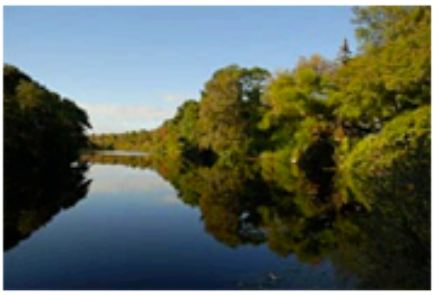
Climate Change Adaptation Chapter: Marshfield, Massachusetts

University of Massachusetts, Amherst
Regional Planning Department



Sally Miller
Toni Marie Pignatelli
Jonathan Cooper
Rory Fitzgerald
Joshua Chase
Filipe Antunes Lima

Dr. Elisabeth Hamin

Regional Planning Studio 2012
University of Massachusetts, Amherst

109 Hills North
111 Thatcher Road
Amherst, MA 01003

Climate Change Adaptation Chapter: *Marshfield, Massachusetts*

Report
December 2012

CREDITS:

Cover photo: Pat Traynor, Marshfield.net

Climate Change Adaptation Chapter for the Marshfield Master Plan

Executive Summary

Climate change, understood as a statistically significant variation in the mean state of the climate or its variability, is the greatest environmental challenge of this generation (Intergovernmental Panel on Climate Change, 2001). Marshfield is already being affected by changes in the climate that will have a profound effect on the town's economy, public health, coastal resources, natural features, water systems, and public and private infrastructure. Adaptation strategies have been widely recognized as playing an important role in improving a community's ability to respond to climate stressors by resisting damage and recovering quickly. Decisions about adaptation strategies made by public and private sectors can protect the financial stability of a Town by limiting the costs associated with recurrent property damage. The best adaptation strategies address current weather risks like storms and flooding, while also preparing the community to better respond to the climate of the future.

Marshfield has opted to plan proactively for the community's resilience to coastal hazards. In recent years the Town has experienced significant flooding and coastal erosion, and recognized this is likely to intensify with climate change. Marshfield is in the process of updating its Master Plan, and this provided an opportunity to mainstream considerations of climate into a range of policies for the Town. In the fall of 2012, the Town contracted with the University of Massachusetts Department of Landscape Architecture and Regional Planning to draft a master plan chapter focusing on climate change adaptation for inclusion in Marshfield's 2013 master plan. The Town's 2013 master plan, being prepared by the planning firm Vanasse Hangen Brustlin, Inc (VHB), is expected to be finalized in 2014.

Based on review of five climate projections for the region, we developed a projection of likely climate changes for Marshfield. By the year 2100, Marshfield can expect sea level rise of approximately two feet, 16 - 30 more summer days with heat over 90 degrees, and increased precipitation in the winters. Along with this will come more severe and frequent flood events.

Climate change does not impact everyone equally. To assess how different groups and areas of Town will be affected by those climate projections, we evaluated the existing social and biophysical conditions in the town of Marshfield. Residents with disabilities, lower income, aging housing stock, and the very young and the very old are likely to be the most impacted by climate change. Development patterns, in particular density, have a strong impact on the biophysical vulnerability, as does poorly draining soils. Ultimately, the assessment found that the areas of both greatest social and biophysical risk include the area behind Humarock near Ferry Hill, Ocean Bluff, and Brant Rock, where there are larger concentrations of socially vulnerable populations, higher population densities, and soils with lower storage capacity.

The following sectors were also inventoried and analyzed for vulnerabilities and impacts from climate stressors: natural resources, coastal infrastructure, stormwater, water supply, wastewater, soft municipal infrastructure, transportation, and private property. Based on review of local conditions, case studies of other communities who have undertaken adaptation planning, and the best practice literature, we recommend that Marshfield begin by considering living shoreline treatments, which act as a natural barrier to alleviate damages caused by storm surge and sea

level rise. Living shoreline treatments utilize the natural growth patterns of vegetation, rocky outcroppings, and dunes that were once present in coastal settings. Segments of Marshfield's coast without seawall protection are primary candidates for this program. Another strategy that Marshfield should consider is resurfacing of the paved areas, especially in the Brant Rock esplanade section and the Standish Street parking lot. By replacing impervious pavements with pervious options such as permeable pavers, stormwater and flood water will be absorbed into the ground quicker and more directly. This treatment will ease excess flooding and erosion. The town should also incentivize floodplain elevation by administering a building elevation grant program. This is a program in which homeowners or business owners elevate their structures to the heights recommended for Marshfield, then are reimbursed for the cost, or at least a substantial portion of the cost. This would reduce or eliminate the town's dependency on the deteriorating seawall.

The above three strategies have been identified as top priority changes that Marshfield can enact to improve their resilience to coming climate changes. Additional strategies have also been organized by dominant themes and included in the matrix located in section four. The simplest approach to adaptation is to incorporate these climate considerations broadly into the Town's planning and policy, so that the changing climate becomes a normal consideration in all of Marshfield's decision-making processes; however, some strategies may require stand-alone implementation. During the process of selecting adaptation strategies, it is important that Marshfield implements measures that suit the overall needs of the town, and takes its most vulnerable populations into account.

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I. Context

Introduction

This chapter will focus on climate change adaptation strategies for the town of Marshfield. Adaptation strategies seek to increase resilience by preparing communities to resist damage from climate stressors and recover quickly from the impacts of hazardous climate events. To inform strategies designed to mitigate damage, and, in the case of a crisis, target relief efforts more effectively, the social and biophysical vulnerability of specific groups and areas within Marshfield have been identified. By providing specific recommendations for increasing resilience, this chapter will help the town of Marshfield prepare to respond to climate stressors in a manner that is cost effective and time sensitive.

State and Regional Context

The Global Warming Solutions Act (GWSA), passed by the Massachusetts Legislature in 2008, directed the Secretary of Energy and Environmental Affairs (EEA) to convene an advisory committee to develop a report, analyzing strategies for adapting to the predicted changes in climate. The *Massachusetts Climate Change Adaptation Report* is the first official overview of climate change as it affects Massachusetts, climate change impacts, and vulnerabilities of multiple sectors ranging from natural resources, infrastructure, public health, to the economy. It also provides suggestions of potential strategies that could better prepare communities for this changing world.

At the regional level, the *South Shore Coastal Hazards Adaptation Study for the Towns of Scituate, Marshfield and Duxbury* was published by the Metropolitan Area Planning Council (MAPC) with support from the Massachusetts Office of Coastal Zone Management (CZM). The study assessed general changes in coastal hazard impacts that could occur due to climate change, primarily the impacts from sea level rise and changes in storm intensity and frequency. The report explored current and potential future coastal vulnerabilities, identified a range of possible adaptation options and provided information about resources that could support local actions and strategies.

Historical Context

Severe coastal storms have always been of concern in Plymouth County and the town of Marshfield. The "Blizzard of '78" caused heavy damage along the entire Massachusetts coast. Winds at nearby First Cliff in Scituate reached 112 miles per hour, and a tidal surge in Scituate Harbor reached 17.5 feet above normal (Fahey, 2008). Several other big storms have occurred in more recent history. The Halloween Storm of 1991, often referred to as "The Perfect Storm," damaged or destroyed over 100 homes in Marshfield alone (NCDC, 1991). More recently, the Blizzard of 2005 dropped over 24 inches of snow on the town (Marshfield Mariner, 2005).

Flooding is one of the most costly impacts of these storms. Between 1978 and 2001, nearly $80 million has been paid out in flood insurance claims in Marshfield and the neighboring towns of Scituate and Duxbury. These three towns comprise 23% of all FEMA payouts in Massachusetts (*Bureau and Statistical Agent, National Flood Insurance Program)*.

2. Climate Change

Climate change is understood as a "statistically significant variation in the mean state of the climate or its mean variability, persisting for an extended period" (p. 711). This is the definition used by the Intergovernmental Panel on Climate Change (IPCC), the leading body in climate change research (IPCC, 2001). Massachusetts has already seen changes in the climate: since 1970, air temperature has risen by almost 2°F, sea surface temperature has risen by almost 2.5°F, there are now more days above 90°F than there used to be, there is less snowpack each winter, and snow melt and spring peak flows are occurring earlier. (Climate Change Adaptation Advisory Committee, 2011; Frumhoff et al., 2006, 2007; Hayhoe et al., 2006). The warmer the air and oceans get, the warmer they will continue to get. Carbon builds up over time in the atmosphere, and climate outcomes lag behind. As a result, regardless of what new emissions may occur globally, there is broad agreement in the climate science community that the decades in the near future will see climatic change. Projections diverge as time progresses towards the end of the century, as this time period will be influenced by the policy choices made in the next decades.

In terms of ways to deal with climate change, one can address the issue through mitigation or adaptation. Mitigation is the effort to reduce greenhouse gas emissions in the hopes that it will curtail climate change. The IPCC has generated a range of climate projections based on various levels of emissions and actions taken to reduce them; research suggests that a reduction in atmospheric greenhouse gases would mitigate the impact on the climate, hence the term "mitigation". Examples of mitigation actions include adopting policies that restrict permissible emissions, or the development of technology to capture emissions from the atmosphere, rendering them inert.

Adaptation, on the other hand, refers to actions taken to improve the resiliency of a place in the face of climate change threats. The IPCC (2007b) defines adaptation as "adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities" (p. 869). Examples of adaptation measures are raising a section of a road in a vulnerable location, or restricting rebuilding in a frequently flooded area.

Methods

In order to develop a climate projection for Marshfield, the findings of peer-reviewed studies and adaptation reports were evaluated and, giving more weight to sources dealing specifically with the local region, predictions for changes in sea level, storm surge, temperature, and precipitation were thoughtfully selected. For municipal planning purposes, these four climate stressors were decided to be the most pressing challenges for Marshfield. The sources that are most heavily referenced are the *Massachusetts Climate Change Adaptation Report* by the Executive Office of Energy and Environmental Affairs and the Climate Change Adaptation Advisory Committee [CCAAC] (2011); the *Climate Risk Information* document by the New York City Panel on Climate Change (2009); and Kirshen et al. report, *Climate Change and Coastal Flooding in Metro Boston: Impacts and Adaptation Strategies* (2008a). The Metropolitan Area Planning Council's *South Shore Coastal Hazards Adaptation Study* (2011) also proved a particularly useful guiding document. A full list of sources may be found in Appendix C. Each source's methods were examined and supporting research studies were consulted to ensure that all

projections represented in this chapter are based on similar assumptions, and follow similar expectations for rates of change. The climate changes discussed in this chapter are based on moderate projections within the range of established climate science; also worth noting is that the chapter's specific projections align closely with other local guiding documents such as those mentioned above.

Sea Level Rise

When addressing sea level rise in coastal Massachusetts, in most cases it is appropriate to refer to relative sea level, which is the interaction of eustatic sea level rise and land subsidence or other processes that affect elevation. Eustatic sea level rise is the result of thermal expansion of oceans as they warm and the melting of continental ice (ice sheets located on land as opposed to sea ice which floats) (Kirshen et al. 2008a, citing Pugh 2004). Land subsidence is lowering in the elevation of a landform because of post-glacial adjustment or tectonic movement; coastal Massachusetts is estimated to have experienced 1.5 mm/year of subsidence over the last 100 years. The combination of eustatic sea level rise and land subsidence has yielded a relative sea level rise of approximately 11.8 inches over the past century (Kirshen et al. 2008, citing Nucci Vine Associates, Inc. 1992).

Projection

Relative sea level is projected to rise approximately 5 inches by the 2020s over the baseline level, which was averaged over 1971-2000 (NPCC, 2009). Marshfield can anticipate a rise in sea level of approximately 12 inches by mid-century (CCAAC, 2011), and 24 inches by late-century (MAPC, 2011). The projection for Marshfield in Figure 2.1 does not take into account continental ice melt, which would significantly and rapidly elevate sea levels.

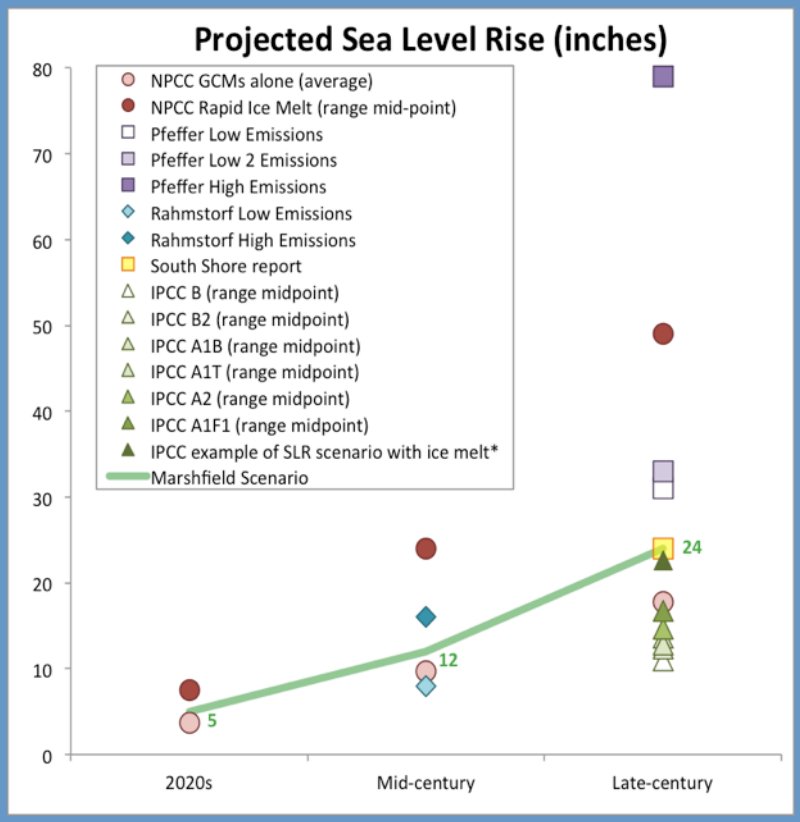


Figure 2.1: Projected Sea Level Rise

Data sources for Marshfield Scenario: NPCC, 2009; Climate Change Adaptation Advisory Committee, 2011; MAPC, 2011. Supporting sources listed in Appendix C. A full page image of this figure is located in Appendix B.

Implications

Sea level rise is one of the most threatening climate hazards for Marshfield. As the water creeps higher, more property will be inundated, the stability of infrastructure will be compromised, the

seawall and other water management structures will experience more rapid wear and tear, and the beach will continue to be denourished—in other words, sand will not be naturally replaced on the beaches. With the low elevation and slope of the beach along most of Marshfield's coast, it is very possible that Marshfield will lose its beaches to the rising tide. Sea level rise also compounds the impacts of storm surge. Marshfield's low-lying nature and coastal development pattern mean that sea level rise and flooding from storms are bound to have a significant impact on property, infrastructure, and the economy. The biophysical vulnerabilities section of this chapter expands on this claim.

Storm Surge

Storm surge refers to the water pushed onto land by storm winds (National Hurricane Center, 2012). As the sea level rises, storm surge will increase due to the larger quantity of water available to be pushed onshore by a storm. The potential for storm surge impact will also increase because of the diminishing relative height of the barrier the stormwater must breach in order to cause flooding. Current average storm surges, as measured nearly a decade ago by the Army Corps of Engineers, are already high enough to cause significant flooding and damage in Marshfield. In a 10-year storm, or a storm whose strength, statistically, has a 10 year recurrence interval, the average storm surge is 9.2 feet; in a 100-year storm, the average storm surge is 10.4 feet; in a 500-year storm, the average storm surge is 11.2 feet (Weiner, 1993).

Projection

Kirshen (2008a) used the Army Corps of Engineers' measurements to project mid-century and late-century storm surge. Projections for the 2020s time range are estimated to be the midpoints between baseline storm surges (considered to be accurate at year 2000) and the 2050 storm surge heights. Figure 2.2 shows that Marshfield can expect to see a 9.7 foot surge from a 10-year storm, a 10.9 foot surge from a 100-year storm, and a 11.7 foot surge from a 500-year storm by the 2020s. Around year 2050, 10.2 feet are expected from a moderate storm; 11.4 feet are expected from a severe storm; and 12.2 feet are expected from an extreme storm. Finally, in approximately 2100, Marshfield is projected to experience 12.2 feet from a 10-year storm, 13.4 feet from a 100-year storm, and 14.2 feet of storm surge from a 500-year storm.

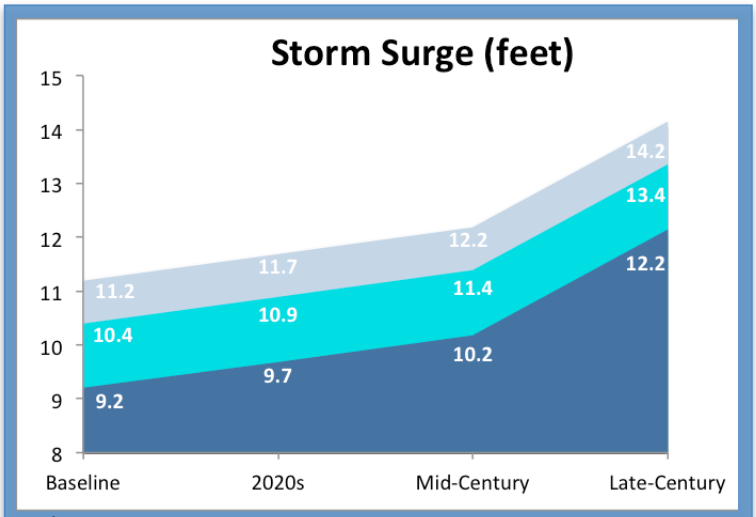


Figure 2.2: Projected Storm Surge
Data sources: Kirshen, 2008a; NPCC, 2009.

The height of storm surge is not the only concern associated with storm-related flooding; the frequency of extreme storm events is increasing. Table 2.1 shows the expected storm frequency based on sea level rise alone (NPCC, 2009) and a 100-year storm frequency projection based on a study of recent sea level anomalies (Kirshen, 2008b). The different methods produce a large

	2020s	Mid-Century	Late-Century
"10-Year Storm"	8 - 10 years	3 - 6 years	1 - 3 years
"100-Year Storm" (NPCC)	65 - 85 years	35 - 55 years	15 - 35 years
"100-Year Storm" (Kirshen)	-	< 2 - 15 years	< 2 - 5 years
"500-Year Storm"	380 - 450 years	250 - 330 years	120 - 250 years

Table 2.1: Projected Storm Surge Frequency
Data sources: NPCC, 2009; Kirshen, 2008b..

range, but the implication is clear. For a town that currently experiences floods that breach its seawalls once or twice a year, these projections are no small consideration. This chapter's policy recommendations will take both the expected height and frequency of storm surge into consideration.

Implications

Storm surge is the most damaging of the climate stressors because water inundates the land very quickly in great quantity, which makes effective drainage very difficult. It also washes in with enough strength to damage buildings, natural features, and infrastructure. It is the hazard with the potential to cost the most in damages, and therefore represents an opportunity to put in place adaptation strategies that will improve the long-term resilience of the town.

Precipitation

Precipitation changes since approximately 1900 have been characterized by a gradual rise in overall precipitation; in fact, "the most recent 30 year normal precipitation for Massachusetts is the highest it has been since records started to be" (CCAAC, 2011, p. 17). The increase had been distributed mostly from spring through fall, but another seasonal pattern has been observed in more recent decades. Winter precipitation has been increasing by up to 0.15 inches per decade, and the most significant trend has been the shift from snow to rain (Frumhoff et al., 2006). New England has already experienced a change in the quantity and type of snow that falls in winter. The number of days when the ground is covered with at least a dusting of snow has decreased, and the snow itself can be described as wetter and slushier. Research shows that there has been little change in light precipitation events but significant change in heavy precipitation events. More precipitation falls in a shorter period of time, making flash flooding a bigger problem than in the past (Kunkel et al., 2008).

Projection

Changes in climate patterns for the Northeast U.S. will bring more precipitation on average per year, as well as more dramatic variation in precipitation. Annual precipitation projections for the town of Marshfield are shown in Figure 2.3. Average annual precipitation is expected to rise by as much as 5% by the 2020s (NPCC, 2009), 5-8% by mid-century, and 7-14% by late century (Climate Change Adaptation Advisory Committee, 2011).

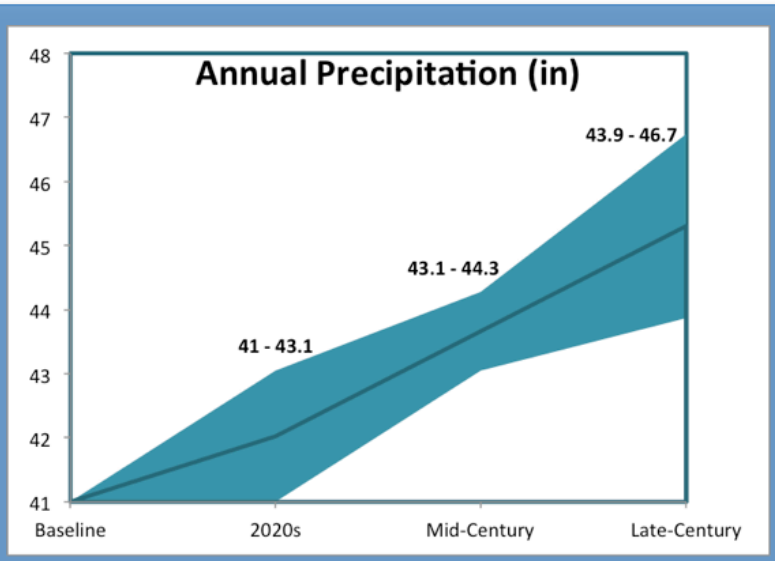
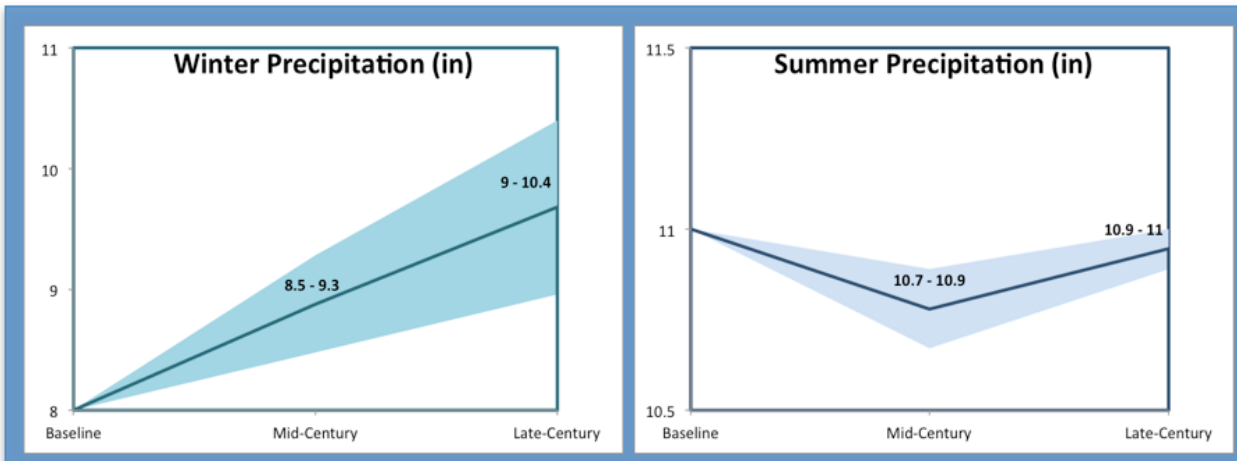


Figure 2.3: Projected Annual Precipitation
Data sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.

Seasonal differences will become more pronounced, with more precipitation falling in winter, more winter rain and less snow, and no change or even a decrease to summer precipitation. Figures 2.4 and 2.5 show seasonal precipitation projections for the town of Marshfield. By mid-century, Marshfield is projected to see a 6-16% increase in winter precipitation, and a -1 to -3% change in summer. By the end of the century, projections predict a winter increase of 12-30%, and a summer change of -1-0% (CCAAC, 2011). For the foreseeable future, precipitation is projected to continue to become more intense, and these heavy precipitation events are expected to be more frequent (Frumhoff et al., 2007).



Figures 2.4 and 2.5: Projected Winter and Summer Precipitation
Data sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.

Implications

More precipitation will increase flooding, and an increase in short downpours will make flash

flooding more common than it already is. This will be a larger problem in some parts of Marshfield than others, as is detailed by the soil drainage analysis in the biophysical vulnerability section of this chapter. Massachusetts is located in a region of the Northeast that is likely to see the biggest decrease in snowfall; this has serious implications for the winter recreation and tourism industry, and also will change the snowmelt and stream flow patterns that have reliably contributed to water resources in the past (Frumhoff et al., 2007).

Temperature

Temperature is already on the rise in the Northeast U.S., which is unsurprising since it is a precursor to other climate changes that are beginning to emerge. Reports show that this region has seen an increase of nearly 0.5°F each of the past several decades and, as with changing precipitation levels, there are seasonal differences. Average winter temperature is rising faster than that of the summer (Frumhoff et al., 2006, 2007; Hayhoe et al., 2006).

Projection

Estimates state that by the 2020s, average annual temperature will rise by 1.5-3°F (NPCC, 2009) from a baseline average temperature of 46°F. By mid-century, average annual temperature is projected to rise 3.8-5.2°F, and by late-century the projected change is 5.2-9.5°F (CCAAC, 2011). These estimates are displayed in Figure 2.6.

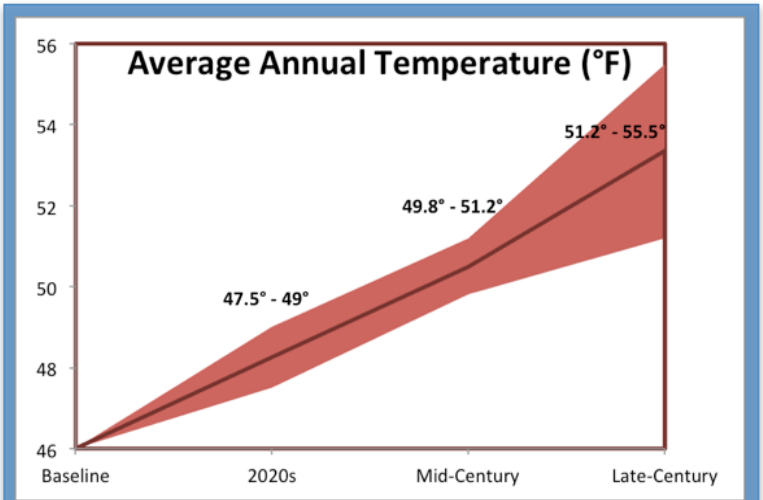


Figure 2.6: Average Annual Temperature
Sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.

As shown in Figure 2.7, days above 90°F are expected to rise from an average of 12-14 per year to 23-29 per year by the 2020s, 29-45 per year by mid-century, and 30-60 by around year 2100 (NPCC, 2009). The extensive range in late-century projections is the result of divergent emissions scenarios. The lower bound, indicating 30 days per year, presumes that significant climate change mitigation policies will have taken effect by mid-century; the upper bound of 60

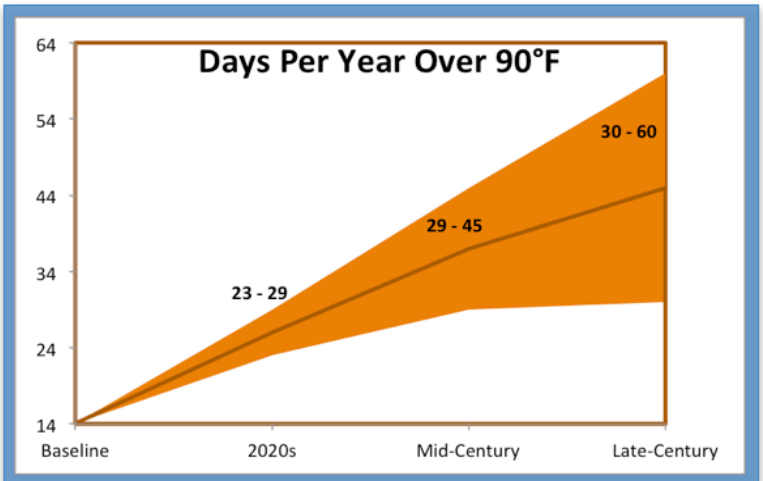


Figure 2.7: Days Over 90°F
Sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.

days per year assumes that emissions will rise unchecked.

Implications

Rising temperature, in addition to impacting other shifts in climate patterns, has implications for communities as well. More hot days and heat waves put vulnerable populations such as the elderly, small children, and individuals with breathing difficulty in more danger because of a decline in air quality. Agriculture would be impacted as well: the growing season would start earlier and end later, and could change the types of produce that thrive in the region.

