New England Climate Adaptation PROJECT

Summary Climate Change Risk Assessment
Barnstable, Massachusetts

March 2014

PRODUCED BY:

Massachusetts Institute of Technology Science Impact Collaborative

Consensus Building Institute

National Estuarine Research Reserve System

Acknowledgements

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About the MIT Science Impact Collaborative

The Massachusetts Institute of Technology Science Impact Collaborative (MIT SIC) is a research group focused on developing and testing new ways of harmonizing science, politics and public policy in the management of natural resources and resolution of environmental disputes. MIT SIC's tools and approaches include collaborative adaptive management, joint fact-finding, scenario planning, collaborative decision-making, multi-stakeholder engagement, and role-play simulation exercises.

MIT SIC was established in 2003 with initial support from the United States Geological Survey. Today, the research group has numerous partners and supporters, ranging from the U.S. National Estuarine Research Reserve System to the Dutch research organization TNO. By engaging in community-based action research projects, MIT SIC researchers—including doctoral students, masters students, and faculty from the MIT Department of Urban Studies and Planning—train emerging environmental professionals while simultaneously testing the latest environmental planning methods and providing assistance to communities and policy-makers who seek their help.

Visit the MIT Science Impact Collaborative website for more information:
http://scienceimpact.mit.edu

About the Consensus Building Institute

The Consensus Building Institute (CBI) is a not-for-profit organization founded in 1993 by leading practitioners and theory builders in the fields of negotiation and dispute resolution. CBI's experts bring decades of experience brokering agreements and building collaboration in complex, high-stakes environments — and possess the deep understanding required to tackle negotiation and collaboration challenges in their practice areas. CBI's founder, managing directors, and many of their board members are affiliated with the Program on Negotiation at Harvard Law School and the MIT-Harvard Public Disputes Program.

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About the Waquoit Bay National Estuarine Research Reserve

The National Estuarine Research Reserve System (NERRS) is a network of 28 areas representing different biogeographic regions of the United States that are protected for long term research, water-quality monitoring, education, and coastal stewardship. The reserve system is a partnership program between the National Oceanic and Atmospheric Administration(NOAA) and the coastal states. Reserve staff work with local communities and regional groups to address natural resource management issues, such as climate change, non-point source pollution, habitat restoration, and invasive species. Through integrated research and education, the reserves help communities develop strategies to deal successfully with these coastal resource issues. Reserves provide adult audiences with training on coastal and estuarine issues of concern in their local communities. They offer educational programs for students, teachers, decision-makers, and community members. Reserves also provide long term weather, water quality and biological monitoring as well as opportunities for scientists and graduate students to conduct research in a "living laboratory."

The Waquoit Bay Reserve is located on the south shore of Cape Cod, Massachusetts, on the border of the towns of Falmouth and Mashpee. The Reserve's more than 2,700 acres encompass open waters, saltwater and freshwater marshes, barrier beaches, sand dunes, rivers, mixed pine and oak forests, and sand plain grasslands. The Waquoit Bay Reserve works with partners to preserve land and water, investigate compelling issues facing our coast and provide educational and outreach opportunities for communities throughout the Cape Cod region.

Visit the Waquoit Bay National Estuarine Research Reserve website for more information: http://www.waquoitbayreserve.org

Table of Contents

Executive Summary

Barnstable faces several climate-related risks, the most notable being the risk of increased flooding due to rising sea levels, more intense coastal storms, and more extreme precipitation events. Alongside flooding, Barnstable's future will likely include more frequent heat waves and droughts, as well as changes to coastal habitats with significant implications for the tourism industry. These risks threaten Barnstable's population, buildings, infrastructure, landscapes, and ecosystem health. Barnstable has improved its physical infrastructure and services in response to related historical climate events. However, there is much more that can and needs to be done.

This Summary Risk Assessment presents how the climate could change in Barnstable over the 21st century, and outlines the town's key climate change risks as well as possible adaptation options to address these risks. This assessment was developed by the New England Climate Adaptation Project with the primary objective of providing targeted content for a role-play simulation exercise for Barnstable residents. While the information gathered by this project alone is not sufficient to guide Barnstable's planning and adaptation efforts, it may begin to inform local officials and town residents about potential future climate risks and adaptation options. Barnstable could benefit from a more detailed risk assessment.

This report consists of two sections. Section 1 outlines potential future climatic conditions of Barnstable based on climate change projections downscaled from the five nearest meteorological stations in East Wareham, Hyannis, Edgartown, New Bedford, and Rochester, MA. Historical and future trends are included for both temperature and precipitation. Sea level rise projections are based on data from the Woods Hole tidal gauge. Climate change projections are presented for two scenarios—a high emissions scenario and a low emissions scenario—which are used to represent the uncertainty in future quantities of global greenhouse gas emissions. Projections are presented in terms of three time scales -- short term (2010-2039), medium term (2040-2069), and long term (2070-2099) -- to capture change over time. The historical baseline refers to the time period between 1980 and 2010.

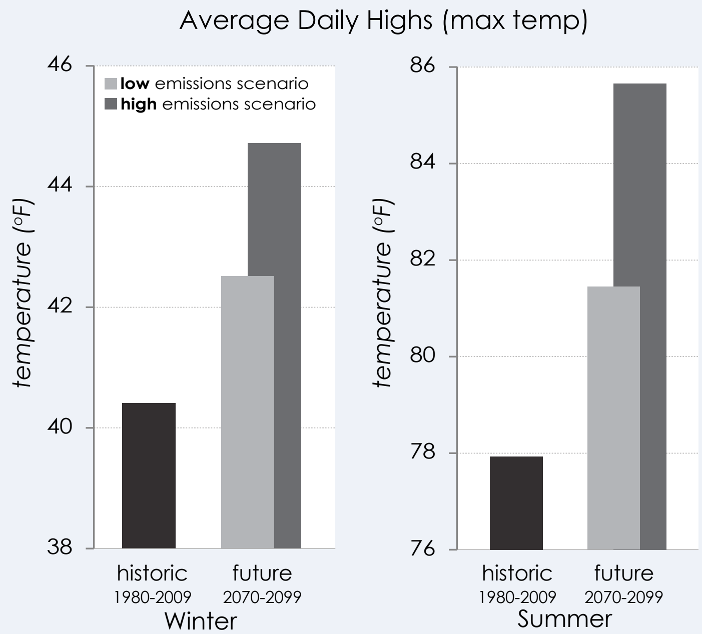
Section 2 discusses how future climatic changes (including those in temperature, precipitation, and sea level) combine with other factors (such as the built environment, economics, demographics, and natural context) to create integrated risks and increased vulnerability for Barnstable. This section pairs each risk with sample adaptation methods that prioritize reducing exposure and sensitivity, and increasing adaptive capacity. Vulnerabilities and adaptation options were developed based on input from town officials and Barnstable's experience with past climate-related issues, as well as a review of published documents, such as the Barnstable Multi-Hazard Mitigation Plan. Examples of potential adaptation options include movement out of floodplains, increasing flood insurance, protecting natural areas, enhancing water supply sources, and creating more cooling centers.

Even though some climate change impacts seem to be a long way off, many adaptation measures may take years of planning, coordination, and investment in order to come to fruition. Additionally, the choices and investments Barnstable makes today will either increase or decrease the town's vulnerability to current and future climate-related risks. Barnstable can increase its resilience in the face of a changing climate, but doing so will require that residents, business owners, and local and regional agencies work together and begin preparing for a changing climate now rather than waiting to confront the challenge after the damage has been done.

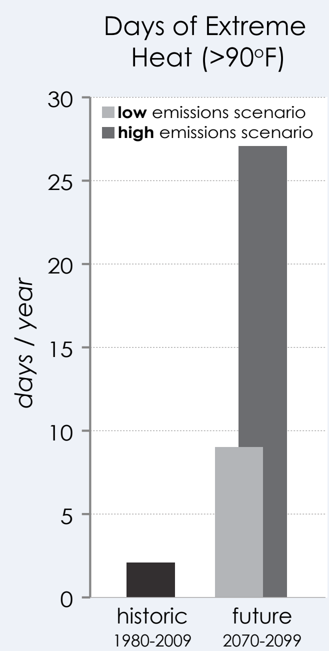
What do climate projections tell us about Barnstable by the end of the century?

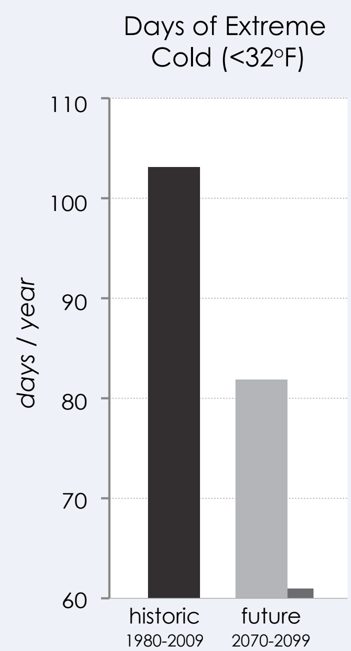
Hotter Annual Temperatures. In the long term, average annual maximum temperatures could increase between 2.9°F and 6.4°F.

Warmer Summer Evenings. Climate change will have a greater warming influence on nighttime minimum temperatures than daytime maximum temperatures, both of which will increase. Especially in the long term, summer nights will not cool down as much as they did in the past.

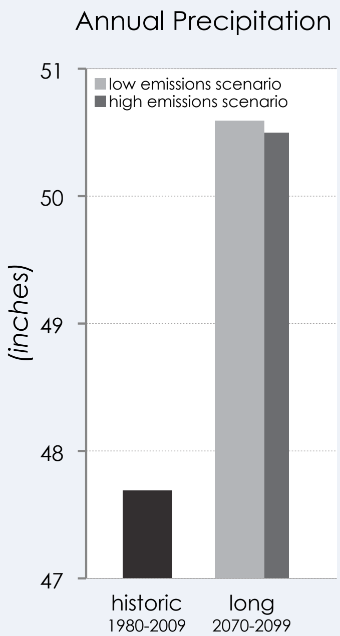


More Extreme Heat Events. Less Extreme Cold Events. While Barnstable historically experienced an average of 2 extreme heat events (days where temperatures rise above 90°F) per year, long term projections indicate that Barnstable may see as many as 27 events per year under the high emissions scenario. In the long term, Barnstable may also experience between 20 to 40 fewer annual extreme cold events (days where temperatures drop below 32°F)—dropping from an historic average of 103 events per year to as few as 61 events per year under the high emissions scenario.

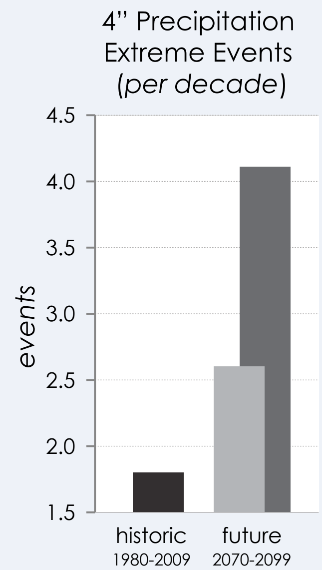




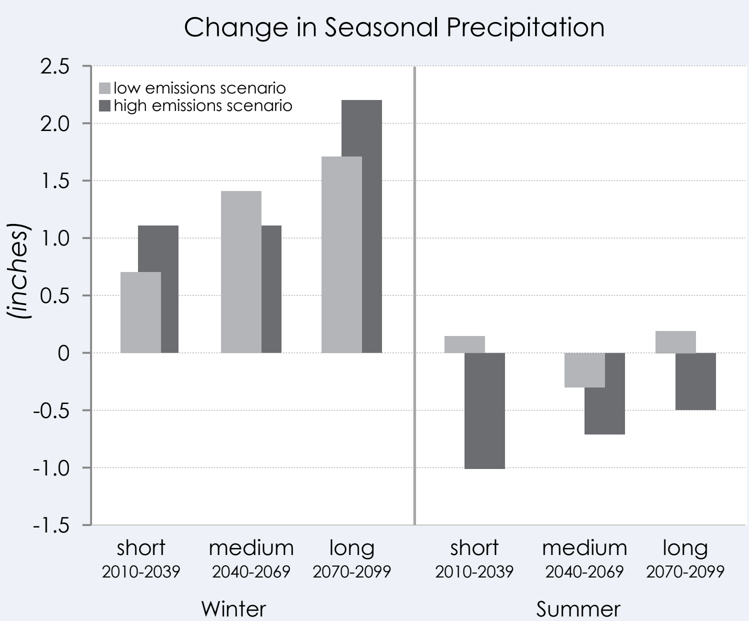
More Annual Precipitation. Average annual precipitation is expected to increase in Barnstable. Over the long term, Barnstable may see as much as 2.8 additional inches of annual precipitation.



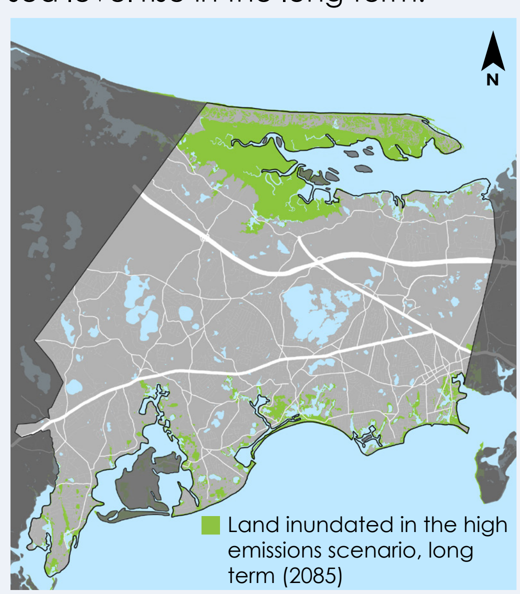
More Extreme Precipitation Events. Historically, Barnstable experienced an average of 1.8 events per decade where 4 inches of precipitation fell in 48 hours. In the long term, under the high emissions scenario, Barnstable may see as many as 4.1 such events per decade.



Wetter Winters, Drier Summers. By the end of the century, under the high emissions scenario, Barnstable may see 2.2 more inches of precipitation during the winter season.



Sea Level Rise. Projections reflect a significant rise in sea level under both the high and low emissions scenarios, with the high emissions scenario predicting upwards of 5 to 6 feet of sea level rise in the long term.



What are the major risks for Barnstable and what can be done?

Flooding

Climate change will likely increase Barnstable's risk of both coastal and inland flooding, a significant concern given that flooding is already one of the predominant hazards in the region.

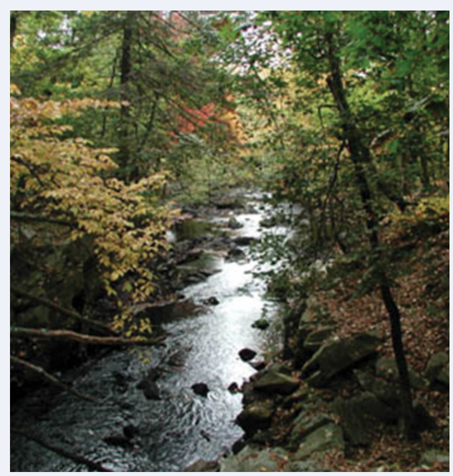
Sea level rise is expected to significantly increase flood risks along both the north and south shores of the town, as higher sea levels will lead to higher surges during storms. Additionally, climate change may cause stronger coastal storms and hurricanes, which may add to increased coastal flooding risk.

Increased risk of inland flooding may occur for a number of reasons. Sea level rise will reduce the ability of rivers and streams to absorb water during major precipitation events. Additionally, sea level rise may raise groundwater levels. Higher groundwater levels and reduced capacity of waterways to take on water during storms may interact with more frequent extreme precipitation events to cause more frequent and severe inland flooding in Barnstable. This trend could be exacerbated by continued development in and around Barnstable, which may create more stormwater runoff resulting from additional impermeable surfaces.

Examples of Adaptation Options

Floodwalls
ex: New Hampshire

Flood Resilient Building Design
ex: Providence, RI



Wetland Restoration
ex: Woonasquatucket,RI

Drought

Climate change is expected to increase the occurrence of drought in the Town of Barnstable as a result of reduced summer precipitation and higher temperatures, resulting in more evaporation and transpiration. Drought may lead to water supply shortage and increased risk of wildfires.

