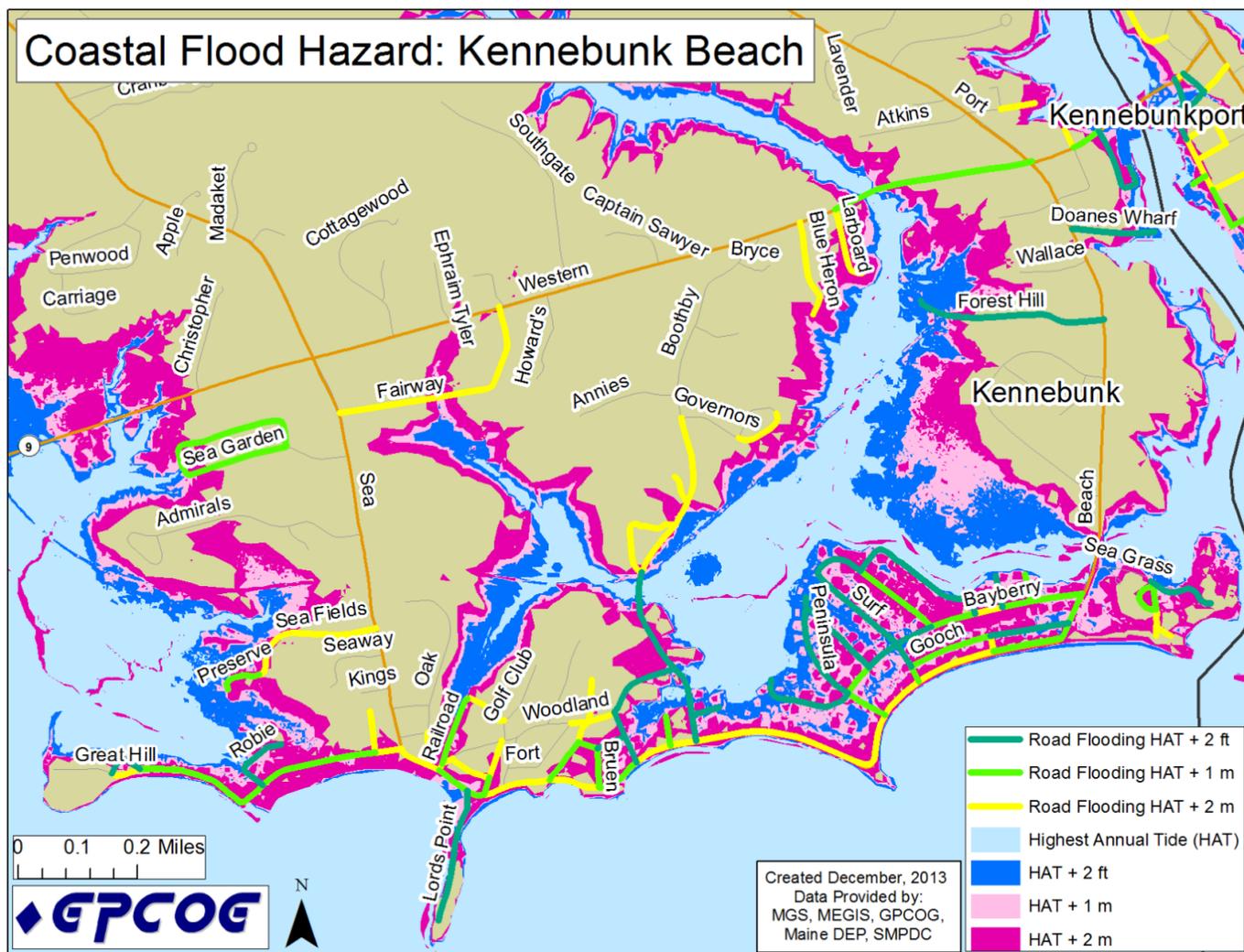
This analysis suggests that, with 2 meters of coastal flooding, Kennebunk’s wastewater facility on Water Street may be vulnerable to inundation. This analysis did not show vulnerabilities to other public facilities at 2 feet or 1 meter of flooding. It is likely that road flooding would occur with all levels of flooding, however. The SSM analysis found that at 2 feet of flooding 6 road segments are vulnerable, at 1 meter of flooding 12 are, and at 2 meters of flooding 20 segments are vulnerable. This suggests that further analysis of road network flood vulnerability should be undertaken to ensure the integrity of evacuation routes.

Figure 38: Kennebunk Coastal Flood Hazard



It is likely that significant damage would occur to private real estate along Kennebunk’s coastal beaches; with neighborhood-wide inundation occurring as flooding approaches 2 meters. Even at flood levels of 2 feet, significant road inundation is likely to occur. Many roads, even though not inundated themselves, would be cut off as flooding inundates choke points.