3. Vulnerability

Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed; its sensitivity; and adaptive capacity (IPCC, 2001). In assessing vulnerability a predictive judgment is made on how different groups of people and places will be affected by the impacts of climate change. In this section, we explore how the sum of Marshfield's existing social and biophysical conditions render the town vulnerable to climate stressors. This information can inform planning strategies designed to mitigate damage and, in the case of a crisis, target relief efforts more effectively.

Methods

A variety of frameworks, methodologies, and tools exist for identifying, quantifying, and prioritizing vulnerabilities. Currently, there exists no single 'correct' or 'best' conceptualization of vulnerability that would fit all assessment contexts (Fussel, 2007). The assessment strategy developed for this report is informed primarily by the "Hazards of Place Model" shown in Figure 3.1 (Cutter, 1996). This model presents 'place vulnerability' as the intersection and interaction between social vulnerability and biophysical vulnerability. Social vulnerability is shaped by elements in the 'social fabric of society,' such as socioeconomic indicators, cognition of risk, and response ability. Biophysical vulnerability, however, is shaped by a site's geographic context, which includes its elevation, topography, or proximity to a given hazard (Cutter, 1996).

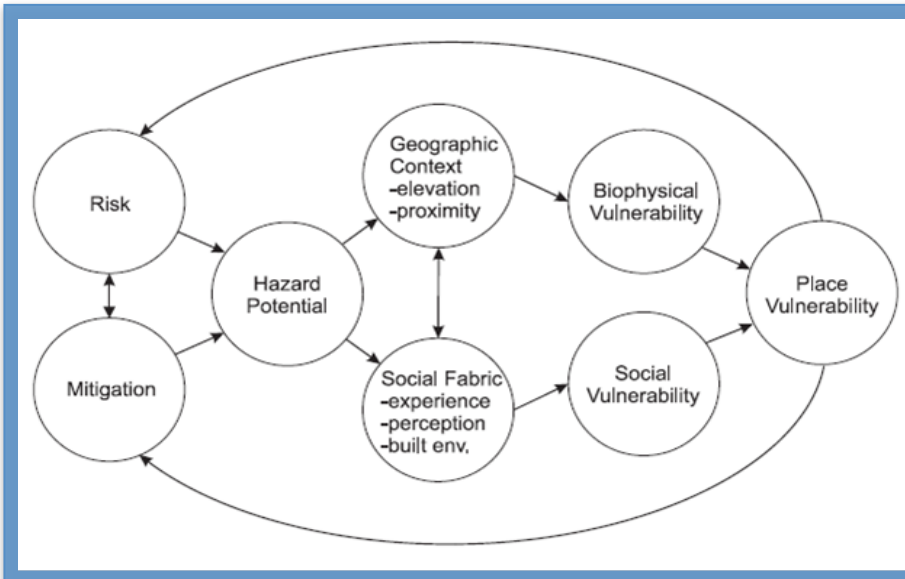


Figure 3.1: Hazards of Place Model
Source: Cutter, 1996.

To assess the social vulnerability of the town of Marshfield, census data for commonly used indicators of vulnerability were compiled. Commonly used indicators of vulnerability include age, sex, economic status, and educational attainment. Since vulnerability is a relative measure, data for the town of Marshfield were compared to regional, state, and national data.

To assess the biophysical vulnerability of the town of Marshfield, an inventory of existing geographic conditions was conducted. This inventory included analysis of population density, development patterns, critical infrastructure sites, flood zones, and soil storage capacity. Applying climate change projections to the town of Marshfield, maps showing the impact of current and future sea level rise, storm surge, and precipitation were developed. Most maps were created using data provided by the Massachusetts Office of Geographic Information (MassGIS). Inundation maps were created using LiDAR data, which provides very precise and high-resolution images. This data was provided by MassGIS and accessed through the University of Massachusetts. LiDAR data was transformed and manipulated in the ArcMAP GIS. Sea level and storm surge predictions were compared to the elevation data to identify areas of the town under threat from inundation. Projected storm surge heights include projected increases in sea level.

Social Vulnerability Assessment

Social vulnerability, for the purposes of this report, is understood as the product of social inequalities that influence or shape the susceptibility of various groups to harm and that also governs their ability to respond (Cutter et al., 2003). Identification of vulnerable populations is important so that risks to these community members and the community at large can be mitigated with the strategic implementation of adaptation strategies. This section of the report highlights the populations most vulnerable to climate change in the town of Marshfield.

Indicators

Economic status is perhaps the most commonly used indicator of social vulnerability. In addition to a stand-alone indicator, economic status also affects other indicators such as literacy, educational attainment, and health status. Since the town of Marshfield is a moderate to high-income community, identifying vulnerable populations is a challenge. According to the Hazard and Vulnerability Research Institute, Plymouth County, where Marshfield is located, ranks among the 20 percent least socially vulnerable counties in Massachusetts and the nation (2005-09). Despite this report, census tract level data shows that indicators of poverty, age, disability, and housing stock are of significance for the Town.

Poverty

Poverty levels are an important indicator of social vulnerability because people living below the poverty threshold often have limited access to goods and services that could protect them from the impacts of climate stressors and help them recover following a climate related event. For instance, evacuating a potentially dangerous area is more challenging for households without an automobile and securing flood insurance may be cost prohibitive. Figure 3.2 shows that although Marshfield has a low poverty rate of approximately 4 percent, the census tract including Brant Rock belongs has a poverty rate of 7.1 percent, well above the town's average (US Census Bureau, 2010).

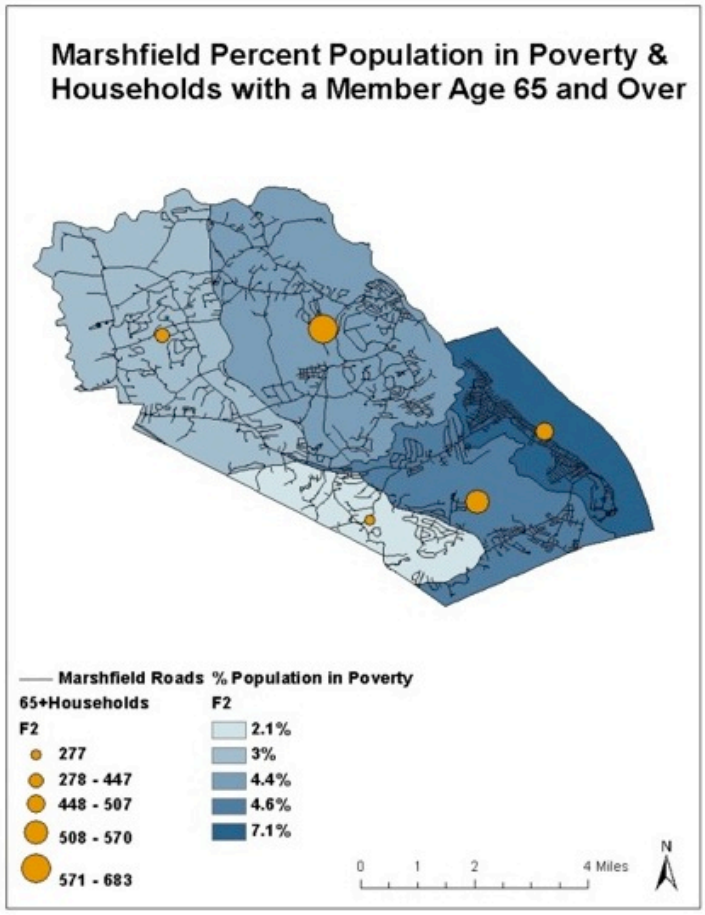


Figure 3.2: Poverty and Age

Source: United States Census Bureau, 2010.

Age

Vulnerability is greatest for those at the extremes of the age spectrum primarily because of mobility constraints. For example, the very young and old are more likely to face obstacles to evacuation in the event of an emergency. As Figure 2.2 shows, the proportion of residents in Marshfield who are over the age of sixty-five is highest along the coast, where the risk of climate related hazards is greatest.

Disability

Individuals with disabilities tend to be more vulnerable because their needs are often overlooked or ignored in a disaster situation. As Figure 3.3 shows, the portions of Marshfield's adult population affected by cognitive, self-care, and independent living difficulties exceeds both state and national levels. Of the population between the ages of 18 to 64, 4.5% have a cognitive difficulty, over 2% of the population experiences a self-care difficulty, and nearly 4% have an independent living difficulty.

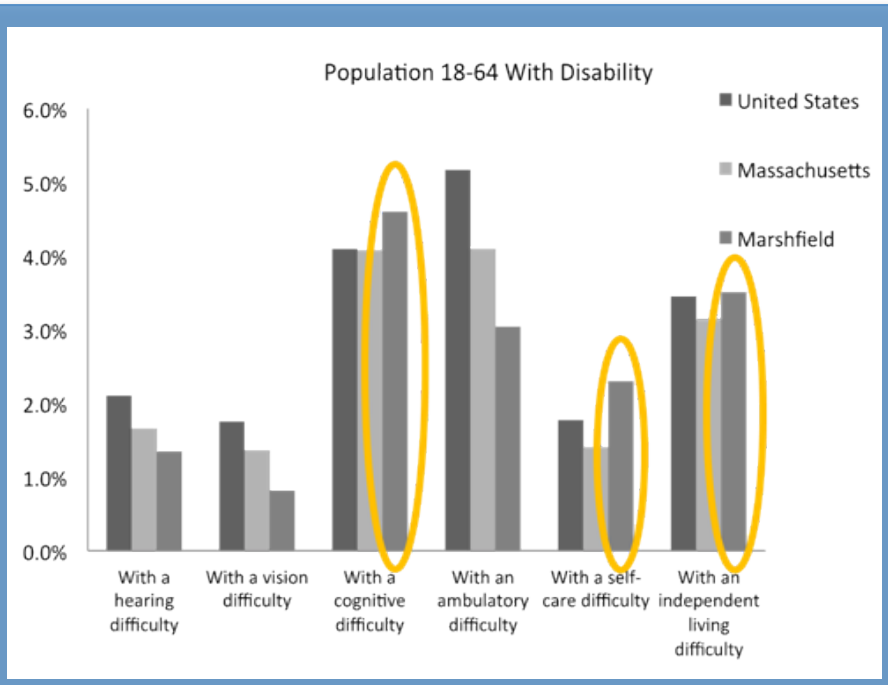


Figure 3.3: Disabilities
Source: United States Census Bureau, 2010.

Housing Stock

Areas of higher density and greater seasonal use tend to be more vulnerable because evacuation is more challenging and seasonal residents are often unable to secure their homes in advance of a climate related crisis. As Figure 3.4 shows, housing density and seasonal units are highest in the northeast, along the South River and into Ferry Hill.

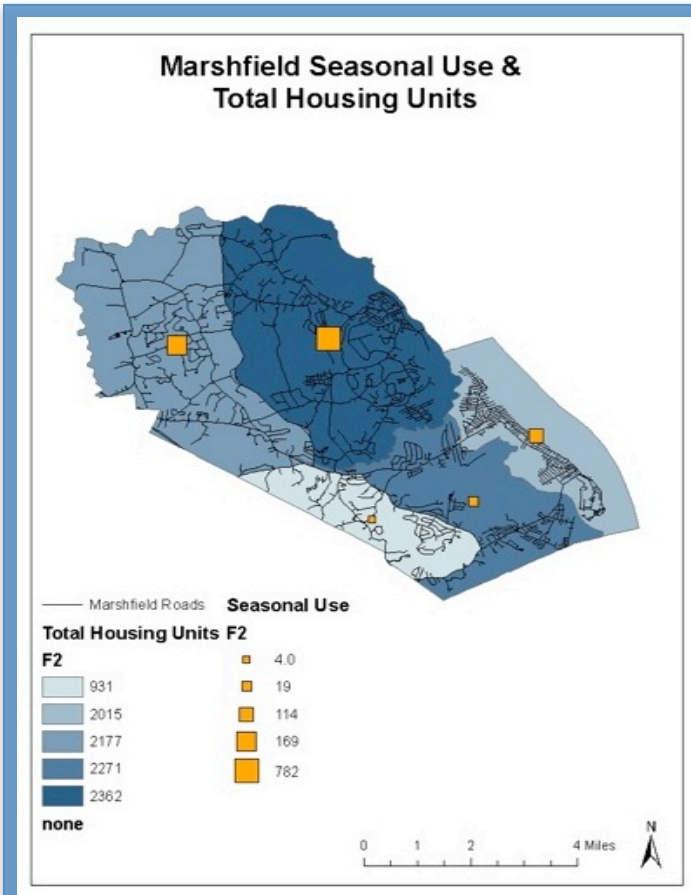


Figure 3.4: Housing Stock
Source: United States Census Bureau, 2010.

Biophysical Vulnerability Assessment

Biophysical vulnerability, for the purposes of this report, is understood as the product of the geographic context, including site location and proximity to the hazard (Cutter et al., 2003). Identification of vulnerable locations and infrastructure is necessary so adaptation strategies can be tailored to reduce the impacts of climate stressors on particular areas and resources. This section of the

report includes an assessment of existing biophysical conditions in the town of Marshfield and highlights the locations most vulnerable to the impacts associated with sea level rise, storm surge, and precipitation.

Existing Biophysical Conditions

Marshfield's biophysical conditions are greatly influenced by the town's coastal location. Extensive saltwater wetlands exist throughout Marshfield, and are fed by the town's three rivers: the North River, the South River, which meet at New Inlet, and the Green Harbor River. The salt marshes are fed by the tides, which reach far inland and frame the town's hilly upland terrain to the west and north. The South River flows seaward behind Humarock, a coastal barrier beach in Scituate that was left behind by the last ice age. The barrier affords a measure of protection from storms and winds to the inland residents behind it. South of Humarock, the coastline faces the open ocean. A line from Brant Rock to Race Point in Provincetown marks the boundary of Massachusetts Bay and Cape Cod Bay. This delineation may help explain the distinction between the coastal processes affecting beaches to the north and south of Brant Rock (Applied Coastal Research, 2005). The residential and commercial development along the coast exposes a large number of the town's properties to flooding and storm damage, especially in the flood-prone areas of Ocean Bluff, Brant Rock, and Ferry Hill.

Indicators of Biophysical Vulnerabilities

Elements of Marshfield's built and natural environment render particular areas vulnerable to sea level rise, increased storm surge, and precipitation. This section of the report, created with data from the Massachusetts Office of Geographic Information, highlights the areas that will be most affected by the aforementioned climate stressors.

Sea Level Rise

The impacts of sea level rise in Marshfield will be most pronounced along the shore and near the wetlands, as shown in Figure 3.5. The Green Harbor River marsh will become larger and, during storms, more likely to flood the area around the Dyke Road culvert. Towards the end of the century, the Green Harbor River will encroach onto Ocean Bluff properties along Bass Creek and West Brook Meadows, as shown in Figure 3.6. The southern end of Ridge Road will be similarly affected by marsh expansion along the South River. As shown in Figure 3.7, Trouants and Macombers Islands may regularly become inaccessible due to frequent inundation from high tides. Permanent inundation is projected along the beach in Brant Rock, affecting the area's many residents and visitors.

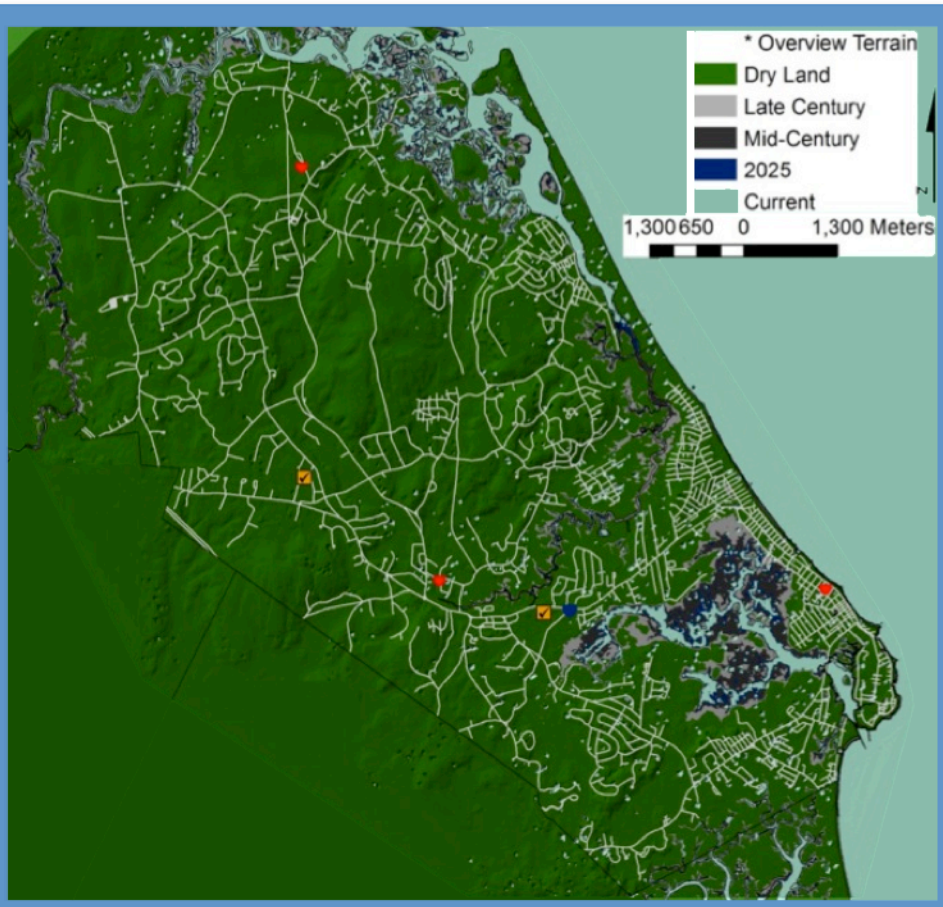


Figure 3.5: A map showing the projected sea level rise for Marshfield. The fire and police stations, as well as the libraries (yellow checks) are shown for reference.

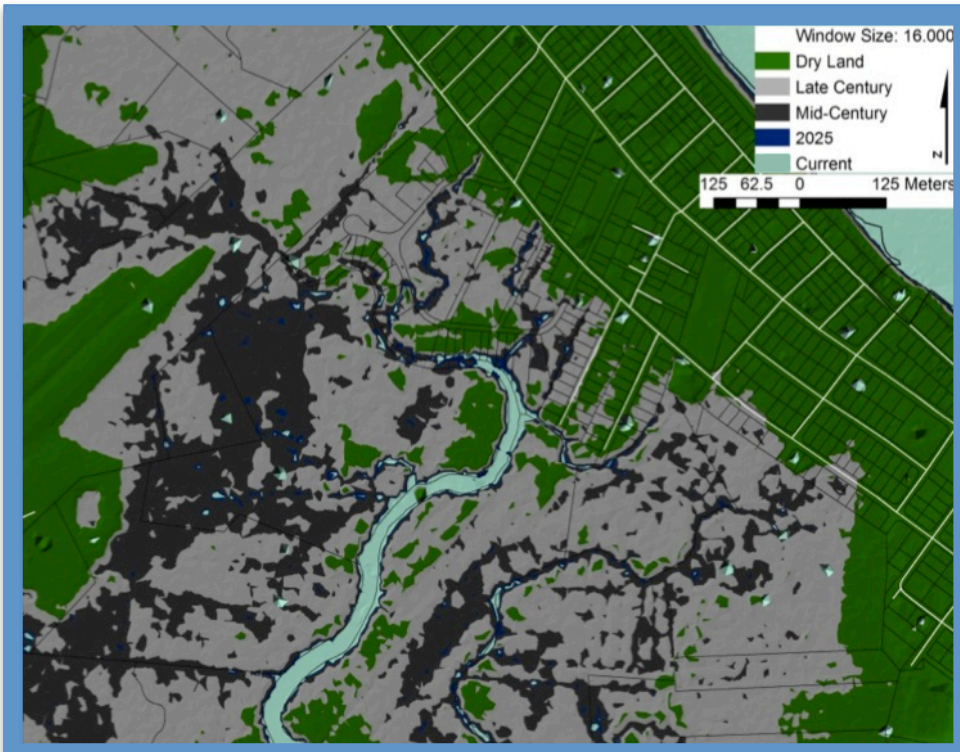


Figure 3.6: Projected inundation of the inland side of Ocean Bluff due to sea level rise.

Figure 3.7: Projected inundation due to sea level rise in and around English Salt Marsh.

Storm Surge

The frequency and intensity of storms are projected to increase due to climate change. The resulting storm surge poses a threat to Marshfield's infrastructure. Currently, the town already experiences frequent storm surge related flooding in the Brant Rock and Ocean Bluff neighborhoods. The following maps show the possible storm surge inundation from what is currently referred to as a "100-year storm," but this concept is not static. First, the term "100-year storm" is only accurate for the time period in which it was determined. As Table 2.1 indicates, storms of the magnitude currently described as "100-year storms" will become more frequent in the coming years, as will the storms currently classified as "10-year storms" and "500-year storms." Secondly, the storm surge maps are based solely on elevation, and do not take the unique characteristics of an exact geographic location into account. For example, Dyke Road protects the Green River Marsh to some degree, as does the entrance to Green Harbor. The storm surge inundation maps do not take barriers such as these into effect.

In these maps, the present-day sea level is shown in light blue and represented in the legend as "Normal." The extent of present-day storm surge is shown in dark blue, and represented in the legend as "Current." The storm surge level predicted for 2025 is shown in dark grey, while the storm surge for mid and late century are shown in light grey and white, respectively. Where appropriate, landmarks have been included as reference points: red and blue shields represent fire and police stations, respectively, and a black check on a yellow background denotes a library. Roads are shown in white, and finer-scale maps include parcel outlines in black. Figure 3.8 shows the entire town, while Figures 3.9 through 3.12 show the same effect in some selected villages of Marshfield.

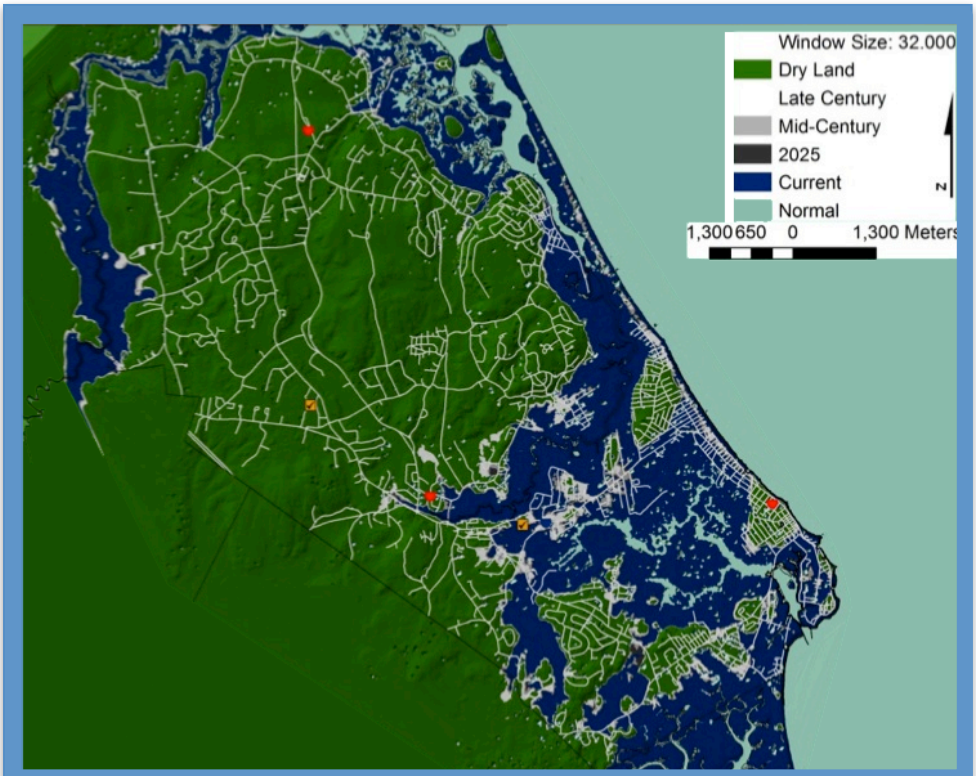


Figure 3.8: Possible inundation from a "100 year" storm surge event.
Data source: MassGIS.

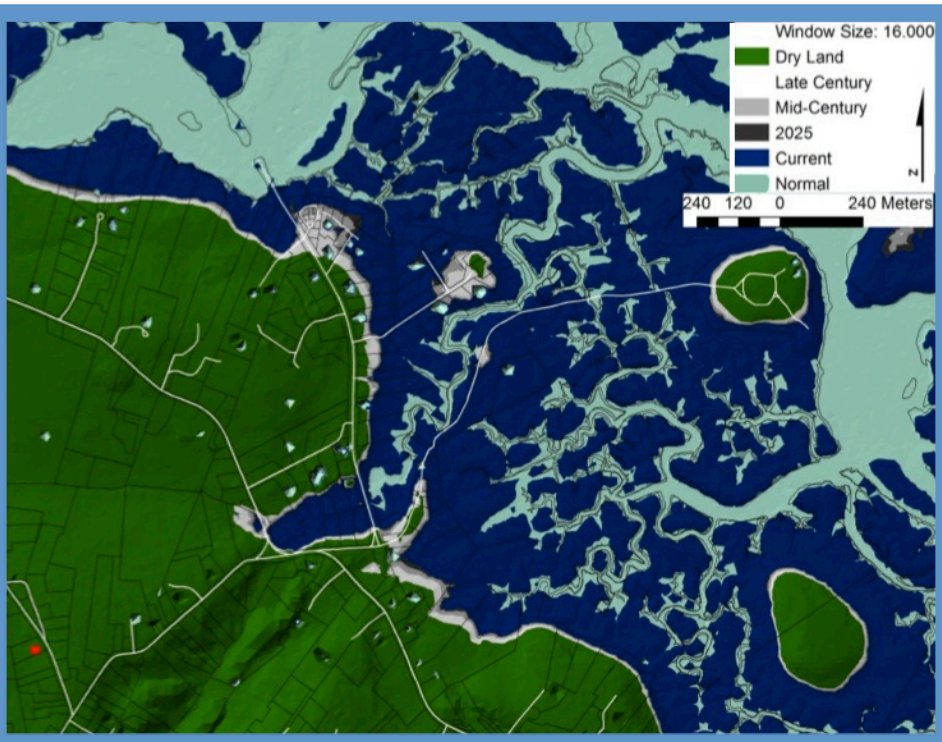


Figure 3.9: Damons Point and North River Marsh.
Data source: MassGIS.

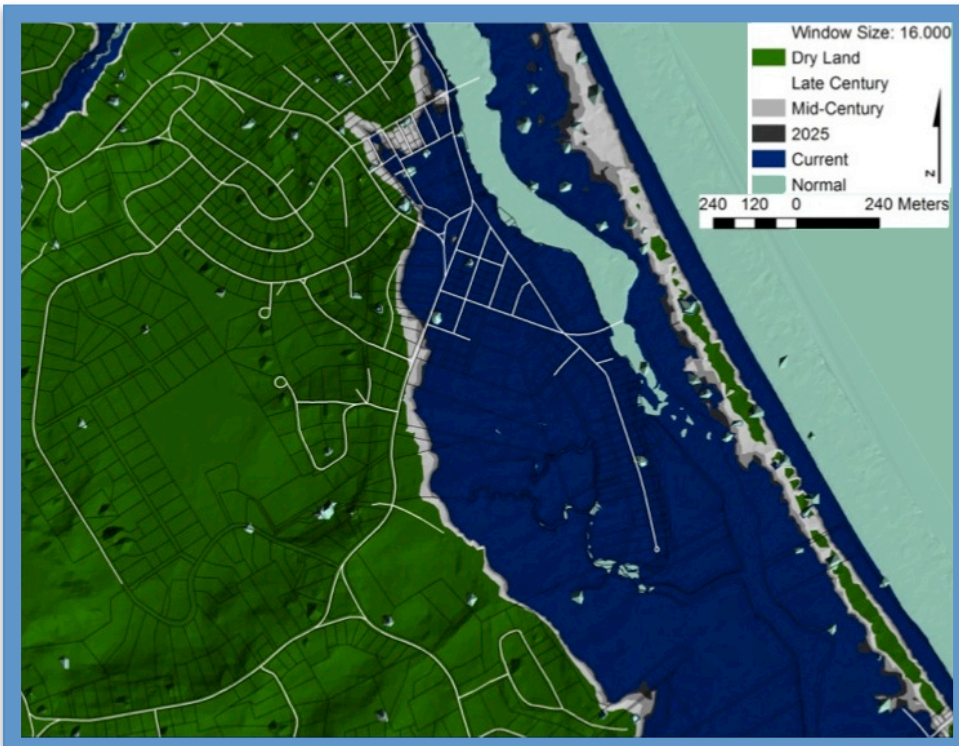


Figure 3.10: Ferry Hill.
Data source: MassGIS.