Heat Waves

Heat waves are driven by extreme temperature events, which are expected to increase significantly in Barnstable. Heat waves are particularly dangerous for human health and infrastructure when they last for long periods of time, when evenings do not cool down, and when heat is coupled with high humidity.

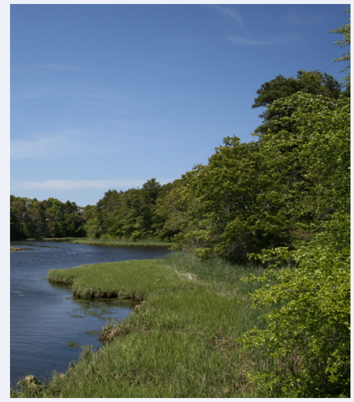
Tourism and Economic Vulnerability

Tourism is one of the primary sources of economic development in Barnstable. A longer summer season and warmer winters may extend Barnstable's tourist season, which could have a positive economic impact. However, the potential negative impacts of climate change on Barnstable's beaches, marshes, and other natural and recreational assets may outweigh any benefits of an extended tourist season. In addition, tourist infrastructure in flood-prone areas, such as along the coast, is vulnerable to sea level rise and coastal storms. Further, many of Barnstable's most valuable homes and properties are in areas that are at risk from coastal flooding and sea level rise, and impacts on these properties could detrimentally affect the town's economy and tax base.

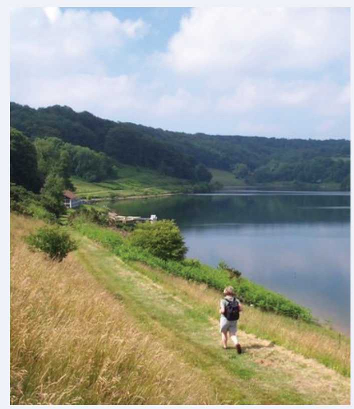
Ecosystem Change

The Town of Barnstable supports unique and essential coastal habitats and a network of freshwater wetlands which will be significantly affected by future climatic changes. Sea level rise is expected to inundate coastal habitats, threatening sensitive eelgrass beds, shellfish harvesting areas, sand dunes, and tidal marshlands. Additionally, changes to ocean circulation patterns are expected to change the biochemistry of marine ecosystems. Increased inland flooding is likely to affect freshwater wetland ecosystems by reducing water quality and increasing scouring and erosion. Lastly, warmer temperatures will further stress species that are already under pressure from increasing encroachment and pollution.

Examples of Adaptation Options



Vegetated Waterways
ex: Barnstable, MA



Additional Reservoir
ex: West Hartford, CT

Protected Shorelines
ex: Barnstable, MA

Section 1: Future Climate in Barnstable

This section highlights temperature and precipitation projections that have been downscaled for Barnstable by averaging results from the five closest meteorological stations in East Wareham, Edgartown, Hyannis, New Bedford, and Rochester, Massachusetts. Statistical downscaling translates coarse global climate model projections to the spatial scale of local weather station observations (Stoner et al., 2012). This is done by quantifying historical relationships[1] between large-scale weather features and local patterns. Two irreducible uncertainties govern the use of multiple projections in estimating future change. The first is the sensitivity of the climate to increased atmospheric concentration of CO_2, which is addressed through the use of multiple computational models. The second is predicting how much CO_2 and other greenhouse gases will be emitted over the next century, which is addressed through use of multiple emissions scenarios. In order to capture the full range of future climate changes that Barnstable might experience during the 21st century, this project looks at the projections of four global climate models (GFDL, HdCM3, PCM and CCSM3) and two Intergovernmental Panel on Climate Change (IPCC) emissions scenarios (A1fi, reflecting the highest projections of emissions and B1, reflecting the lowest projections of emissions) (Figure 1). Projections are presented in terms

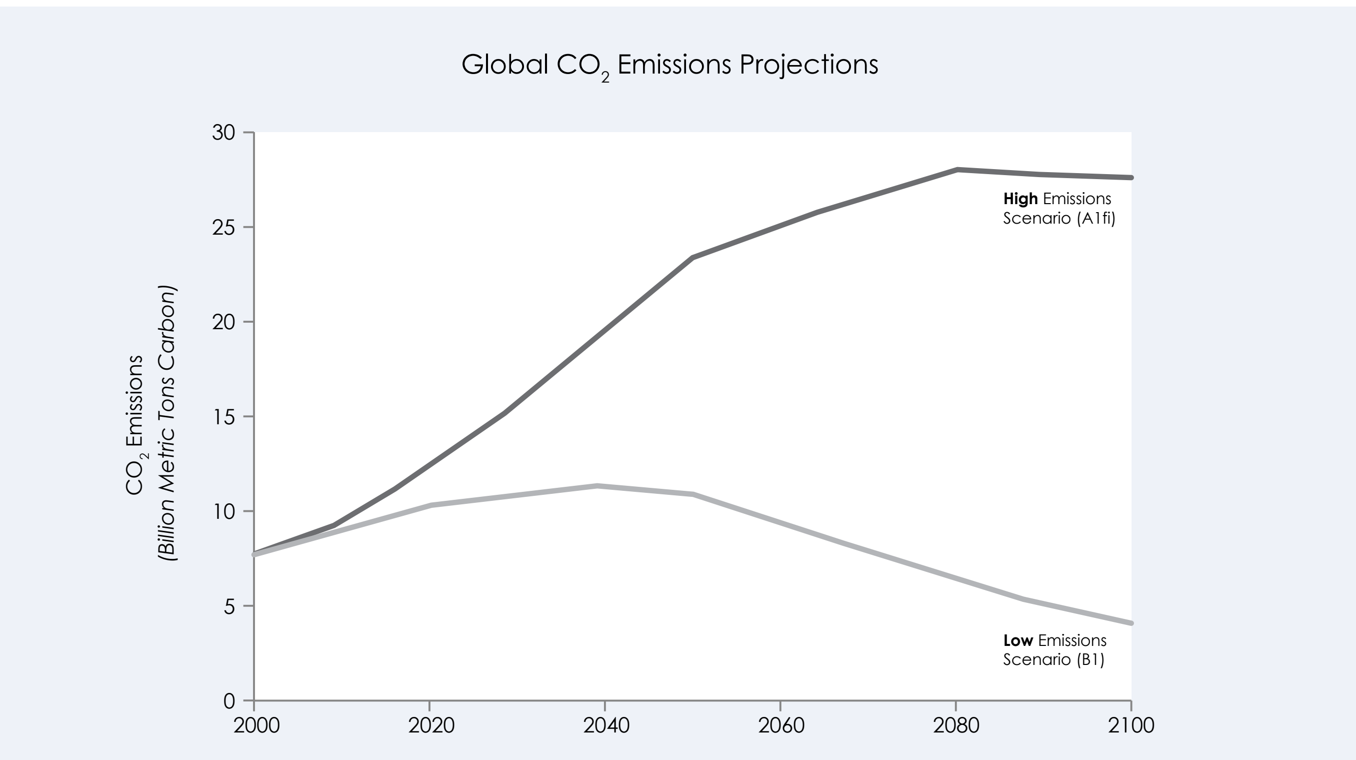


Figure 1. Global CO_2 Emissions Projected over a Century for High and Low IPCC Scenarios

1 It is worth noting that the historical period represents a relatively short and recent series of data relative to the period of anthropogenic greenhouse gas emissions – namely 1980-2009. That is, the historical period does not represent an era "pre-climate change," but is instead a baseline created due to available record-keeping. As an example, the New York Panel on Climate Change 2013 report states that for each decade between 1900 and 2011, the annual mean temperature rose by 0.4° Fahrenheit, precipitation increased by 0.7 inches, and sea level rose by 1.2 inches.

of three time scales –- short term (2010-2039), medium term (2040-2069), and long term (2070-2099) -- to capture change over time. Sea level projections were produced through statistical analysis of the relationship between global temperatures and sea level rise. A full description of the statistical downscaling methodology and sea level rise projections used for this report is provided in Appendix 1.

Temperature

Average Daily Temperatures:

The average temperature in Barnstable is projected to increase moderately over the next century (Figure 2). This change is exhibited through increases in both the daily low temperatures (minimum) and daily high temperatures (maximum). The high emissions scenario (A1fi) corresponds with larger and faster temperature increases as compared to the low emissions scenario (B1). Average daily lows are expected to increase between 2.1 and 3.6°F by midcentury (2040-2069) based on the low and high emissions scenarios, respectively. By the end of the century (2070-2099), average daily lows may increase by as much as 6.1°F under the high emissions scenario. Daily maximum temperatures are expected to increase by nearly identical values—about 2.4 to 3.8°F in the medium term and about 6.4°F in the long term under the high emissions scenario (Figure 3a).

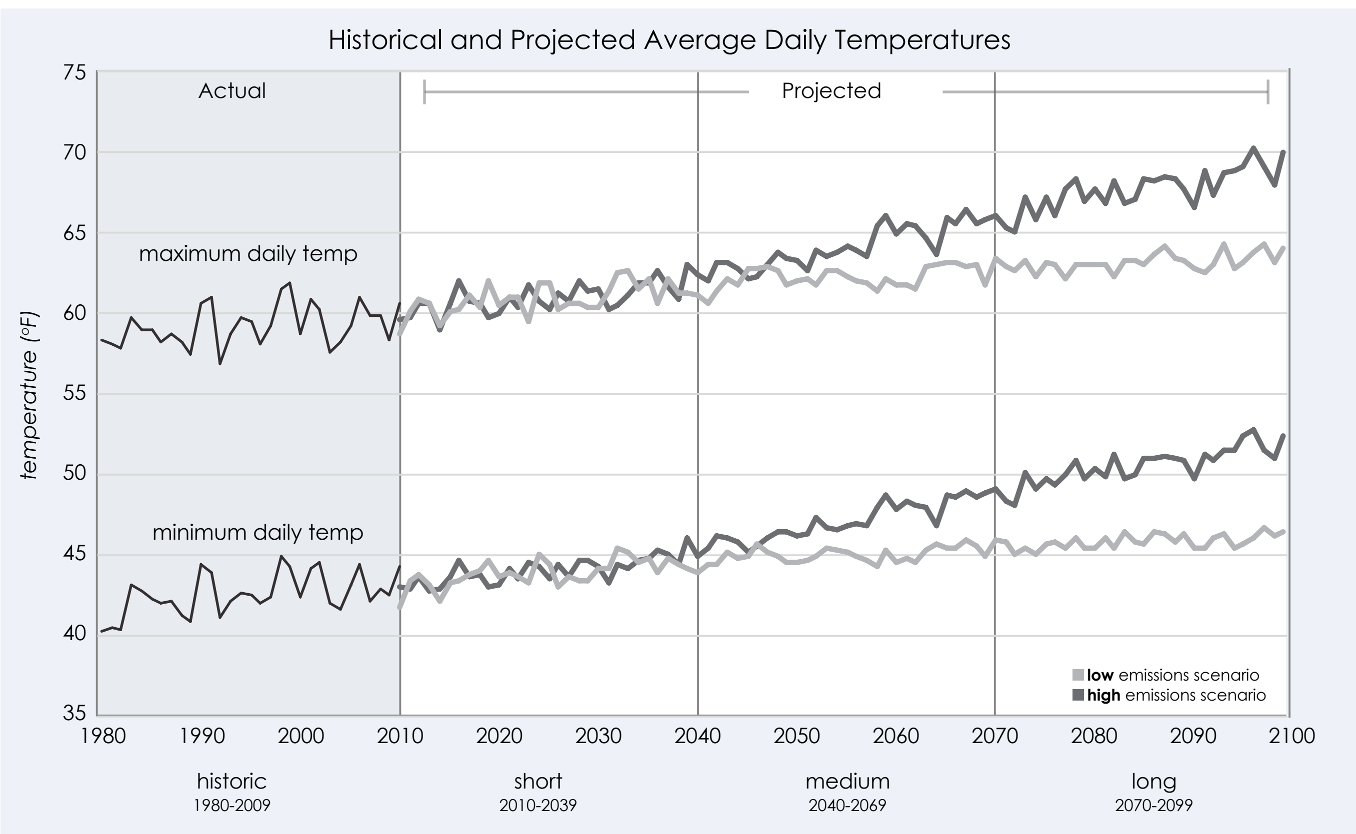


Figure 2. Historical (Actual) and Future (Projected) Daily Temperatures for Barnstable Based on Different CO_2 Emissions Scenarios and Timeframes

Seasonal Highs and Lows:

Both summer and winter average daily temperatures are projected to increase over the next century. This includes both minimum (daily lows) and maximum (daily highs) temperatures. The projections indicate that climate change will have the greatest influence on maximum summer temperatures. By the end of the century, summer maximum daily averages may increase between 3.6 and 7.7°F, which would raise the average daily high in the summertime to between 81.5 and 85.6°F (Figure 3b). Summer minimum daily averages in Barnstable will potentially increase between 2.8 and 6.2°F in the long term, which means summer nights will not cool down as much as they have in the past. In the long term (2070-2099), winter minimum temperatures may increase between 3.1 and 6.3°F, a more than 25% increase from the historical baseline of 24.5°F (Figure 3c). Winter maximum daily temperatures will also increase, from a historical baseline of 40.4°F to as much as 44.7°F by the end of the century under the high emissions scenario.

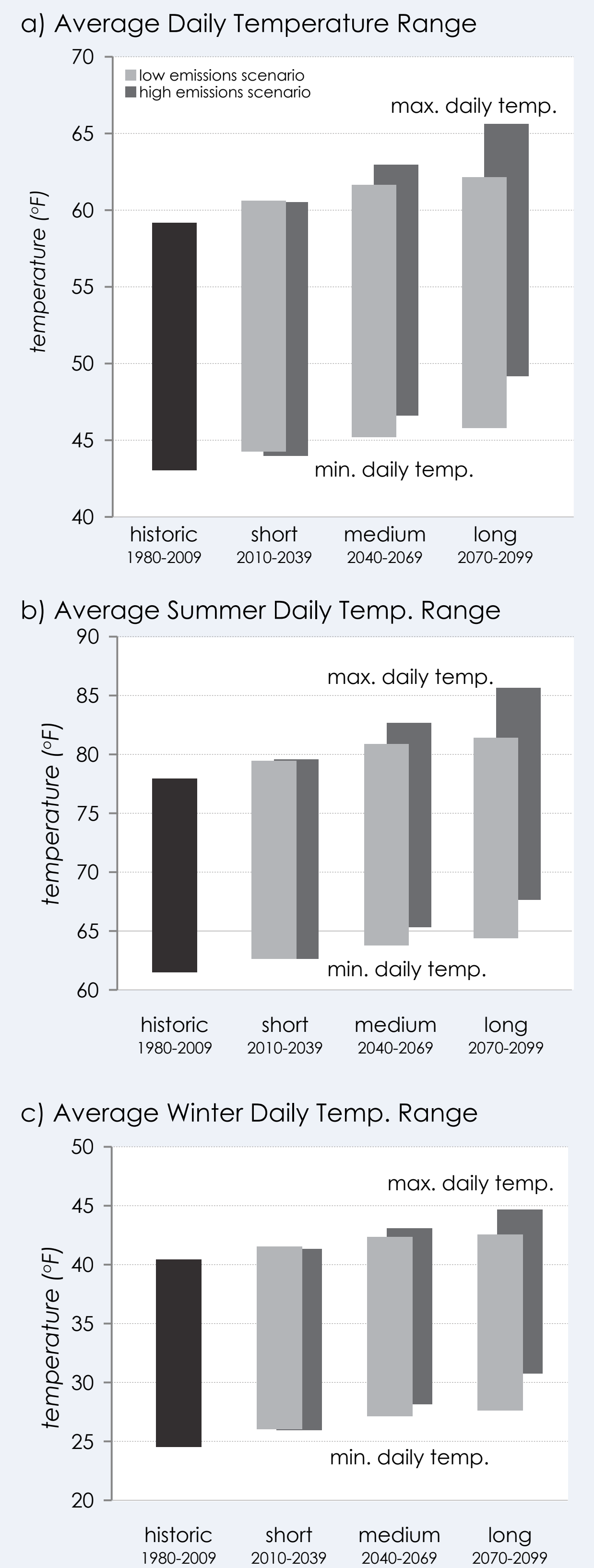


Figure 3. Future Average Daily Lows and Highs as Compared to Historical Baseline

Extreme Temperature:

Barnstable is projected to see a significant change in the number of extreme temperature events over the next century. Extreme cold events characterize days when the temperature drops below 32°F (freezing) while extreme heat events characterize days when the temperature rises above 90°F. Historically (1980-2009), Barnstable experienced an average of 103 extreme cold events and 2 extreme heat events per year. Climate projections forecast that, in the short term (2010-2039), Barnstable may see around 10 fewer extreme cold days (about a 10% decline) and 4 to 5 more extreme heat days (more than twice as many as historically) per year. In the long term (2070-2099), Barnstable may see up to 41 fewer extreme cold events and 24 additional extreme heat events per year. In other words, by the turn of the century Barnstable may experience more than a month's worth of days where temperatures that historically dropped below freezing no longer do, which will reduce the amount of precipitation that falls as snow rather than rain, among other impacts. It is important to note that there is significant variation across the projections for the five cities that were used to generate climate predictions for Barnstable. In the long term under the high emissions scenario, New Bedford may see as few as 49 extreme cold days, while Rochester is projected to see as many as 81. There is also great variation between cities in terms of extreme heat events. Edgartown is projected to see a 35-fold increase in the number of days when temperatures rise above 90°F, while Rochester and New Bedford may only see a 9-fold increase.