Figure 39: Kennebunk Beach Coastal Flood Hazard

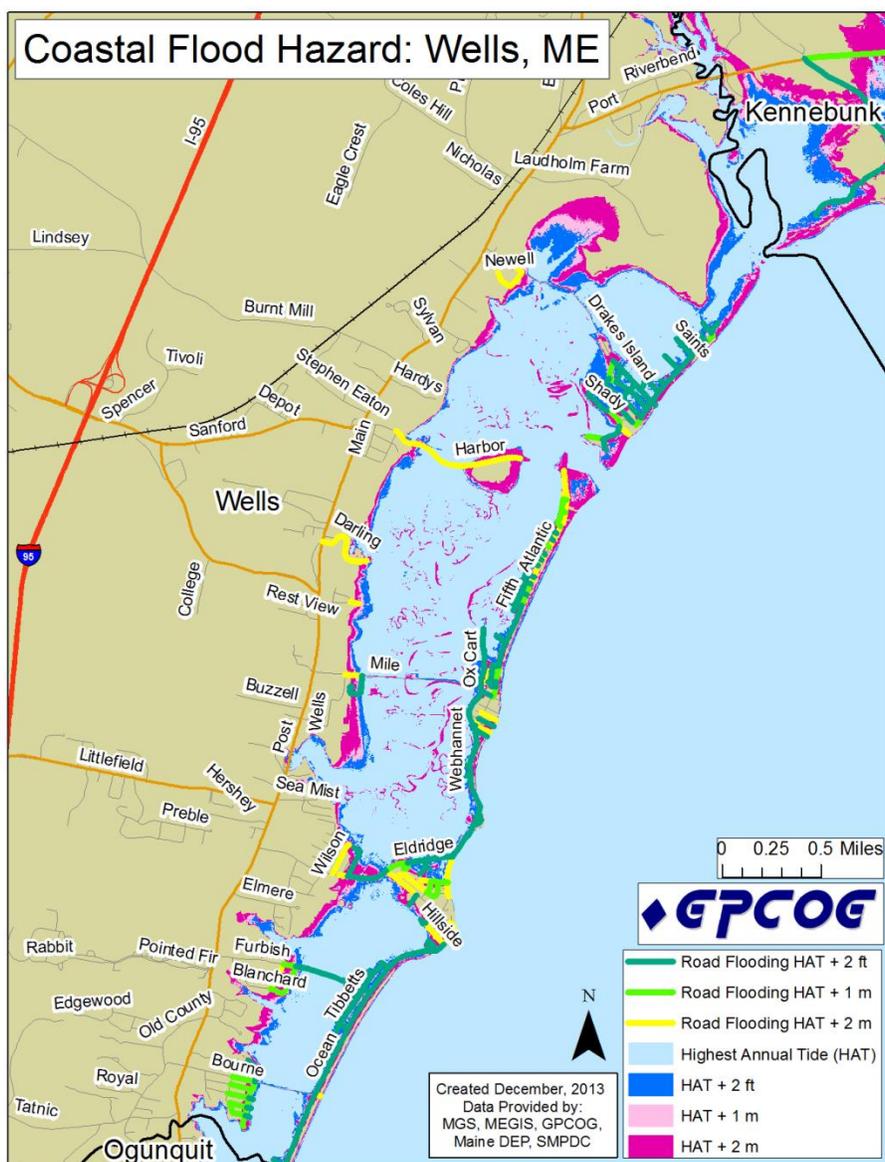


Marsh migration is also likely to be an issue in Kennebunk. This will particularly be an issue along lowlands adjacent to the Kennebunk River. Even modest amounts of SLR could cause extensive changes to marshland in this area.

## 16. Wells

Of the infrastructure used in this analysis, Wells was not found to have a significant vulnerability at the 2 meters flood event. Wells was not part of the CHRT analysis; however its vulnerability was studied in detail by MGS in an earlier study in 2006. The MGS study, and this analysis, both found that even small amounts of SLR have major implications for Wells. Significant impacts in terms of destruction of infrastructure, public and private facilities, and marsh migration can all be expected.

Figure 40: Wells Coastal Flood Hazard

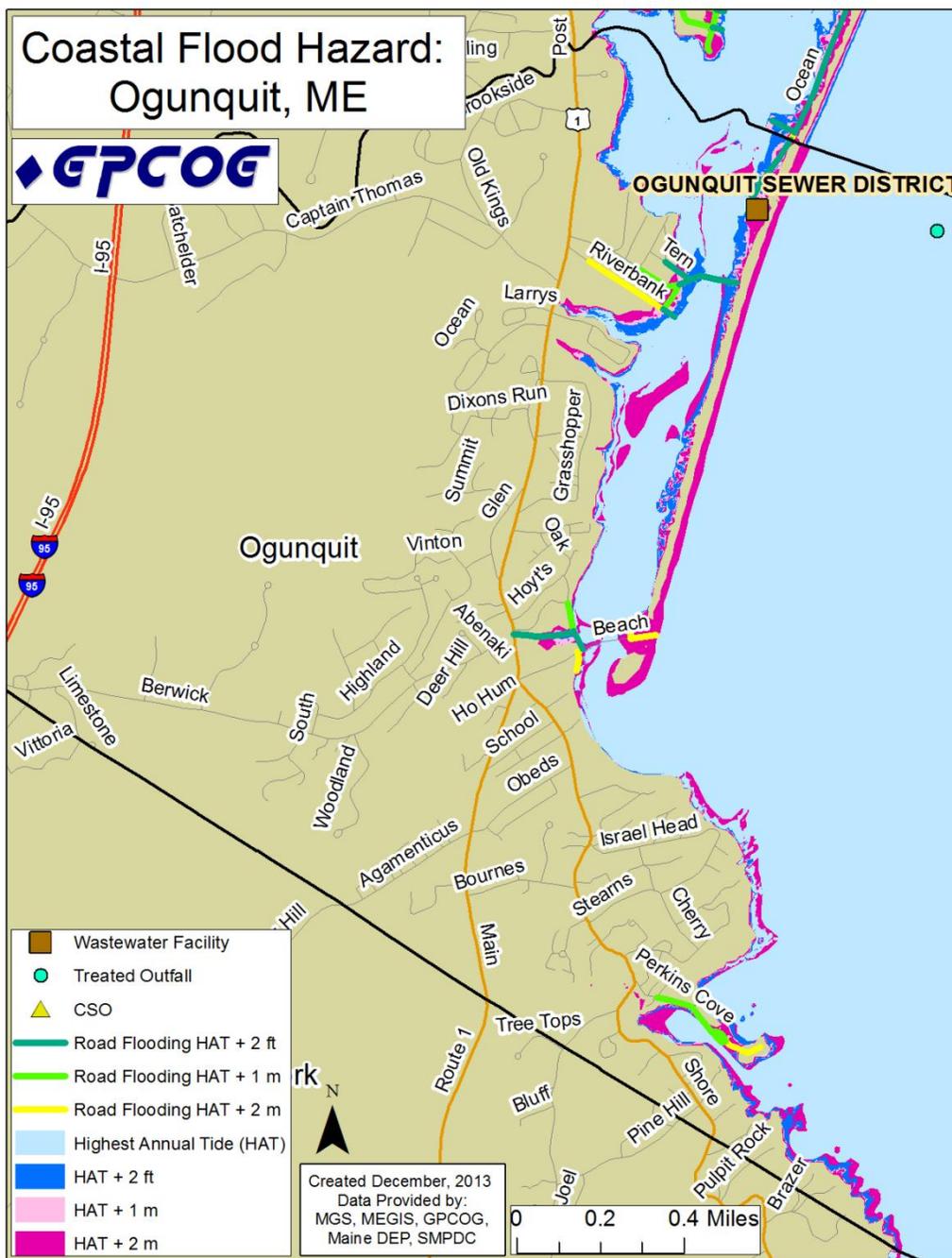


It is likely that a great deal of private infrastructure in Wells is vulnerable, as apart from the Wells Reserve much of its coastal margin is densely developed. It also appears likely that much of its coastal roads, possibly including important evacuation routes, would be disabled in a flood event. The SSM analysis found that at 2 feet of flooding 121 road segments are vulnerable, at 1 meter of flooding 158 are, and at 2 meters of flooding 203 segments are vulnerable. For this reason, a more detailed study of road network vulnerability in Wells is highly recommended.