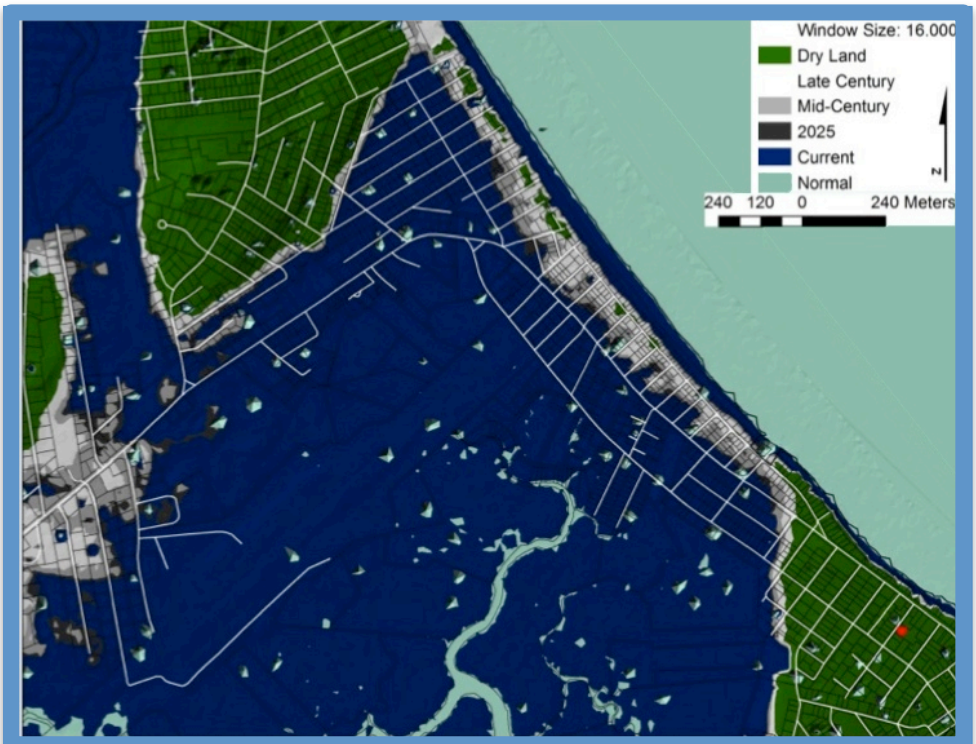


Figure 3.11: Ocean Bluff
Data source: MassGIS.

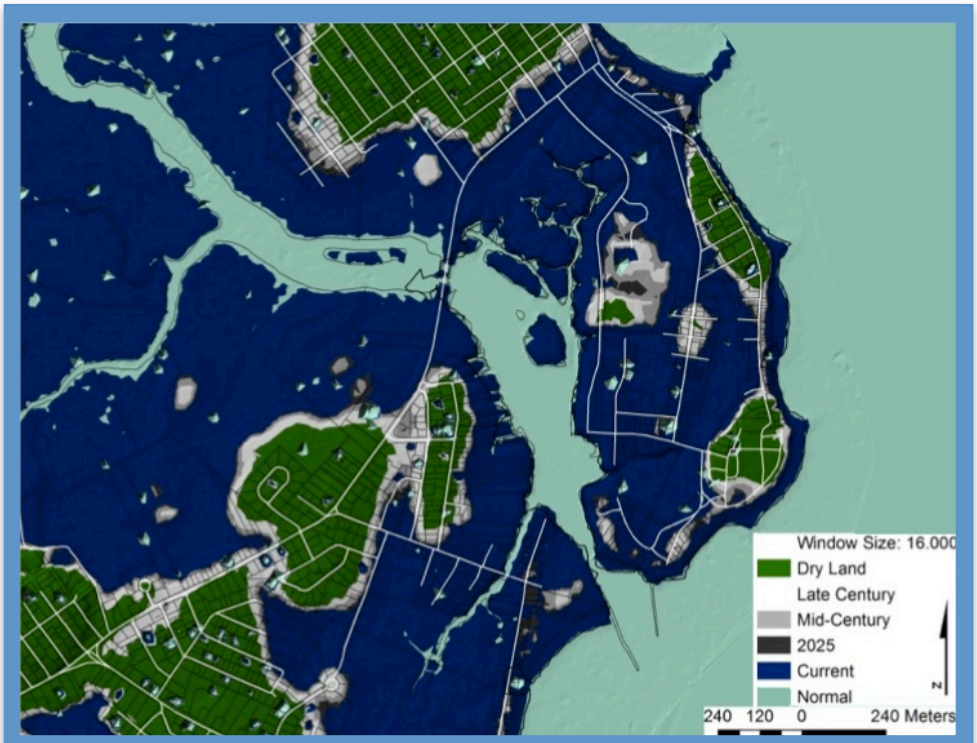


Figure 3.12: Brant Rock and Green Harbor
Data source: MassGIS.

Precipitation

As a coastal community in the South Coastal Watershed, Marshfield is downstream from all its neighbors to the west. Of the watershed's 240.7 square miles, the North and South Rivers alone drain 43.6 percent of the land area, or 105 square miles (Executive Office, 2012). With overall precipitation during major storm events projected to increase, especially in winters, the damaging effects of stormwater runoff and flooding will increase in frequency and severity. Areas that are low-lying, heavily developed, or at major stormwater collection points will reach carrying capacities more quickly than upland or well-drained areas. Impervious surfaces, such as roads, parking lots, and roofs, take up 11.6 percent of Marshfield's land area. Show in white below, these surfaces provide no precipitation storage, instantly transferring the rain that lands upon them to the stormwater system.

Figure 3.13 describes the capacity of Marshfield's fairly sandy, loamy soils to absorb rainfall from precipitation events. As expected, storage capacity diminishes closer to the coast, and in the wetlands along rivers and marshes. Upland areas in the town's center are fairly well-drained, but show the impacts of development. Densely settled areas, major roads, and areas of commercial and industrial development are less able to store water during precipitation events, despite their presence in well-drained soils. Some areas of concern, therefore, are in the Ferry Hill, Green Harbor, and Ocean Bluffs and Brant Rock neighborhoods, where residential density is high and drainage capacity is low. These areas are circled.

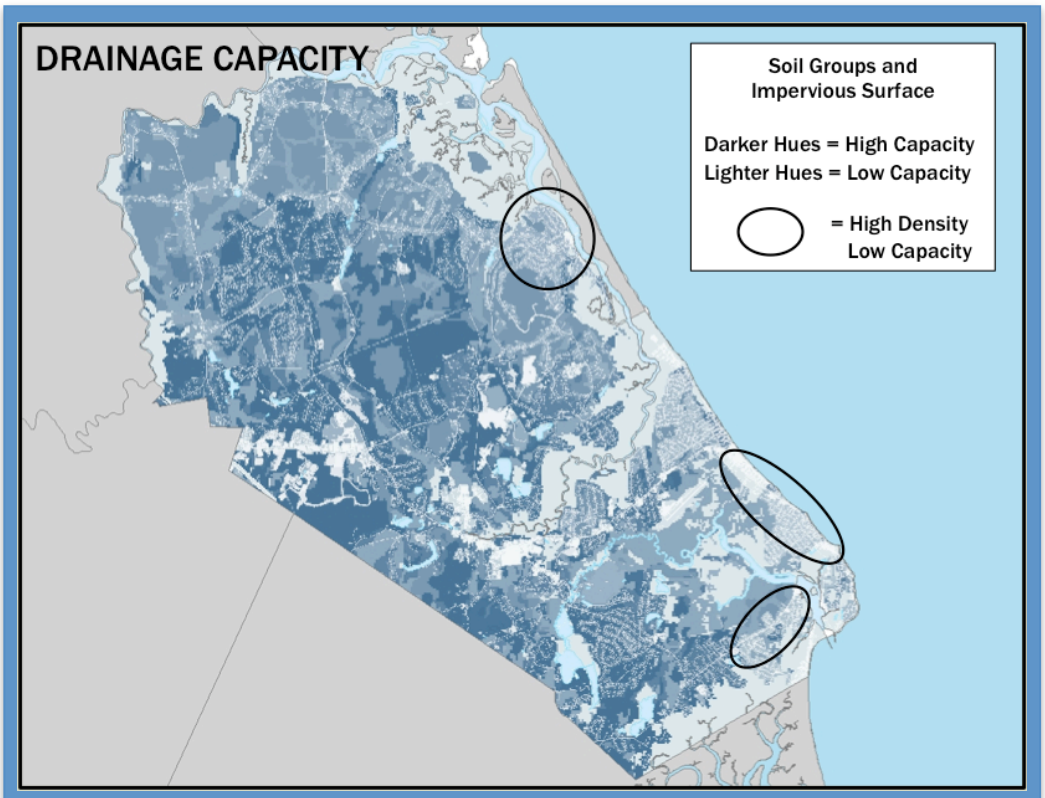


Figure 3.13: Soil drainage capacity and development.
Data source: MassGIS.

Implications of Vulnerability

The vulnerability assessment conducted for this report indicates that most of the Marshfield coast, in particular the area behind Humarock near Ferry Hill, Ocean Bluff, and Brant Rock are the most socially and biophysically vulnerable to climate change. These areas are home to a disproportionate number of residents identified as socially vulnerable based on economic status, age, housing stock, and disability status. In addition, these areas are more biophysically vulnerable than other locations in Town due to characteristics of the built environment and geographic proximity to potential hazards arising from sea level rise, storm surge, and precipitation.

4. Adaptation Planning

Adaptation is defined as the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities (IPCC, 2012).

Climate Action Plan

Adaptation planning is essentially planning for both current climatic conditions and changes in the climate that are expected to occur. Adaptation planning, unlike mitigation, does not attempt to reduce greenhouse gas emissions in hopes that it will curtail climate change. To address the emissions that are contributing to global warming and exacerbating Marshfield's need to rapidly adopt adaptation strategies, a climate action plan which seeks to identify ways in which Marshfield can reduce the town's overall emissions should be adopted.

Adaptation Committee

To ensure the success of adaptation planning in Marshfield, a committee should be formed to support the implementation of strategies and provide continued oversight of the planning process. The composition of the committee should represent the diversity of stakeholders present in the town, including residents from different villages and town employees from different departments. The committee should seek to increase stakeholder involvement by providing the public with information on their mission, as well as ongoing updates on the actions being taken towards reducing the impacts of climate change.

Adaptation Goals

Adopting climate change adaptation goals can help guide actions that will enable the community to reach and maintain an acceptable level of functioning and structure in the face of potential hazards. Since actions will be required of individuals, businesses and government, it is recommended that community members participate in identifying shared goals that will inform the trajectory of adaptation planning. The following are examples of adaptation goals adopted by the City of Santa Cruz (2007).

- Protect the unique coastal character, scenic beauty and culture in the natural and built environment from being compromised by climate change stressors
- Support local initiatives, legislation, and actions to respond to climate change
- Build resilience into municipal programs, policies, and infrastructure

- Encourage climate change resilience planning and actions in private companies, institutions, and systems essential to the Town's functioning

- Encourage community involvement and public-private partnerships to respond to potential climate impacts

- Ensure the town remains a safe, healthy and attractive place with a high quality of life for its residents, businesses and visitors

Integration of Projections

The Town should consider climate change projections when making any and all decisions regarding land use and infrastructure. All town departments should be provided with the projections. Projections should be reviewed prior to considering proposals for development, redevelopment and improvements.

Adaptation Strategies

This section discusses the town of Marshfield's current approach to reducing the impacts of sea level rise and storm surge. In addition, it proposes a new approach that integrates four key strategies intended to mitigate the impacts of sea level rise, storm surge, increased precipitation and temperature on the populations and areas identified as most socially and biophysically vulnerable. The section also proposes additional adaptation strategies appropriate for town-wide application.

Existing Approach

The Town of Marshfield relies on a 2.36 mile long seawall, along with another 2.04 miles of revetment with additional smaller sections of rip rap slope, timber bulkheads and jetties, to mitigate the impacts of sea level rise and storm surge along the coast. Historically, this has been the primary strategy employed by the Town to protect the properties in this area. However, Marshfield's seawall was built with the main purpose of dampening wave intensity, and was not intended to offer full flood protection (FEMA, 2012). Frequent breaching of the wall and subsequent flooding of coastal properties indicates that this approach alone is not highly effective.

The seawall, much of which was built in the 1930's, has seen large sections fall into disrepair. Recent reinvestment in sections of the seawall, which have brought it up to the standards specified by the US Army Corps of Engineers, have not prevented waves topping the structures. While it may be possible for the Town to continue to reinvest in this infrastructure, the financial costs associated with this strategy are high. The price tag for total replacement of the seawall and other shore protection structures, in 2006 dollars, is $48.7 million (Vine Associates, 2006). While this would bring the seawalls, revetments, and other types of shore armors up to the highest standards set forth by Army Corps, it would not alone mitigate the impacts associated with projected increases in storm surge and sea level rise.

In addition, there are environmental and social costs associated with relying solely on the seawall. The armoring of the coastline reduces the volume of sediment that is normally deposited by ocean currents. This sediment deficit results in the depletion of beach sand and the lowering of beach profile, which further destabilizes seawalls. This process of beach erosion will only be

exacerbated by sea level rise and increased storm surge. If the town relies solely on the seawall, Marshfield will continue to lose its beach and this will impact the character of the town and the experience of residents and visitors.

Proposed Approach

The Town of Marshfield should employ multiple strategies to mitigate the impacts of climate change on the town's most vulnerable populations and areas. Integrating multiple strategies that complement one another by targeting different stressors simultaneously will reduce the intensity and frequency of impacts.

Each of the key strategies identified below has capital costs. Further study is required to reliably estimate these costs, but where possible we have highlighted opportunities for cost sharing with state and federal agencies. The Town of Marshfield needs to anticipate some significant coastal infrastructure costs in the capital improvement planning process, regardless of whether the chosen approach remains rebuilding and increasing the height of the sea wall, or utilizing a more diversified selection of strategies from those proposed below. The costs associated with the proposed strategies could be viewed as alternatives to the complete reconstruction of the seawall- a project with an estimated price tag of $48 million. In light of this, funding for the following alternative strategies may be more reasonable than would first appear.

Key Strategies

The following strategies, which target Marshfield's most vulnerable populations and areas, should be considered as an integrated approach to adaptation planning. While these strategies have been selected as "best fits" for the town of Marshfield, the Town should consider hiring an engineering consultant to identify the viability of these strategies in specific locations and develop a plan for the treatment of selected locations.

Living Shoreline

Marshfield's coastal infrastructure was constructed for three purposes: to stabilize a coastline subject to changes wrought by high wave energy; to prevent flooding in all but the most serious storm events; and to ensure the safe and unobstructed passage of vessels to and from Green Harbor. While the assorted seawalls, revetments, groins, and jetties have performed well enough to enable residential and commercial interests to develop along the coast, a number of studies within the past decade have established the long-term limitations of such hard infrastructure, and identified some of the unintended consequences such installations can bring. In recent years, structural inventories and budgetary realities have raised questions among residents about the future of coastal infrastructure in Marshfield.

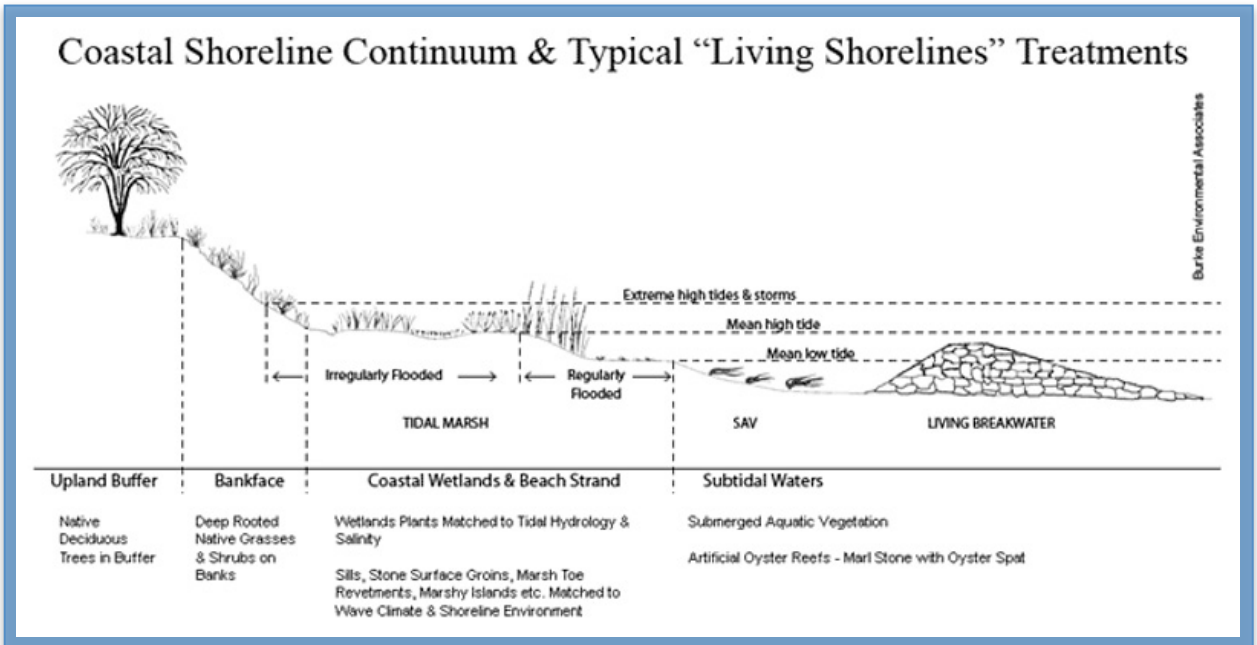


Figure 4.1: Living shorelines schematic.
Source: NOAA - http://www.habitat.noaa.gov/restoration/techniques/lsimplementation.html

Over time, any structure will succumb to the ocean's presence. Residents of Marshfield have seen first-hand how abruptly hard infrastructure can give way, and how quickly the expense of maintaining and upgrading such a system can reach into the tens of millions of dollars (Bourne, 2006). These calculations only escalate in light of the oncoming changes in climate Marshfield will confront in coming decades. As an alternative to this looming problem, a hybridized defense program based on the Living Shoreline principles illustrated in Figure 4.1 may help reduce the town's dependence on the hard infrastructure that currently separates the town from the shoreline.

In the strictest sense, Living Shorelines are comprised of plantings and natural stabilization materials alone, along with clean sand and fill where beach nourishment is necessary. This approach is not appropriate for Marshfield, which is subject to high-energy waves throughout the year. Instead, a hybrid stabilization program incorporates both hard and soft infrastructure, along the width of the coastal area. Elements of a hybridized Living Shoreline system include:

- Living Breakwaters – offshore installations of recycled concrete, capable of absorbing wave energy and providing habitat to oysters and other reef-building organisms.
- Subaquatic Vegetation – eelgrass beds planted shoreward of the breakwaters, to stabilize sediments and dampen wave energy.
- Rock Sills – freestanding rocks placed closer to shore, reaching approximately one foot above the mean high water mark, to dampen wave energy and prevent sediment loss.

- Marsh Grasses – plantings in the intertidal area, established to filter upland runoff and extend aquatic habitat.

- Sand Fill – clean dredge used where necessary to soften the beach slope, and provide a surface for vegetation adapted to the irregular flooding that accompanies extremely high tides. In some instances, this can reach up to an existing seawall or sit atop a revetment.

- Coastal Trees and Shrubs – native vegetation planted behind the bank, to capture and filter upland runoff, minimize bank erosion, and absorb winds and salt spray (NOAA OHC, 2012).

Application in Marshfield

Two sections of Marshfield's coast appear to hold the least complicated path to a hybridized Living Shorelines installation. The Rexhame Beach area, from the Scituate border south to Parker Street, is ideal: development is confined to the parking lot at the end of Standish Street, there is no hard infrastructure to work around, and costal vegetation is already well-established on site. A robust installation here would be able to build on the existing ecosystem, transmit some of its stabilization benefits to downdrift coastal areas, and educate the public about the purpose and value of this technique. As this site currently receives no protection from breakwaters, it may be possible to use only vegetation and natural materials here, keeping costs to a minimum.

The second segment is just south of the first, in an area bounded by Porter Street to the north and Rexhame Road to the south. Development along this quarter-mile of coast is noticeably recessed from the beach, with a relatively low density of housing units. These characteristics may provide the Town with some flexibility in working with landowners, some of whom may be interested in the number of benefits the hybridized technique provides. If projects in both these segments are successful, residents between the two projects may wish to incorporate a similar hybridized structure. As with all ecosystems, connectivity enhances function, and in this instance the total length would reach over 1.25 miles. While this scenario would not directly address the more densely settled areas to the south, successes in this northern section of Marshfield's coast could provide researchers, practitioners, and local, state, and national agencies with valuable data, which could prove beneficial to additional projects along the coast.

Case Study

Redhill Coast – Kaohsiung County, Taiwan

A number of communities in the United States have implemented Living Shorelines on smaller scales, or in less challenging contexts. Taiwan, however, is a community with coastal infrastructure and beach erosion concerns on a scale even larger than Marshfield's. Similar to Marshfield's experience, a typhoon's destruction in 1951 led to the construction of Taiwan's first seawall. (Hsu et al., 2008).

According to Hsu et al., the response to the earliest experiences of coastal erosion was the construction of additional miles of seawall, and since then the island nation's coastal armaments have grown to a length of approximately 337 miles. By 1981, the first detached breakwaters were built on the southern coast of Taiwan, at Redhill Coast in Koahsiung County. According to

Hsu et al., the six units, 80 meters long and 3 meters wide, have mitigated the erosion of the coast's sandy bluff. Due to the presence of breakwaters alone, beach erosion has stopped, and native grasses have begun to repopulate the bare cliff.

Benefits of Strategy

A hybridized Living Shorelines installation is designed to provide a series of interrelated benefits, capable of managing a series of interrelated coastal issues. The combination of hard and soft infrastructure, which dampens and absorbs wave energy along the width of the coast, is graded to provide the functional equivalence of an entirely hard-infrastructure strategy. Studies have shown that the first eight feet of marsh are capable of dissipating 50 percent of wave energy (Broome et al., 1992). Erosion from cross-shore transport and Aeolian transport is slowed by the presence of grasses and woody plants: the dense network of rhizomes, roots, stems, shoots, and leaves are able to trap sediments and sand, slowing the rate of transport. Along with the seeded breakwaters, this network also provides habitat and forage to a variety of coastal species, both residential and migratory. This treatment provides aesthetic benefits as well, as residents and visitors are able to walk or wade through the sights and sounds of a thriving and functional ecosystem (Thomas-Blate, 2010).

Challenges to Strategy

The Living Shorelines method is still a relatively new approach to resource management. As a result, there are limitations to the body of available research, and the relevance of case study outcomes. Research and assessment has primarily focused on lower-energy environments, similar to those found in Ferry Hill: protected from waves and winds by a barrier, subject primarily to tidal fluctuations, and free from extensive shoreline hardening (NOAA OCR, 2012). As a result, site-specific feasibility studies will need to precede any plans to shift to softer infrastructure, to address questions pertaining to viability, cost, and scale. First, the major issue to be resolved is whether a hybridized Living Shorelines installation will be able to withstand the high-energy waves Marshfield receives. Second, although per-foot costs for organic plantings and other natural materials are a fraction of the cost for a seawall or other structure (a $50-100 range versus a $500-1,200 range), the hybrid program envisioned here, with offshore breakwaters and rock sills, will elevate the costs out of the lower range (Chesapeake Bay Foundation, 2007). In Marshfield's most developed coastal areas, the beach width fronting coastal banks is less than 45 feet (Bourne, 2006). In order for a bank face to remain stable, its slope cannot exceed 30 percent. Where sea walls are 12 feet high, then, the bank face will require at least 40 feet of beach.

This last issue ties the Living Shorelines approach to other strategies. Beaches can extend outwards via beach nourishment programs, inwards via land repurposing, or through a combination of both. Beach nourishment, however, may be particularly ill-suited to the perpendicular forces of cross-shore transfer processes, which dominate Marshfield's coast north of Brant Rock (Applied Coastal Research, 2005). However, as the dynamics of cross-shore transport have not been researched as thoroughly as the more common alongshore transport process, more research is needed before this can be answered definitively.

Resurfacing of Impervious Pavement

Current and future storm surges as well accompanying severe weather floods are both of safety and economic concern for Marshfield. One contributing factor that compounds the damages and extent of flooding is impervious pavements. Impervious pavements such as asphalt and concrete are impermeable surfaces that transfer rainfall and floodwaters directly into nearby storm drains and then into the sea and nearby rivers. Surface pollutants, especially chemicals and fluids from vehicles are leached into these water bodies (Frazer, 2005).

More pertinent to Marshfield is the flooding that is exacerbated by the lack of permeability of these surfaces. Water essentially has nowhere to go as it is unable to be absorbed into the ground. This causes flooding during storm events and lunar high tides, especially in the low-lying areas of Brant Rock. By resurfacing the impervious pavement with permeable pavers in this area, Marshfield will be taking proactive steps to reduce flooding. Permeable paving consists of an assortment of sustainable materials and techniques for permeable surfaces. These options are comprised of both a base and sub-base that allow the movement of storm water through the surface (US Green Building Council). This then reduces flooding in the designated area of use. Examples of these options include:

- Permeable Grass Paving Grids/ Turf Stone - concrete blocks that form a gridded pattern on the ground and allow grass to grow in the gridded spaces. These spaces allow for water infiltration while also creating a softer, more aesthetically pleasing look on the landscape.

- Permeable Paving Blocks/ Drain Pave - offers a solid surface that is similar to a standard paving stone while still maintaining the high level of water drainage.

- Paving Stones - Although not as stable as grass paving grids or permeable paving blocks, paving stones and gravel can be utilized to increase filtration while also providing a solid surface for a parking lot or roadway.

- Aggregate Base Mix - a mixture of recycled asphalt and stone dust can be layered to provide light coverage on the graded area (Uni-Eco-Stone).

Application in Marshfield

The commercial esplanade of Brant Rock, as shown in Figure 4.2, has been identified as a vulnerable location based on projections, social, and biophysical characteristics. Re-surfacing the impervious pavement in the Brant Rock area is an important step that Marshfield can take to reduce flooding in the commercial district. Because this location is so low-lying and vulnerable to flooding, the area has seen considerable disinvestment. Businesses are leaving the area because of the risks and financial burdens associated with flood damages. Other commercial establishments such as Haddad's and The Venus Restaurants have either elevated their structures, or retreated further inland. The Brant Rock Esplanade streetscape consists of 1.06 acres of impervious surface that could benefit immensely from permeable paving treatments. Another location to prioritize in receiving this treatment is the Standish Street Parking lot near Rexhame Beach. This impervious parking lot holds parking for 200 vehicles and covers 2.33 acres directly adjacent to the beachfront.

Figure 4.2: The Brank Rock Esplanade highlighted in orange.
Data Source: Google Maps 2012

Case Studies

Chadbourn Street Installation-Wrightsville Beach, North Carolina

5,600 square feet of pervious pavement was installed on a 100-foot stretch of roadway in the coastal community of Wrightsville Beach, North Carolina. The concrete cost approximately $3-$4/sq. ft. (for labor and concrete) and has been effective in reducing run off from stormwater and flooding in this ocean front location. Wrightsville Beach appears be pleased with the porous concrete's performance. A street sweeper clears sediment that collects on the surface (North Carolina Green Building). This location, directly situated between the Atlantic Ocean and Banks Channel, is a particularly vulnerable site to flooding, much like the Brant Rock esplanade.

Silver Lake Beach Parking Lot, Wilmington, Massachusetts

Silver Lake is an important recreational resource along the Ipswich River Watershed that supports swimming, fishing, wildlife viewing, and boating. However, the lake was degraded from nutrients, sediment, and bacteria from the surrounding conventional stormwater systems. Using permeable pavers around the beach parking area, this site has seen a decline in runoff due to severe rainwater and storms. All permeable surfaces infiltrated as well as, or better than, designed, with infiltration rates ranging from 49 inches per hour to almost 10,000 inches per hour well above the rate that stormwater would build up over these surfaces (Department of Conservation and Recreation, n.d.), The benefits provided with these pavers include reduction to flooding and erosion from excess rainwater and infiltration and purifying of the water seeping into the soil. This project was funded from a grant from the Environmental Protection Agency. This location as it borders a freshwater lake is not susceptible to sand and salt spray the way the Brant Rock Esplanade is. Despite the contextual differences, this is an encouraging case study

displaying the success of securing national funding and grants for environmentally friendly, low impact development projects. Perhaps Marshfield can look into funding options like these for future projects such as the resurfacing of Brant Rock.