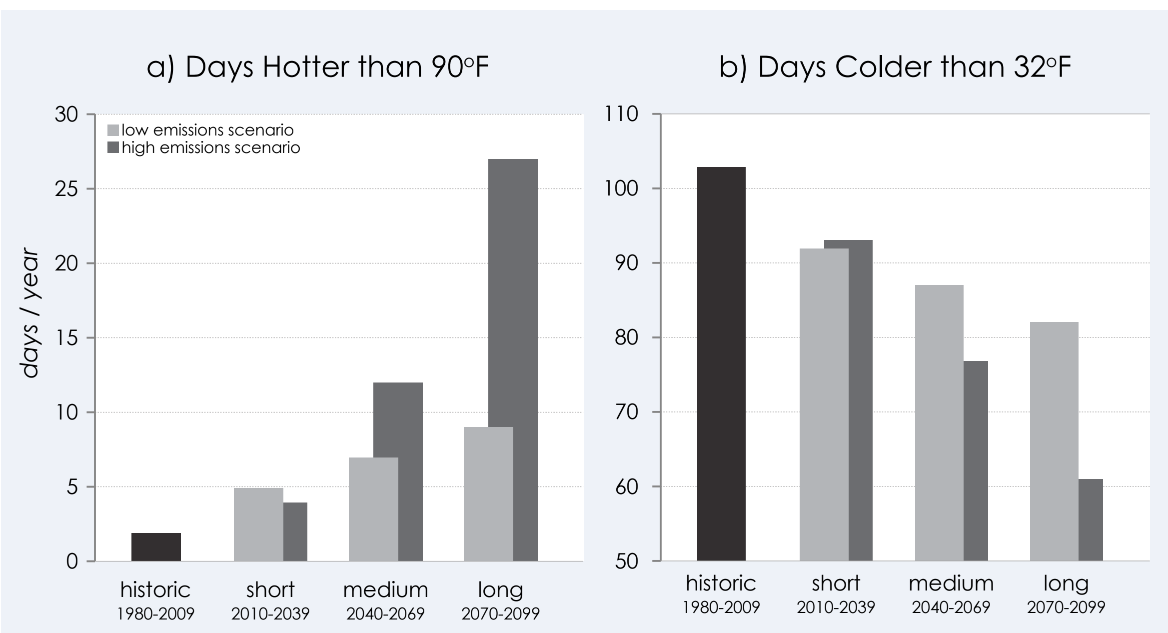


Figure 4. Extreme Temperature Events

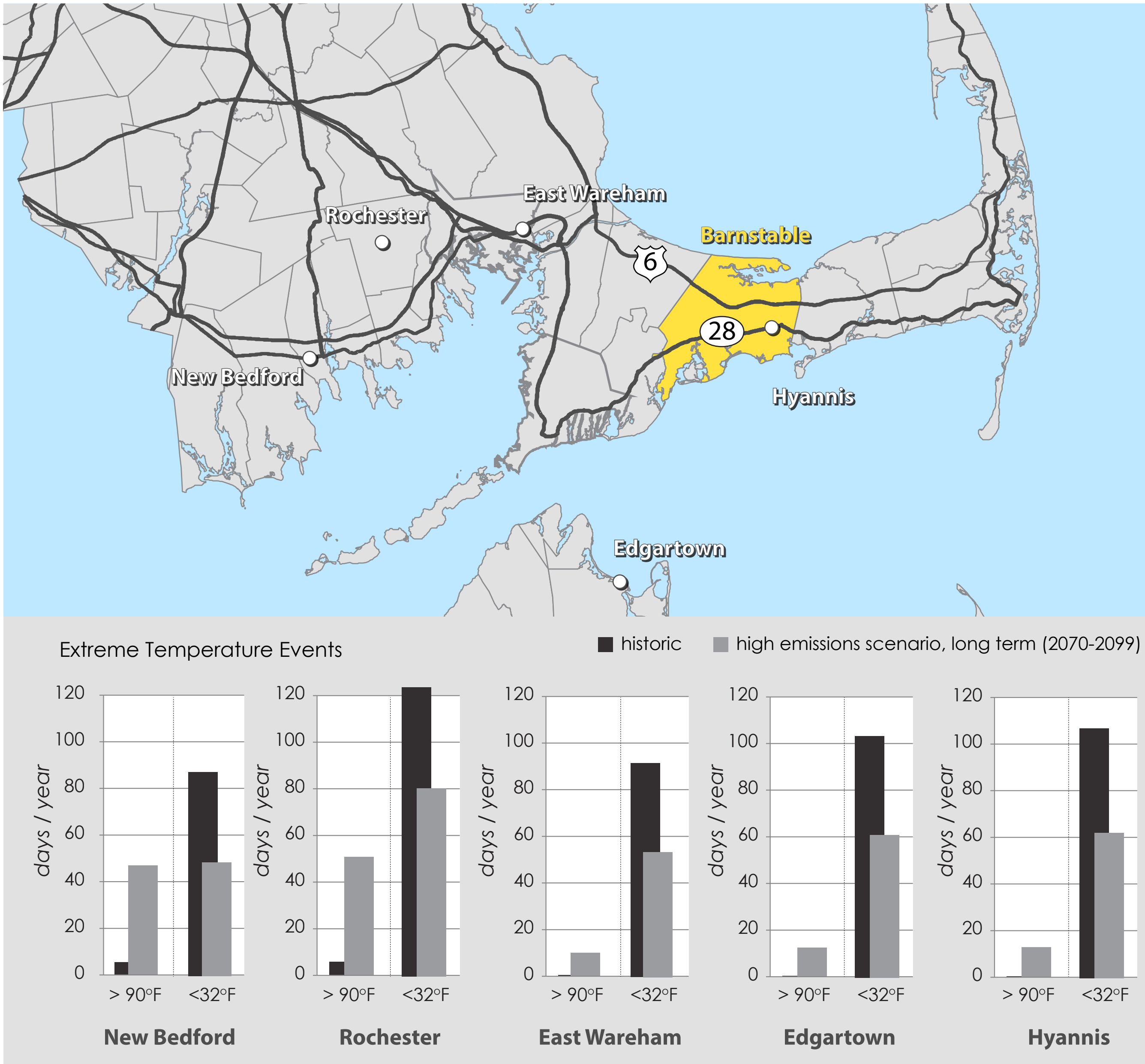


Figure 5. Extreme Temperature Projections across the Five Cities: Long Term, High Emissions Scenario

Table 1. Potential Impacts of Higher Temperatures

Change	Potential Impacts of Higher Temperatures
↑	**Health impacts:** Extended and magnified heat events will increase risk of heat strokes, air pollution, and vector borne diseases.
↑	**Infrastructure damages:** Extreme heat and heat waves may damage roads and electricity transformers.
↓	**Water supply:** Higher temperatures will result in more precipitation falling as rain rather than snow. Snowpack functions as a natural reservoir to store water outside of manmade reservoirs for drinking water supply. The reduction of snowpack may reduce spring and early summer supplies. Higher average temperatures can also be associated with increased evaporation and transpiration which could further reduce water availability.
↓/↑	**Agriculture productivity:** Higher temperatures may cause a longer growing season, supporting agricultural benefits in crop production. Higher temperatures could also harm agricultural crops that are not suited for higher temperatures.
↑	**Ecosystem stress:** Higher temperatures can cause populations and habitats to migrate to lower temperature areas (high elevation or higher latitude), where possible. Ecosystems that cannot migrate or adapt to changing climatic conditions may degrade or collapse.
↓	**Snow removal costs:** Governments and property managers may be able to reduce their budgets for snow removal due to fewer extreme cold days.
↓/↑	**Heating and air conditioning bills:** People may save money if the warmer winter temperatures enable them to reduce the amount of energy needed to heat buildings. Conversely, higher summer temperatures may lead to higher air conditioning costs.

Precipitation

Average Annual Precipitation:

There is high variability in average annual precipitation, both historically and in future projections (Figure 6). Comparing an average historic baseline (1980-2009) to short term, medium term, and long term averages more clearly reflects precipitation trends (Figure 7). The projections show little change in average annual precipitation in the short term (Figure 7). In the medium term, however, both the low and high emissions scenarios show an increase in annual precipitation of about 0.7 to 0.8 inches (Figure 7). Increases in precipitation become pronounced in the long term, with both the low and high emissions scenarios predicting an increase in annual precipitation of 2.7 inches over the baseline. As with extreme temperature, there is significant variation among the annual precipitation projections for the five cities used to generate Barnstable's climate projections. In the long term under the high emissions scenario projections, New Bedford is projected to see a modest 2.7% increase in annual precipitation, whereas East Wareham may see an over 8% increase (Figure 9).

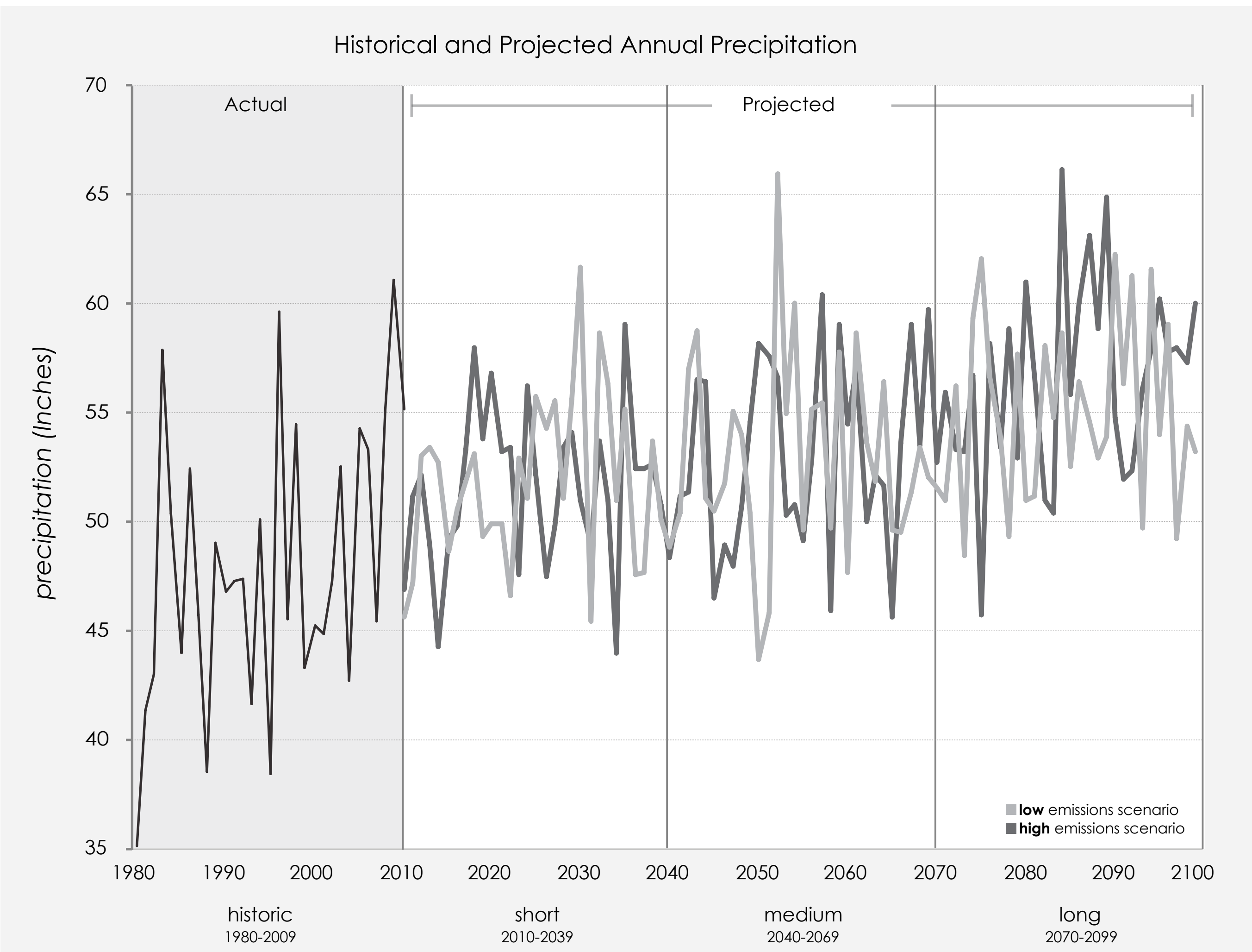


Figure 6. Historical and Future Average Annual Precipitation Trends

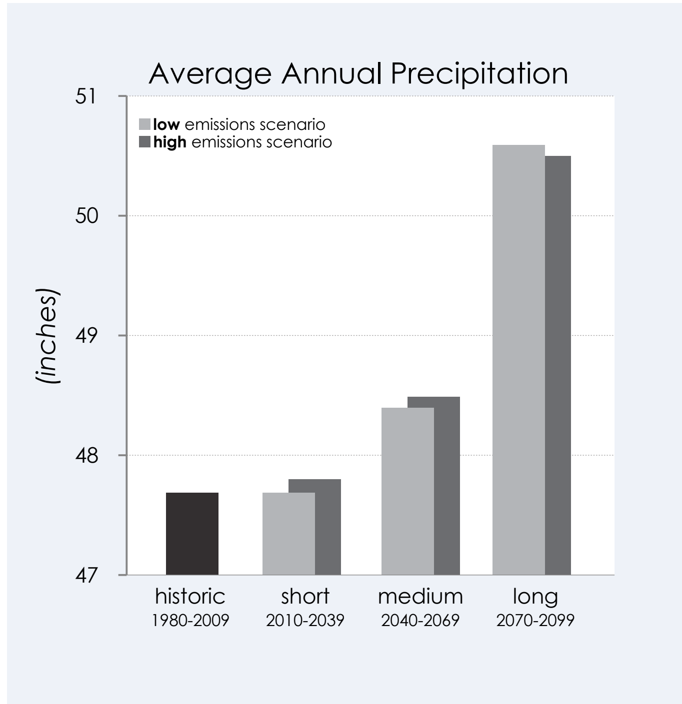


Figure 7. Comparison of Historical to Short, Medium, and Long Term Average Annual Precipitation Projections