## 17. Ogunquit

This analysis shows that Ogunquit faces a serious threat as a result of SLR. MGS and SMPDC collaborated to assess threats to Ogunquit. These analyses found that the wastewater treatment plant is particularly vulnerable, and would be inundated with SLR, storm surge (or both combined) of 2 meters above HAT. In addition, a significant amount of road infrastructure and private real estate is also likely to be at-risk. This analysis found that at 2 feet of flooding 8 road segments are vulnerable, at 1 meter of flooding 14 are, and at 2 meters of flooding 21 segments are vulnerable.

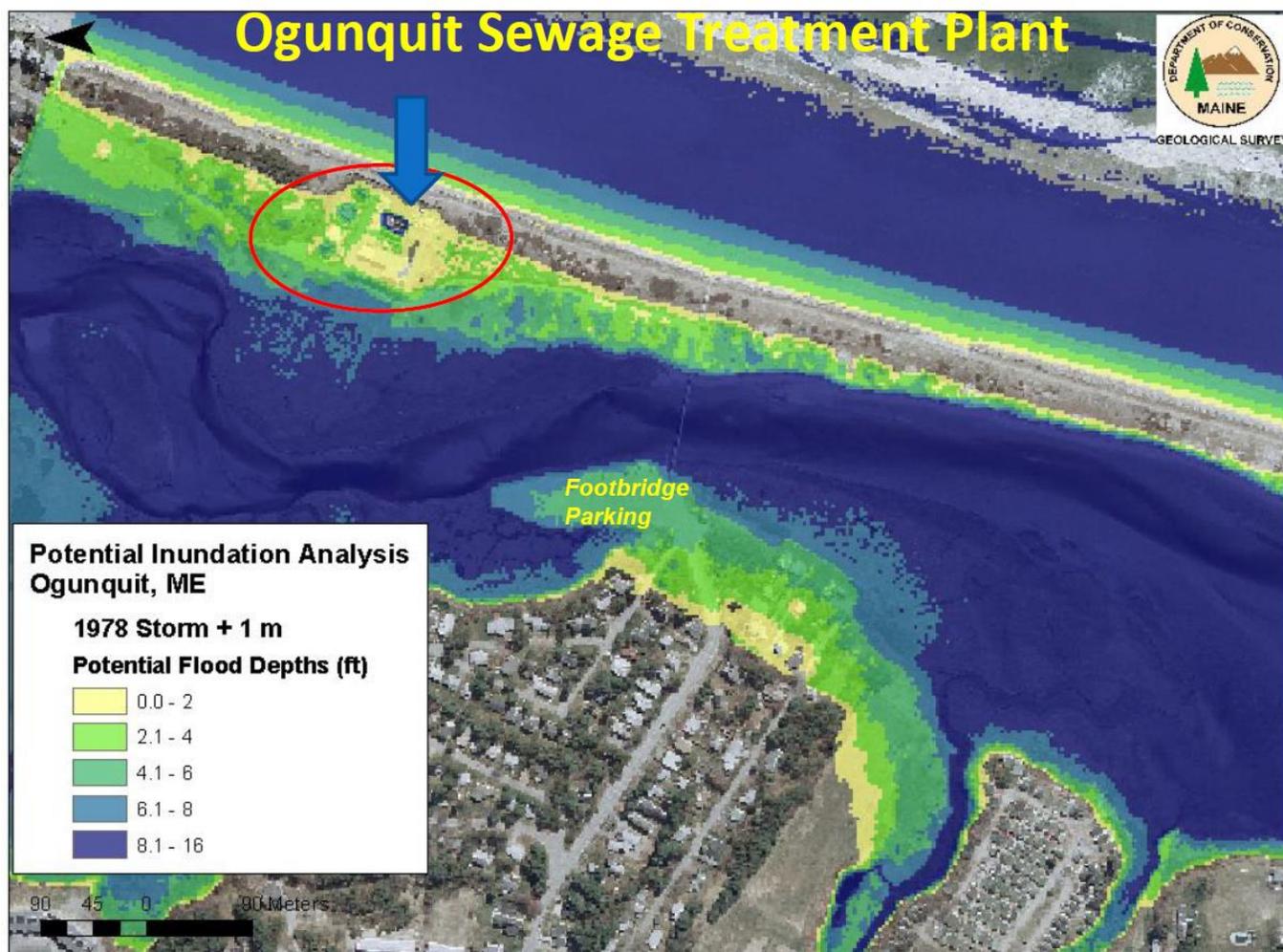
Figure 41: Ogunquit Coastal Flood Hazard



As this LiDAR generated image shows, extensive inundation would occur along Ogunquit Beach and at the public parking facility for the beach. The CHRT analysis noted similar results, with special concern raised about the wastewater treatment plant. The scenario shown below is the 1% annual probability storm + 1 meter of SLR.