Benefits of Strategy

Converting hardscape pavements, especially along the Brant Rock esplanade will help to alleviate the damages associated with flooding and storm surge. By making changes to the roadway infrastructure, Marshfield will be preparing for a more resilient future through implementing these green infrastructure techniques. These methods, like the use of permeable pavers will improve the water quality of the rain and storm water seeping into the soils. Cleansing takes place through percolation into the sand and soil, which acts as a natural filter for storm water. Additional co-benefits of pervious pavement installation include: reduction of the heat island effect and aesthetic benefits for the neighboring properties. The light color of concrete pavement absorbs less heat from solar radiation than darker pavements, and the open pore structure of pervious concrete stores less heat (US Green Building Council). In addition, if flooding is decreased in this area it may invite greater investment, which would benefit the businesses as well as the entire town.

Challenges to Strategy

As discussed earlier, all of the four main strategies presented in this recommendation section are not stand alone options, but are presented as suggestions that will work well in site-specific locations throughout Marshfield. The weaknesses associated with resurfacing of the pavement infrastructure include costs associated with repaving. Understanding these costs makes identifying key locations of use very important.

Other weaknesses include the maintenance costs associated with cleaning the pavers and the initial installation costs required in investing in these strategies. As soils become saturated, drainage capacity decreases. When this occurs, these permeable paving options will not be effective in alleviating flooding. Proper maintenance for the pavers involves biannual vacuum sweeping and high-pressure washing, which can be accomplished with a conventional street sweeper. This program removes the sediment and debris that accumulate in the drainage openings, and ensures the continued functioning of the pervious surface. Maintenance costs vary, but the inflation-adjusted estimate from one source places the cost at $275 per year in 2011 dollars (Lake Superior Streams, ND).

Building Elevation Grant Program

The Building Elevation Grant Program is based on the point that elevating homes is one of the safest ways to protect property owners from the dangers associated with flooding. The Commonwealth of Massachusetts agrees with this statement; Massachusetts state building codes require that new and substantially repaired structures have their lowest floor built above Base Flood Elevation (BFE). However, the Base Flood Elevation heights in use in Massachusetts do not account for projected sea level rise and the consequential rise in storm surge. This also means that more homes may be vulnerable to flooding than the FEMA flood zones portray; the implication of this is that some homes may be physically vulnerable to flooding, but may not have flood insurance since it is not required outside FEMA's flood zones. Municipalities may want to see new homes and other structures elevate higher than the state requirements, or see property owners outside the limits of the FEMA flood zones elevate. In order to accomplish this

the local governments must use creative strategies due to state law, which prohibits municipalities from enacting building codes more stringent than the state code.

Application in Marshfield

In this strategy, Marshfield would administer this program in which homeowners or business owners elevate their structures to the heights recommended for Marshfield in Table 4.1, then are reimbursed for the cost, or at least a substantial portion of the cost. There is currently no strategy in place that encourages property owners to elevate existing buildings before they suffer significant flood damage, and the Town and its residents would benefit from a planning program that addresses this.

The Town could model this program after Scituate's home elevation program, which would allow homeowners to apply for 75% reimbursement from FEMA with approval from the Town's Conservation Commission (Town of Scituate, 2012). FEMA is eager to support projects that reduce the potential for flood damage to NFIP (National Flood Insurance Program) properties, because of the high cost of payout for damages compared to the relatively low premiums brought in by property owners' insurance payments. Since it is evident that Marshfield and its neighbors are likely to file an increasing number of claims because of climate change and deteriorating seawalls (MAPC, 2012), partnering with FEMA on this grant program would be mutually beneficial.

Seabrook has structure type-based elevation requirements for new structures or substantial repairs. Structures with more longevity or more costly repairs are required to be elevated higher than others (Rockingham Planning Commission, 2009). Marshfield could adopt similar structure type-based recommended elevations modeled after Seabrook's regulations. This model departs from Seabrook's in two ways: where Seabrook's is based on 9 foot BFE, the proposed program for Marshfield uses 11 feet as the Base Flood Elevation because this is the elevation below which Marshfield prohibits the building of habitable space. Seabrook's program also differs because it is a building code regulation, whereas changing local building codes to be more stringent than the state regulations is a practice that cannot be used in Massachusetts.

Possible modifications to this program:

- Reimburse the remaining 25% of the cost of elevation left after FEMA's 75% reimbursement with Town funding.

- Offer grants from the Town to property owners in advance of the elevation construction, and then seek reimbursement to the Town from FEMA.

- Update Marshfield's Floodplain Zoning Bylaw so that the Town strongly recommends elevating to the heights proposed in Table 3.1 when new structures are built or substantial repairs are completed after flood damage.

- Request that buildings be elevated to a standard height (such as two feet above BFE) instead of using the structure-type based elevation recommendations in Table 4.1.

Structure Type	Recommended Elevation
Accessory Structures	12 feet (11 feet BFE + 1 foot)
Single Family Residential/Multi-Family (<5 units)	13 feet (11 feet BFE + 2 feet)
Multifamily (>5 units)	14 feet (11 feet BFE + 3 feet)
Commercial Development	14 feet (11 feet BFE + 3 feet)
Essential Facilities (Schools, Hospitals, etc.)	15 feet (11 feet BFE + 4 feet)
Public Infrastructure	16 feet (11 feet BFE + 5 feet)

Table 4.1: Recommended Building Elevations for Marshfield.
Source: Table is modeled after Seabrook's Design Flood Elevation Standards table.

Case Studies
Marshfield and Scituate have interwoven shorelines and share the problem of flooding across their borders. Marshfield's and Scituate's adjacency and previous collaboration on coastal hazard mitigation planning make Scituate's program a logical model for Marshfield.

Scituate has a Flood Grants Committee – a committee Marshfield will want to establish if using this strategy – and the program administration also includes the Building Commissioner and the Town Planner, who oversees the program. The following excerpt from Scituate's Elevation Grant Program (2012) Guidelines outlines the application process:

> The Town will review plans and estimates prior to applying for elevation grant funds to make sure all costs are appropriate. In this regard, the Town must receive the following prior to requesting funds for an elevation project:
>
> - Applications for home elevations must include three detailed estimates for the elevation from a general contractor. These must be on the letterhead of the general contractor, and bear his signature. Each general contractor must provide at a minimum, sub-bids from the building mover, if required, and foundation contractor (includes pile driver.) Lump sum estimates will not be accepted. Any contractors working on an elevation performed with grant funds must have all licenses required by the State of Massachusetts.
>
> - A set of plans approved by the Conservation Commission, and suitable for obtaining a building permit. A licensed surveyor and structural engineer must complete plans for a home elevation.
>
> - Proof of participation in the National Flood Insurance Program such as a copy of the current Declarations Page from the homeowners' flood

insurance policy.

- Documentation of historic storm damage, including records of prior insurance claims, for at least two flood events.

- An Acknowledgement of Requirement to Maintain Flood Insurance signed and notarized.

Homeowners will be expected to use the contractor with the lowest of the three estimates for home elevation. If for some reason you do not want to use the lowest bid, you must provide the Town with written justification. The use of a contractor other than the low bidder must be approved prior to application for a building permit. Applicants for grants for utility elevation are also encouraged to obtain several estimates to get the best price.

Benefits of Strategy

As was mentioned earlier, Marshfield's seawall was primarily intended to protect residents and infrastructure from the strength of the waves, not to offer full protection from flooding. When floodwaters breach the shores and seawall, elevated homes and businesses keep the people and property inside them safe from flooding. Establishing this program would offer residents and business owners an opportunity to take proactive measures to protect themselves, and to do so with funding assistance from the Federal government and, possibly, the Town government. Property owners who elevate their buildings would see a decrease in their flood insurance costs, and the Town could benefit financially as well. Depending on the funding structure of the program, the Town could save a large amount of budget capital that would otherwise have been spent continuing to repair the seawall. Co-benefits include a potential increase in property values due to the resilience of homes near the waterfront, water resource protection because of the reduction of pollutants from flooded structures, stimulation of the local construction industry, and reinvestment in flood-prone areas.

Challenges to Strategy

The quantity of administrative work required for this program is the strongest challenge to it. Marshfield would have to establish the program in conjunction with FEMA and Massachusetts agencies that administer FEMA programs in the Commonwealth.

Additional Strategies

In addition to the three key strategies, which target the populations and areas identified as most vulnerable, the following strategies are appropriate for town-wide application. The adaptation strategies are organized by the topics shown in the left-most column. These topics are referenced in each Sector Implication section. The Marshfield Adaptation Strategies Matrix indicates the climate stressors addressed by each strategy, as well as the co-benefits of and the pathways to implementation. The Town should consult this matrix when developing an adaptation implementation plan in order to select strategies that effectively address a full range of climate stressors and maximize co-benefits. The use of the matrix will allow the Town and stakeholders to reference a menu of options that work together to improve the resilience of the community.

Marshfield Adaptation Strategies Matrix

	Strategy	Description	Climate Stressor Addressed	Co-Benefits	Pathway to Implementation (When, Where, How)
Key Strategies	*Emphasize "Living Shorelines" Treatments*	"Living Shoreline" strategies view coasts as an ecological continuum, utilizing a variety of different materials at points on that continuum. In subtidal waters, living breakwaters, such as oyster reefs, are combined with seagrass beds to reduce wave energy. Coastal wetlands and beaches are outfitted with a variety of marsh grasses, rock sills, fiber logs, and other soft structures to stabilize the shoreline and retain sediments. The bank face and upland buffer areas are graded gently, and planted with trees, grasses, and woody shrubs to hold the sloping sand and soil in place. Segments of Marshfield's coast without seawall protection are primary candidates for this program, but older segments nearing the end of their functional lives may be appropriate locations, as well. (NOAA Restoration Center) Reconstruct wetlands to replace those lost to development or expansion. Rehabilitate wetlands that are unhealthy, i.e. affected by invasive species, experiencing eutrofication, etc. Plant eelgrass beds to protect shellfish beds.	Storm Surge, Sea Level Rise	Living Shorelines improve water quality via filtration and (upland) runoff reduction, create habitat for valuable terrestrial and aquatic species, and enhance storm surge protection. This measure would also preserve the recreational utility of the beach.	The Town should begin the consulting process as soon as possible and begin implementation at the north end of the beach by the 2020s. The Town should engage a firm in this process who will contribute civil/environmental engineering, restoration ecology, and landscape architecture expertise to design a suitable Living Shoreline for Marshfield. The Town may also need to consult with the Army Corps of Engineers.
	Brant Rock Re-Surfacing	Re-surfacing the paved area in the Brant Rock commercial esplanade and the Standish Street parking area is a measure that would allow precipitation and pooling floodwater to drain more effectively, reducing the flood damage to businesses and stormwater runoff to surrounding properties. There are multiple pervious surface treatments Marshfield can choose from based on their affordability and appearance.	Precipitation, Storm Surge	The visibility of this project due to its public location could inspire residents to take similar actions on their own properties.	Locations for this treatment that should be viewed as phase 1 implementation sites include the Brant Rock esplanade and the Standish Street beach parking lot which can accomodate 200 vehicles. These areas are top priority sites for this treatment as the Brant Rock esplanade already experiences extreme flooding and erosion damage and the Standish Street parking area is a large expanse of impervious surface where this type of treatment could greatly benefit the drainage in the surrounding area. The Town will need to evaluate the pervious surface options and select the best fit for the coastal environment. A maintenance plan should be considered to ensure the proper sweeping of the pervious pavers. This is typically neccessary 3 times a year, but in this coastal location with salt and sand, the process may require additional maintenance and sweeping. Town officials should consult paving specialists when moving forward with this treatment.
	Building Elevation Grant Program	Marshfield could begin administrating a building elevation grant program in which homeowners or business owners elevate their existing structures to heights recommended for Marshfield based on structure type, then are reimbursed for the cost, or at least a substantial portion of the cost. The Town could model this program after Scituate's home elevation program which would allow homeowners to apply for 75% reimbursement from FEMA with approval from the Town's Conservation Commission. Marshfield could also make changes to this model, for example the Town could redirect funding that would have paid for seawall repair to reimbursing the remaining 25% of the cost of elevation. Another possibility	Storm Surge, Precipitation, Sea Level Rise	Depending on the funding structure of the program, the Town could save a large amount of budget capital that would otherwise have been spent continuing to repair the seawall. Additionally, as climate changes become more apparent and more homes are threatened by flooding, the property value of homes that have taken early measures to	Marshfield's Town Planner should meet with Scituate's Town Planner to discuss what has worked, what hasn't, and why. After gaining this highly relevant information from its neighbor, Marshfield can then tailor its own plan for implementing the program. The Town must work with FEMA and state agencies that administer FEMA programs to establish a sustainable program that

Marshfield Adaptation Strategies Matrix

	Strategy	Description	Climate Stressor Addressed	Co-Benefits	Pathway to Implementation (When, Where, How)
Administrative Actions	*Form Adaptation Committee*	A volunteer committee could act as stewards for this plan, responsible for supporting its implementation. This would ensure strategies intended to mitigate identified impacts of climate change would be implemented swiftly and receive continuous evaluation.	Sea Level Rise, Storm Surge, Precipitation, Temperature Rise	A committee would allow for more public involvement in the adaptation process.	Forming this committee should be the first, or one of the first, steps Marshfield takes in its adaptation implementation. The Town would accomplish this by establishing the committee and inviting citizens to apply for appointment by the Board of Selectmen. The Board could take on the goal of appointing a geographically and socially diverse committee and may want to seek a community member with expertise relating to climate change adaptation to serve on the committee.
	Establish Integrated Water Management	The Metropolitan Area Planning Council (MAPC) recommends that Marshfield (as well as Scituate and Duxbury) consider adopting a long-term integrated water management (IWM) method of approaching water supply, wastewater, stormwater, and water resource management as a unified system. This would allow the Town to focus on identifying the best ways to protect water resources using a range of solutions that require blurring the lines between the above systems. The MAPC advocates looking to the Association of Metropolitan Water Agencies' Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs for more guidance with this method (MAPC, 2011). The State of California's Integrated Water Managment Plan can be used for guidance as well <http://www.waterplan.water.ca.gov/cwpu2009/index.cfm>.	Sea Level Rise, Storm Surge, Precipitation, Temperature Rise	The Town may save money on future projects because consolidated solutions may be found, and more funding sources may be available.	Since this is a strategy that may impact other adaptation options, steps should be taken early to put this practice into effect so that following strategies may be implemented smoothly, without interruption by a shift in management. This is a measure that involves rethinking the Town's approach to some of its infrastructural systems, so a discussion should be fostered between Public Works, Planning, the Town Engineer, Conservation Commission, and any other parties who may have a stake in or a helpful perspective on integrating water managment. The Town may want to seek technical support from MAPC when developing this idea.
	Land Acquisition	Marshfield could increase its practice of giving homeowners the option of selling their property, including developing rights and built structures, to the Town. FEMA would supply 75% of the buyout funds and the remaining 25% would be contributed by the Town and State. The land is then cleared and becomes public property which, by law, is permanently designated as open space land (MAPC, 2011). Town funding could come from the Community Preservation Fund.	Sea Level Rise, Storm Surge, Precipitation	Acquired land can be used to create new waterfront parks, wildlife habitats, or other public amenities.	Though this practice may not become popular in the immediate future, increasing public awareness of its merits soon may improve the likelihood of its use. This option is already available, so the recommended adaptation strategy would be to expand public knowledge about it. A public education campaign about homeowners' flood-related options is recommended.
	Transfer of Development Rights	To reduce damages to property and improve safety of residents, Marshfield may want to consider instituting Transfer of Development Rights. This is a planning technique that allows owners of undeveloped land in vulnerable areas to sell their development rights to landowners in resilient places. In this application, owners of land that is vulnerable ("sending areas") to flooding would be able to sell their rights to develop that land to another landowner in Marshfield with higher ground. Landowners in these "receiving areas" would then have the right to develop their property beyond the current accepted density. The value of development rights are negotiated by the landowners themselves, which means that the technique allows for the inclusion of the property market. (MAPC, 2011; Massachusetts Smart Growth/Smart Energy Toolkit. http://www.mass.gov/envir/smart_growth_toolkit/pages/mod-tdr.html)	Sea Level Rise	Allowing for denser development in designated "receiving areas" would support desirable mixed-use projects.	Marshfield may want to attempt other strategies to manage floodplain development, such as improving Land Acquisition practices, before exploring the option of Transfer of Development Rights. The new Master Plan may indicate appropriate "receiving areas" where increased density would be favorable. The Town should first assess its quantity of undeveloped privately-owned land in floodplains ("sending areas") to measure the suitability of this strategy, in addition to the measurement of suitable "receiving areas". The Town should also educate the public about how Transfer of Development Rights works as part of the public education campaign on property owners' flood-related options.

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Marshfield Adaptation Strategies Matrix

	Strategy	Description	Climate Stressor Addressed	Co-Benefits	Pathway to Implementation (When, Where, How)
Coastal and Floodplain Land Use	*Purchase of Development Rights*	Instituting Purchasing of Development Rights would enable Marshfield to reduce damages and improve safety in flood areas. In this practice the property owners in vulnerable areas can sell their development rights to the government or a land trust. The property is then protected by a conservation, or agricultural, easement issued by the government, but the original landowner keeps the ownership of the land itself. The land can then be used as open space or agricultural land, and cannot be developed. Community Preservation funds may be used by the government to purchase the landowner's development rights. (MAPC, 2011; Wisconsin Environmental Initiative, 1997) http://weigogreener.org/uploads/media/Understanding_Purchase_Transfer_Dev_Rights.pdf	Sea Level Rise	Farmland or wetlands property would be preserved in its current state with permanent protections.	Marshfield may want to attempt other strategies to manage floodplain development, such as improving Land Acquisition practices, before exploring the option of Purchase of Development Rights. The Town should first assess its quantity of undeveloped privately-owned land in floodplains to measure the suitability of this strategy. The Town should also educate the public about how Purchase of Development Rights works as part of the public education campaign on property owners' flood-related options.
	Setbacks	Marshfield's Wetlands Bylaws currently require 75 foot set-back zones for new structures, plus 50 foot "no disturbance" zones for new structures and 25 foot "no disturbance" zones for existing structures. The U.S. Environmental Protection Agency advocates that setbacks of at least 100 feet should be adopted to allow bodies of water to maintain a state of equilibrium (MAPC, 2011). The Town may want increase set-back zones accordingly, since the protection of its water resources from the intrusion of nutrients and contaminants is vital to the Town's sustainability.	Sea Level Rise	Water quality may improve, which has positive implications for drinking water, fisheries, wildlife habitats, and recreational water use.	Marshfield's setback bylaws should be upgraded as soon as possible, since the Wetlands Bylaws apply mostly to new structures. The earlier the upgrade is implemented, the more structures it will apply to. Mean high tide levels of all bodies of water should be measured periodically to ensure that setback zones stay up to date with sea level rise.
	Rolling Easements	Rolling easements enable the Town to maintain a buffer of public open space between development and a body of water that allows for migration as the water level rises. This planning policy establishes a plan for retreat actions that will be taken when shoreline migration is observed. The EPA has a very thorough resource on the application of Rolling Easements: http://www.epa.gov/cre/downloads/rollingeasementsprimer.pdf (MAPC, 2011; EPA, 2011)	Sea Level Rise	Public access to beaches will be maintained, which is important to Marshfield's culture and economy.	It is best to establish Rolling Easements as early as possible, when the threat of damaging floods is at its lowest in relation to the future. The Town should initiate this practice around its wetlands where sea level rise is most likely to encroach upon private property in the future. The initial depth of the easement should match the existing set-back depth from bodies of water. It is important to effectively educate the public about this practice, particularly about the conditional nature of the easements. This could be done as part of the public education campaign on property owners' flood-related options.
	Essential Seawall Repair	After applying more sustainable solutions, repair seawall in necessary locations to dampen wave energy in storms.	Storm Surge	Focusing resources on only essential seawall repairs will conserve the Town's budget while working in tandem with softer infrastructure, such as Living Shorelines techniques.	Marshfield should begin this process after a plan is in place for the Living Shoreline treatment. The 2006 seawall assessment study can be used to identify essential seawall repair locations. Once the Living Shoreline plan is in place, Marshfield can prioritize seawall repair locations based on the 2006 seawall assesssment and the expertise of the engineers hired to create the Living Shoreline plan. Since the Town already has a Capital Improvement Plan in place for the seawall, it will not be difficult to secure funding, though a new Town approval process may be required by the revision of the shoreline treatment plan.

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Marshfield Adaptation Strategies Matrix

	Strategy	Description	Climate Stressor Addressed	Co-Benefits	Pathway to Implementation (When, Where, How)
	Public Education and workshop on property owners' flood-related options	Produce educational materials and hold an event or series of events to inform home owners and business owners about flood-related strategies the Town is considering that affect private property, and to work with the public to determine which options are favorable among property owners. Residents and business owners may also have ideas about how best to tailor strategies to fit Marshfield's needs.	Storm Surge, Sea Level Rise, Precipitation	Ensures that public is well-informed prior to public meetings where they are asked to make decisions or give input, and that they have contributed to the ideas put forth. Contributes to environment of open Town government, which encourages public involvement.	This public education campaign should be developed after the Town has considered the flood-related strategies that would work best for Marshfield, and has developed the strategies enough to give details about how each program would work. Printed materials about the various planning techniques that could be used to improve the resilience of the Town to climate change would be helpful for distribution, and could include information about an upcoming public workshop. A public workshop could then be planned, which would be attended by stakeholders and perhaps a representative of the MAPC who may be able to answer questions about planning techniques being used elsewhere in the region.
Transportation	*Road Elevation*	Elevate the critical infrastructure that keeps the accessibility functions of the transportation network operational in Marshfield. This includes Dyke Road which leads out to the low lying coastal area of Brant Rock.	Storm Surge, Sea Level Rise, Precipitation	Elevating Dyke Road could be an opportunity to expand and repair the water management infrastructure there.	The town engineer should work closely with the Army Corps of Engineers to establish guidelines to move forward with roadway elevation. Top sites for elevation include Dyke Road where drastic flooding is already occuring on a regular basis. Also importatant is establishing funding options which the town can apply for.
	Abandon Transportation Infrastructure	Abandon transportation infrastructure located in extremely vulnerable or indefensible areas. Potentially relocate. Site new facilities in less vulnerable locations.	Storm Surge, Sea Level Rise	Eliminating access in critically vulnerable locations will reduce infrastructure costs for the town which include sanding, salting the roads, and maintenance. These transportation routes may also be utilized for bike and pedestrian corridor access.	The Town should use the storm surge and sea level rise maps included in this chapter to evaluate the location and expected timing of the vulnerability of its infrastructure. Marshfield Town Officials should meet with residents who use the transportation infrastructure to determine potential solutions that will meet the needs of the Town. By meeting with members of the areas and discussing alternate routes Marshfield can move forward in establishing safer community based infrastructure.
	Alternative Transportation Options	Identify system alternatives such as increased bus service in the event of car interruption as well as a broader regional mobility perspective, considering all transport modes.	Storm Surge, Sea Level Rise	Provides increased access to transportation for residents who lack use of a car while also reducing emissions.	The Town can look for nodes of development where key transit options will best be incorporated. These include the vulnerable areas of Brant Rock, Green Harbor, and Damon's Point. Working in conjunction with the GATRA bus line is one option the Town can look to in regards to increasing these transit options. Marshfield can provide increased access routes for the elderly population. These transit options will only benefit the Town as they will provide a transportation network that will service the entire community in both disaster and normal conditions.

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Marshfield Adaptation Strategies Matrix

	Strategy	Description	Climate Stressor Addressed	Co-Benefits	Pathway to Implementation (When, Where, How)
Stormwater	*Downspout Removal*	This program responds to the expectation that storm events will intensify as a result of climate change. As Marshfield receives precipitation in shorter, more intense bursts, the town's storm water network will be overloaded with increasing frequency. As an alternative to increasing the network's capacity, a downspout disconnection program (paired with rain-barrel installation) promotes the value of holding water on-site to reduce runoff. This project informs citizens of the association of storm water runoff with pollution, flash flooding, and erosion, highlighting the hydrologic connection between the upland / inland portions of Marshfield and the lowland / coastal portions. Rain barrels and rain gardens delay the release of precipitation into the storm network, softening the "spike" that can overload the system. (City of Toronto, 2010)	Precipitation	Precipitation collected in rain barrels can be used for a number of other purposes. Rain gardens enhance the presence of native plants in the landscape.	Some residents will voluntarily participate in the program once notified of its existence. With a year or two of notice and preparation, most of the town could meet minimum requirements. The program is very flexible; it can be phased in based on priority areas and subsidized to generate buy-in.
	Collaborate with inland communities	Work with inland communities to identify strategies that will reduce the rate of water discharge in Marshfield. This would reduce flooding and pollution.	Storm Surge, Precipitation	Reduces need for dredging related to sedimentation; Limits rate of wetland expansion; Maintains the quality of drinking water; Prevents pollution that affects fisheries and agricultural lands	This is a strategy that will require ongoing attention. Collaboration should begin as soon as possible. When an adaptation committee is formed, they should reach out to neighboring communities. These communities should be encouraged to adopt adaptation plans that compliment the strategies employed by Marshfield.
	Impervious Surface Replacement	This program responds to the disproportionate contribution of paved surfaces to the quantity of precipitation runoff. Paved surfaces are coated with oils, heavy metals, fuels, and other automotive byproducts, which are washed into storm water networks during precipitation events. Resurfacing regulations can gradually reduce the amount of paved surface in the automotive network, enabling precipitation to filter through to the subsurface. By setting a runoff maximum for driveways and parking lots, businesses and residents will be able to choose from a number of different options: gravel, sand, permeable pavers, tire channels, and the like. Similarly, when low-traffic residential streets along the coast require resurfacing, the town can make use of appropriate permeable surfaces. (EPA, 2000)	Precipitation, Temperature	Provides better traction in rain and snow. Limits use of de-icing chemicals; Reduces accumulation of debris in storm water catchments. Reduces presence/cost of subsurface construction and detention elements. Reduces heat island effect.	Policies relating to this practice may be implemented as soon as Marshfield establishes the program as it will work for the Town. Phased implementation is advisable with this strategy. The Town would need to pass bylaws specifying revised runoff limits, and determine the best way to phase in regulation without thwarting business cycles.
	Improve Stormwater Drainage Capacity	Design new infrastructure and assets to withstand future climate conditions (larger drainage capacity, stronger structures to withstand high winds, materials suited to higher temperatures). Retrofit existing structures and facilities. Build protective features such as retaining walls, levees, and vegetative buffers.	Storm Surge, Precipitation	Improved drainage capacity will help to elevate flooding concerns while reducing runoff that leads to erosion.	Areas of ongoing concern could also be addressed as soon as possible. Drainage capacity could be increased over time, as improvements to the wastewater infrastructure are required.
	Open Space Protections	Increase the protection awarded to lands currently in Chapter 61, to ensure they are not developed. Developing additional land will limit the amount of stormwater that can be absorbed and may increase flooding.	Storm Surge, Precipitation, Temperature	Reduces pollution associated with increased precipitation and storm water. Maintains the existing feel of the town. Provides public health benefit in the form of recreational opportunities. Vegetation assists with maintaining air quality and reduces heat island effects.	The Town should consider its Open Space Protection options as soon as possible. This strategy should be addressed in the master planning process, as part of the Town's larger vision for land use.