Figure 8. Dock. Town of Barnstable Long Beach, Centerville

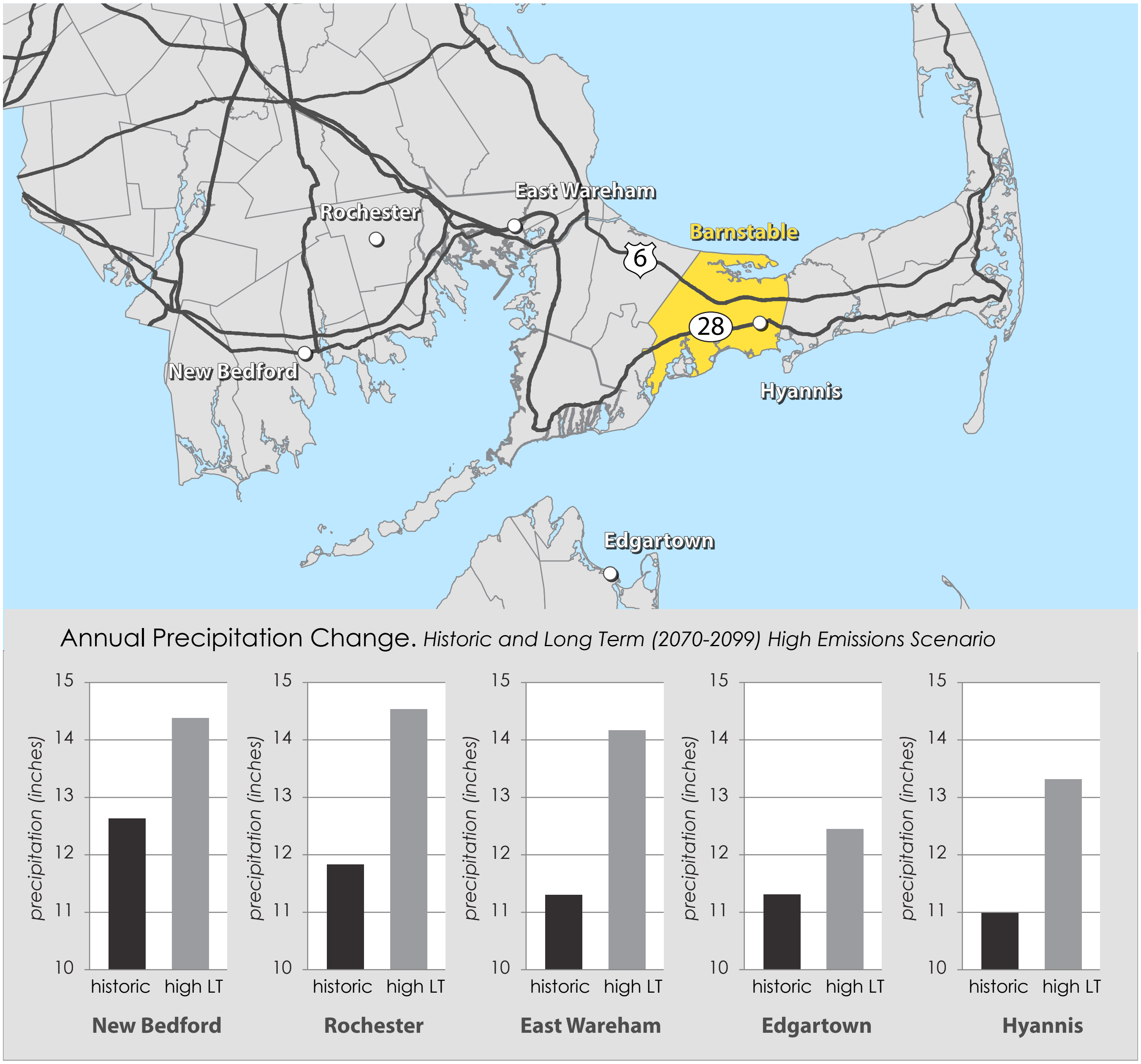


Figure 9. Comparison of Long Term High Emissions Scenario Annual Precipitation Changes across Five Cities.

Seasonal Precipitation:

Seasonal precipitation projections show that winters will become slightly wetter while summers may become drier. Winter precipitation is predicted to increase by 1.7 to 2.2 inches on top of the historical baseline of 11.6 inches (Figure 10a). In contrast, projections show a decrease in summer precipitation for all time scales under the high emissions scenario (Figure 10b). Summer precipitation may decrease by 0.7 inches in the medium term. In the long term, summer precipitation may increase by 0.2 inches under the low emissions scenario or decline by 0.5 inches under the high emissions scenario.

Extreme Precipitation Events:

Barnstable is expected to see more extreme precipitation events in the future, especially under a high emissions scenario (Figure 11c). Extreme precipitation events are characterized by storms with heavy precipitation within short time intervals. Extreme precipitation events are a key driver of flooding in Barnstable, so this projected increase could have significant impacts on flooding risk in the area. Between 1980 and 2009, Barnstable experienced 13 events per year where 1 inch of precipitation fell within 24 hours, and between 5 and 6 events per year where 2 inches of precipitation fell within 48 hours. In the long term, the former events may increase to around 15 events per year, while the latter events may increase to between 8.5 and 9.5 events per year, nearly doubling historic numbers.

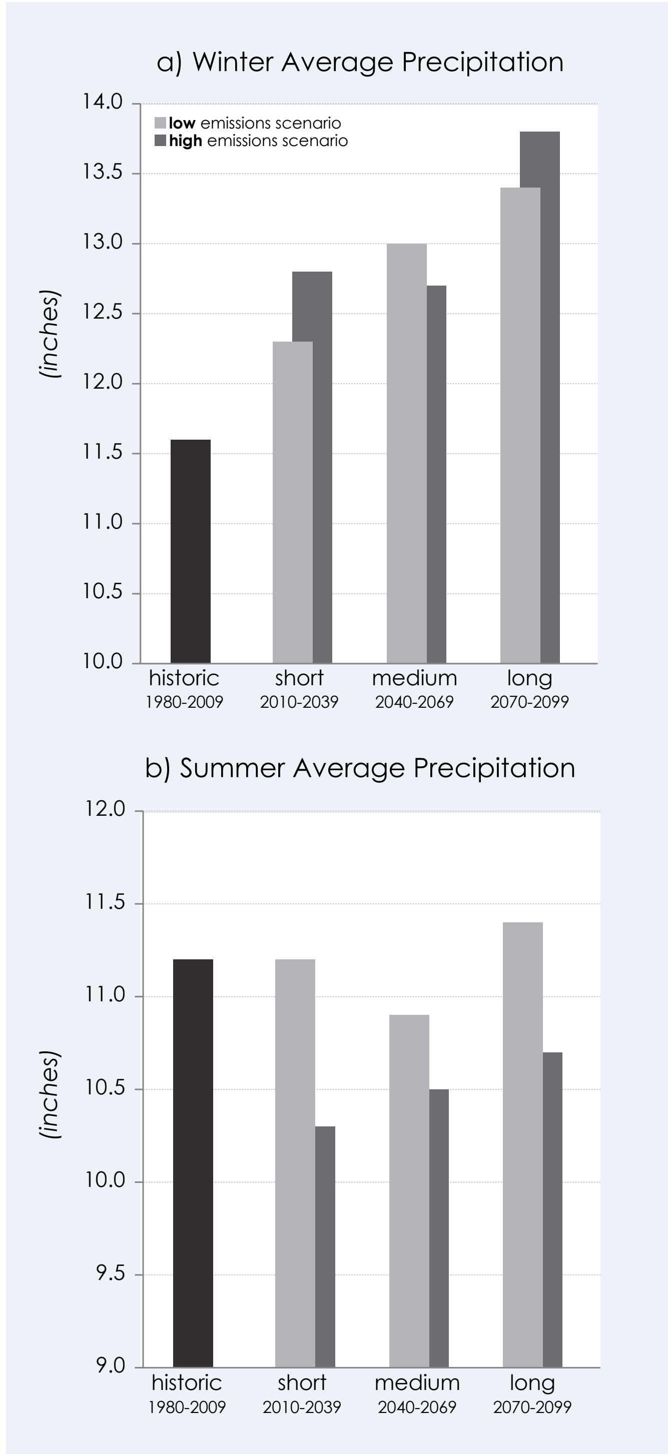


Figure 10. Seasonal Precipitation Pattern

Events where over 4 inches of precipitation fall in 48 hours are considered very extreme and rare, and are therefore counted by events per decade. Historically, Barnstable experienced about 1.8 events of this nature per decade. The town is projected to see as many as 3 events of this type per decade in the short term under the low emissions scenario, and as many 4.1 of these events per decade in the long term under the high emissions scenario, more than doubling the frequency of such severe precipitation events.

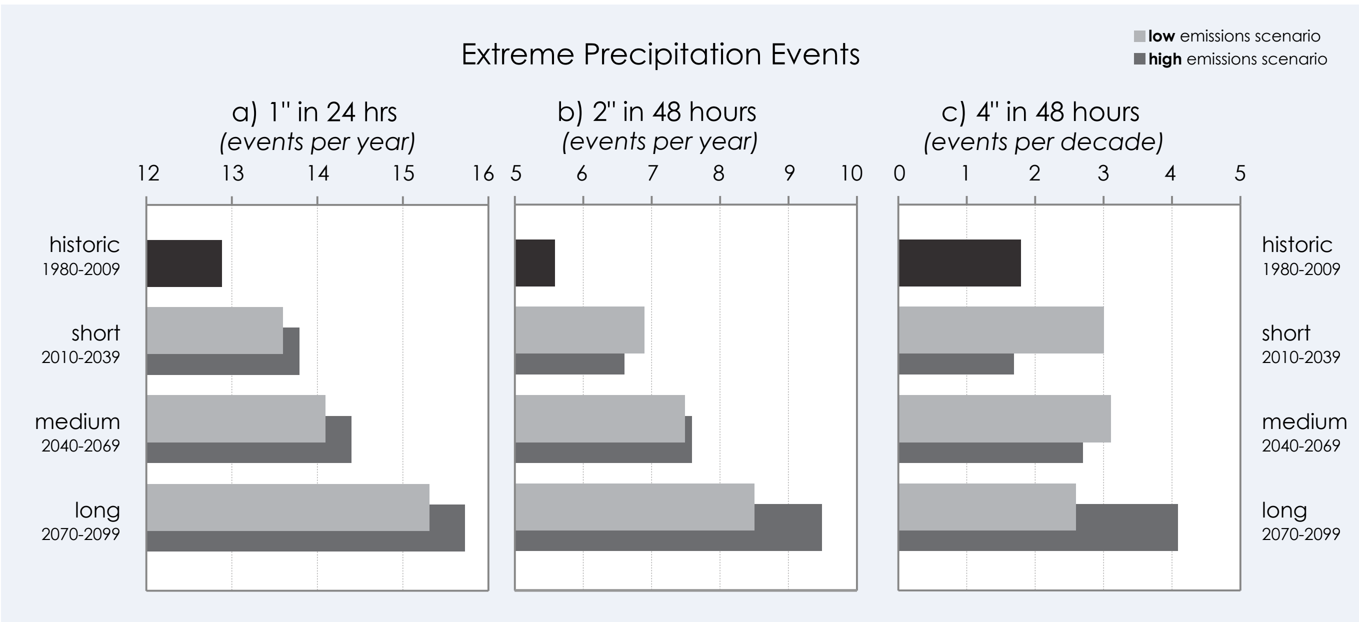


Figure 11. Extreme Precipitation Events

Table 2. Potential Impacts of Precipitation Changes

Change	Potential Impacts of Precipitation Changes
↑	**Flooding:** One of the key impacts associated with higher precipitation and more extreme precipitation events is increased flooding risk, which can potentially damage houses, businesses, and infrastructure and disrupt livelihoods.
↑	**Erosion:** Flash flooding and storm surges associated with extreme precipitation events may lead to increased erosion, especially along steep slopes and non-vegetated soil.
↓	**Water quality:** Increased stormwater runoff associated with precipitation events could increase the concentration of water-borne pollutants in urban streams.
↑	**Vector borne disease:** An increase in the amount and duration of standing water may lead to an increase in pests and vector borne diseases such as West Nile Virus.

Sea Level Rise

Projections indicate ongoing sea level rise throughout the century under both the high and low emissions scenarios. In the long term, Barnstable's sea level may rise by upwards of 5 to 6 feet over 2000 levels under the high emissions scenario (Figure 12). In the short term, sea level may rise between half a foot to a full foot over 2000 levels under the low and high emissions scenarios, respectively.

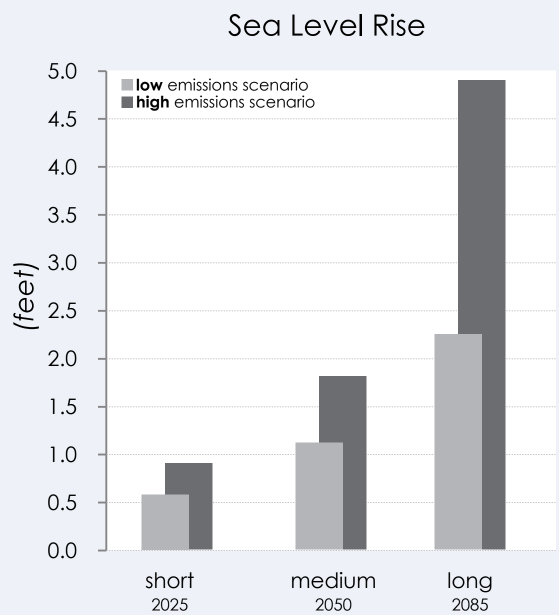


Figure 12. Sea Level Rise Projections

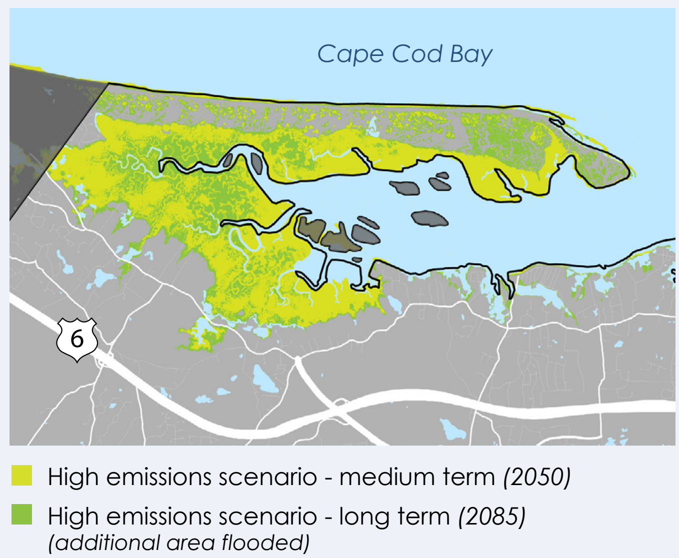


Figure 13. Coastal Sea Level Rise. Mean Sea Level Inundation

Table 3. Potential Impacts of Sea Level Rise

Change	Potential Impacts of Sea Level Rise
↑	**Daily tidal inundation:** Sea level rise will likely increase the extent of daily tidal inundation with social, economic, and ecological implications.
↑	**Coastal Flooding:** Coastal flooding risk will increase due to sea level rise, especially when coupled with increases in extreme precipitation events and possible increases in hurricane intensity.
↑	**Groundwater levels:** Rising groundwater levels may damage infrastructure and property along the coast. Rising water may mean that Barnstable's aquifer becomes contaminated with salt ocean water.

Section 2: Integrated Risks and Adaptation Options

This section of the report builds on the climate change projections and possible impacts from Section 1 and applies them to community systems and assets in Barnstable to examine some of Barnstable's key climate change risks, vulnerabilities, and adaptation options. Figure 14 represents the approach we used to understand and assess risk. This approach is based on the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Extreme Events (2012). Risk (white circle) is the likelihood of impact resulting from the interaction of:

- a ***threat,*** an event caused by natural variability and/or anthropogenic climate change, and

- ***vulnerability,*** the sensitivity, exposure, and adaptive capacity of a place and its likelihood to be adversely affected.