Figure 42: Flood Inundation Depth Scenario, Ogunquit

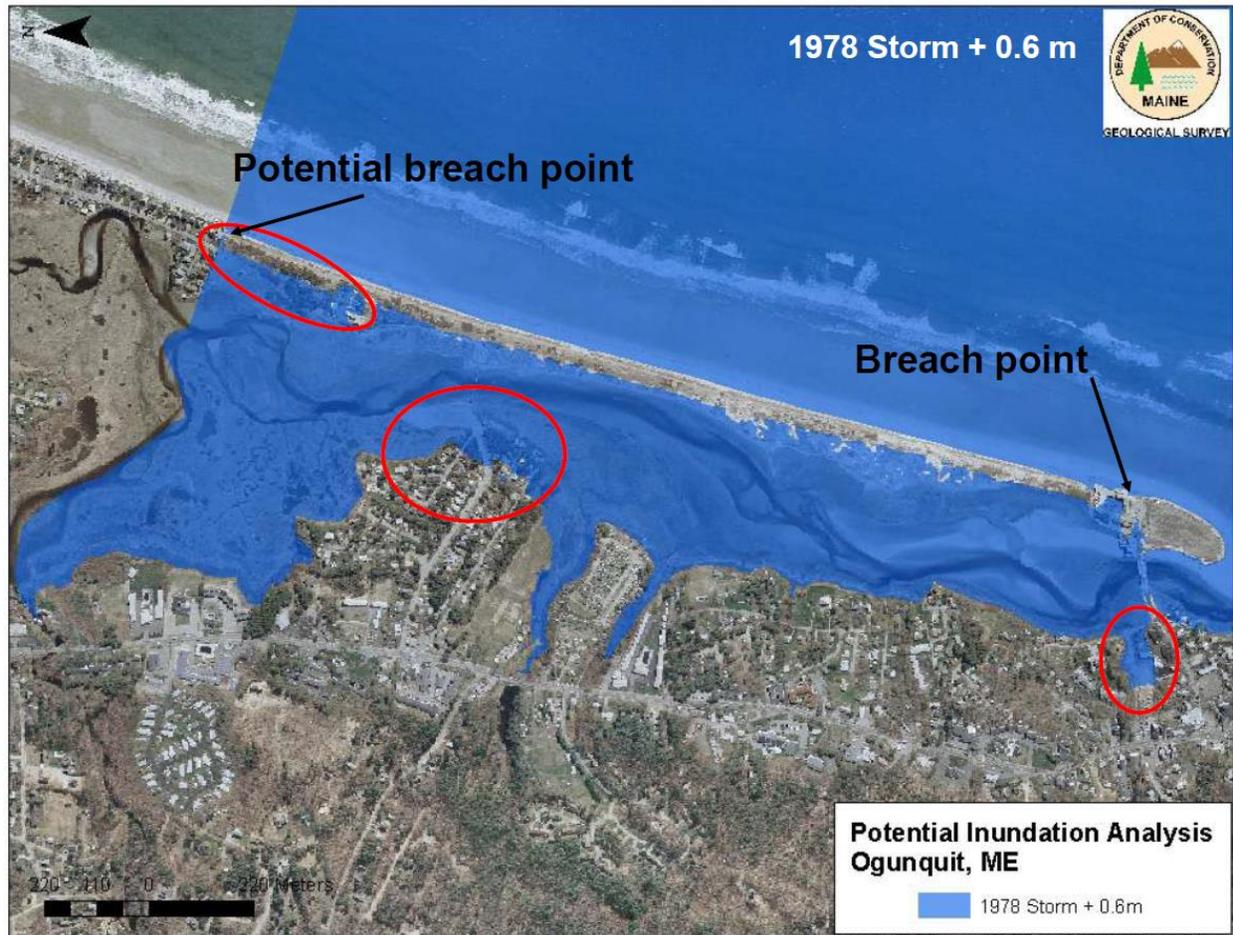
Source: Preparing Ogunquit for Sea Level Rise and Coastal Hazard Resiliency (Slovinsky, 2011)



In addition, the CHRT process found significant inundation at several businesses in the town, as well as the loss of the footbridge parking facility. It also noted that Ogunquit would see extensive marsh migration as a result of SLR. Even modest amounts of SLR could cause extensive changes to marshland in Ogunquit.

Figure 43: Inundation Analysis, Ogunquit

Source: Preparing Ogunquit for Sea Level Rise and Coastal Hazard Resiliency (Slovinsky, 2011)