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Marshfield Adaptation Strategies Matrix

	Strategy	Description	Climate Stressor Addressed	Co-Benefits	Pathway to Implementation (When, Where, How)
Water Resource Protection	*Alternative Road De-Icer*	In order to protect the Town's water resources from non-flooding-related groundwater salination and salt runoff to bodies of water, Marshfield should consider treating roads with a salt alternative during winter storms. http://www.ci.gillette.wy.us/Modules/ShowDocument.aspx?documentid=97	Precipitation	Alternatives exist that last longer and work at lower temperatures, thus improving De-Icer performance and saving the Town money.	Changing the Town's substance used for de-icing roads is a process that could be done immediately under the purview of Public Works. The Town could sell its remaining salt de-icer to another municipality, or could continue to use the existing method until the stock runs out, at which point the change to the alternative de-icer would be made. Public Works should explore alternative de-icer options, local providers, and costs. The Town should inform the public about the change and the reasons for it, as well as any impacts the change may have on the public.
	Propane Tank Securement	Improved propane tank securement ensures that during storm events, the propane tanks do not break loose and contribute to non-point source pollution.	Storm Surge, Sea Level Rise, Precipitation	Public health benefits of reduced chemicals in the environment. Also, reduces the potential of an explosion.	This strategy should be implemented as soon as possible, as it is low cost. When people request a permit for household propane tanks, the Town would make issuance contingent on appropriate securement of the tank.
	Public Education on Chemical Storage	Produce educational materials informing residents about proper storage of chemicals (i.e. not in the basement) and small propane tanks to ensure that these pollutants are not contributing to non-point source pollution.	Storm Surge, Sea Level Rise, Precipitation	Public health benefit associated with reducing chemicals in the environment. Ensures Marshfield's natural resources remain safe for consumption and commercial, as well as recreational use.	This public education campaign should be developed as soon as possible. Printed materials could be posted on the town's website and distributed to the public.
	Public Education on Alternatives to Herbicides and Pesticides	Produce educational materials informing residents of alternatives to herbicides and pesticides to ensure that these pollutants do not contribute to non-point source pollution.	Precipitation, Temperature	Public health benefit associated with reducing chemicals in the environment. Ensures Marshfield's natural resources remain safe for consumption and commercial, as well as recreational use.	This public education campaign should be developed prior to the spring growing season. Printed materials could be posted on the town's website and distributed to the public.
	Catchment Filtration System	Install Catchment Filtration System to filter stormwater. This will reduce contaminants deposited in water bodies and groundwater.	Storm Surge, Precipitation	Reduces need for dredging related to sedimentation; Limits rate of wetland expansion. Ensures Marshfield's natural resources remain safe for consumption and commercial, as well as recreational use.	The installation of catchments could occur when improvements to the existing wastewater infrastructure occur. In addition, there could be a requirement that large developers install catchments prior to receiving development approval.
	Potable Water Pressure	If aquifer salination becomes a problem, the Town may need to sacrifice certain wells or use abandoned wells to inject potable water into the ground to create a pressure barrier between the aquifer and the seawater (Johnson, 2007).	Sea Level Rise, Temperature Rise		This is a contingency measure that ideally will not be needed once other actions to protect the Town's water resources have been taken. Temperature rise, which is an anticipated climate change, will have a deleterious impact on the water supply, so obtaining potable water to inject into unused wells would be a problem unto itself. The Town may want to collect and purify rainwater for use in short-duration water supply losses.

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Marshfield Adaptation Strategies Matrix

	Strategy	Description	Climate Stressor Addressed	Co-Benefits	Pathway to Implementation (When, Where, How)
	Sewer District Expansion - Southwest	Since aquifer contamination by septic systems is a concern near the Webster Street wells and the potential for contamination rises as flooding becomes more frequent, the sewer district should be extended to the residential areas in the southwest corner of the Town.	Sea Level Rise, Storm Surge	Prohibiting the use of septic systems in floodplains is worth FEMA Community Rating System credit.	This is an action the Town should take as soon as possible, since the Webster Street wells are already threatened by contamination. Marshfield could look to the state government or FEMA to help pay for this project. MAPC is likely to be a good source for determining outside funding options.
	Wastewater Management Options - North and South Rivers	Near the North and South Rivers, though the water quality has been somewhat improved by recent actions and will continue to improve because of regulations, the high level of bacteria indicates that these areas should be included in plans for future wastewater management upgrades in order to protect the drinking water supply as flash flooding becomes more frequent (Cox et al, 2010). If contamination becomes a problem due to individual septic systems along the North and South Rivers, Marshfield should evaluate options such as Decentralized/Clustered Wastewater Management or expanding the sewer district to those areas. <http://water.epa.gov/infrastructure/septic/manuals.cfm>	Storm Surge, Sea Level Rise	Prohibiting the use of septic systems in floodplains is worth FEMA Community Rating System credit.	The wastewater management system north and northwest of the current sewer district may not require attention if the bacterial levels decrease and remain stable. This measure is a contingency option in the event that the contamination becomes a larger problem, and will probably not be needed in the immediate future. Marshfield's Town Engineer and Department of Public Works should collaborate to find the best solution. It may be that a simple improvement in the oversight of the individual septic systems' management would rectify the problem.
	Wastewater System Assessment	The wastewater treatment plant is vulnerable to flooding from 100- and 500-year storm events, but the specific damages that would occur are unknown (Shelander, 2012). A site assessment is recommended to ascertain which adaptation strategies would best protect the infrastructure.	Storm Surge, Sea Level Rise	The Town may be able to combine this assessment with an energy audit, allowing Marshfield to identify energy-saving measures and supporting the process of becoming a Green Community.	This assessment would ideally be done as soon as possible. The storms to which the WWTP is vulnerable are becoming more frequent, and the high cost of damages and the impact on the community that would stem from failure of the treatment plant call for proactive measures. This assessment should be done by a professional who is well informed about the impacts of flooding on wastewater systems. King County, Washington released a study if its own system in 2008 which used LiDAR data to determine accurate elevation of infrastructure. <http://your.kingcounty.gov/dnrp/library/archive-documents/wtd/csi/csi-docs/0807_SLR_VF_TM.pdf>
	Mosquito Control	Focus energies at eliminating larvae by stocking freshwater bodies with species such as Gambusia holbrooki, also know as the Eastern Mosquitofish. This is an alternative to spraying for mosquitoes that would reduce the pollutants discharged into the environment.	Precipitation, Temperature	Reduces public health concerns associated with spraying chemicals.	Marshfield should attempt to implement this practice, or an alternative suggested by an environmental expert, before summer 2013. Work with an evironmental expert to identify most effective implentation strategy with regards to location and timing based on lifespan of mosquitos.

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Marshfield Adaptation Strategies Matrix

	Strategy	Description	Climate Stressor Addressed	Co-Benefits	Pathway to Implementation (When, Where, How)
Public Health	*Tree Plantings*	This program addresses the anticipated changes to temperature and precipitation levels resulting from climate change. As summer temperatures increase, so does the importance and difficulty of thermal regulation. As an alternative to increasing the use of air conditioners and other high-energy, low-efficiency options, an extensive network of trees, planted now, will ease the burden of Marshfield's hotter (and hottest) days. Street trees, with broad habits and extensive coverage, provide shade for residents outdoors, and reduce the temperature at ground level - particularly around heat-absorbing pavement. Trees also filter and purify air, helping to offset the respiratory ailments associated with warmer, less-greened municipalities. The cumulative physical benefits of temperature, aesthetics, comfort, and air quality are also known to generate psychological benefits for residents, as well. (Design for Flooding, 2011)	Temperature Rise, Precipitation	Reduction in storm water runoff along streets and sidewalks. Enhanced soil stabilization along stream banks. Can be paired with additional low-impact catchment and detention programs. Aesthetic benefits to addition of trees. Stimulus to local landscaping and nursery businesses.	Marshfield would benefit from identifying candidate streets for tree plantings by 2020. Two areas to consider are along Ocean Street west of Foster Avenue, and along Island Street. The Town could launch a tree planting campaign aided by volunteers who work with local landscaping and nursery businesses to plant appropriate trees in locations designated by the Town.
Heat Wave	*Green Roofs*	This program addresses the increase in temperature extremes and precipitation intensity forecasted by climate change. Contemporary roofing practices maximize impermeability and precipitation sheeting, but minimize thermal regulation. Green roofs, which consist of broad "planters" and turf rolls, are capable of reducing heating costs in the winter, cooling costs in the summer, and breaking down airborne pollutants all year long. Installation costs are roughly 1.5 times the price of a conventional roof, but require less maintenance and last more than twice as long. (City of Chicago, 2006)	Temperature Rise, Precipitation	Cost savings in winter and summer. Extended life span of the roof. Controls storm water runoff. Additional native plants and habitat in the landscape.	The Town should begin promoting this option within the next few years, in hopes that a number of homeowners will participate by 2020. Marshfield can incentivize the investment to encourage residential buy-in. Additionally, the town can sponsor a number of workshops and information sessions for local roofing companies and residents interested in learning more about green roof technology, installation, maintenance, and costs.
	Cooling Stations	Marshfield provides cooling stations when needed at The Council on Aging and the Marshfield Library. In event of extreme heat, The Council on Aging can be expected to stay open until 4:30pm and the Library until 8pm. Publicly accessible information states that The Council on Aging may stay open as late as 10pm in extreme heat waves. Marshfield should consider establishing a shuttle program to transport seniors, residents with mobility difficulty, and residents without access to cars, to cooling stations. Best practices for cooling stations would be to remain open to the public until after the hottest part of the day has passed, regardless of standard business hours. The EPA offers thorough guidance for helping residents through extreme heat events. <http://www.epa.gov/heatisland/about/pdf/EHEguide_final.pdf>	Temperature Rise	Publicly accessible solutions such as community cooling stations increase social capacity and strengthen community bonds.	Cooling station best practices should be examined, and an updated protocol should be released to the public before the summer of 2013. Any cooling stations added to the Town's protocol should be accessible by public transportation. Marshfield's Adaptation Committee, The Council on Aging, and Marshfield Emergency Managment Agency should work together to develop a plan that makes cooling stations work as well as possible for residents and visitors in the event of extreme heat.
	Neighbor Check-In Program	This program woud be a natural extension of Marshfield's Council on Aging's "Are You Okay?" and "Friendly Visitor" programs. Seniors, families with small children, or residents who must leave pets at home can sign on for this service, and volunteers in the town can set up phone trees and home visits accordingly. If someone is struggling with the heat, a volunteer could call for a shuttle to a cooling station. Philadelphia's Hot Weather Health-Watch should be referenced as a Best Practice. <http://www.epa.gov/heatisland/about/pdf/EHEguide_final.pdf>	Temperature Rise	Public volunteer networks increase social capacity of a community to withstand stressors.	This program should be developed before the summer of 2013. The Neighbor Check-In Program could be established in the same way as the other Council on Aging programs.

matrix pg. 8

5. Sector Implications

Natural resources, coastal infrastructure, stormwater infrastructure, water supply, wastewater systems, soft municipal infrastructure, transportation, and private property will be impacted by changes in the climate. This section provides an inventory of existing resources and details the vulnerabilities and impacts likely to be experienced from a changing climate, as well as strategies that could mitigate damage and exploit opportunities in each sector.

Natural Resources

Various scenes in the landscape, both built and non-built, define a community's character. The natural landscape, including forests, meadows, wetlands, rivers and beaches, and the working landscape, including farms and harbors, play a prominent role in how residents perceive their sense of place and what makes it special. These landscapes provide a variety of functions in a community – signifying "small town feel," purifying water, and infusing the local economy with tourism dollars (Town of Rhinebeck, 2008).

Existing Resources

The Town of Marshfield is fortunate to have an abundance of natural resources. This report will focus on the town's coastline, wetlands, fisheries, and agricultural lands.

The most important natural feature of Marshfield is its open coastline. On the east, the town faces the sea from its boundary with Scituate south to the Duxbury line, a distance of more than four and one half miles. The structure of the coastline varies from the barrier beaches at Rexhame, Sunrise Beach, Esplanade, Bluefish Cove and Green Harbor, to the eroding coastal banks of Ocean Bluff, Brant Rock, and Blackman's Point and to the only natural rock outcroppings, one at Brant Rock and one at Bluefish Point. The 39-acre Rexhame Beach, near the northern end of the town's shoreline, lies between the South River and the Atlantic Ocean. This area is reserved for a bathing beach and recreation area for the residents of the town. In addition there is some public access to the water at other points, including Damon's Point, the South River ramp, the Town Pier, and Brant Rock (Cox et al., 2010).

Countless wetland areas exist in town, either as perched water trapped by heavy clay or as springs seeping from the base of gravel deposits. These wetlands include river corridors, ponds, marshland, and cranberry bogs. There are more than 1,000 acres of conservation owned wetlands (Marshfield Conservation Commission, 2002). Additionally, the Commonwealth of Massachusetts owns the English Salt Marsh Wildlife Management Area, 166 acres of estuary on the North and South Rivers. A large area of what used to be salt marsh is now a fresh or brackish water polder. The polder was created by constructing a dike and a large gate, which prevents flooding at high tide (Cox et al., 2010).

Marshfield has two fishways, one where the Green Harbor River flows into Green Harbor and another on the South River in Veterans Park. Marinas in these areas afford access to the open ocean and support the presence of a commercial fishing fleet. Fish can now enter the upper Green Harbor River above the dike through an opening in a new adjustable tide gate installed to help restore the Green Harbor River estuary. There are fish runs and spawning habitat on the Second Herring Brook and the North and South Rivers. The runs and spawning habitat support alewife, blue herring, Atlantic salmon, and rainbow smelt. In addition, there are six shellfish growing areas in Marshfield within the North River, South River, and Green Harbor River

Estuaries (Cox et al., 2010).

Two areas of historically productive farm land exist in Town: the Two Mile Farm, bordering the North River, and the nearly level section southeast of Marshfield Village between the Neck Rock (Ocean Street), Webster Street, and Cut River. (The Daniel Webster estate and farm was on Webster Street.) In total, 243 acres of agricultural land and eight working cranberry bogs are present in Marshfield. The majority of this land is used and zoned as residential and, although currently protected under Chapter 61 designation, could at any time be removed from this protection and be developed (Cox et al., 2010).

Vulnerabilities and Impacts

The Town of Marshfield's natural resources are vulnerable to sea level rise and increased storm surge, precipitation, and temperature.

The armoring of a coastline temporarily reduces the erosion in that area but also reduces the volume of sediment that is normally deposited by ocean currents and replenishes the beach deposition. This sediment deficit results in a recession and narrowing of beaches, increased erosion and an increase in coastal storm damage during storm events (Cox et al., 2010). The process of beach denourishment will be exacerbated by sea level rise and increased storm surge.

Sedimentation is a problem in Marshfield's wetlands as a result of antiquated road drainage systems. Aside from the effects of pollutants being carried into the wetlands, the sediment load also holds pollutants, including petroleum products, fertilizers, and pesticides, that affect overall ecosystem health (Cox et al., 2010). With increased storm surge and precipitation, the resulting increase in stormwater runoff will intensify the sedimentation process and concentration of pollutants in the town's wetlands. In addition, storm surge and precipitation will cause expansion of the wetlands, which could result in losses to publicly and privately held land.

Fishing provides the base for an economic sector important to the town of Marshfield. It also is an important cultural practice that gives identity to residents and the community. Climate stressors such as storm surge and increased precipitation threaten critical shore-based infrastructure, such as docking facilities, processing facilities, and other elements of working waterfronts (Tuler et al., 2012). Sediment deposition in Green Harbor and Marshfield's navigation channels already necessitates regular dredging. Acceleration of sedimentation from changes in the climate will place a significant financial burden on the Town. In addition, many river segments and shellfish growing areas are being impacted by non-point source pollution and nutrient leaching from septic systems. This process will be exacerbated by the impacts of storm surge and precipitation, which will cause increased flooding and rising water tables. This has an adverse impact on the town's ability to maintain a healthy fish population. In fact, declining water quality has already resulted in the closure of some shellfish beds because of high levels of e. coli resulting largely from the leaching of septic systems into the groundwater (Cox et al., 2010).

Ocean acidification and shifting temperatures are expected to impact fish populations, locations, and reproduction (Ocean Studies Board, 2010; Frumhoff et al., 2007). "Ocean acidification is the result of an increase in carbon dioxide absorption by ocean water and the corresponding decrease in pH. As seawater becomes less alkaline (more acidic), less calcium carbonate is

available for corals, shellfish, and other sea life to build their shells and skeletons" (NOAA, 2010). With regards to shifting temperatures, research suggests that loss of reproductive productivity in fish may result, as the more nutrient-rich cold water is prevented from mixing with warmer, nutrient-poor surface waters. As water temperatures shift, species' ranges may also shift, in part because their food requirements may be harder to meet (Ocean Studies Board, 2010). Areas historically fished may no longer support the targeted species, which can exert further pressures on health and safety of fishermen because they must travel further distances.

Marshfield's agricultural lands, though primarily fallow, have scenic value and provide food and cover for wildlife. The same is true of the cranberry bogs, particularly during harvest season. Unfortunately, shifting temperatures will have an impact on agricultural production. Cranberries require long periods of winter chill for optimum flowering and fruit development. As winter temperatures increase, the chilling requirements for these fruits will not be met. This is of serious concern, because there are currently no known low-chill cranberry varieties (Frumhoff et al., 2007). Rising winter temperatures are also expected to drive the continued northward expansion of agricultural pests as well as weeds such as kudzu. This would further impede crop production and potentially pressure growers to increase their herbicide and pesticide use (Frumhoff et al., 2007). In addition, the majority of Marshfield's agricultural lands are under the protection of Chapter 61, which means they could be removed from this protection at any time and developed. If developed, their ability to absorb and filter increased precipitation associated with climate change would be reduced and this could exacerbate flooding and pollution in other areas of the town (Cox et al., 2010).

Best Fit Strategies

Topics to view in Adaptation Strategies matrix:

- Emphasize "Living Shorelines" Treatments
- Land Acquisition
- Open Space Protection
- Catchment Filtration System
- Wastewater System Assessment
- Tree Plantings
- Green Roofs

Stormwater and Coastal Infrastructure

With or without climate change projections, Marshfield's stormwater and coastal infrastructure systems present significant short and long-term challenges to the Town. As in most communities, there are two stormwater management systems in Marshfield: natural, and conventional. Natural stormwater management systems rely on trees, soils, leaf litter, ponds, riverbanks, and wetlands to manage a sudden influx of precipitation during a storm event. Conventional stormwater systems, however, swiftly channel precipitation from roads and parking lots to streams, ponds, and other surface waters, by way of storm drains, culverts, and piping. In some instances, basins are constructed to detain water as well, in place of the natural components described above.

However, Marshfield also relies on coastal armoring and tide regulation to protect its residents from the dangers associated with heavy rainfall, storm surges, and extremely high tides.

Existing Resources

Marshfield's natural stormwater management system consists of its thousands of acres of undeveloped and protected land. Forests, meadows, forested wetlands, and riparian corridors are found in the town's upland woodlands, along the banks of its rivers, and among its marshes. This system's stormwater capacity is indirectly managed as a part of ongoing conservation efforts in the town, but it is responsible for a sizeable amount of stormwater absorption.

The town's conventional stormwater management system is comprised of some 4,000 catch basins directing excess rain and ground water to approximately 400 outfall pipes. In recent years, a number of detention basins have been constructed to receive the stormwater from fully developed commercial parcels, and slow the rate of runoff. Figure 5.1, from Marshfield's municipal GIS service, locates each of the town's several thousand storm drains. Their concentration around Route 139 suggests that the most heavily trafficked road in town is delivering untreated runoff to the ocean by way of the town's streams.

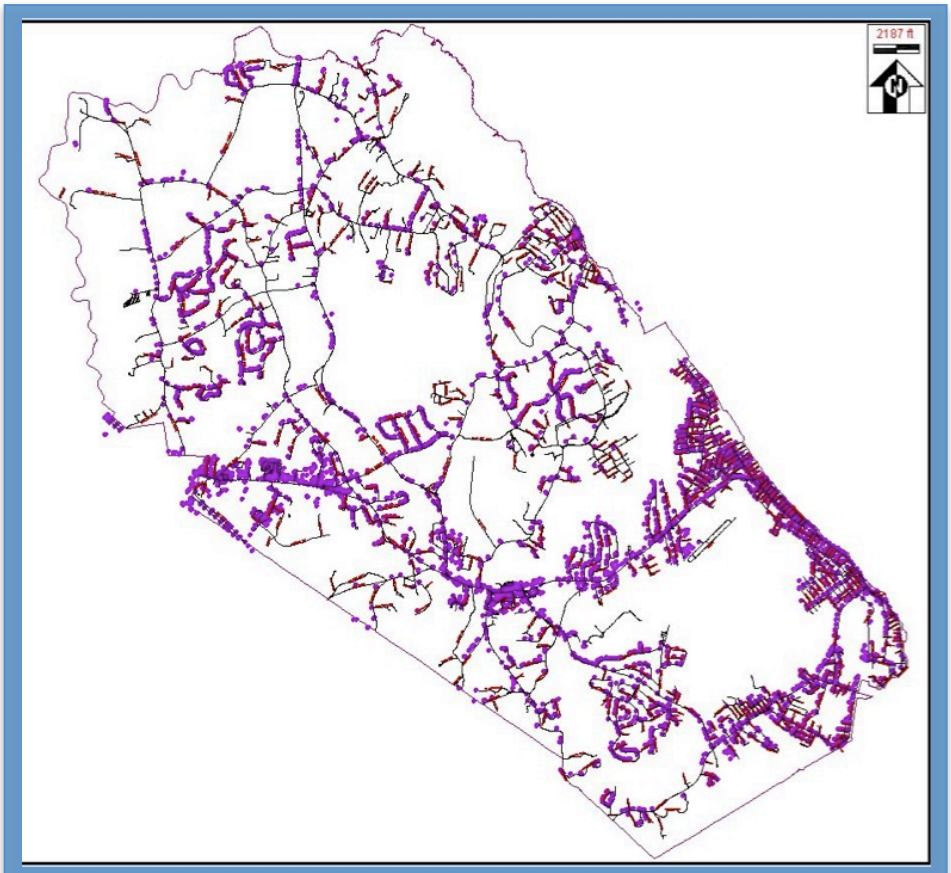

Figure 5.1: Marshfield Stormwater Catchments
Source: Town of Marshfield Online GIS, 2012.

Marshfield's coastal infrastructure extends from Rexhame Road to Bay Avenue, with occasional gaps in between. Seawalls make up the bulk of the armoring, and jetties extend into the ocean by the Brant Rock Esplanade. The entrance to Green Harbor is protected by two jetties, and the Green Harbor Marina abuts the tidal gate that is installed beneath Dyke Road.

Vulnerabilities and Impacts

Marshfield's stormwater and coastal infrastructure systems are most vulnerable to the climate change hazards of precipitation intensity, sea level rise, and storm surge.

While Marshfield has made significant strides in the past two decades as part of the National Pollutant Discharge Elimination System permit process, aging or undersized culverts and other components will become less and less stable as storm intensity increases. As storm intensity increases, spikes in runoff volume become sharper and peak more quickly. This runoff makes its way into the town's brooks and streams, along with runoff from upstream communities. Stream banks cave under the pressure of rapid inflow from outfall pipes large and small, exposing the roots of plants that stabilize the shore, and depositing soils father downstream.

The relative success that sea walls and storm drains have achieved has led to an extreme reliance on them, but their continued success is in question. Increases to storm surge levels, along with baseline sea level rise, will push coastal infrastructure to its limits with increasing frequency. Seawalls will require repair more often, reducing the lifespan of the investment. Marshfield's oldest sea wall was built during Franklin Roosevelt's presidency, when fewer than 2,500 people called Marshfield home. The population is now more than ten times that amount, and the Ocean Bluff/Brant Rock neighborhoods are most likely to feel the effects of aging infrastructure first, from the east and the west.

Best Fit Strategies

Topics to view in Adaptation Strategies matrix:

- Emphasize "Living Shorelines" Treatments
- Establish Integrated Water Management
- Essential Seawall Repair
- Downspout Removal
- Open Space Protections
- Improve Stormwater Drainage Capacity
- Catchment Filtration System
- Tree Plantings
- Green Roofs

Water Supply and Wastewater Systems

"Water is the primary medium through which climate change influences Earth's ecosystem and thus the livelihood and well-being of societies" (UN-Water, 2010). It is difficult to think of a climate change hazard that does not involve water in some way. With three rivers, approximately

twelve miles of coastline, and over 1,000 acres of conservation wetlands and estuaries, Marshfield is no stranger to water as a powerful force of nature. The Town's water and wastewater systems include the public water supply, a public sewer district with wastewater treatment facilities, and private septic systems.

Existing Resources

Water is a resource of great importance to Marshfield. Approximately 90% of the town's drinking water comes from public water supply wells, which access the Plymouth-Carver Aquifer; private wells supply the remaining 10% of households. The surrounding Towns of Duxbury, Scituate, and Pembroke also receive some of their water from the Marshfield pumping system.

A portion of the town is sewered, including the Ocean Bluff, Brant Rock, and Green Harbor-Cedar Crest neighborhoods, as well as the inland Ocean Street corridor. The remainder of the town uses septic systems for wastewater management. The Town's wastewater treatment plant and main pump station are located in Brant Rock, with an additional wastewater treatment facility located at the High School (Cox et al., 2010).

Vulnerabilities and Impacts

Marshfield's water and wastewater systems are most vulnerable to the climate change hazards of sea level rise and storm surge. Seawater intrusion and flash flooding are damaging to both systems, but in different ways.

The public water supply system functions by accessing the underground Plymouth-Carver Aquifer, pumping to treatment facilities, then distributing water to 90% of Marshfield's households. Sea level rise could cause the water source to be contaminated by the inflow of salt water to the fresh water aquifer (also known as aquifer salination). This would be exacerbated by other effects of climate change. More dramatic and more frequent storm surges would bring more salt water over the land to then drain into the soil. An increase in the frequency of winter storms would lead to an increased use of salt to melt road ice; that salt then finds its way into the groundwater. Increased temperature would lead to higher usage of water, which could cause the water table to drop. Because of the difference in density between salt water and fresh water, the fresh water level must remain higher than the seawater in order to keep salt water from intruding (Freas et al., 2010; Johnson, 2007). Water treatment facilities may also become inundated by rising sea levels, which would be compounded by storm surge; the infrastructure could then fail, causing interruption in water supply and high costs of repair. Temperature rise also compromises the water supply system because warmer water invites more algal bloom, which leads to toxicity and taste and odor problems (Freas et al., 2010). Marshfield's water treatment facility is on relatively high ground, but some wells are in danger of being contaminated by materials in the surrounding soil, which is a problem that is exacerbated by flooding.

The vulnerability of the wastewater treatment facility is shown in Figure 5.2. In order to function properly using flow by gravity, a wastewater treatment plant must be elevated lower than the area it serves. For this reason, wastewater treatment plants are often located in floodplains, which is the case in Marshfield. The Town's wastewater treatment plant is adjacent to the Green Harbor River and susceptible to 100- and 500-year flood levels. Most of the southern half of Marshfield is sewered, which protects the aquifer under the most densely populated area of Town from being contaminated by nutrients leaching from inundated septic tanks. However, the southwest corner of Marshfield is not yet serviced by sewer, and the Webster Street wells are in danger of being removed from the water supply system because of septic contamination (Cox et al., 2010). Shellfish beds in the North and South Rivers have also been affected by bacteria originating mostly from septic systems (Cox et al., 2010).

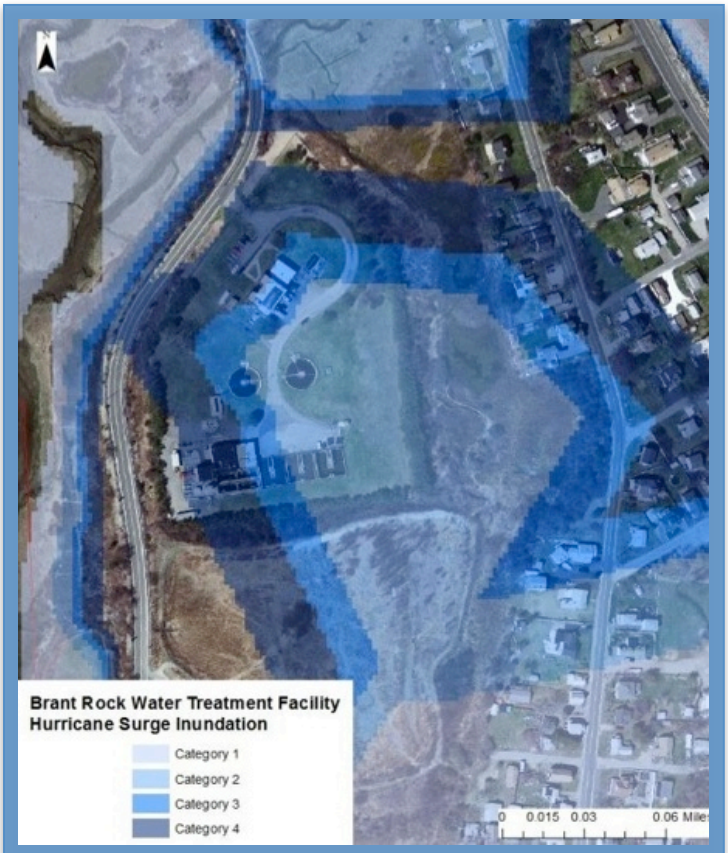

Figure 5.2: Projected Inundation of Wastewater Treatment Plant
Source: Shelander, 2012.

Best Fit Strategies

Topics to view in Adaptation Strategies matrix:

- Establish Integrated Water Management
- Sewer District Expansion – Southwest
- Wastewater Management Options – North and South Rivers
- Public Education on Chemical Storage
- Public Education on Alternatives to Herbicides and Pesticides
- Propane Tank Securement
- Catchment Filtration
- Wastewater System Assessment
- Alternative Road De-Icer

- Potable Water Pressure

Municipal Services

The Town of Marshfield's municipal services allows for the delivery of vital services to residents. For the purposes of this report, municipal services includes town offices, emergency services such as police and fire, the library, schools, as well as open spaces and parks.