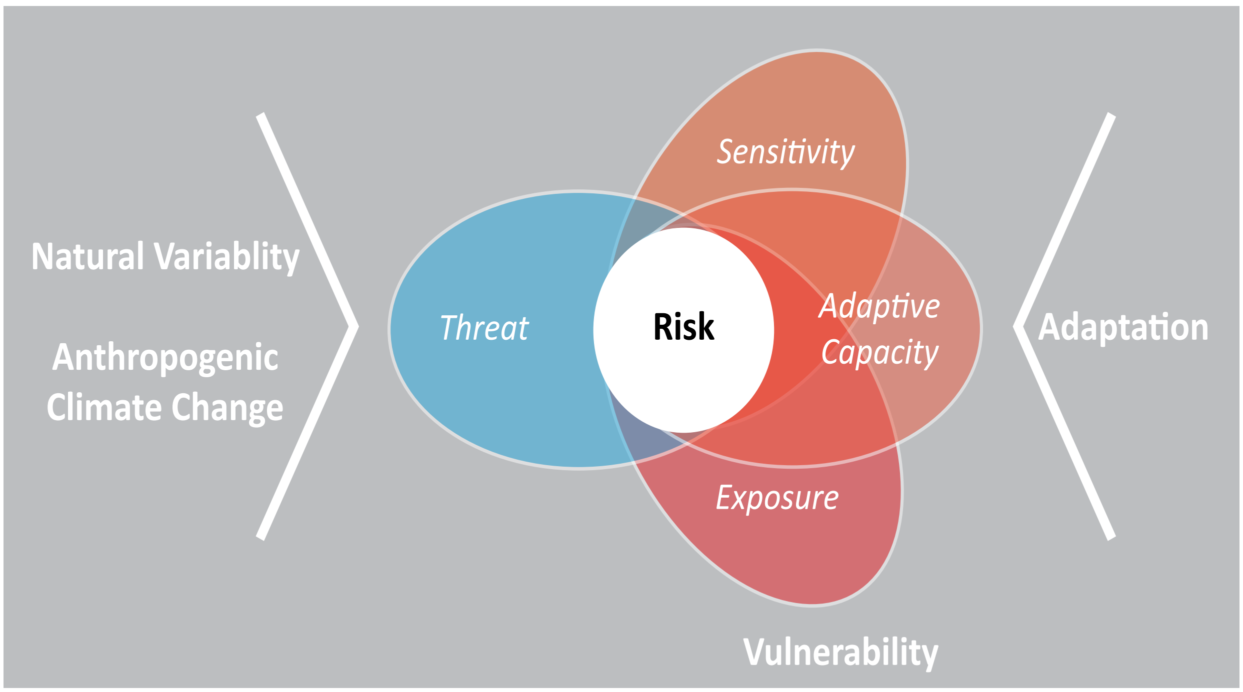


Figure 14. Integrated Risks (Adapted from IPCC SREX Report)

Climate adaptation focuses on reducing local and regional vulnerability. Adaptation options (right side of the diagram) reflect alternative mechanisms that can be used to reduce Barnstable's risk to a given climatic threat through minimizing exposure (e.g. moving out of harm's way), reducing sensitivity (e.g. implementing storm-resistant building techniques), and increasing adaptive capacity (e.g. creating wide vegetative buffers). Adaptation options can be broadly grouped under four categories: 1) no action, 2) accommodation, 3) protection, and 4) retreat. The adaptation options that are appropriate in a given situation will depend on a number of factors, including, but not limited to: the magnitude of the threat; the timeframe and probability of the threat; the associated economic, social and ecological cost of the risk; and availability of resources and knowledge at the time.

Accommodation options focus on reducing the sensitivity of a system to a threat. Such approaches include things like early warning systems, the modification of ground floors of buildings to decrease flooding damage, and removal of critical infrastructure from ground floors. Protection options reduce exposure by preventing the threat from occurring or reaching the population. Protection measures include building seawalls and restoring or creating wetlands to prevent flooding from occurring. Lastly, retreat options reduce exposure by moving the population away from the threat, such as through relocation, setback requirements, and phasing out development in high-risk areas. In contrast to climate change adaptation, climate change mitigation practices that reduce global greenhouse gas emissions aim to lessen the speed and severity with which regional climates are changing and, as a result, minimize climate change risks globally and in the long term by reducing threats.

This section highlights several risks including flooding, drought, heat waves, fiscal vulnerability, and ecosystem changes. Specific vulnerabilities for Barnstable were identified through consultation with key individuals from the city and climate change experts, as well as a review of published literature including the Town of Barnstable's Multi-Hazard Mitigation Plan (2010). See Additional Resources in Appendix 2 for more in-depth narratives and diverse examples of adaptation options.

Flooding

RISKS

The risk of flooding is expected to increase in the Town of Barnstable over the next century due to climatic changes. Coastal flooding is projected to increase in intensity due to both sea level rise and an increase in the severity of storms associated with warmer temperatures. In addition to coastal flooding, the risk of inland flooding may increase as a result of rising groundwater levels due to sea level rise and more frequent extreme precipitation events.

According to the 2010 Multi-Hazard Mitigation Plan written for the Town of Barnstable, flooding is ranked as the highest hazard. In Barnstable County, flooding generally occurs as a result of Hurricanes and Nor'easters (Town of Barnstable). Coastal areas on Cape Cod Bay (north side of Barnstable) suffer more from exposure to northeasters, while those on Nantucket Sound (south side of Barnstable) are most affected by tropical hurricanes. Inland flooding, while less prominent of an issue for Barnstable, is also a concern. Inland flooding occurs when rivers and streams overflow their banks, or when water is unable to infiltrate the ground due to impermeable surfaces. Figure 15 shows both the 100-year floodplain (an area with a 1% chance of flooding in a given year) and the 500-year floodplain (an area with a 0.2% chance of flooding in a given year). These floodplains reflect proposed 2014 changes to 1984 delineations developed by the Federal Emergency Management Agency (FEMA) as part of a nationwide update of flood insurance rate maps (FIRMS). This flood map is currently under appeal, so the floodplain boundaries are subject to change.

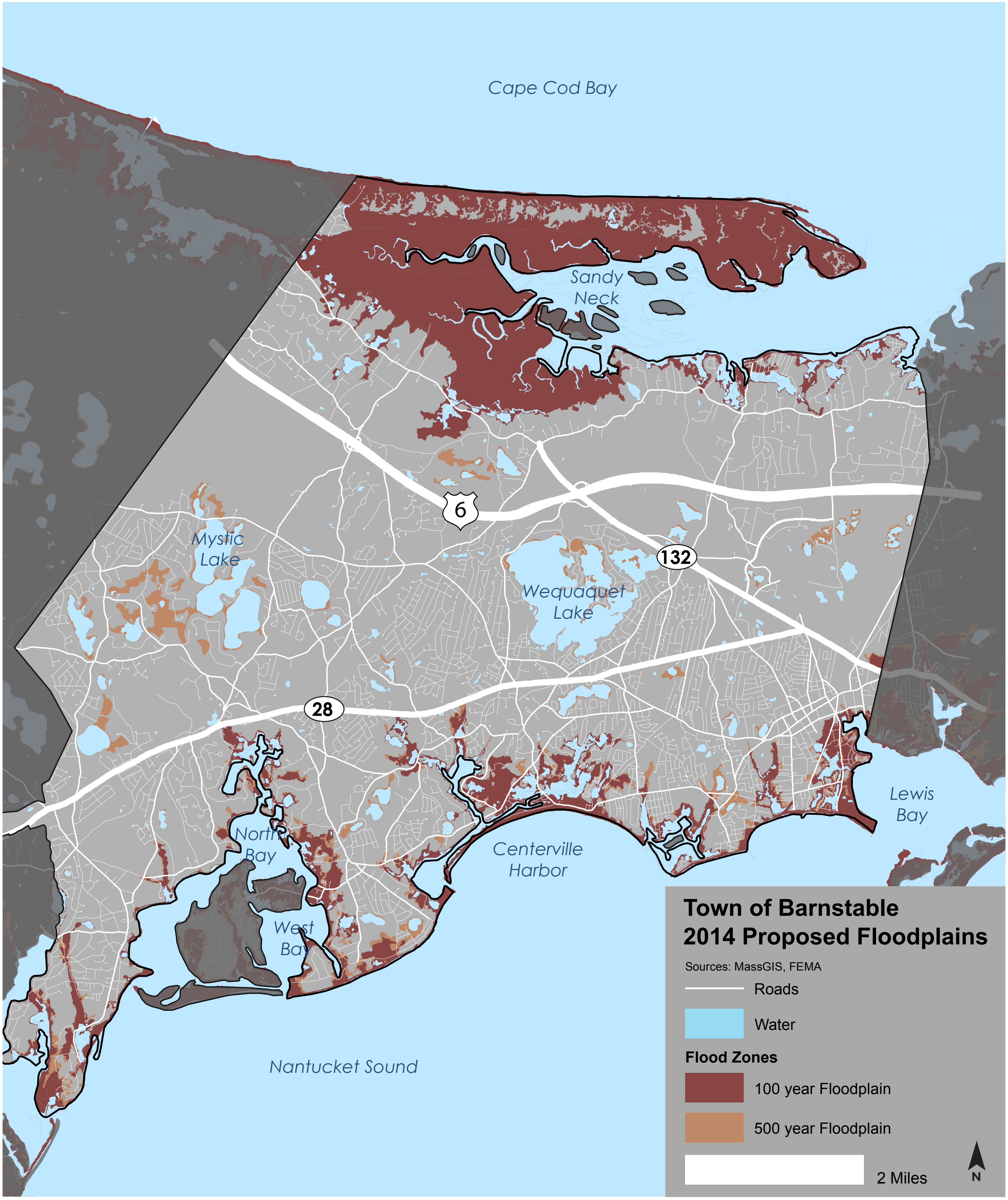


Figure 15. Town of Barnstable Proposed (2014) 100 and 500 year Floodplains

Coastal Flooding

Sea level rise poses a serious risk to coastal development and ecosystems. The impact of sea level rise is already manifesting on the Cape, evidenced by the submersion of low-lying lands, erosion of beaches, conversion of wetlands to open water, increased salinity of estuaries and aquifers, and exacerbated coastal flooding (Town of Barnstable, 2010). In the long term, sea level is projected to rise by upwards of 5.9 feet under the high emissions scenario, which would significantly increase coastal flooding along both the northern and southern shores of Barnstable (Figure 16)[2]. Higher sea levels would also lead to higher storm surges, such that when coastal storms occur they will be more likely to result in expansive and severe flooding along the coast (EPA, 2013). Cape Cod and the Mid-Atlantic will likely be disproportionately affected by sea level rise, due to the concurrent subsidence of coastal land in the region.

In addition to increased risks associated with sea level rise, climate experts suggest that the magnitude of coastal storms such as Nor'easters and hurricanes will also increase due to warmer temperatures and increased moisture associated with projected climatic changes (Trenberth et al., 2013). Nor'easters are lower-energy storms than hurricanes, but they occur more frequently, last longer, and cover more area than hurricanes, causing significant damage. Since the 1970s, Nor'easters have struck New England more frequently and with greater intensity (NE Aquarium, 2014). Hurricane inundation data represents potential coastal flooding that may occur from critical combinations of hurricane track direction, forward speed, landfall location, and high astronomical tide. Figure 17 reflects the current hurricane inundation areas for the Town of Barnstable by categories. The area inundated by hurricanes is projected to increase with sea level rise. It is also possible that increasing temperatures will amplify the intensity of hurricanes.

Inland flooding

Barnstable may see an increased risk of inland flooding due to climatic changes, including more frequent extreme precipitation events as well as further tidal inundation and higher groundwater levels associated with sea level rise. Barnstable is projected to see a rise in the number of extreme precipitation events— particularly events with 2 inches of precipitation in 24 hours and 4 inches of precipitation in 48 hours. These severe precipitation events result in high volumes of water falling in short periods of time, resulting in high runoff volumes. Flooding may be further exacerbated as rising sea levels correspond with higher groundwater levels and further tidal inundation. In addition, more development will increase the amount of impervious surface in the watershed, which will reduce the infiltration capacity and lead to faster runoff rates.

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2 This map was generated using publicly available spatial data from state and county GIS departments. Sea level rise is relative to NAVD88 at the nearest tide station (Chatham, MA). This includes LiDAR data, administrative boundaries, and natural features. After conversion to the appropriate vertical datum (NAVD88), simple geoprocessing tools were used to reclass the elevation data and add sea level rise.

More sophisticated techniques – for instance the SLOSH model – require better quality data regarding storm surge heights and winds resulting from historical or predicted hurricanes, as well as engineering considerations such as infrastructure and unique bay and river configuration. As such, the maps in this assessment are intended for visualization purposes only.