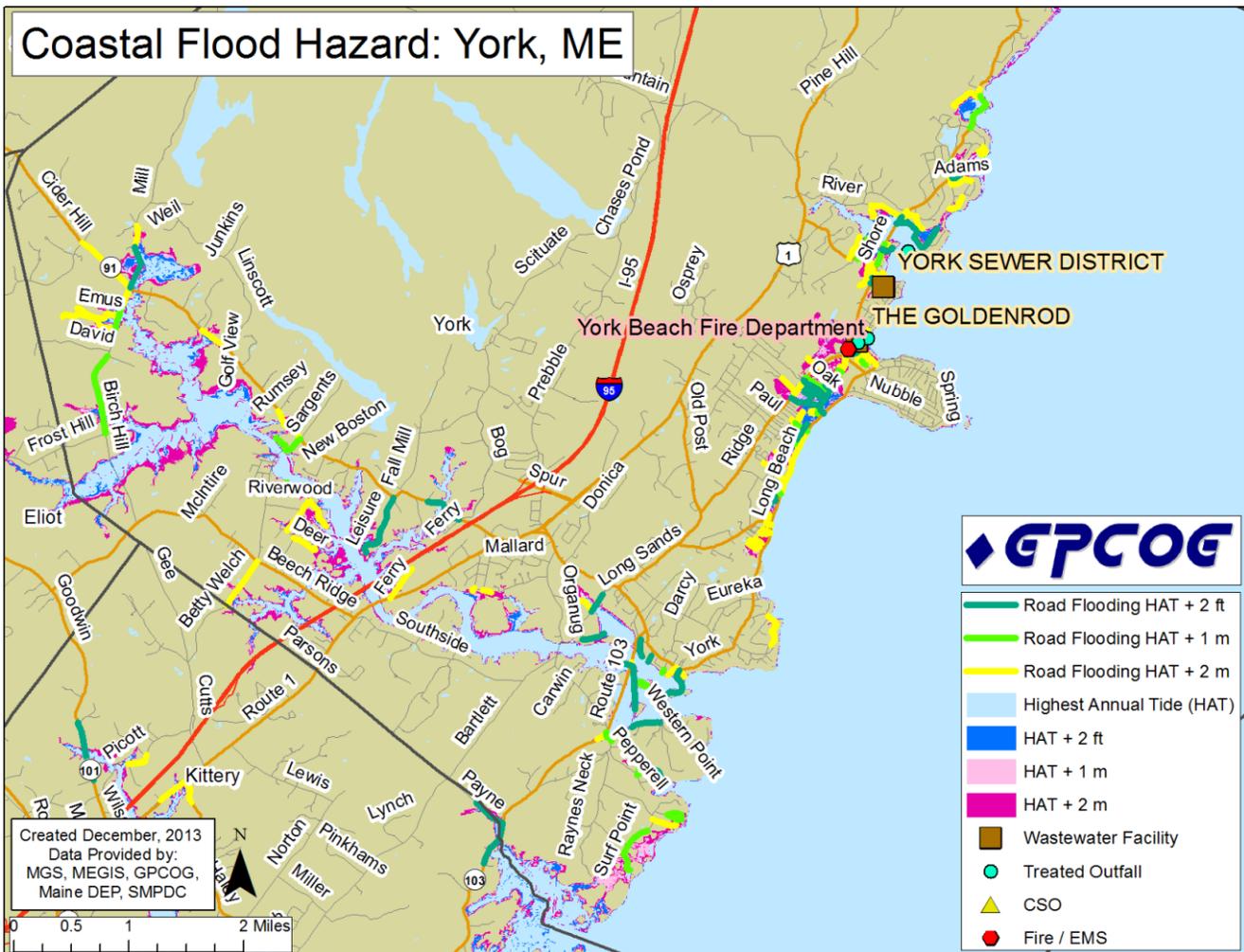


The above slide, from the CHRT analysis, is of particular interest. It shows potential breach points in the barrier beach that protects developed areas in the town from waves during flood events. However, given a high enough flood event (or combination of SLR and storm surge) eventually the beach may breach. This would result in much higher levels of damage in the town. It could also cause significant erosion and further weakening of dunes currently protecting the town.

## 18. York

This analysis showed that York has many areas of coastal flooding vulnerability. For example, significant inundation is found to occur in the York Beach and York River areas. Inundation along the York River is likely to cause a significant inland migration of saltwater wetlands. Inundation could spread as far inland as Eliot and parts of northern Kittery. Significant loss of private and public facilities and infrastructure is possible. Key at-risk infrastructure in York Beach includes a wastewater treatment facility and the fire station. A wastewater discharge facility at a local business, the Goldenrod, is also shown to be vulnerable. In addition, a large number of road segments in the town may be vulnerable. The SSM analysis found that at 2 feet of flooding 48 road segments are vulnerable, at 1 meter of flooding 85 are, and at 2 meters of flooding 190 segments are vulnerable.

Figure 44: York Coastal flood Hazard





York was analyzed by SMPDC and MGS as part of the CHRT initiative. For York, this process included various flood scenarios plus the historic 1978 “100 Year” flood, or about 3 feet on top of highest annual tide. It found a number of additional vulnerabilities, particularly to the transportation system. The most extreme example is shown below, which is the HAT plus 1.8 meters of SLR. Disabled roads are shown in red. The accompanying table is an example of how the scenario based approach can be used to understand and communicate the problem of SLR combined with storm flooding.

Figure 46: York Potential Future Conditions, 2100

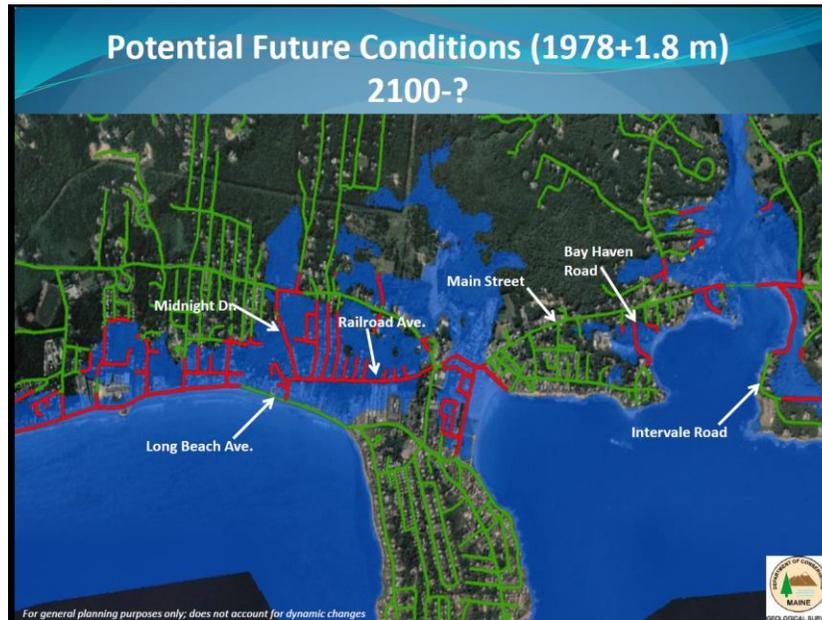
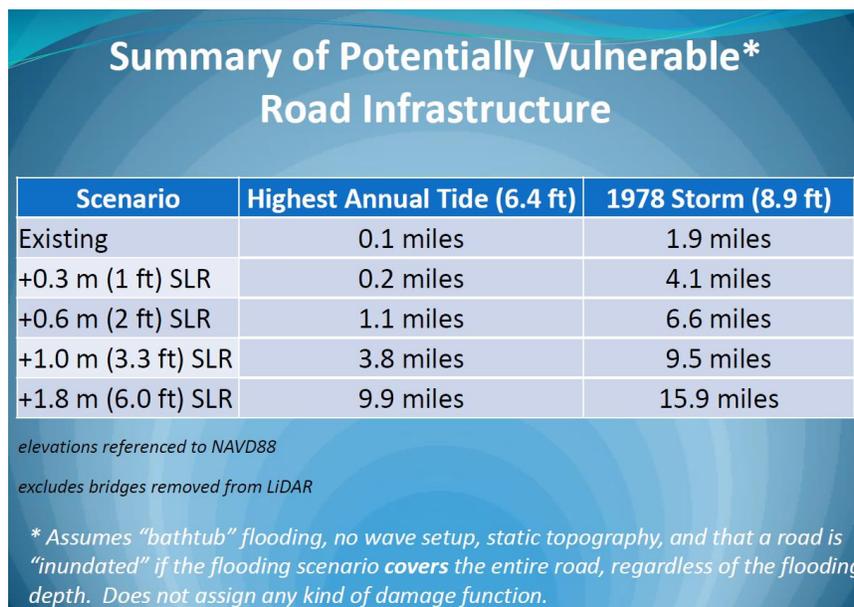
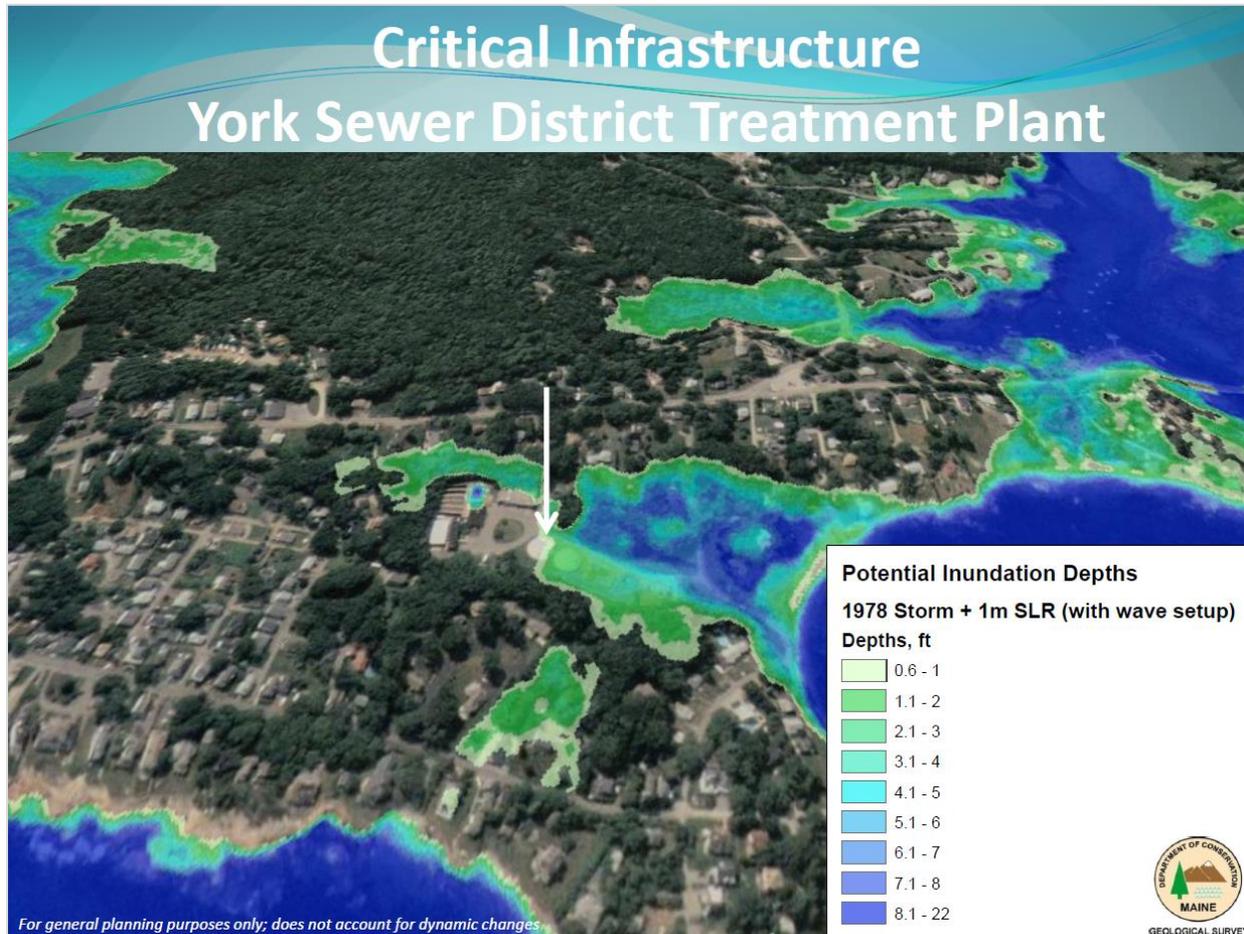