Existing Resources

The Town of Marshfield owns and operates a Town Hall, three fire stations, a police station, emergency operations center, seven schools, two libraries and a number of parks.

Vulnerabilities and Impacts

The municipal infrastructure in the town of Marshfield is most vulnerable to storm increased precipitation and storm surge. In addition, increased temperatures may have an impact on the costs associated with cooling municipal buildings.

Repairing structural damage caused by strong winds, heavy rain, and flooding will place a financial burden on the Town. In addition, it will reduce citizen access to the critical services provided by the municipality. Damage to the police and fire department could compromise the Town's ability to deliver emergency services. This is of great concern during storm events when emergency services are necessary to ensure the health and safety of the general population. Furthermore, municipal buildings are often used as shelters during storm events. If these buildings are declared unsafe, the Town will be unable to provide safe accommodations to displaced citizens.

In Marshfield, several service buildings are considered to be particularly vulnerable in a storm scenario (FEMA Flood Plain Map). While Town Hall, one fire station, and the police department are not located in a flood plain, one of the fire stations is located close to the shore and is surrounded by areas where flooding is common. The emergency operations center, one of the libraries and one of the schools are also potentially susceptible to flooding.

Both flooding and increased temperatures will have health implications for the town. Exposure to mold growth associated with water damage can cause respiratory problems. Increased temperatures can also cause respiratory problems. Prolonged heat waves can also cause an increase in mortality rates among senior citizens, particularly when daily temperatures exceed 90 degrees Fahrenheit for days at a time.

Increased temperatures associated with climate change will place a financial burden on the Town because of the additional cost associated with air conditioning. Installation of cooling systems and alterations to structures will be costly. This is especially true for schools, where high temperatures in May and September may lead to temporary closures.

Marshfield's primary source of electricity comes from the state's electric grid. This grid is fed, in part, by the private NSTAR Corporation. The lack of alternative energy sources in Marshfield may render the town vulnerable to power outages.

Best Fit Strategies

Topics to view in Adaptation Strategies matrix:

- Building Elevation Grant Program
- Road Elevation
- Open Space Protection
- Tree Plantings
- Green Roofs
- Neighbor Check-In Program

Transportation Systems

The ability of transportation infrastructure and operations to efficiently move people and goods from one location to another is vital to the health of the economy and community. This is especially true for the town of Marshfield, where a large portion of the population commutes long distances to work: the mean commute time for Marshfield residents is thirty-five minutes (US Census Bureau, 2010). This is longer than the average commute time for both the state and the nation. In addition, 82% of residents travel by car with no passengers.

Existing Resources

The transportation system in Marshfield includes all roads, public transportation routes, ports, and the municipal airport.

The town has a mix of state owned roads, town owned roads, and private roads that the Town maintains and private roads and common driveways closed to public passage. Many of the private roads maintained by the Town are unpaved with substandard width and have inadequate stormwater systems. One hundred and sixty miles of road link the town to major routes. There are two major roadways in Marshfield: Route 139, that intersects with Route 3, and circles through town, and Route 3A, a secondary North-South route.

Public transportation to Boston is provided via the Old Colony Rail Line, which has several stations within 25 minutes of Marshfield. The MBTA subway system to Boston currently terminates in Braintree, 14 miles from the center of Marshfield. The Port acts as both a fishing harbor for commercial fishing and local recreation, but does not provide ferry service. However, commuter boats leave from the nearby town of Hingham. The GATRA bus, which runs regularly through town, links various nodes in Marshfield to neighboring towns such a Duxbury and Kingston.

Marshfield Airport-Harlow Field (GHG) is located just outside Boston's Class B airspace to the southeast. It consists of two paved asphalt landing strips that are 3,000 and 75 feet long. It functions as a runway for business and private aircrafts. Service from the Marshfield airport connects residents and visitors to Boston as well as the neighboring airports of Provincetown and Plymouth. There are also a series of MedFlight landing spots along the coastal areas of Brant Rock and Green Harbor.

Vulnerabilities and Impacts

The Town of Marshfield's transportation systems are vulnerable to impacts related to storm surge, increased precipitation, and increased temperature. The impact of these stressors could dramatically affect the Town's ability to sustain commerce, public health, safety, welfare, and safety and security.

Marshfield's coastal transportation infrastructure, including beach roads and the harbors, are most vulnerable to extreme weather events that are marked by high winds, waves, and storm surge (CCAAC, 2011). Inland transportation infrastructure also may be affected by flooding. Other impacts to the transportation system include erosion, heavy snowfall, and increased temperature. Erosion can cause flooding and road washout that is costly and dangerous. Accessibility is cut off when reconstruction efforts are required to repair arterials and circulation routes. Heavy snowfall – a hazard predicted to increase as climate change progresses – could lead to flooding and the general costs associated with storm cleanup will place a financial burden on the municipality. Elevated temperatures can cause roads and train rails to buckle and warp, which could lead to accidents (Sperry, 2012). In addition, there is a paucity of alternative transportation modes and routes available to provide backup and continuity of service in climate related stress situations.

Best Fit Strategies

Topics to view in Adaptation Strategies matrix:

- Road Elevation
- Abandon Transportation Infrastructure
- Alternative Transportation Options
- Improve Stormwater Drainage Capacity

Private Property

Private property, for the purposes of this report, is considered the land, buildings, possessions, and operations owned and operated by residents and businesses in the town of Marshfield. While the major investment of the typical American family remains the home, people also own automobiles and commercial business establishments.

Existing Resources

Approximately 11,000 housing units are present in the town of Marshfield and nearly 9,000 of those units are single-family homes. Over half of the homes in Marshfield are valued between $300,000 and $500,000, with a median home price of $416,100 (2010 ACS 3-yr). Marshfield is also home to 217 privately owned business establishments (2010 ACS 3-yr) and boasts a thriving Chamber of Commerce.

Vulnerabilities and Impacts

Private property can be affected by the impacts of sea level rise, storm surge, increased precipitation, and temperature. Severe coastal storms can cause widespread flood damage to physical property and enterprises. With an increase in sea level and precipitation, flooding will

be more severe and occur more often. In Marshfield, these impacts are already seen with a spring, or astronomically high, tide. Wind damage is another hazard. Category 2 hurricanes can bring sustained wind speeds of 100-110 miles per hour and while category 3 or 4 hurricanes are currently uncommon in New England, warming temperatures may enable tropical storms to maintain their strength as they travel further up the East Coast. These stronger storms have the potential to bring wind speeds of 150 miles per hour or higher to Marshfield. Changes in climate also have the potential to alter the shoreline, making it necessary to rebuild docks and other facilities, and to decrease lot sizes and the effectiveness of septic systems as the sea and marshes encroach on private property. In addition, revenue losses associated with the closure of businesses due to physical damage is an economic impact that should be of concern to the Town. Frequent damage to physical property may result in decreased property values and disinvestment in structures that are too costly to maintain.

Marshfield's most vulnerable areas, with regards to private property, are centered in two areas: east of Humarock, specifically the area southeast of Ferry Street, and the area comprising Ocean Bluff and Brant Rock. The area to the east of Humarock, at the bottom of Ferry Hill, is at a very low elevation. While Humarock provides some protection to this area, water traveling to the South River could cause flooding. In the area of Ocean Bluff and Brant Rock the properties adjacent to and south of Ocean St (Rt. 139), with the exception of the area of higher elevation around the Brank Rock fire station, are in danger of inundation from a major storm surge event. While these two areas are of primary concern, a comprehensive list of vulnerable locations is included in the biophysical vulnerabilities section. There are currently approximately 2,500 parcels in danger of inundation from a 100-year storm. However, by the end of the century, a 100-year storm could place over 4,000 parcels in danger of flooding.

Best Fit Strategies

Topics to view in Adaptation Strategies matrix:

- Brant Rock Resurfacing
- Building Elevation Grant
- Land Acquisition
- Purchase of Development Rights
- Public Education and Workshop
- Propane Tank Securement

6. Conclusion

The contents of this chapter are intended to address the topic of climate change in four parts: first, to outline reasonable climate change projections in the short and long term; second, to anticipate the likely impacts of those changes on the town of Marshfield; third, to examine the potential consequences of those impacts; and fourth, to describe adaptation strategies to prepare for or minimize those impacts. While a number of these strategies propose new directions for Marshfield, or are the result of current research and management practices, it is important to

recognize that adaptation is not a new concept, or buzzword for a new era. Marshfield's history is closely tied to adaptation, and the evidence of it is close at hand.

Adaptation is as much a Green Harbor jetty as it an old haying canal in the English Salt Marsh; it is as much a flood-proofed basement as it is a pair of shutters protecting the windows of the town's oldest houses. Adaptation is the reason Enterprise Drive is a quarter-mile east of Route 3, and the reason a Water Resource Protection District covers much of the town's geographic center. Adaptation is why Old Main Street is "old," and New Inlet is "new." Lastly, adaptation is why the seawalls were built, and why the town was part of the 2011 *South Shore Coastal Hazards Adaptation Study*.

Adaptation, then, does not imply a single set of goals, values, methods, stakeholders, or outcomes. Rather, adaptation is shaped by a number of forces: economic, technical, social, environmental, political, and cultural, to name just a few. These forces do not exist in static equilibrium, but shift in accordance with the times. As a result, adaptation strategies reflect the era of their implementation: the problems encountered, the options available, and the anticipated outcome judged most desirable by those involved in the decision.

The *Adaptation Study* serves as a useful illustration for adaptation as it is considered in this place and time. The study was prepared by a regional planning agency in conjunction with the municipalities comprising the study area, with support from two relevant statewide agencies. From this perspective, climate change is an issue that can be understood and addressed at a number of levels, some of which reach beyond town boundaries. If the towns of Duxbury, Marshfield, and Scituate can cooperatively address common issues, then perhaps they will become stronger advocates for shared concerns. This itself requires its own form of adaptation, but can result in more effective partnerships with regional and state officials. However, the motivation for collaboration does not arise simply for the sake of collaborating; it arises out of a recognized potential for interconnected whole to help each individual community adapt to the identified hazards.

In this chapter, adaptation is very much about interconnectedness, as are the climate impacts the adaptation strategies are meant to address. Interconnected strategies function best within an integrated system, in which impacts are distributed. Strategy characteristics mutually reinforce one another, and reduce dependence on any one strategy. A strategy's fitness, as ever, is based on utility. Beforehand, municipalities might have asked, "how well does this strategy solve that problem?" From an interconnected adaptation perspective, however, the question might be posed differently. In evaluating the adaptation strategies presented here, the question became "how many of these issues does this strategy address?"

By the end of this century, Marshfield will have passed into the care of hands unknown to today's residents, though surely related to some of them. It is difficult to know what challenges those residents will be adapting to, but there will be adaptation. Along a coastline, no judgments are final. Unending, however, are the negotiations, collaborations, and conflicts between the people and the sea. As in any negotiation, terms and tactics change as the stakes are raised, and no one wants to be caught in a bluff.

Appendix A: Glossary of Terms

10-, 100-, 500-Year Flood/Storm

Because the 1-percent [annual exceedence percentage] flood has a 1 in 100 chance of being equaled or exceeded in any 1 year, and it has an average recurrence interval of 100 years, it often is referred to as the "100-year flood" (Holmes, 2010). [Similarly, a "10-year flood" is one that stastically has a 1 in 10 chance (10%), and a "500-year flood" has a 1 in 500 chance (0.2%) of being equaled or exceeded in any 1 year.]

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Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate (IPCC, 2012).

Adaptive Capacity

Adaptive capacity is the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2001).

Biophysical Vulnerability

Biophysical vulnerability, for the purposes of this report, is understood as the product of the geographic context, including site location and proximity to the hazard (Cutter et al., 2003).

Climate

Climate in a narrow sense is usually defined as the "average weather" or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years (IPCC, 2012).

Climate Change

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2001).

Exposure

The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected (IPCC, 2012).

Hazard
The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources (IPCC, 2012).

Impacts
Effects on natural and human systems. In this report, the term 'impacts' is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change (IPCC, 2012).

Mitigation
A human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2012).

Resilience
The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions (IPCC, 2012).

Sensitivity
The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2001).

Social Vulnerability
The product of social inequalities that influence or shape the susceptibility of various groups to harm and that also governs their ability to respond (Cutter et al., 2003).

Stressor
Any physical, chemical, or biological entity that can induce an adverse response. (United States Climate Change Science Program, 2008)

Vulnerability
The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. (IPCC, 2001).

Appendix B: Figures & Tables

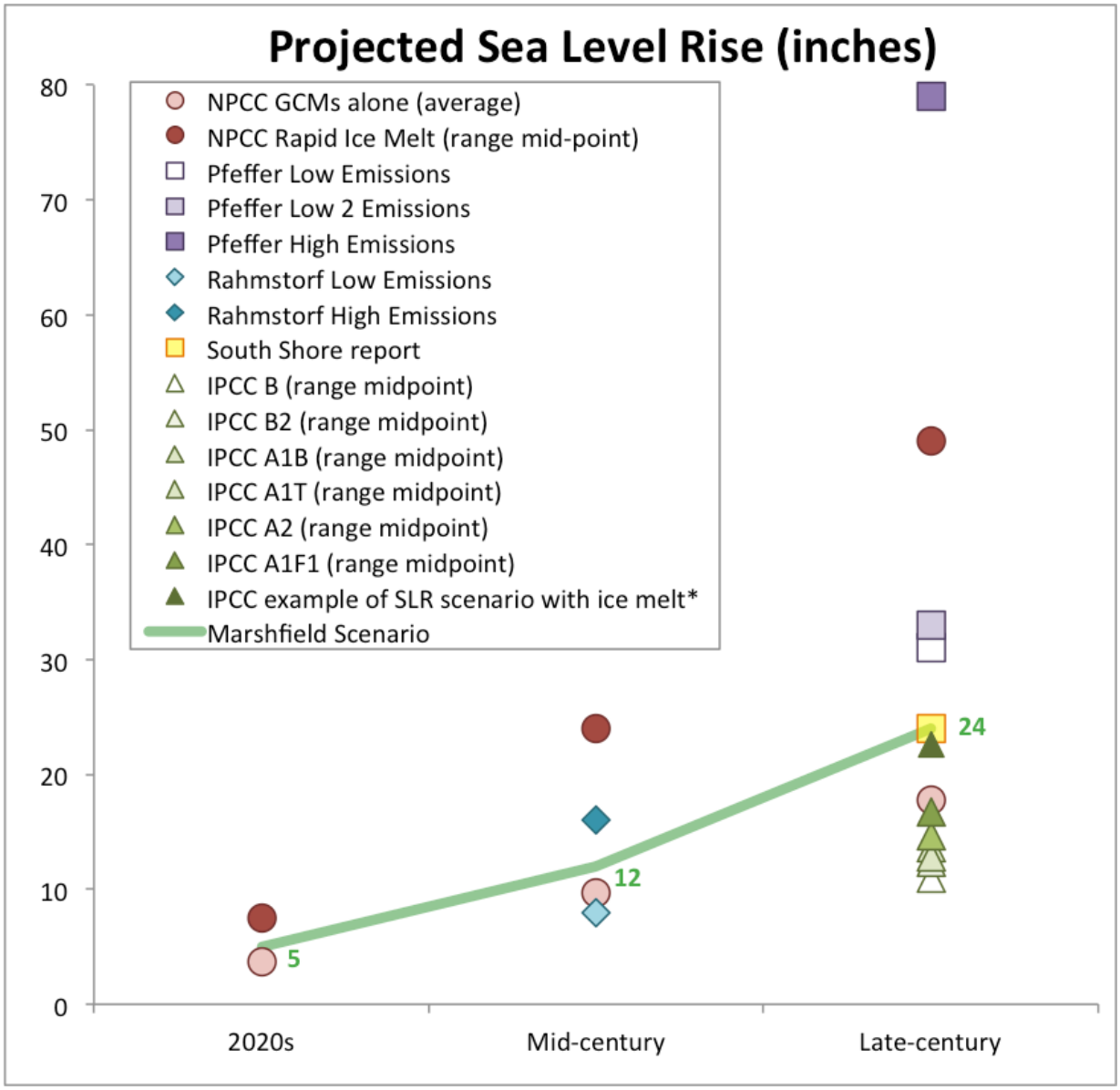

Figure 2.1. *Sources for Marshfield Scenario: NPCC, 2009; Climate Change Adaptation Advisory Committee, 2011; MAPC, 2011. Supporting sources listed in Appendix C.*

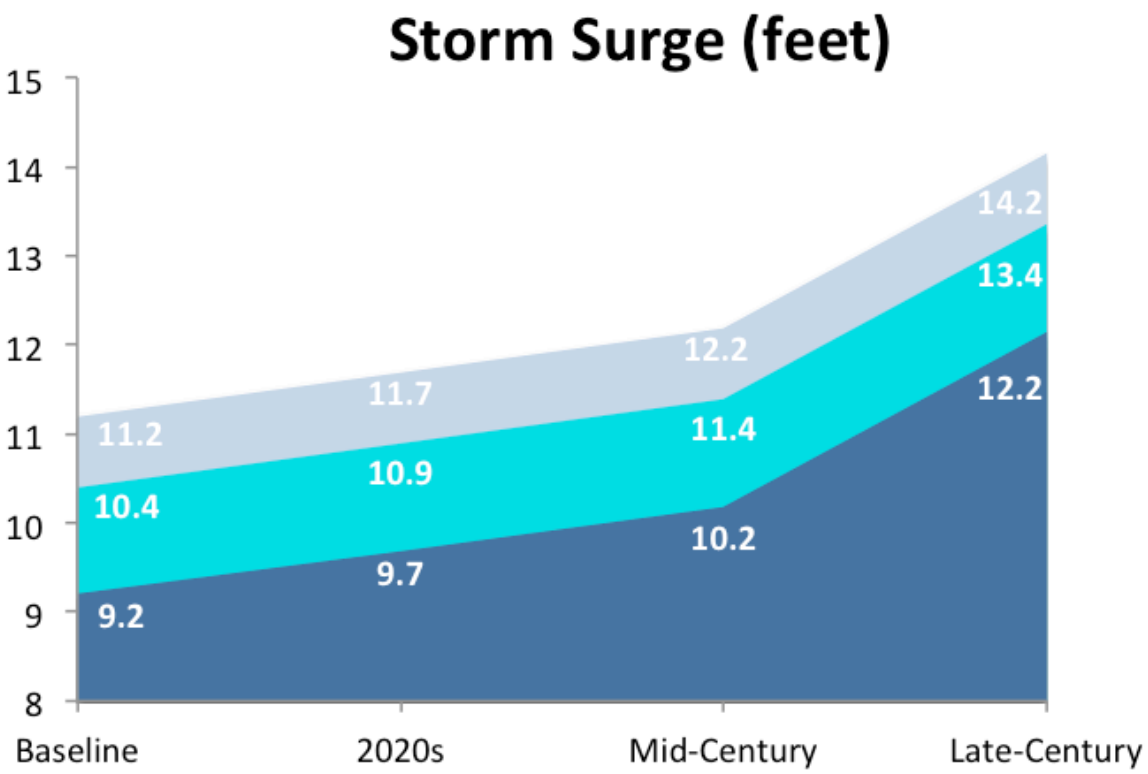

Figure 2.2. *Sources: Kirshen, 2008; NPCC, 2009.*

	2020s	Mid-Century	Late-Century
"10-Year Storm"	8 - 10 years	3 - 6 years	1 - 3 years
"100-Year Storm" (NPCC)	65 - 85 years	35 - 55 years	15 - 35 years
"100-Year Storm" (Kirshen)	-	< 2 - 15 years	< 2 - 5 years
"500-Year Storm"	380 - 450 years	250 - 330 years	120 - 250 years