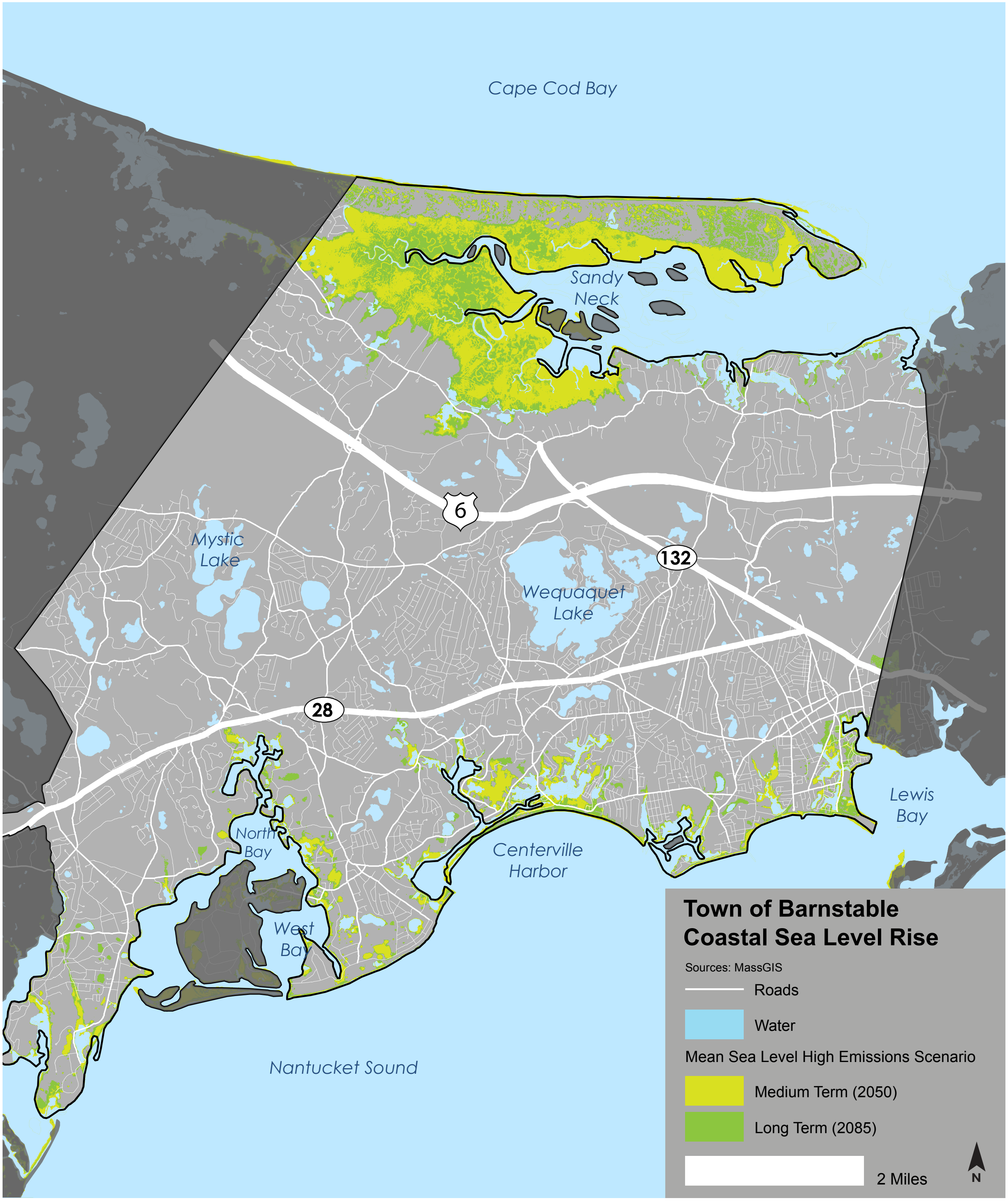

Figure 16. Sea Level Rise along Barnstable's North and South Shores

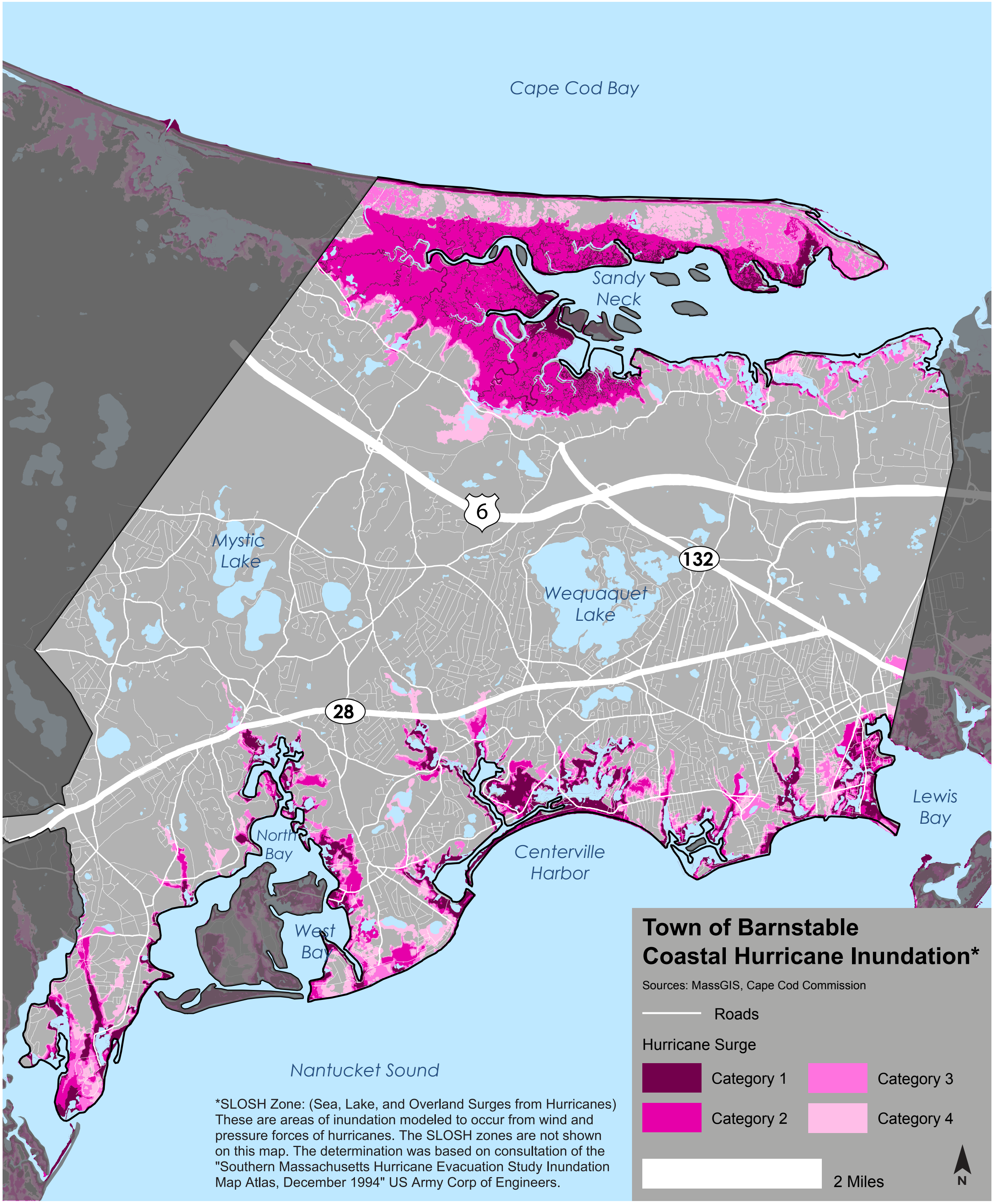

Figure 17. Current Hurricane Inundation

VULNERABILITIES

Neighborhoods and Properties

Properties within the 100-year and 500-year floodplain are expected to become more vulnerable to future flooding under projected climate changes. Buildings can be severely damaged by floodwaters, causing displacement of residents and businesses. Basements can also become damaged from higher groundwater levels and leaks associated with flood events and rising sea levels. Flooding can also cause residences and businesses to lose power and water services, and can result in road closures that interfere with travel and access to key services and facilities.

In 2010, the Town of Barnstable conducted a vulnerability assessment on its coastal properties, using FEMA's 2009[3] 100-year and 500-year floodplains (2010). This assessment found that residential properties are the most vulnerable to flood damage in terms of numbers, square footage, and assessed value, with 1,114 housing units totaling over $425.9 million in value located in flood hazard areas. Commercial properties in the flood zone are worth an additional $38 million. The Villages of Hyannis, Osterville, and Centerville (Figure 18) have particularly high assessed property values within the floodplain. The Town of Barnstable has a total of 11.68 square miles (7,474.78 acres) of property in Hurricane Inundation zones.

Social Vulnerabilities

Displacement caused by flooding is a major social vulnerability. Populations with limited access to mobility, resources, and decision making may be more sensitive to flood impacts. These populations may include lower income households, non-English speaking persons, minority populations, the elderly, very young, and presently ill. According to the State's Executive Office of Energy and Environmental Affairs (EEA) neighborhoods in the Town of Barnstable that reflect potential environmental justice populations include the neighborhoods south of the airport and north of Lewis Bay (Figure 19). Further, figure 20 displays the location of Barnstable's emergency facilities and shelters, public safety facilities, schools; nursing homes and elderly housing, group day care facilities, and senior, youth, and recreation centers in relationship to flood risks.

Infrastructure and Facilities

Flooding may affect critical services and valuable city resources, washing out roads, damaging infrastructure, overwhelming storm sewers, and contaminating drinking water. The Town of Barnstable's 2010 Multi-Hazard Mitigation Plan identified critical facilities and infrastructure at risk from flooding. Ten of the critical facilities identified in the Town of Barnstable are also identified as critical facilities in the region by the Cape Cod Commission. The regional facilities are the American Red Cross, the Barnstable County Complex, Cape Cod Hospital, Barnstable Municipal Airport, Cape Cod Community College, the Barnstable County Fire and Rescue Training Academy, the Humane Society, and the MSPCA Animal Shelter (Figure 21). In addition, the Town of Barnstable identified transportation corridors that may be impaired during a flood emergency, including Route 6A, Mill Way, Commerce Rd, and the West Bay Bridge.

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3 The 2009 FEMA floodplain delineation has been withdrawn and replaced by the proposed 2014 floodplain delineation.

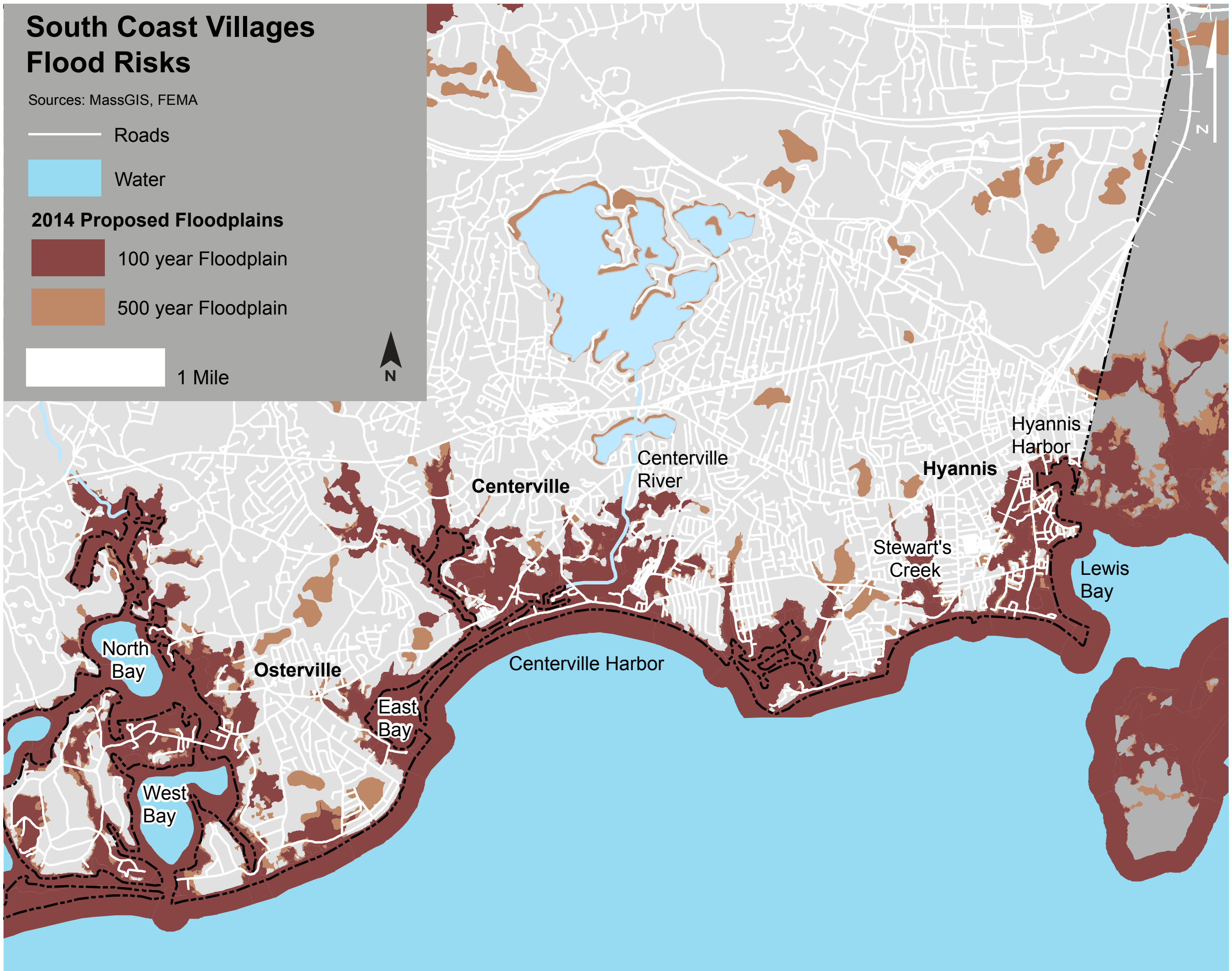


Figure 18. Barnstable Neighborhood Flood Risks

ADAPTATION OPTIONS

Reducing Exposure

One way to reduce the risk of flooding is to reduce the exposure of people and community assets to flooding. For example, "managed retreat" refers to strategically moving people and structures out of floodplains. Once structures have been removed from the floodplains, the land can be restored to provide flood mitigation, wildlife habitat, and open space. The Town of Barnstable's floodplains are currently protected by zoning, wetland, and health regulations such that no new development is directed into floodplain zones. In addition, over 1,000 properties participate in the National Flood Insurance Program (NFIP) and 17 of these properties reflect multiple claims. The City of Cranston, RI, has started a small scale program that purchases homes that have been repeatedly flooded (i.e. multiple claims) using funding from FEMA (City of Cranston, 2012).