Figure 47: York Road Infrastructure Impacts by Scenario



Source Figures 45-46: Considerations for the Town of York Comprehensive Plan Sea Level Rise Chapter (Slovinsky & Lockman, 2012)

Figure 48: York Sewer Treatment Plant Impacts



Source: Considerations for the Town of York Comprehensive Plan Sea Level Rise Chapter (Slovinsky & Lockman, 2012)

As shown in Figure 48, the CHRT also used a technique to model wave effects on top of storm tide and SLR to illustrate potential water depths, highlighting the risk to the wastewater treatment plant.

The CHRT presentation and analysis in York has had a dramatic effect. York has now placed adoption of SLR into consideration for its comprehensive plan. The CHRT analysis suggested using a scenario based approach to develop a phased adaptation plan based on considerations of probability of inundation and degree of criticality to municipal function.

Further work could be done, however. As with the other municipalities in Southern Maine, marsh migration is also likely to be an issue in the city, particularly along lowlands adjacent to the York River. Even modest amounts of SLR could cause extensive changes to marshland in York.

## 19. Kittery

Public facilities were not found to be significantly vulnerable in Kittery according to this analysis. However, a large amount of public road infrastructure may be at-risk. The SSM analysis found that at 2 feet of flooding 23 road segments are vulnerable, at 1 meter of flooding 47 are, and at 2 meters of flooding 84 segments are vulnerable. However, according to the CHRT analysis done by SMPDC and MGS other infrastructure and facilities are vulnerable. The most significant facility found vulnerable by CHRT is the Portsmouth Naval Shipyard. A map generated by this analysis shows the flood depths at the facility generated by 1 meter of SLR and the “100 Year” storm, the 1978 Nor’easter.