Table 2.1. *Data sources: NPCC, 2009; Kirshen, 2008b.*

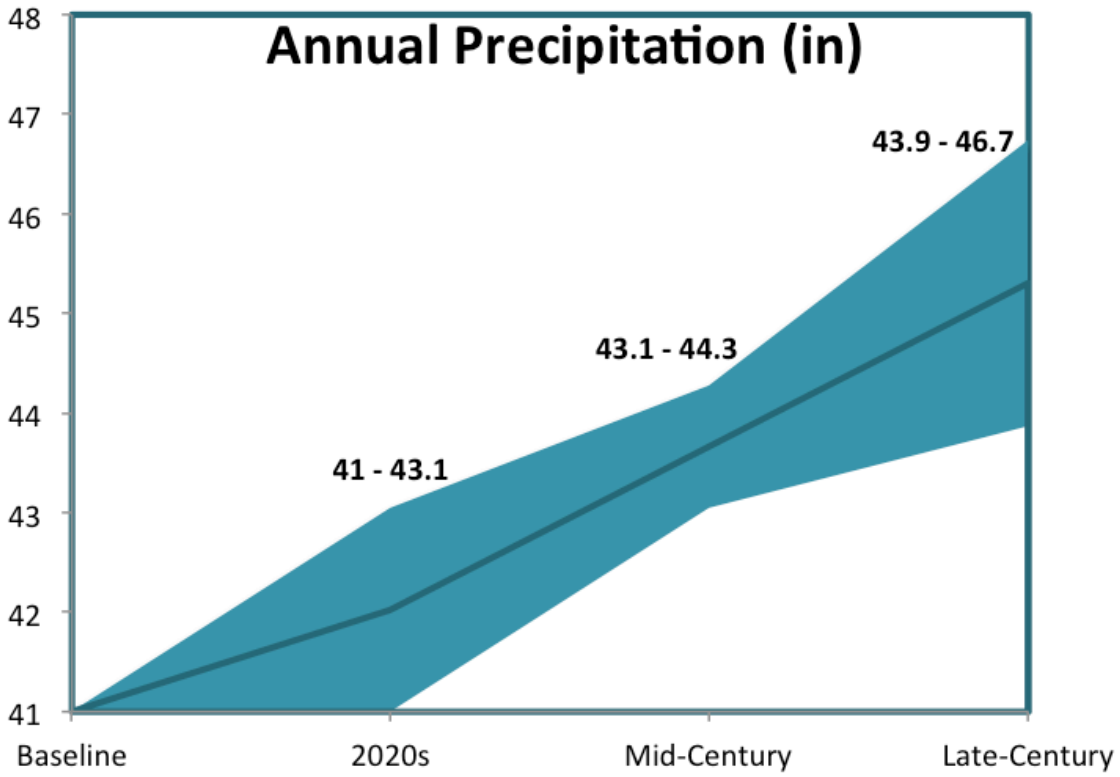

Figure 2.3. *Sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.*

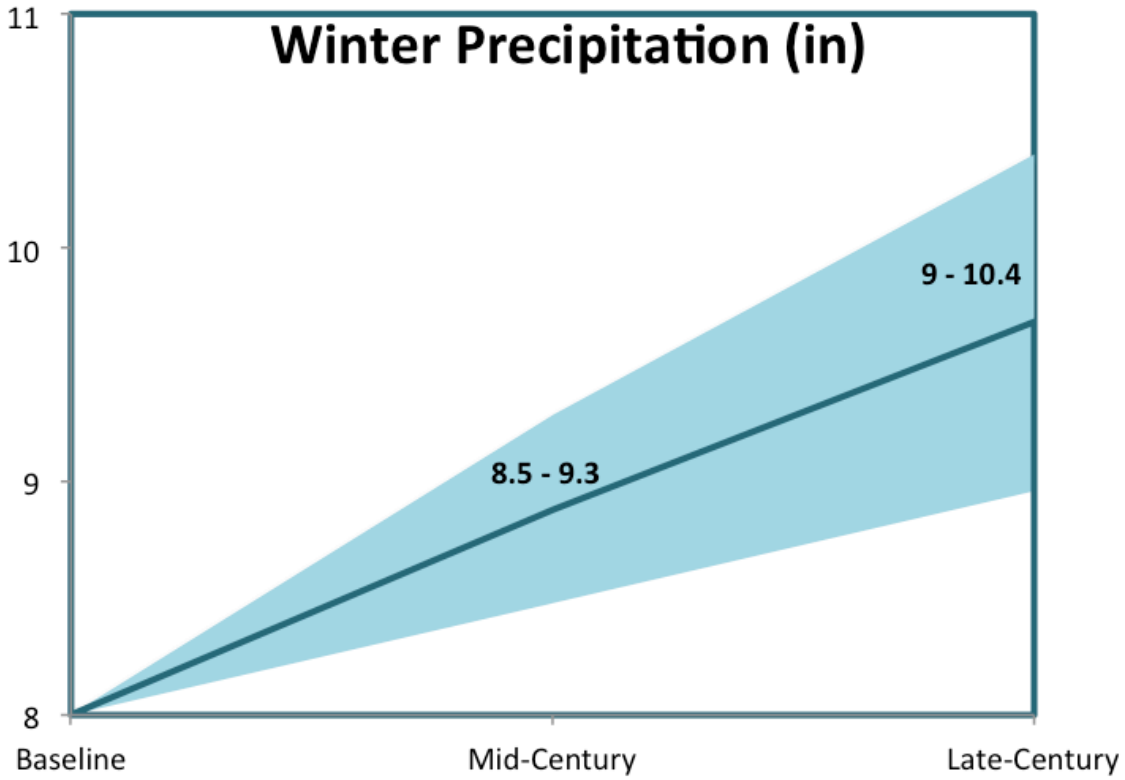

Figure 2.4. *Sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.*

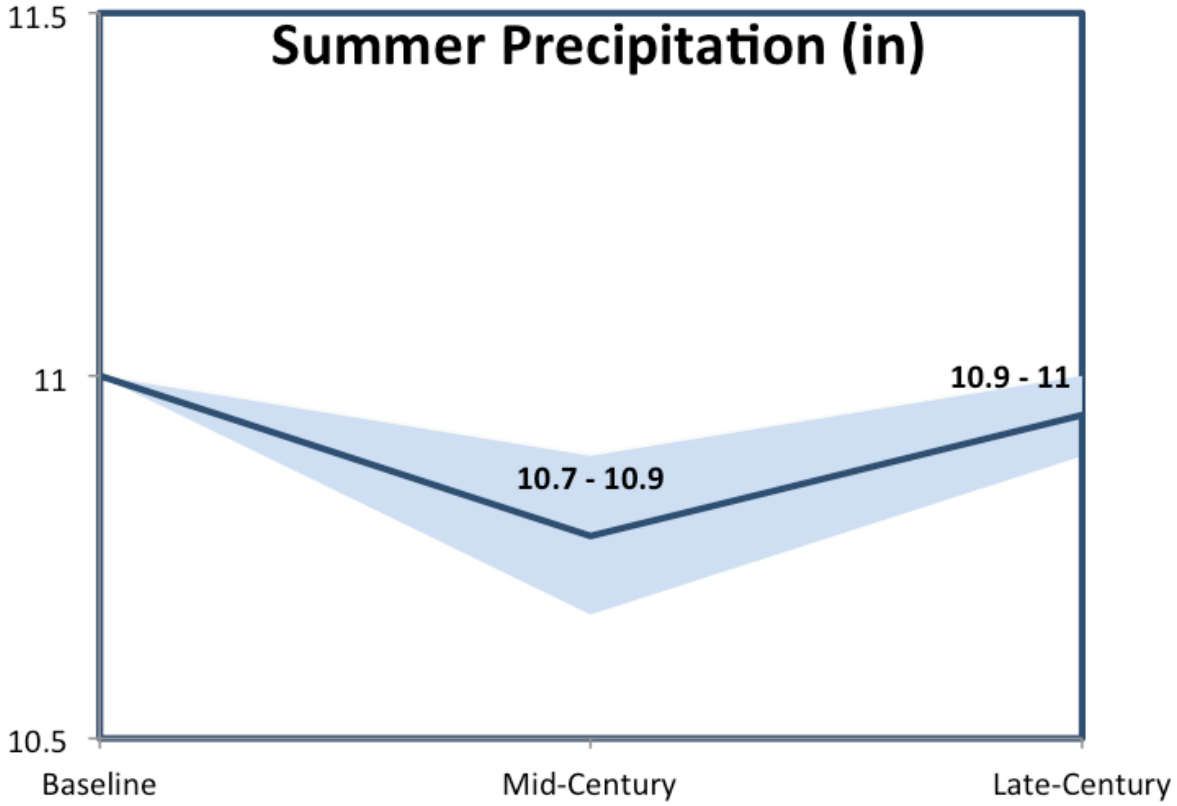

Figure 2.5. *Sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.*

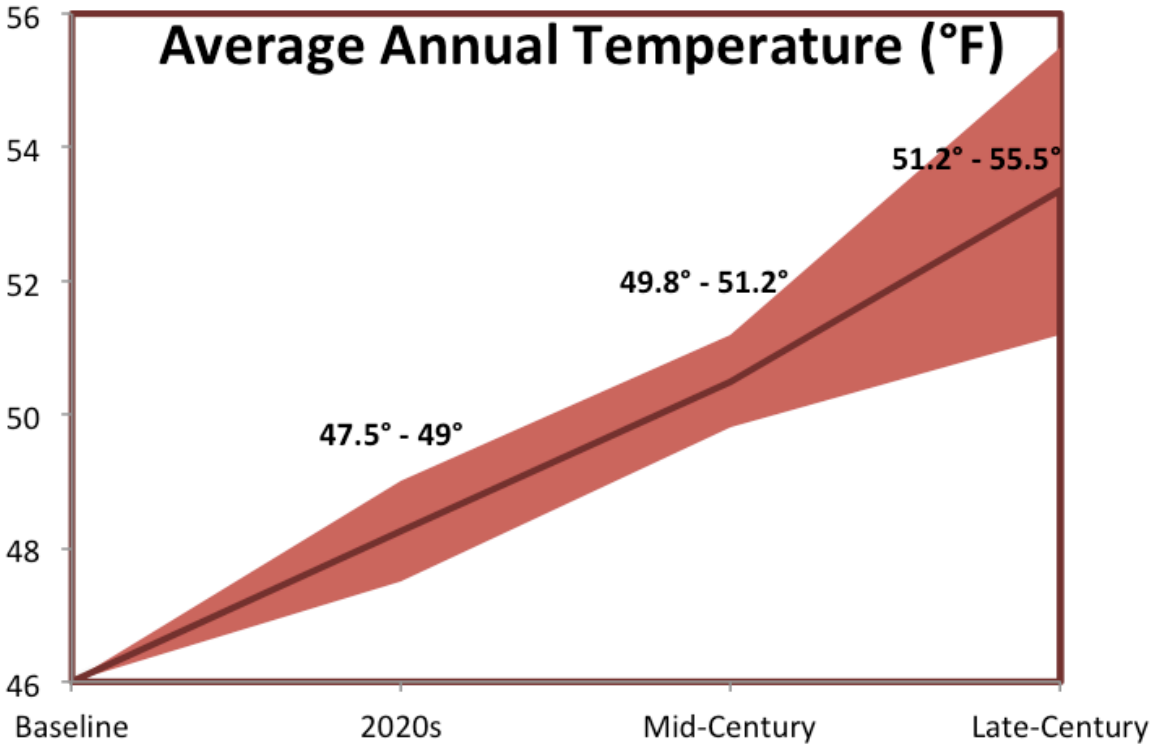

Figure 2.6. *Sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.*

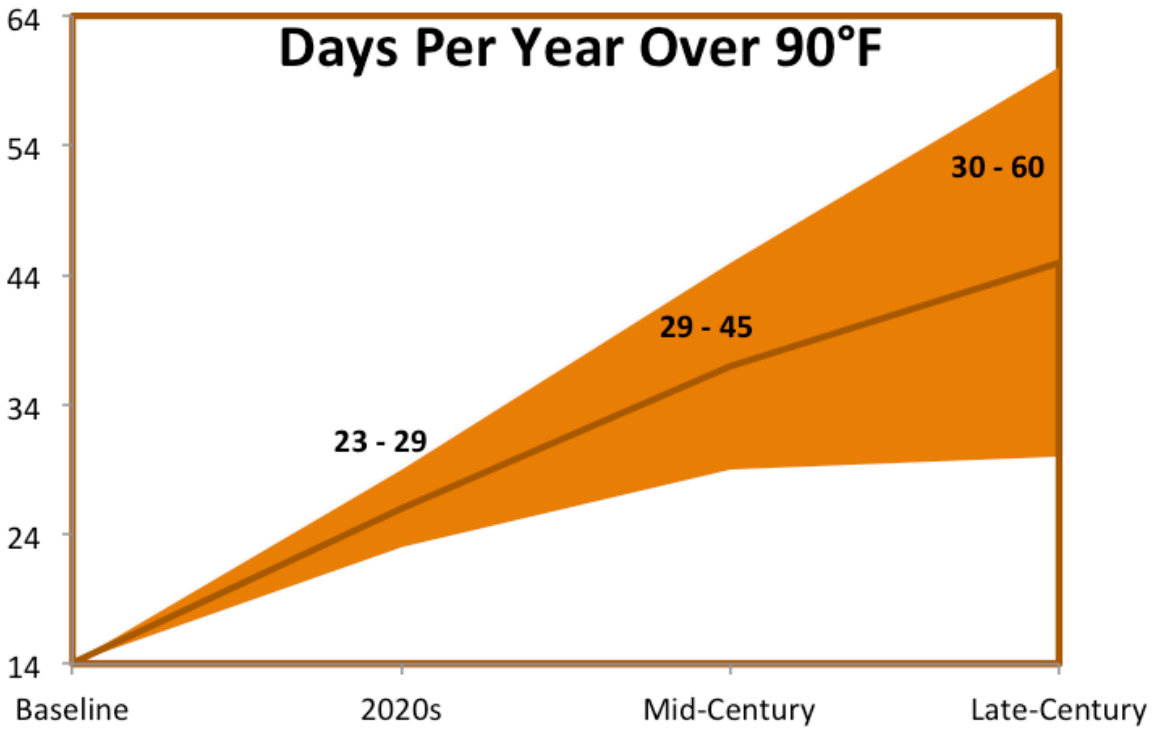

Figure 2.7. *Sources: Climate Change Adaptation Advisory Committee, 2011; NPCC, 2009.*

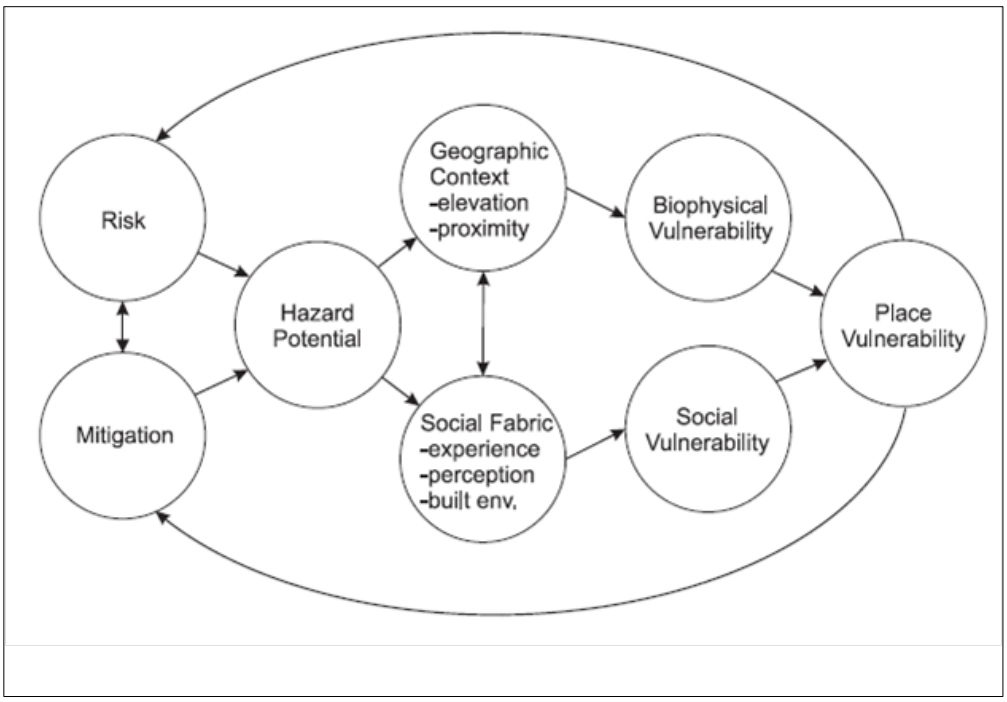

Figure 3.1: Hazards of Place Model. *Source: Cutter, 1996.*

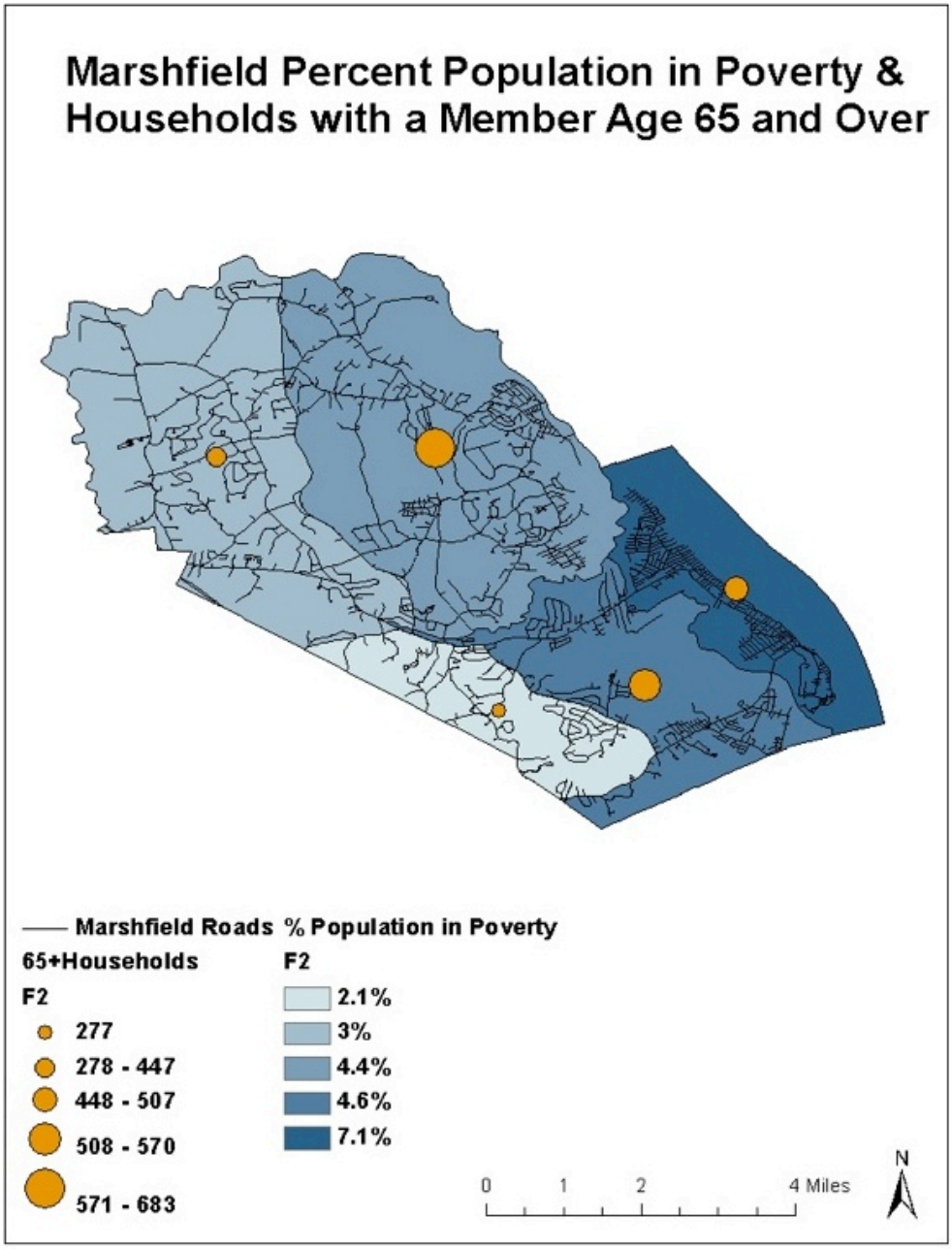

Figure 3.2: *Source: US Census Bureau*.

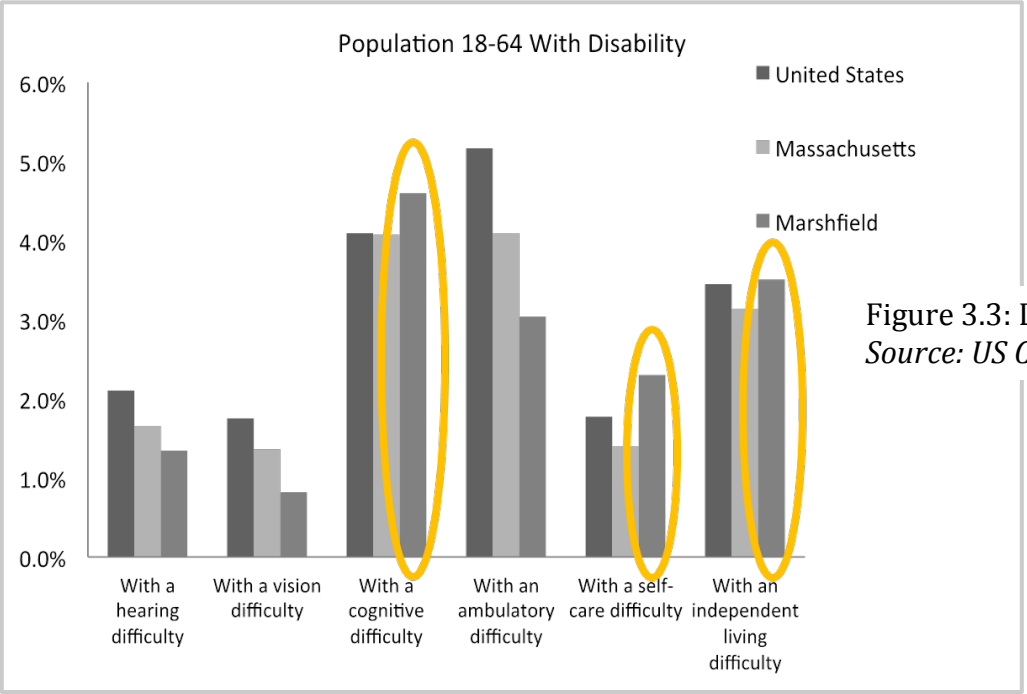

Figure 3.3: Disabilities
Source: US Census Bureau

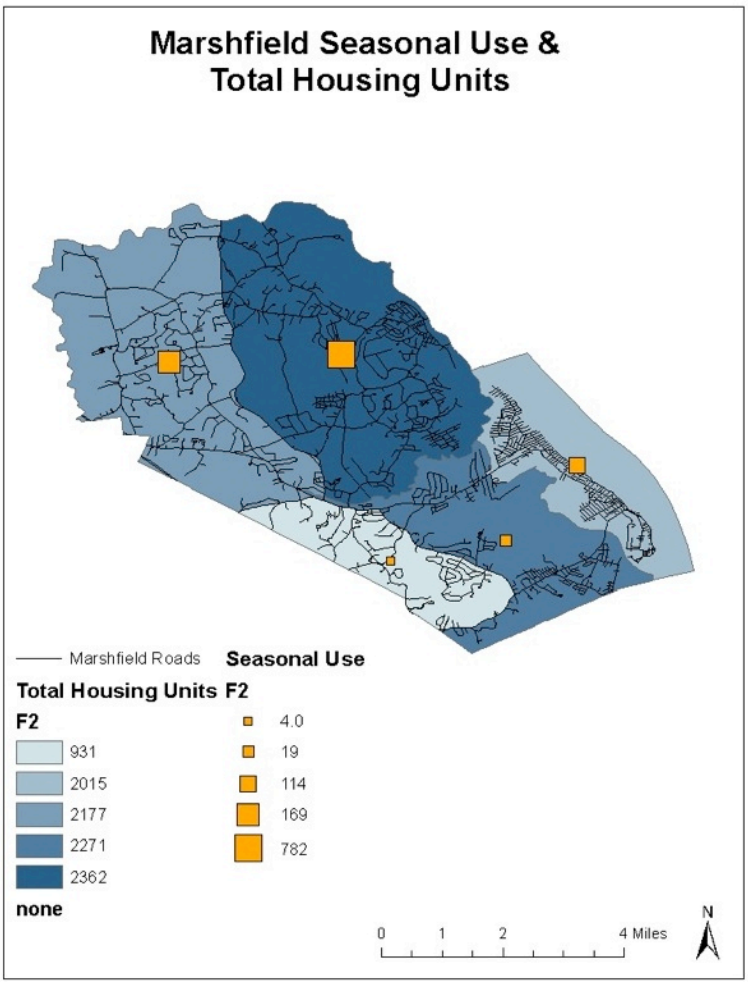

Figure 3.4: *Source: US Census Bureau*.

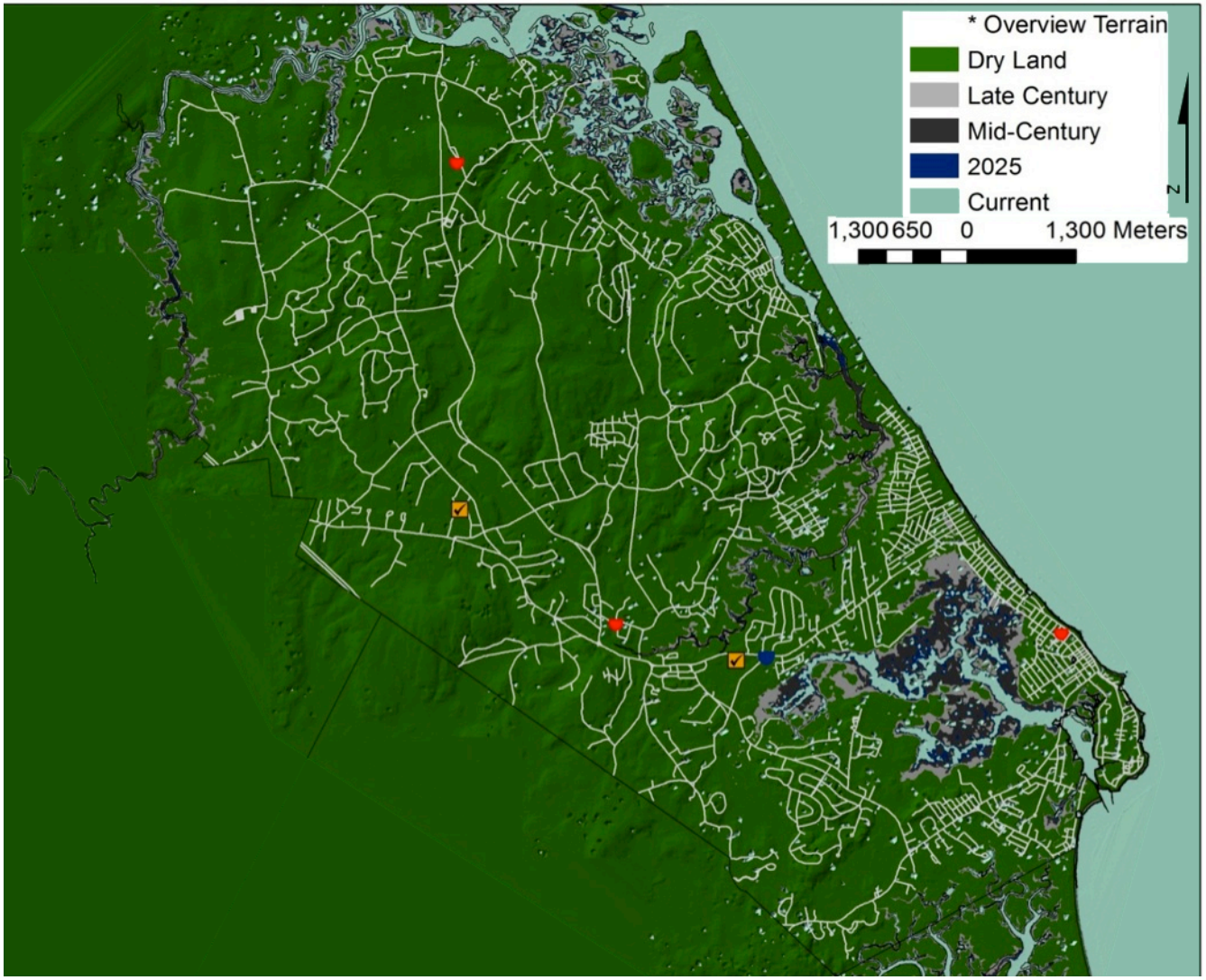

Figure 3.5: A map showing the projected seal level rise for Marshfield. The fire and police stations, as well as the libraries (yellow checks) are shown for reference points.
Data source: MassGIS.

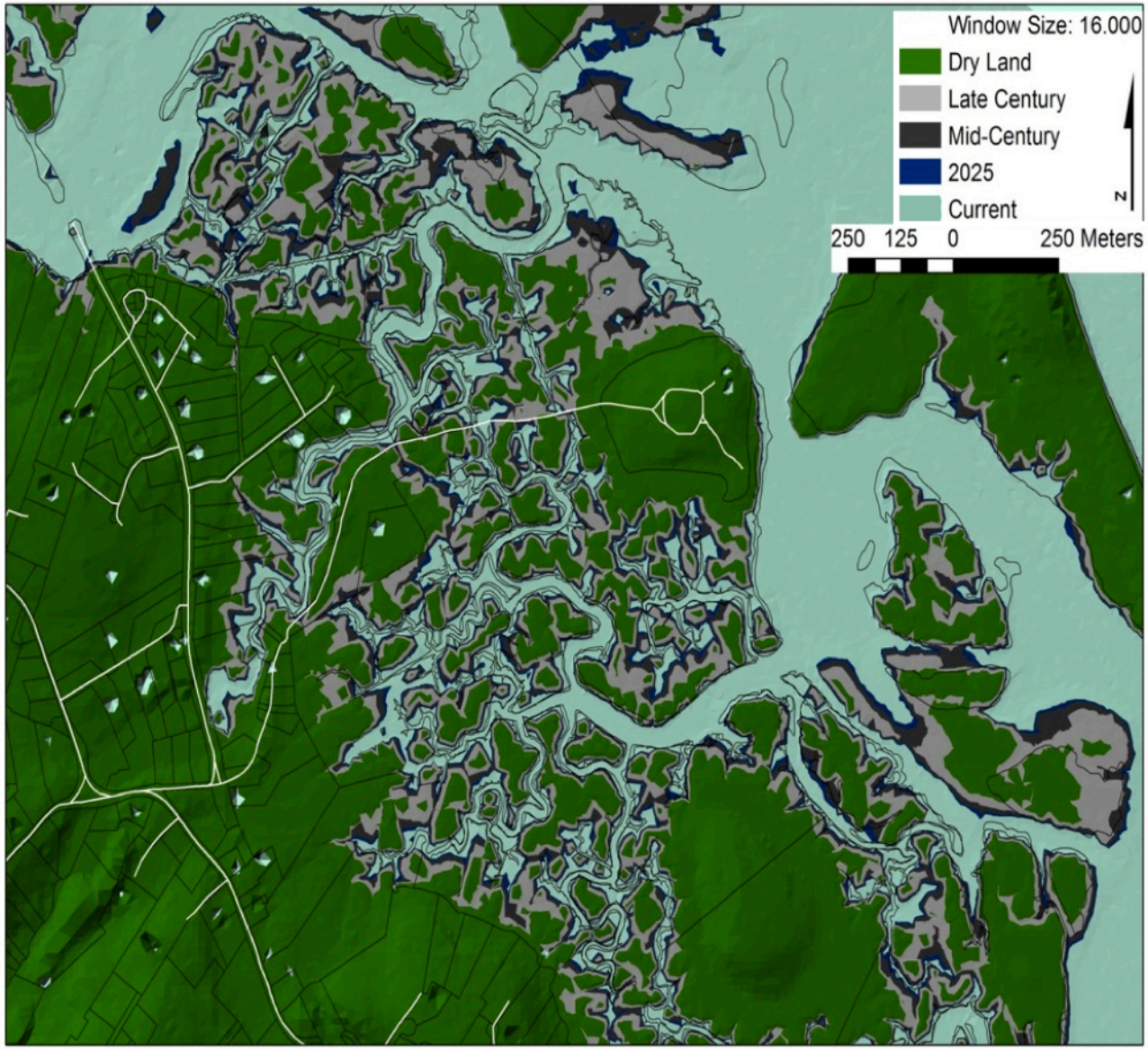

Figure 3.6: Projected inundation in the North River Marsh due to sea level rise.
Data source: MassGIS.

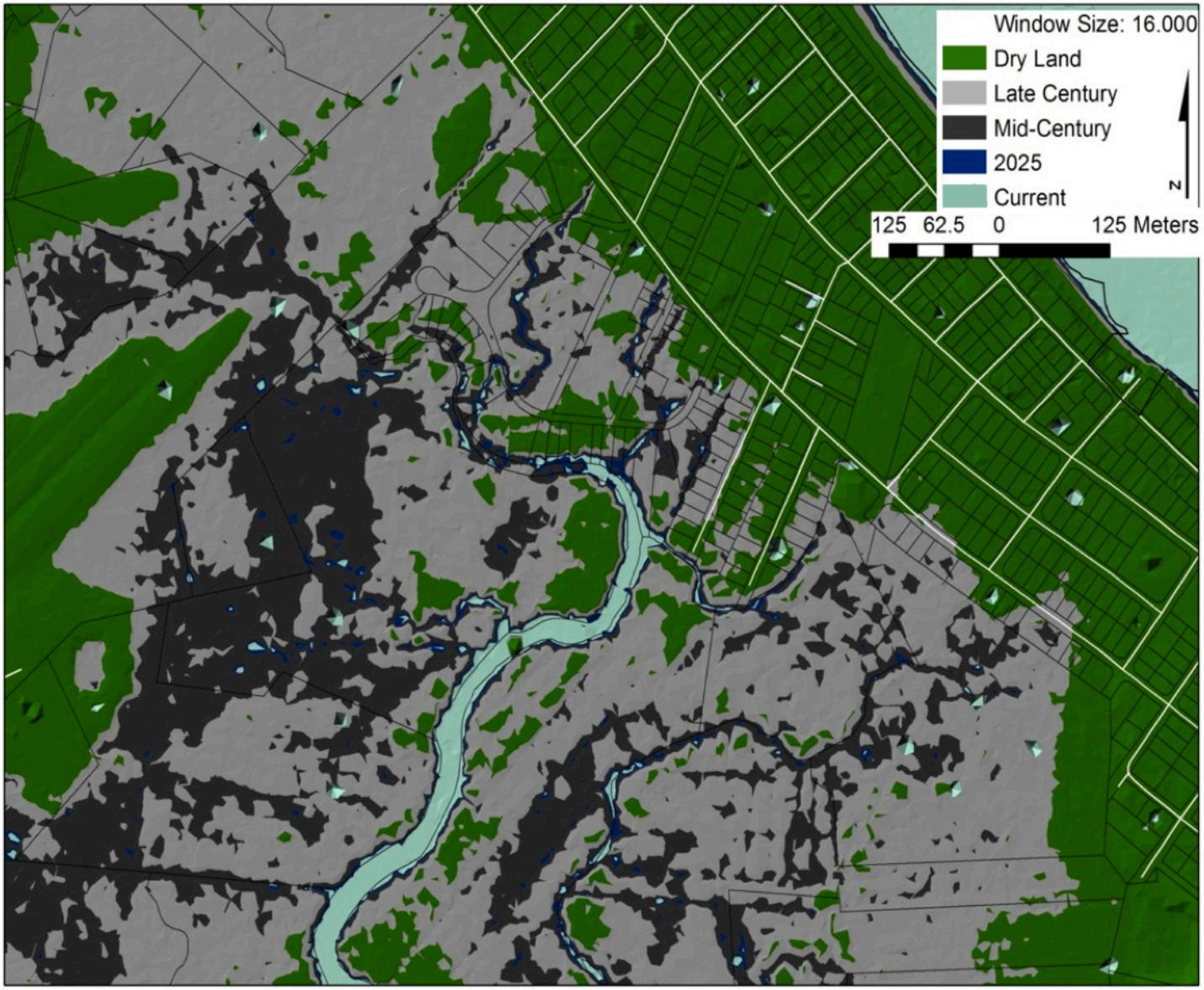

Figure 3.7: Projected inundation of the back side of Ocean Bluff due to sea level rise.
Data source: MassGIS.