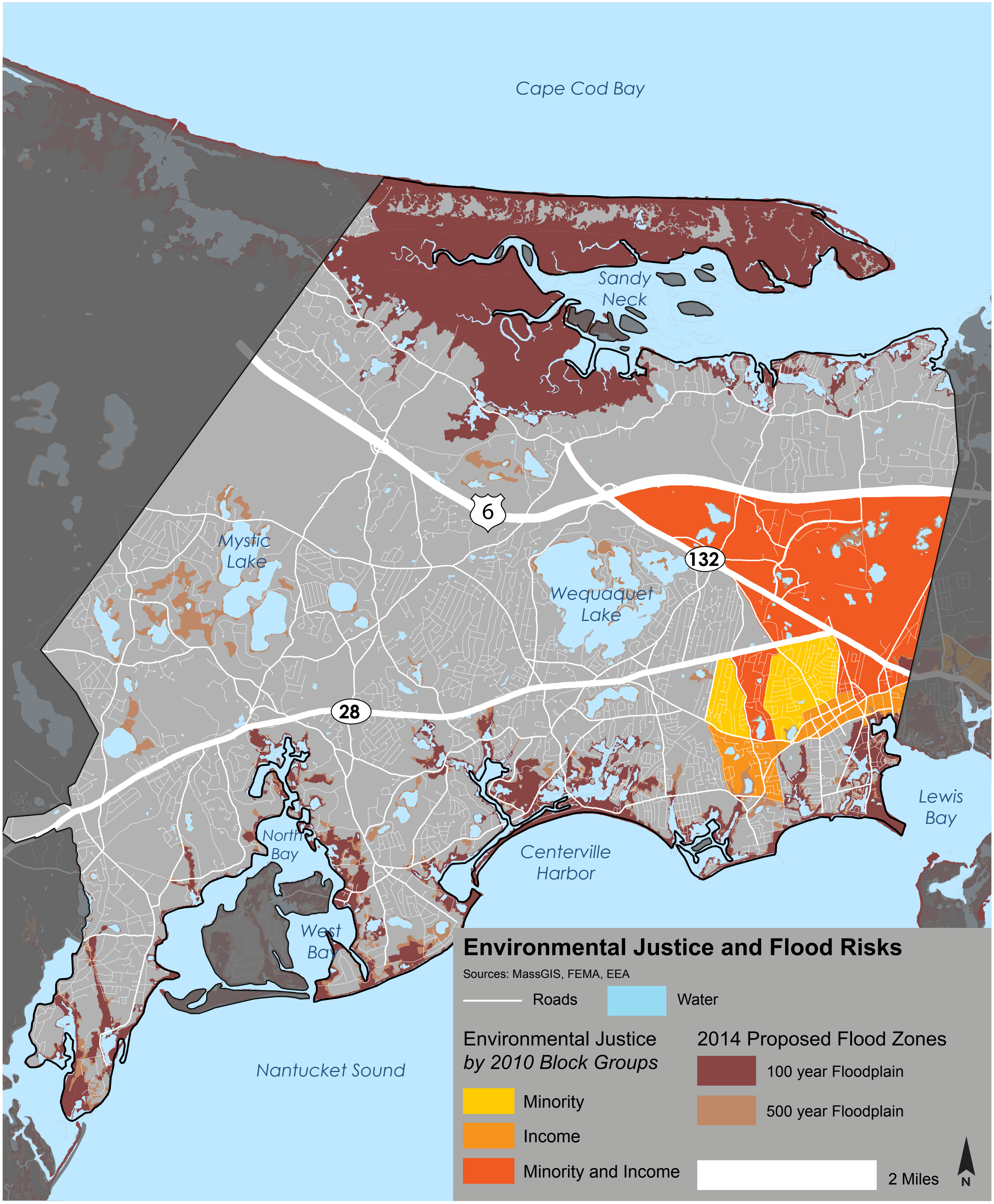


Figure 19. Environmental Justice Neighborhoods and Flood Risks

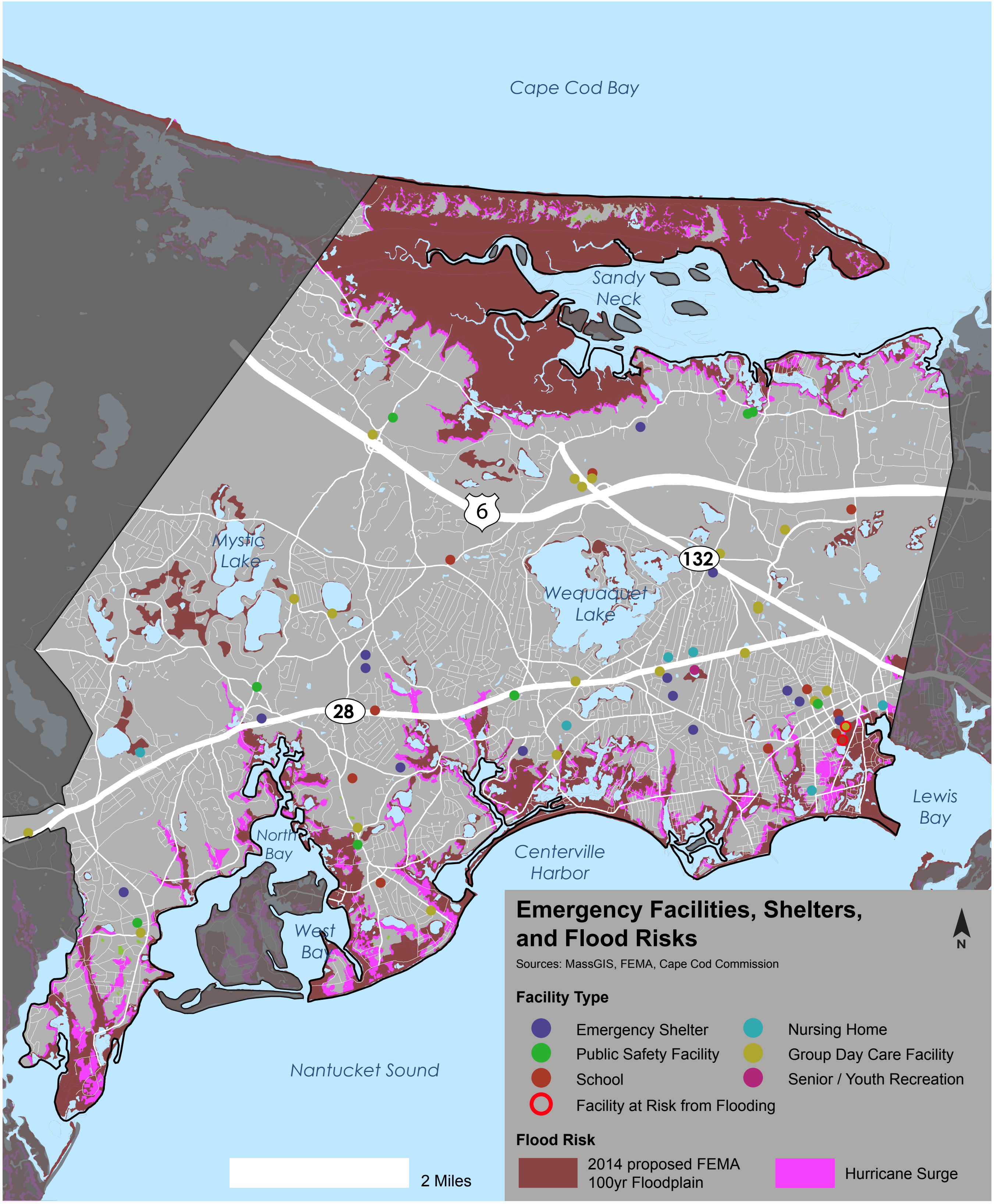


Figure 20. Emergency Facilities, Shelters, and Flood Risks

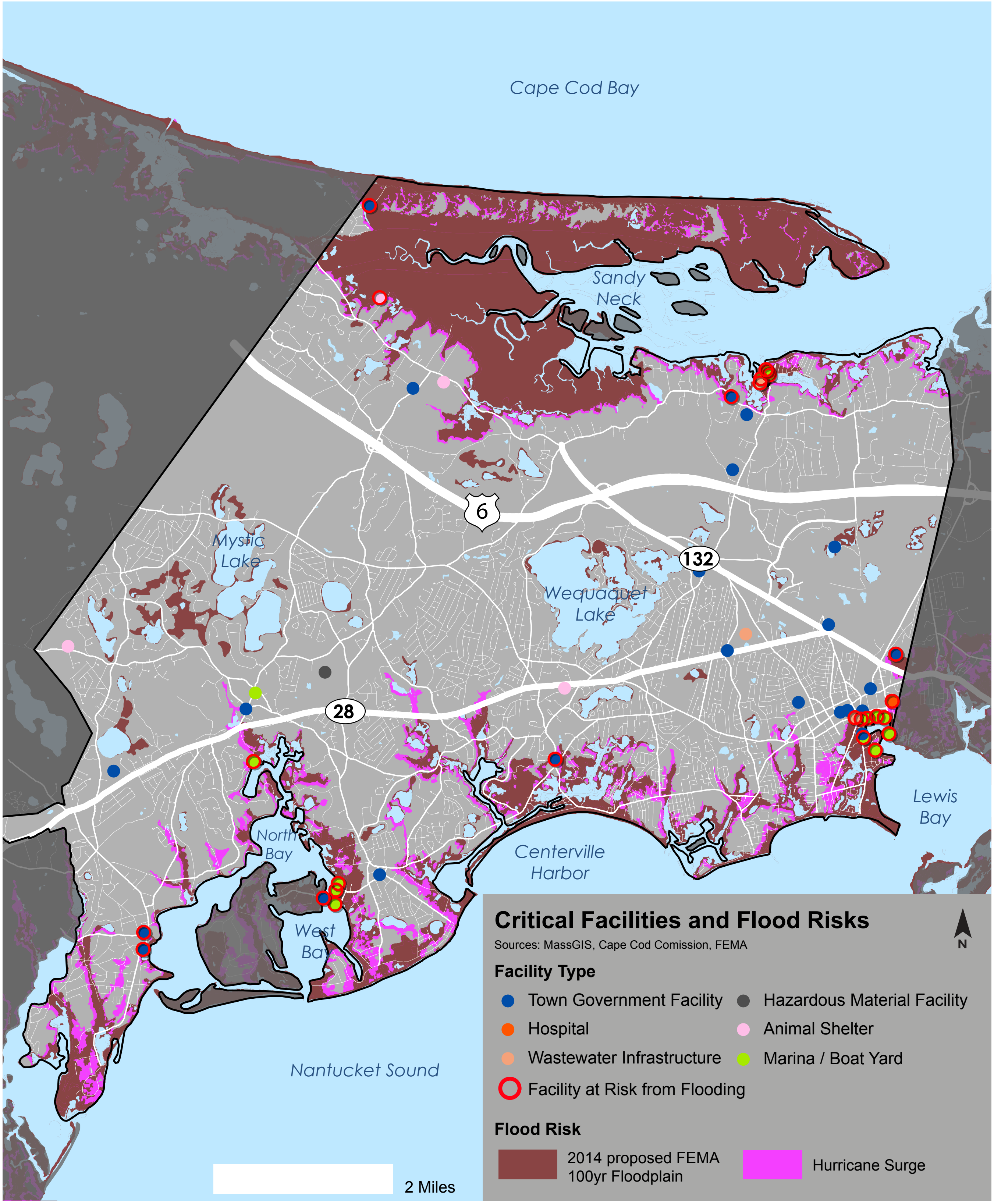


Figure 21. Critical Facilities and Flood Risks

Another way to reduce exposure to river flooding is to use a “protect” strategy, which refers to using structural measures, such as floodwalls, to reduce the likelihood that the rivers will overflow their banks. The downside to structural protection measures is that if they are breached by floodwaters the economic losses tend to be very high, in large part due to the “levee effect”—that is, the tendency of development to occur on the other side of a protective structure. In addition, these structural strategies tend to be less flexible than other options. They need to be designed to a certain specification in advance even though unexpected climate and environmental changes could occur. In Barnstable, many coastal properties are protected by private seawalls and jetties, most commonly for the 1% annual chance of a flood (Town of Barnstable, 2010).

Protection strategies do not always need to be based on infrastructure. Protection strategies can also employ ecosystem services. For example, Barnstable has invested in preserving and improving existing coastal dunes through the use of snow fencing and control of pedestrian access, in part to reduce flood hazards (Town of Barnstable, 2010). Tidal wetlands can further provide protection from flooding by absorbing floodwaters from storm surges and other severe weather events. However, several of Barnstable’s tidal wetlands are restricted by undersized culverts which reduce their capacity for storage. Cranberry bogs constitute a significant amount of additional flood storage capacity (Figure 22). However, there is no formal means of public or private control of cranberry bog flow or water-surface elevations, and further, cranberry bogs are subject to development pressure and may be completely lost as a means for flood storage as land-use patterns change (Town of Barnstable, 2010).

Reduce Sensitivity

Barnstable can reduce its vulnerability to flooding by reducing the sensitivity of community assets to flooding impacts, so that even if an asset is exposed to flooding, the damage is very limited. This is also known as an “accommodation” strategy. This can mean flood-resilient building design (such as homes that are elevated above the projected flood height and buildings that are dry or wet flood-proofed), or flood resistant infrastructure (such as electric transformers that are saltwater resistant).

Increase Adaptive Capacity

Building adaptive capacity, or the ability for people and assets to bounce back from flooding, is an alternative way to reduce Barnstable’s vulnerability. Insurance and other forms of financial security can help people rebuild after a climate-related disaster. Community organizations and affiliations have also been shown to help people recover from disasters more quickly (Swim et al., 2010). Successful efforts employ various strategies that are coordinated in time and location. The Town of Barnstable can support and coordinate with local organizations to facilitate recovery in response to flood events.

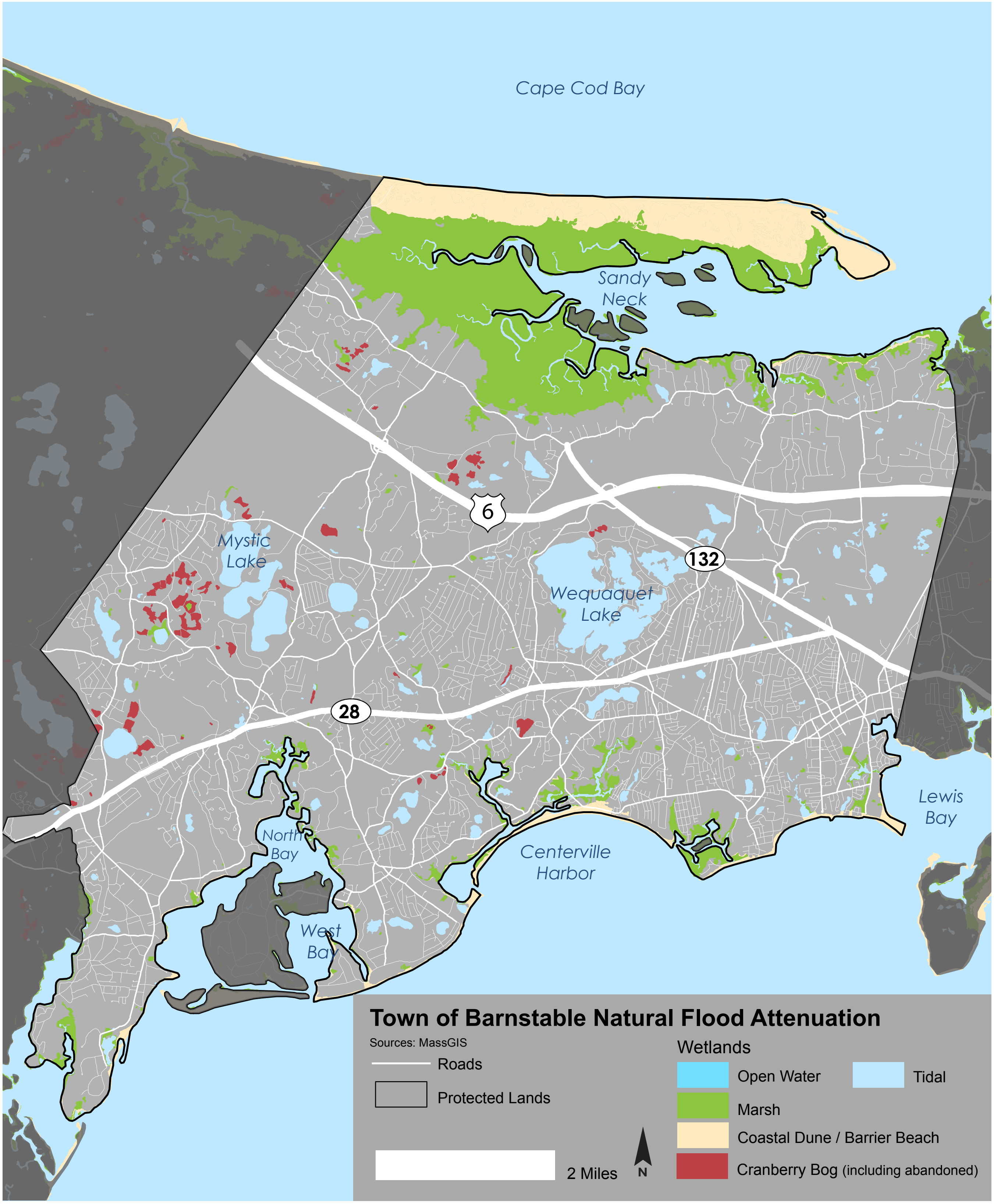
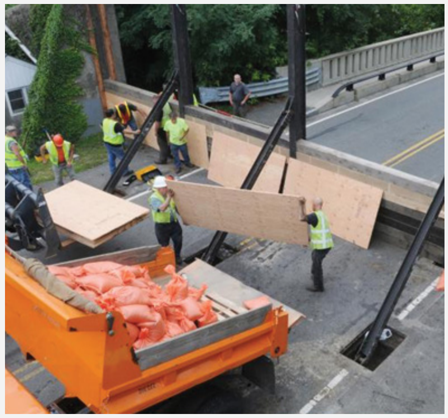
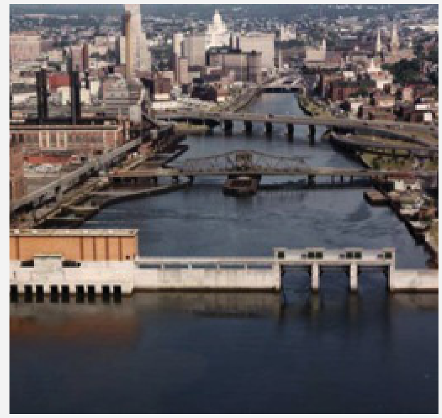


Figure 22. Town of Barnstable Natural Flood Attenuation

a) Restored Wetland



b) Floodwall



c) Hurricane Barrier

d) Pervious Pavement

e) Flood Resilient Building

f) Low Impact Development

Figure 23. Adaptation Options for Flooding

Drought

RISKS

In the future, climatic changes are expected to drive an increase in the occurrence of drought in the Town of Barnstable. The threat of drought in Barnstable is prompted by reduced summer precipitation, higher temperatures that result in more evaporation and transpiration, and potentially by warmer winters that result in less snow pack. For this report, we have not included drought projections because of their high uncertainty. However, previous analysis has suggested that, in the long term, much of New England will experience a significant increase in drought (Hayhoe et al., 2007). For example, short-term drought (up to one month in duration) will likely increase two- to three-fold by the end of the century under the high emissions scenario. The projections show that the amount of summer precipitation will remain about the same, while significant increases in summertime temperatures will lead to heightened evaporation, transpiration, and loss of soil moisture. Historically, while Massachusetts and the Cape receive generous precipitation, occurrences of drought have occurred periodically. The last Drought Watch issued for the Cape was in the winter of 2002-2003 as a result of long term below-normal groundwater levels (Town of Barnstable, 2010).

VULNERABILITY

Drinking Water Supply

The duration and frequency of drought will determine its impacts on water supply. The Town of Barnstable is serviced by the Hyannis Water Supply Division in the Department of Public Works. All of the water comes from 12 wells, located within the Village of Hyannis (Figure 24)(Town of Barnstable, Water Supply Master Plan). A prolonged drought may significantly limit water provision from these wells (EPA, 2010). In addition to drought, a permanent rise in sea level may threaten wells because salt water intrusion may contaminate them. Generally, for the groundwater, the elevation of the salt water near the coast will increase the same amount as the permanent sea level rise. A detailed study could help Barnstable assess risks by looking at the depth of the wells, the present relative location of the freshwater / saltwater interface in the aquifers, and soil characteristics.

Wild Forest Fire

Drought conditions can exacerbate the risk for wildfires in large tracts of pitch pine forests and salt marshes where invasive phragmiteses are prolific (Town of Barnstable, 2010). In 2008, 2,740 fires were reported in the state, affecting almost 1,900 acres of land. A Forest Service study found that Barnstable and Plymouth counties, with their sandy soils, drying winds, and fuel types, are as wildfire prone as the often fire-ravaged regions of southern California. In addition to drought conditions, increasing encroachment by urban development into natural wildlife areas increases fire risks.