Figure 49: Kittery Coastal Flood Hazard

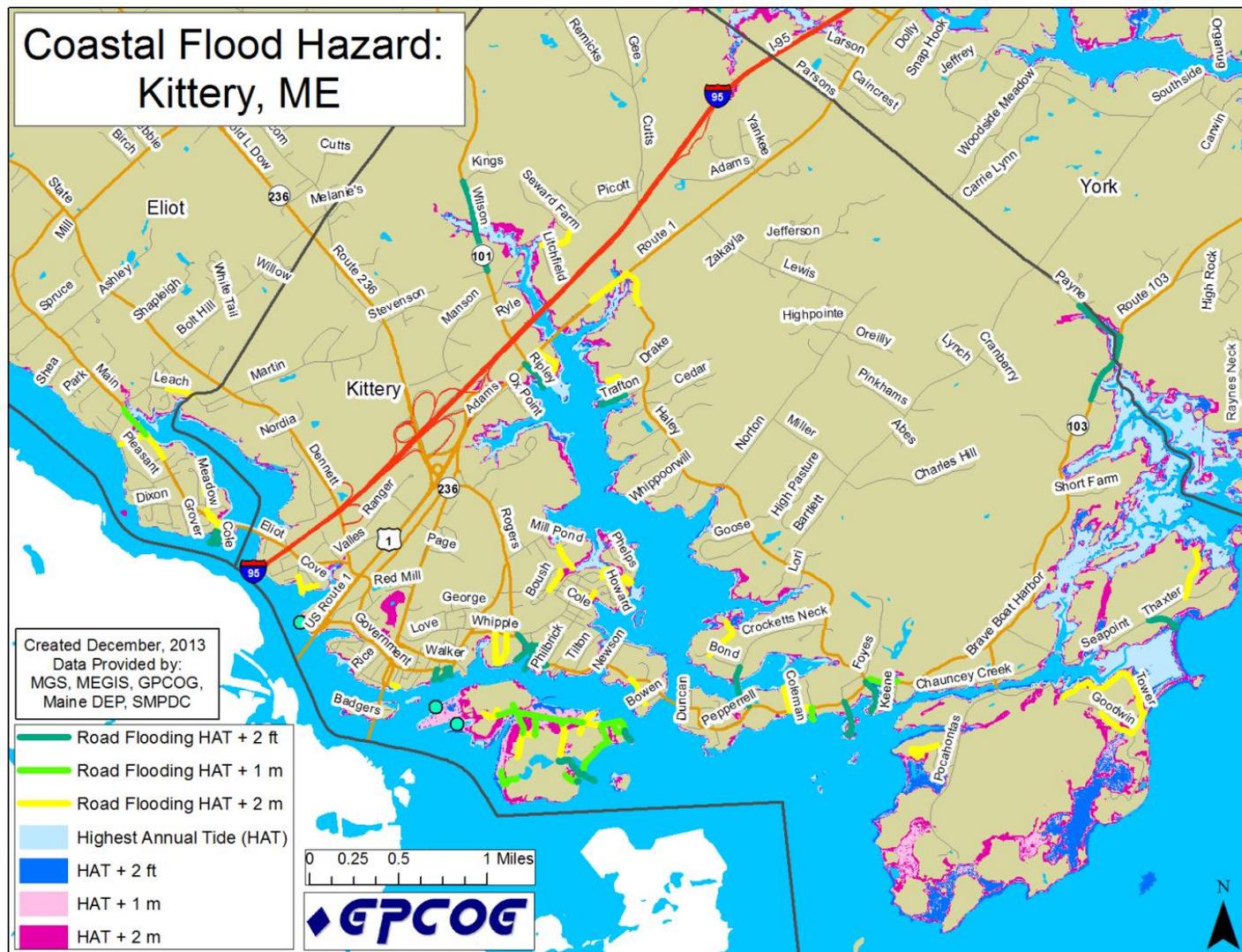
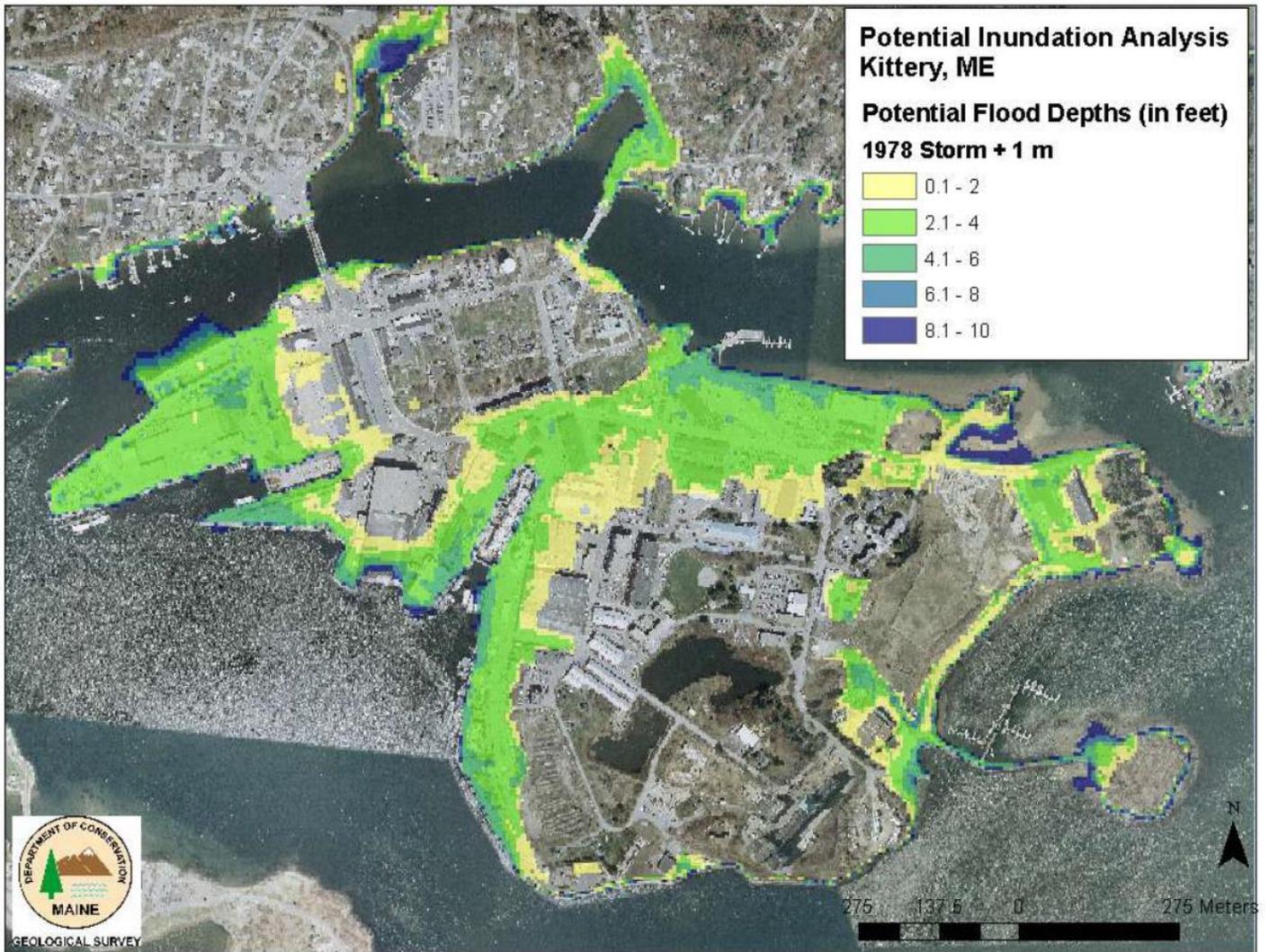