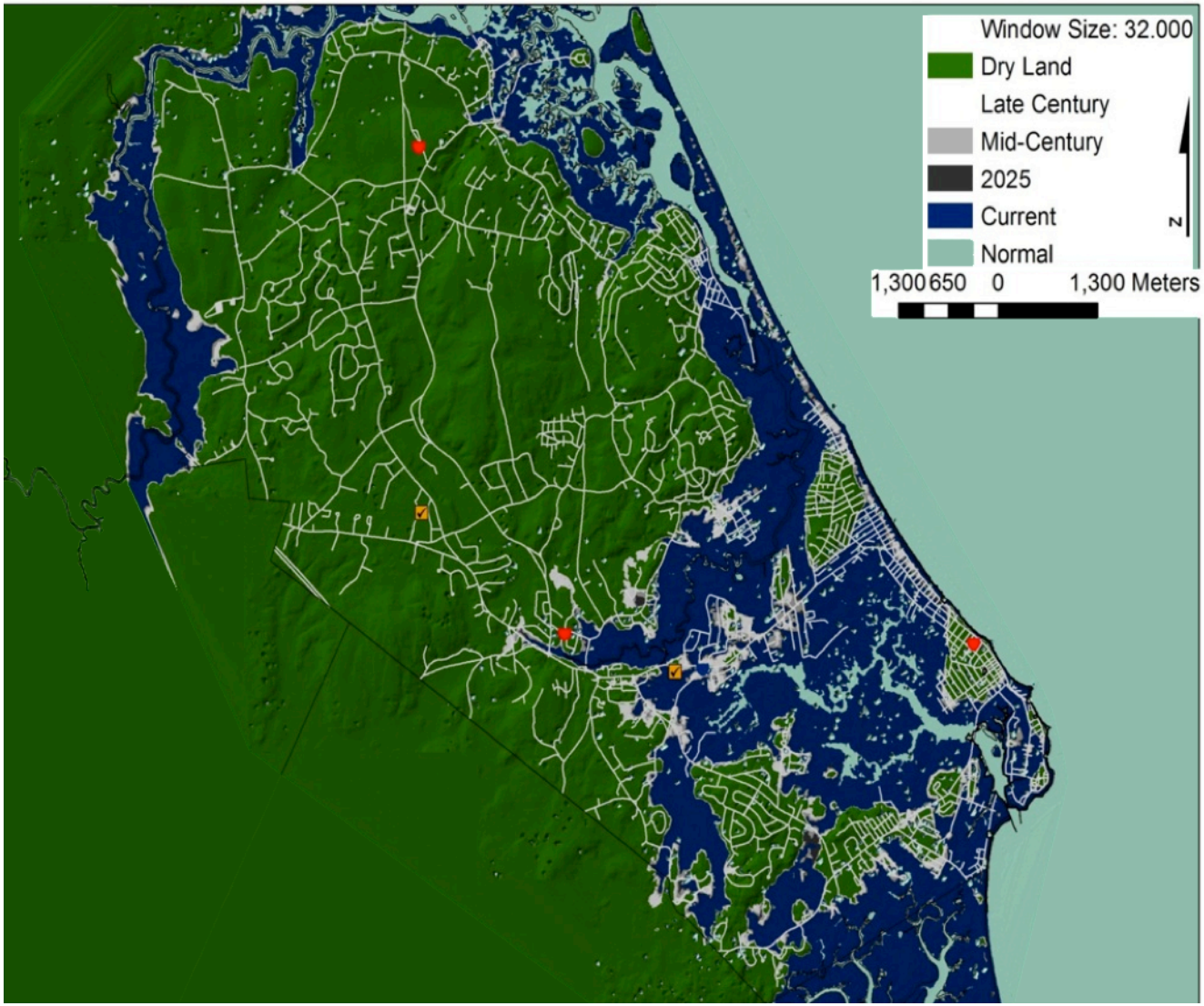

Figure 3.8: Possible inundation from a "100 year" storm surge event.
Data source: MassGIS.

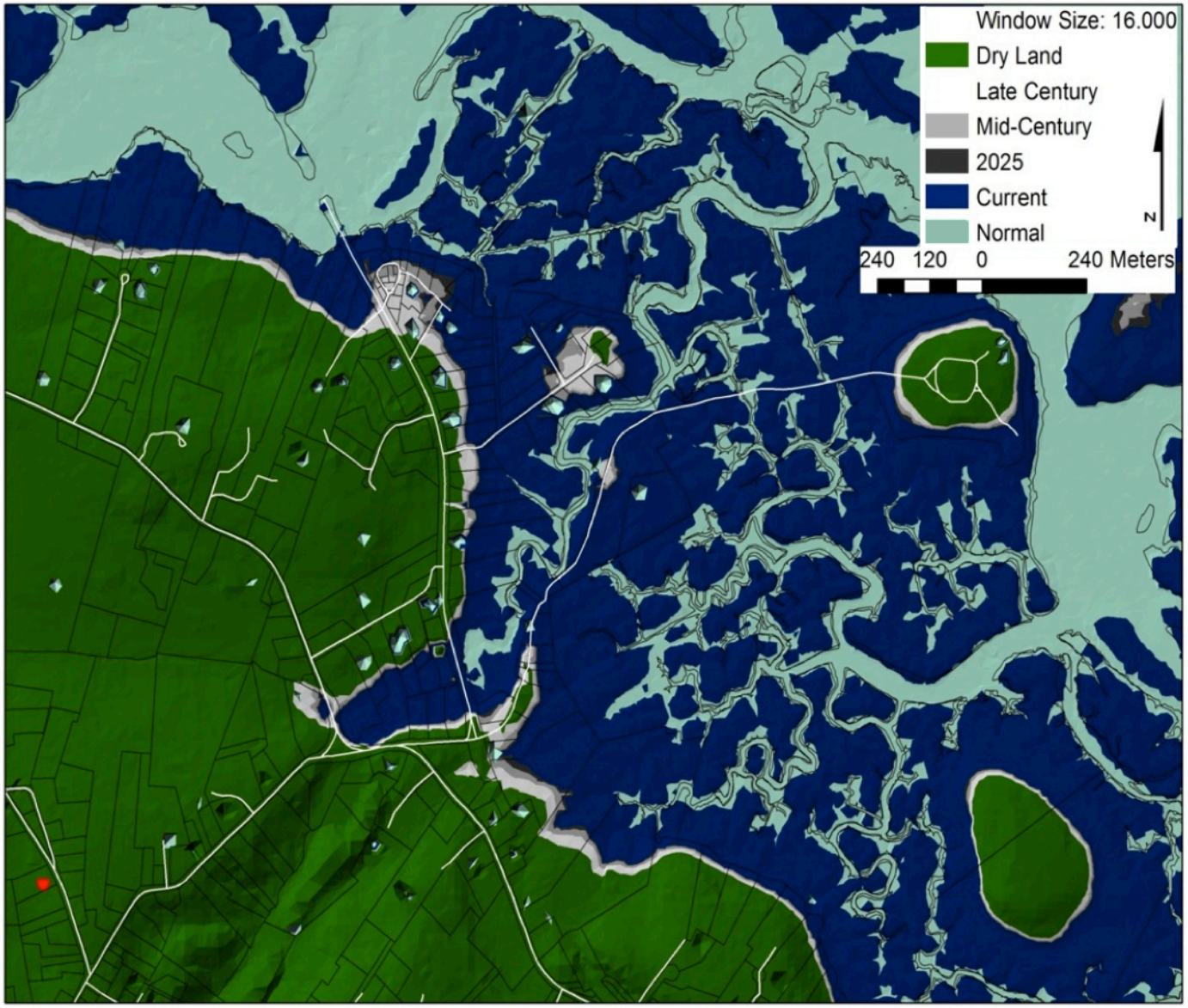

Figure 3.9: Damons Point and North River Marsh possible inundation from a "100 year" storm surge event. *Data source: MassGIS*.

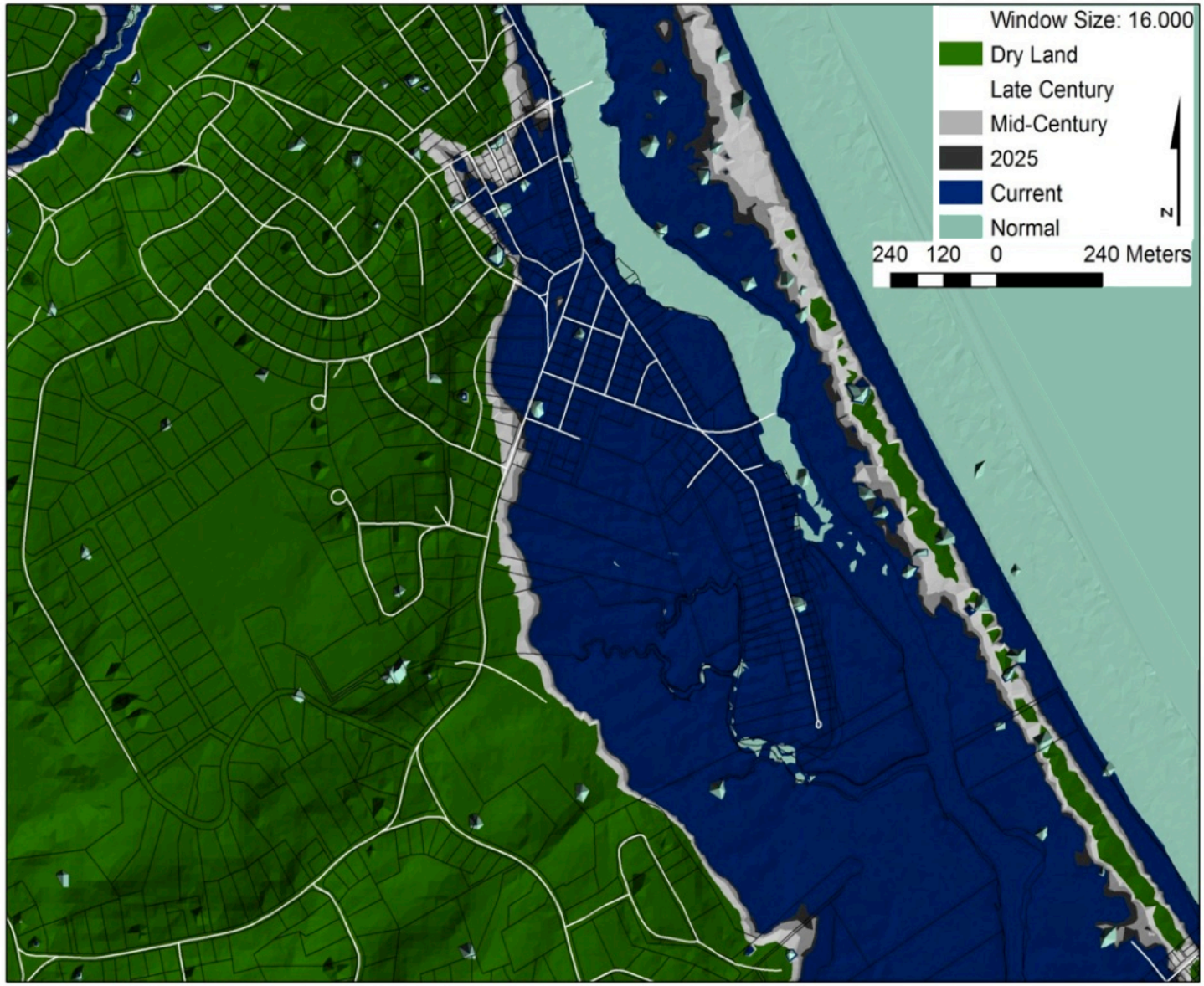

Figure 3.10: Ferry Hill possible inundation from a "100 year" storm surge event.
Data source: MassGIS.

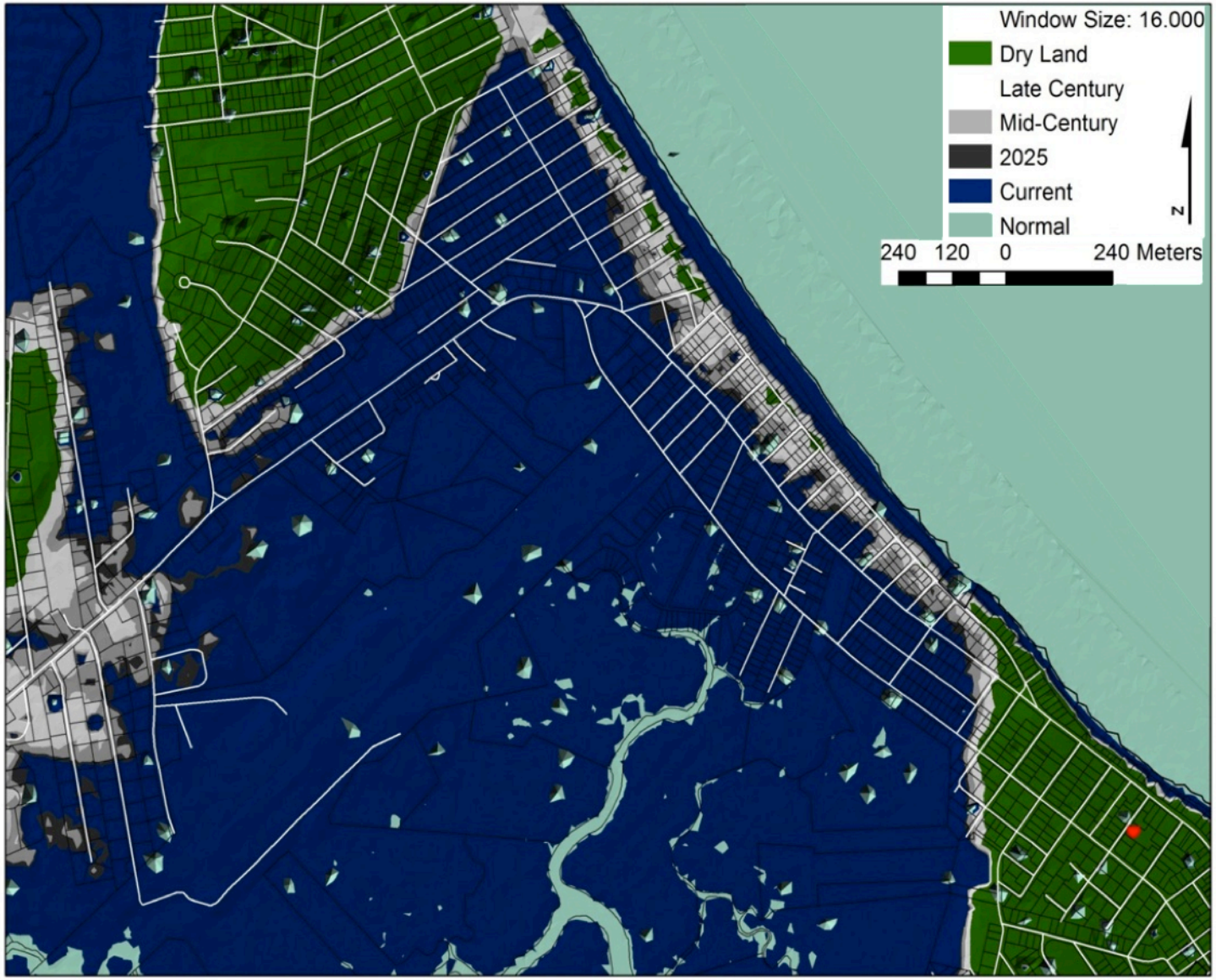

Figure 3.11: Ocean Bluff possible inundation from a "100 year" storm surge event.
Data source: MassGIS.

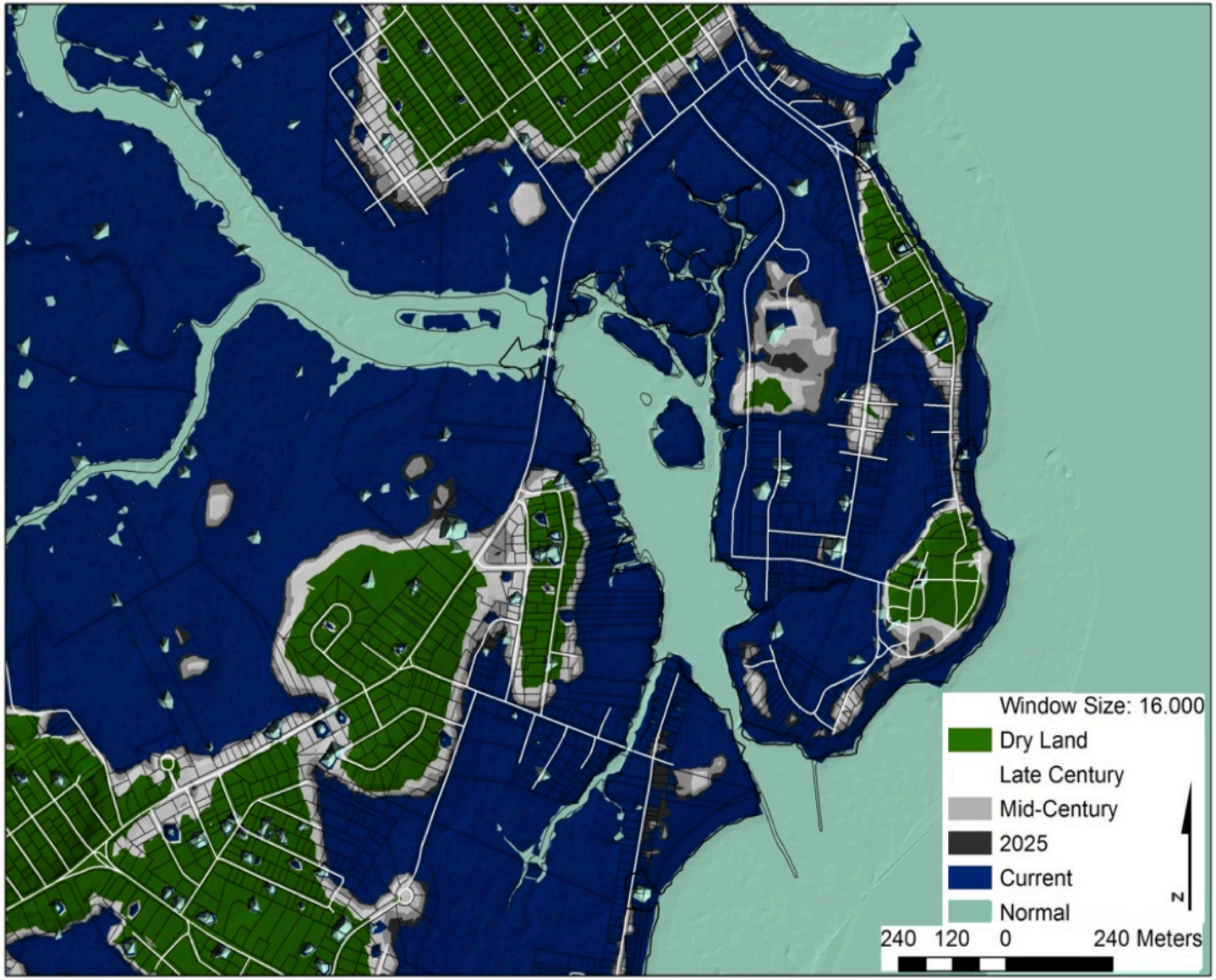

Figure 3.12: Brant Rock and Green Harbor possible inundation from a "100 year" storm surge event.
Data source: MassGIS.

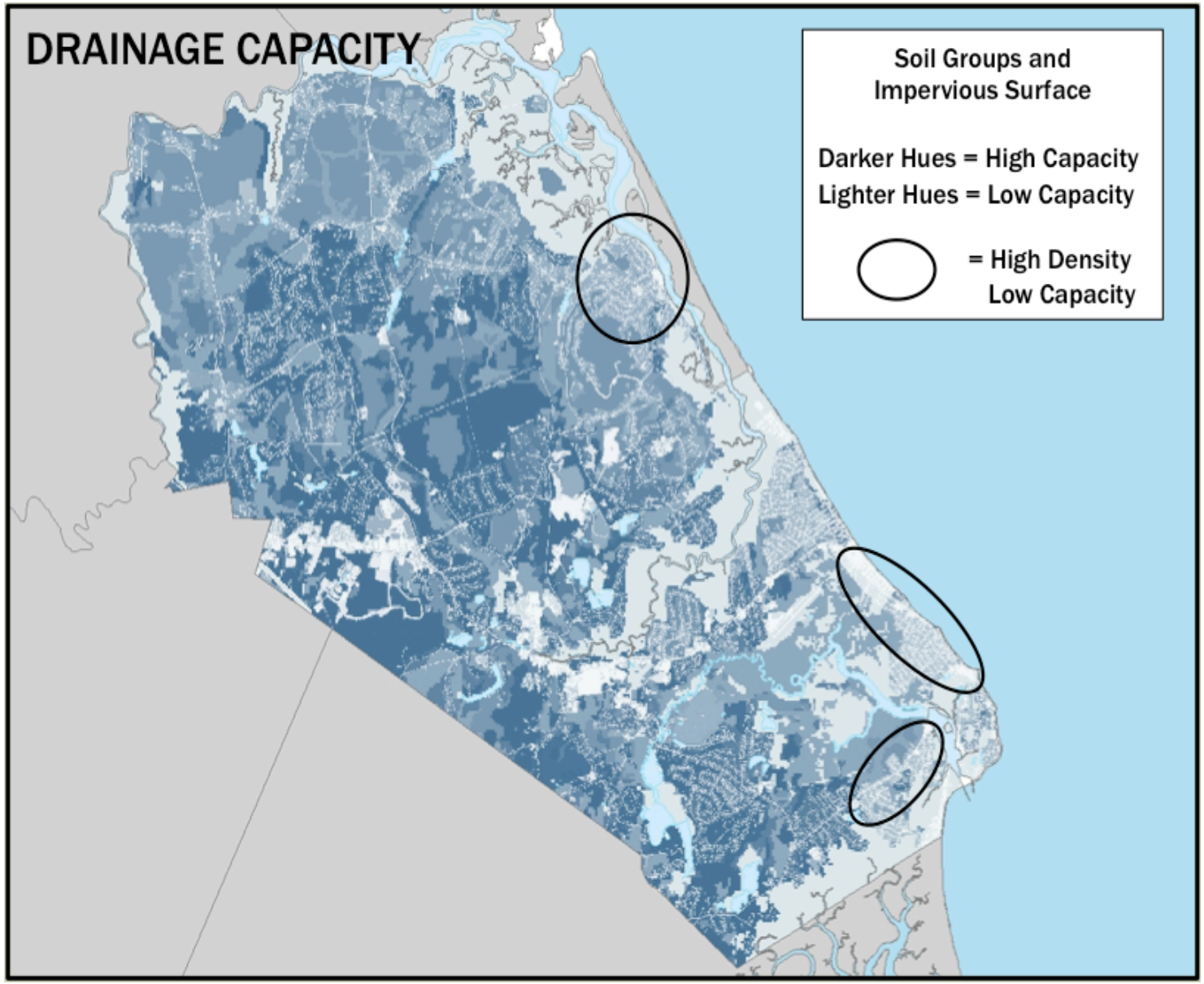

Figure 3.13: Drainage capacity in Marshfield.
Data source: MassGIS.

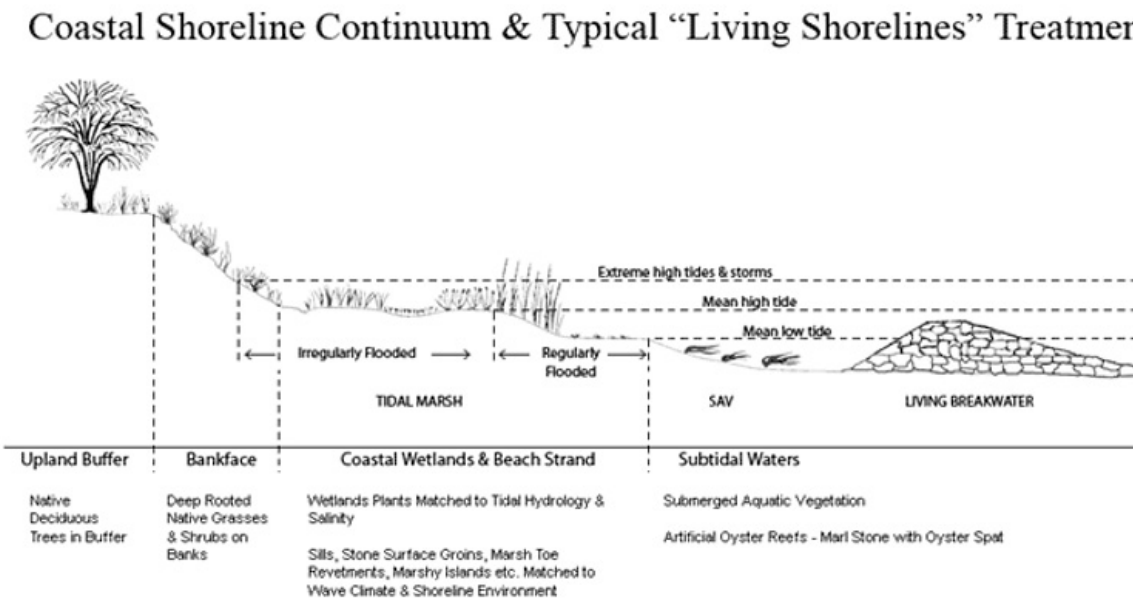

Figure 4.1: Living Shoreline Schematic.
Source: NOAA - http://www.habitat.noaa.gov/restoration/techniques/lsimplementation.htm

Figure 4.2: The Brant Rock Espanade shown in orange.
Image source: Google Earth 2012.

Structure Type	Recommended Elevation
Accessory Structures	12 feet (11 feet BFE + 1 foot)
Single Family Residential/Multi-Family (<5 units)	13 feet (11 feet BFE + 2 feet)
Multifamily (>5 units)	14 feet (11 feet BFE + 3 feet)
Commercial Development	14 feet (11 feet BFE + 3 feet)
Essential Facilities (Schools, Hospitals, etc.)	15 feet (11 feet BFE + 4 feet)
Public Infrastructure	16 feet (11 feet BFE + 5 feet)

Table 4.1: Recommended Building Elevations for Marshfield
Source: Table is modeled after Seabrook's Design Flood Elevation Standards table.

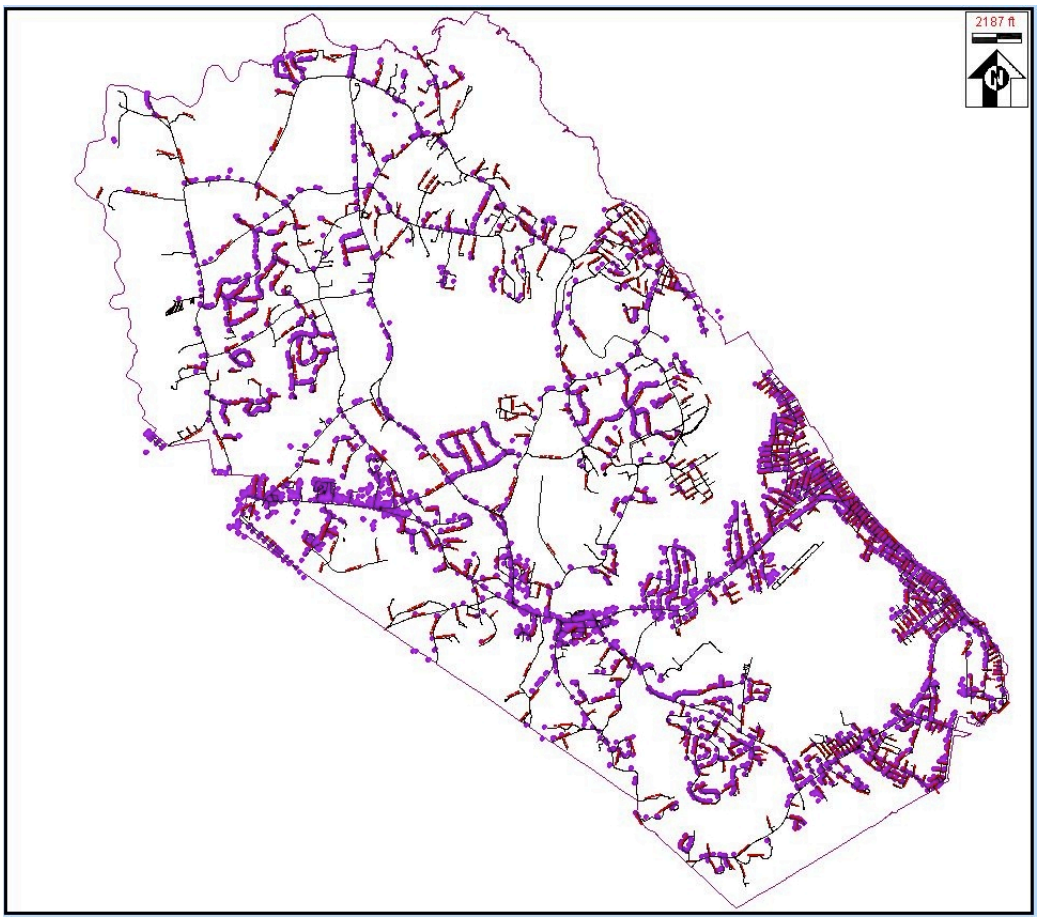

Figure 5.1: Marshfield stormwater catchments.
Source: Town of Marshfield Online GIS, 2012.

Figure 5.2: Projected inundation of water treatment facility.
Source: Shelander, 2012.

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