Figure 50: Portsmouth Naval Shipyard Inundation Analysis

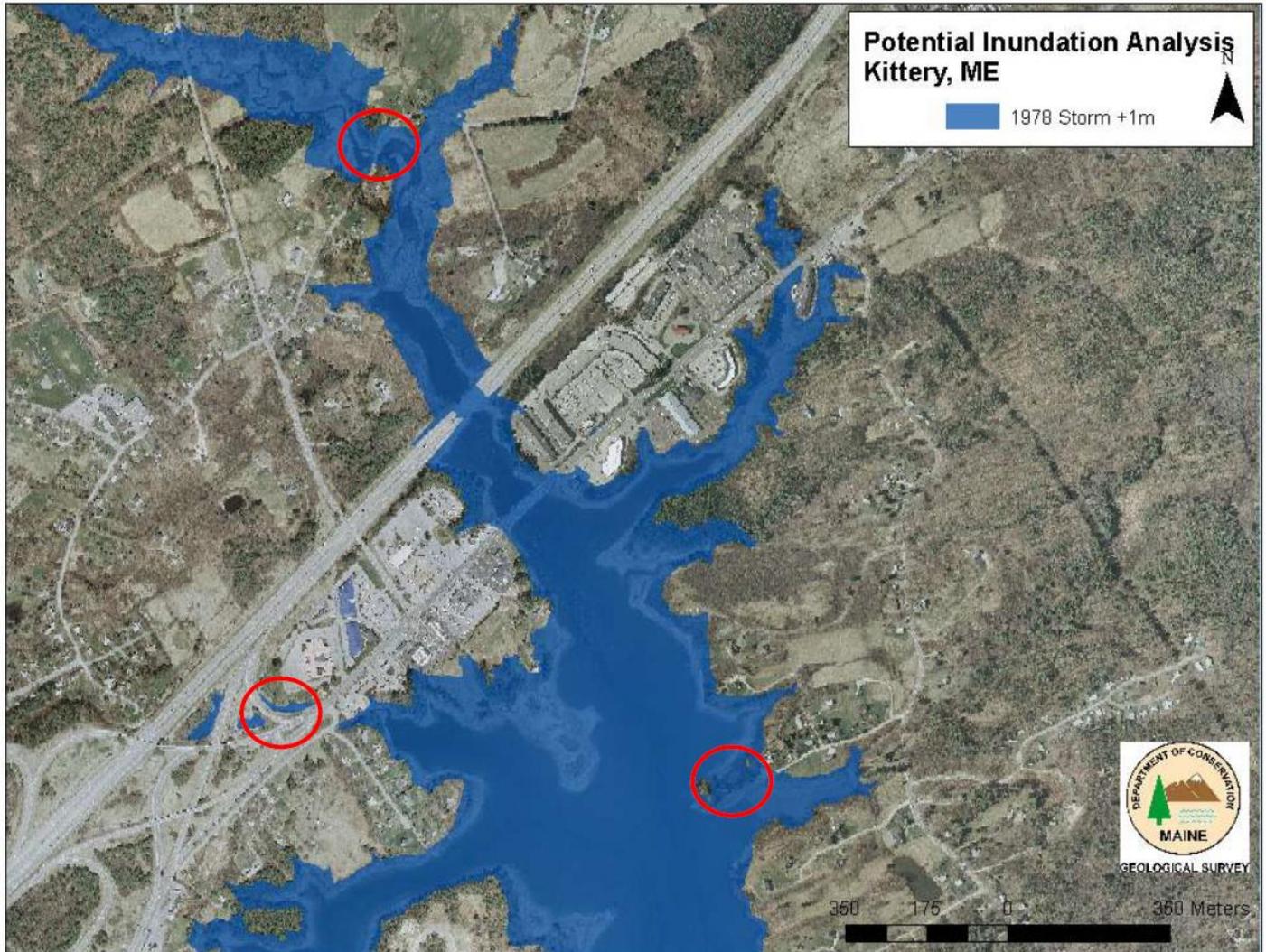
Source: Preparing Kittery for Sea Level Rise and Coastal Hazard Resiliency (Slovinsky, 2011B)



Kittery also likely faces vulnerability to its roads and commercial retail establishments. Under the 1 meter SLR + “100 Year” storm scenario, significant inundation occurs in the neighboring commercial areas along Spruce Creek. Under this scenario, both Interstate 95 and U.S. Route 1 appear to experience some inundation in this area.

Figure 51: Kittery Retail Areas Inundation Analysis

Source: Preparing Kittery for Sea Level Rise and Coastal Hazard Resiliency (Slovinsky, 2011B)



## V. Conclusion: Regionally Applicable Adaptation Actions

This municipality-by-municipality assessment has revealed a number of regionally significant vulnerabilities to coastal flooding in Southern Maine. The impacts are “regional” in two somewhat different senses. In one sense, a number of local impacts in each community are extremely similar to impacts in neighboring municipalities. In these situations, the “regional” impact becomes apparent as communities individually consider pursuing adaptation actions likely to also be considered by other municipalities in the region. In another sense, impacts are regional in that facilities relied on by other communities in the region may be affected by inundation.

In order to best address regional impacts that are similar across many municipalities, adaptation actions should be coordinated regionally. For example, changes to restrict coastal development regulations in one community will have an effect on the demand for coastal development in less-well-regulated communities. For that reason, it behooves communities to coordinate changes to coastal development regulations – such as changes to shoreland zoning, comprehensive plans, etc.

Addressing the other type of regional impact is considerably more challenging. Vulnerable facilities or infrastructure in one community which primarily serve a region are often the sole responsibility of the community in which they are located. For example, road inundation may reduce connectivity to critical facilities from neighboring communities in coastal Maine during storm events. Another type of regional impact is pollution released from inundation events, which may have a regional impact beyond the source community.

It should be stressed that this work is not an exhaustive assessment of coastal flood vulnerabilities for communities in southern Maine. It is, rather, primarily intended to be a conversation starter. This report is intended to serve to help begin the public process for sea level rise adaptation for those communities who have not already had a public process to address the issue. For those communities which have already had such a public process, such as that conducted as part of CHRT or by Bowdoin College, it should help to continue to public engagement process.

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