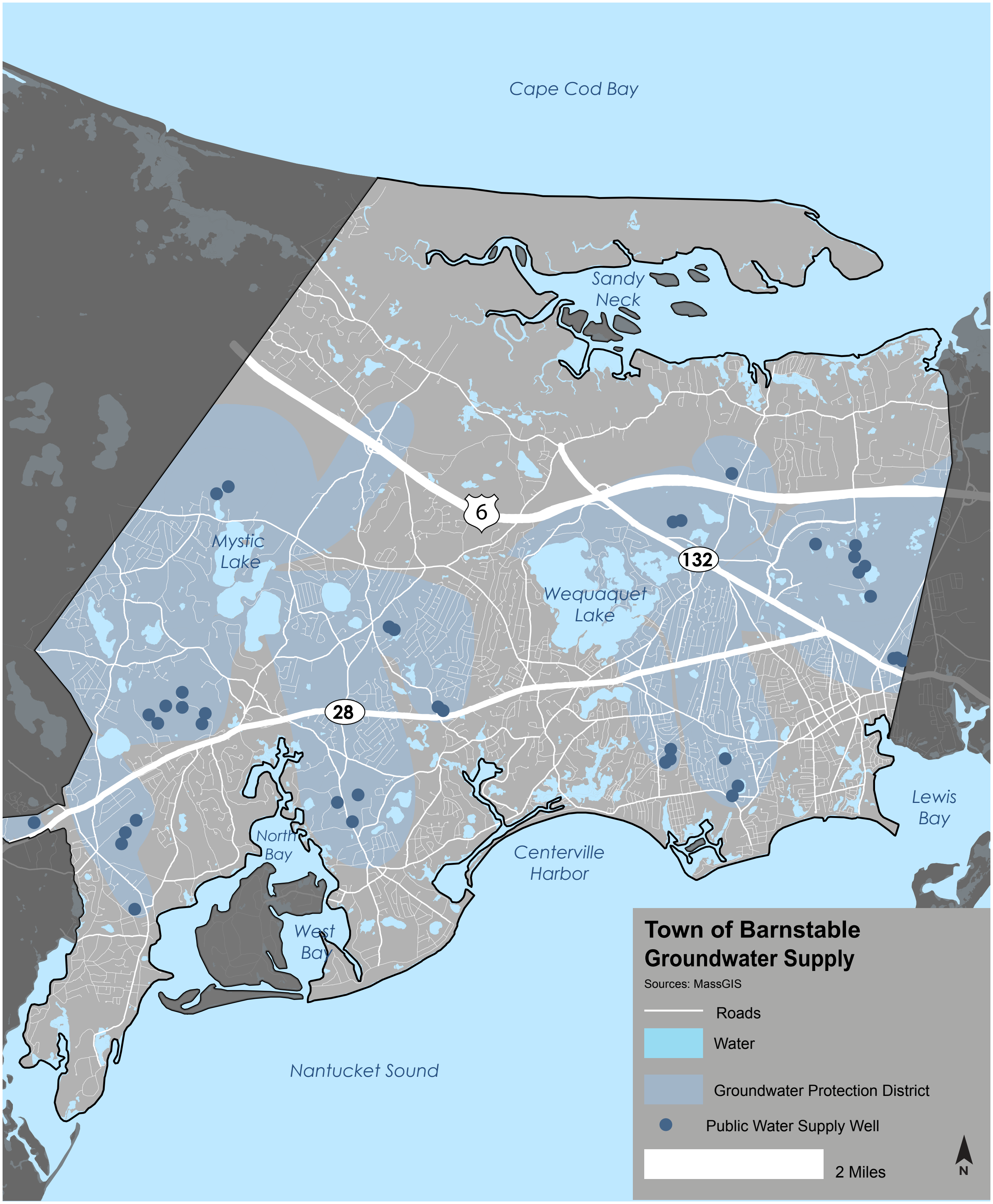


Figure 24. Town of Barnstable Groundwater Supply

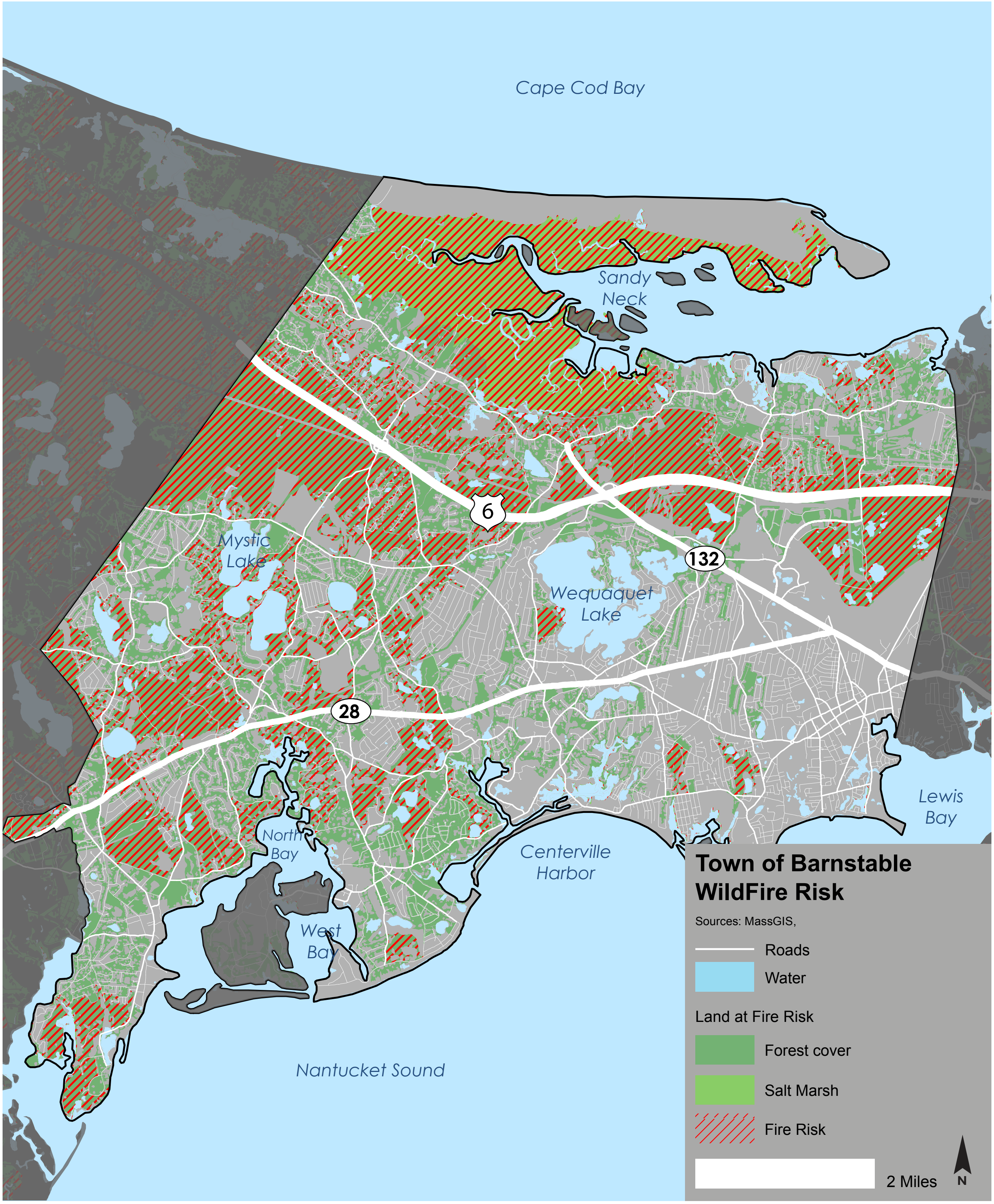


Figure 25. Wildfire Risk Areas

a) Additional Reservoirs b) Water Efficiency c) Irrigation Efficiency

Figure 26. Adaptation Options for Drought

ADAPTATION OPTIONS

Barnstable can reduce its exposure to drought-induced water supply shortages by acquiring additional water supplies. This might involve building a reservoir or coordinating with adjacent municipalities. Decreasing municipal and industrial demands through water conservation may also reduces sensitivity.

The Town of Barnstable's Multiple Hazard Mitigation Plan proposes adaptation options to reduce wildfire risks, such as protecting the Crocker Neck Conservation Area and educating landowners about fire hazards, standards, and preparedness measures (Town of Barnstable, 2010).

Heat Waves

RISKS

Heat waves are driven by extreme temperature events, which are expected to increase significantly in Barnstable. Heat waves are particularly dangerous for human health and infrastructure when they last for long periods of time, when evenings do not cool down, and when heat is coupled with high humidity (Town of Barnstable, Water Supply Plan).

VULNERABILITIES

Social Vulnerabilities

The very young, the very old, and the presently ill are the most vulnerable to the health impacts of heat exposure. People who live in substandard housing without high-quality ventilation and those unable to afford air conditioning are also susceptible to heat exposure impacts. Higher temperatures can also contribute to more air pollution, which disproportionately affects the young and the elderly.

Electricity Infrastructure

Extremely high temperatures can cause wires to sag and come into contact with trees or structures. Prolonged heatwaves can also damage other electricity distribution equipment, such as transformers, that are designed to cool down during the evenings. In addition, peak electricity demand tends to occur during hot summer afternoons and has the potential to cause reliability problems, such as brownouts or blackouts, if electricity demand outstrips supply.

ADAPTATION OPTIONS

Reduce Exposure

An option for reducing the health impacts of heatwaves is to reduce the exposure of vulnerable populations. Strategies include providing cooling centers during heatwaves, retrofitting substandard housing, and providing assistance for people who cannot afford their electricity bills.

Reduce Sensitivity

Options for reducing the vulnerability of electrical infrastructure to heat waves include improving the equipment and implementing energy efficiency measures that reduce stress on the electricity system during heat waves. Many electric utilities employ innovative demand management techniques, including programs that compensate customers who agree to have the electrical supply for certain devices (such as irrigation pumps or air conditioners) cycled on and off during periods of peak demand to reduce overall energy use. Some large industrial utility customers can even agree to run their operations at night, which reduces the load on the system during daytime peaks. General energy efficiency policies and practices also serve to lower average energy demand. Distributing and diversifying electricity sources is another way to improve electrical system reliability during extreme weather events. This could involve backup generation options, electricity storage options, and on-site energy options, such as rooftop solar power. Finally, maintaining and updating aging distribution infrastructure, such as transmission lines and transformers, is important for preventing system failures during heat waves (Vine, 2012).

a) Building Retrofits b) Cooling Center c) Urban Canopy

Figure 27. Adaptation Options for Heat Waves

Tourism and Fiscal Diversity

RISKS

Tourism is one of the primary sources of economic development in Barnstable. Summer residents and short-term visitors come to Barnstable to stay in coastal properties and enjoy its beaches and natural areas. In addition, a large percentage of Barnstable's tax revenue is dependent on the assessed value of coastal properties. Therefore, climate change impacts on the town's natural and built environment have the potential to impact the Town's financial viability.

VULNERABILITIES

A longer summer season and warmer winters may extend Barnstable's tourist season, which could have a positive economic impact. However, the potential impacts of climate change on Barnstable's beaches, marshes, and other natural areas may degrade their environmental quality, which would have negative impacts on the tourism industry. In addition, tourist infrastructure in flood-prone areas, such as along the coast, is vulnerable to sea level rise and coastal storms.

Barnstable's large population of summer-only residents and tourists may provide an additional challenge to Barnstable's adaptive capacity. Seasonal residents and visitors are less likely to have detailed local knowledge or familiarity with emergency response procedures. They also may be less likely to implement personal resilience measures like having emergency supplies or a generator on-hand. Therefore, they may be a particularly vulnerable population in the event of a major storm.

ADAPTATION OPTIONS

Potential adaptation options include diversifying the town's economy and development away from the coast, adapting tourist infrastructure to reduce its vulnerability, and protecting natural areas for their ecotourism value.

Coastal, Inland, and Marine Ecosystems

RISKS AND VULNERABILITIES

Over 6,000 acres of unique marine and coastal habitat are projected to be directly impacted by sea level rise in the long term under a high emissions scenario. In addition to providing essential flood protection services, these lands provide critical habitat for shellfish, juvenile fish, eelgrass and diverse bird species. These habitats are sensitive to saltwater intrusion and extended periods of inundations (Wainwright and Weitkamp, 2013). Sea level rise is anticipated to significantly alter water chemistry within these coastal habitats, creating unprecedented pressures for the communities of plants and animals that live there.

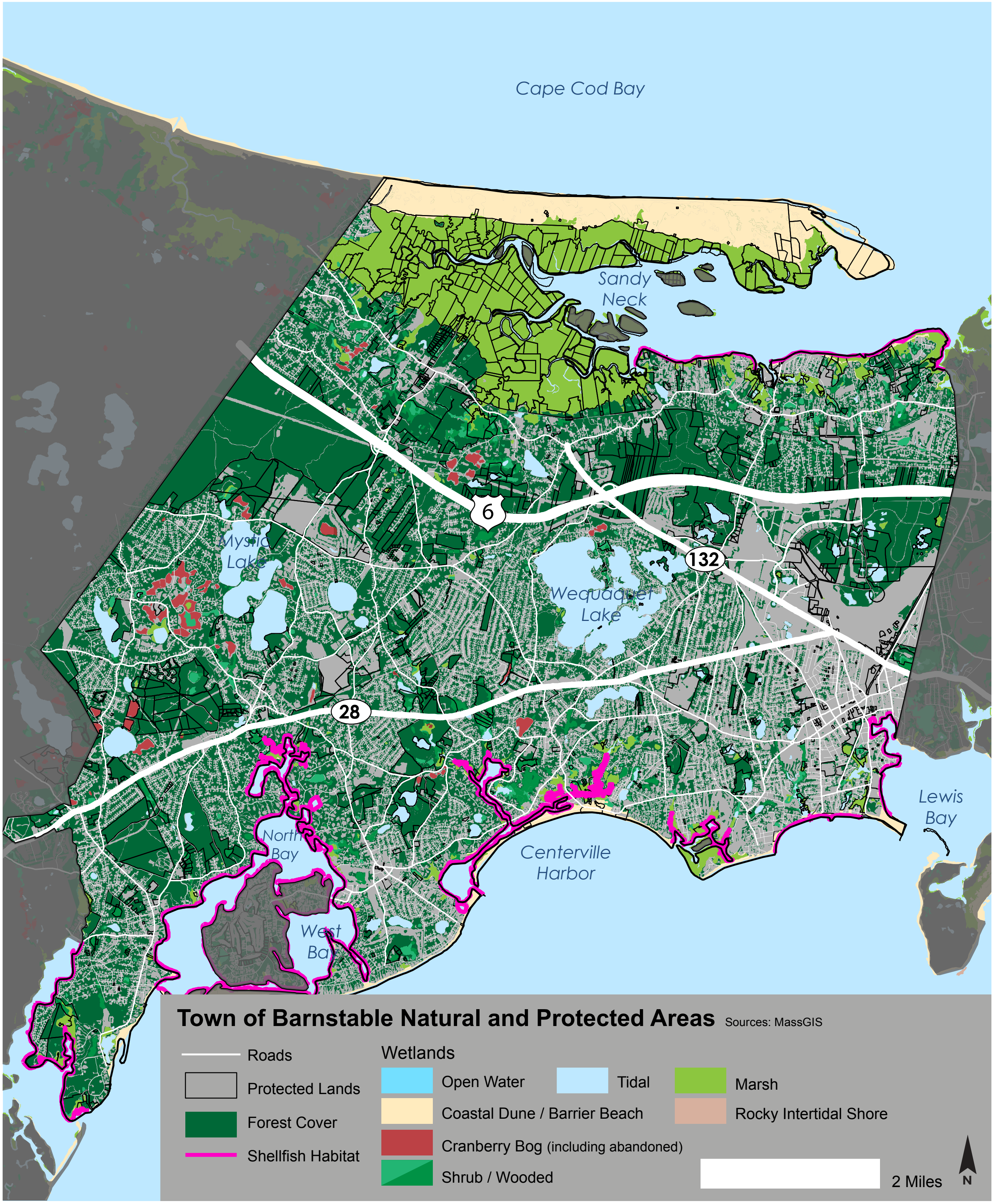


Figure 28. Town of Barnstable's Natural Areas

More frequent extreme precipitation events and warmer temperatures may impose stress on sensitive animal and plant species. Increased urban runoff can contribute to lower water quality in Barnstable's wetlands and waterways. In addition, an overall rise in summer temperatures and decline in summertime precipitation can raise stream temperatures, further reducing water quality. For example, streams and ponds could become too warm to support native fish species. These warmer temperatures further stress sensitive species that are already under pressure from increasing encroachment and pollution. Furthermore, higher nighttime temperatures may increase the incubation of pests, affecting the health of woodland mammals and humans.

Just as increased atmospheric temperatures are disrupting and intensifying the movement of air masses, increased greenhouse gas emissions are also altering ocean currents and the chemistry of the sea. Carbon dioxide is absorbed by ocean water, creating a much more acidic environment across the globe. The acidity represents a threat to shellfish and nearly 40 miles of Barnstable's shoreline is shellfish habitat.

ADAPTATION OPTIONS

Increase Adaptation Capacity
An important adaptation strategy is to increase the ability of ecosystems to bounce back and cope with disruptions—in other words, increase their resilience. Accomplishing this means reducing some of the other human-induced stresses that they face, such as pollution and habitat fragmentation. Healthier populations and habitats will be more likely to adjust to a changing climate. Land behind wetlands can also be set aside to allow wetlands to migrate inland as the sea level rises.

a) Protect Beach Habitat

b) Vegetate Waterway Buffers

Figure 29. Adaptation Options for Ecosystem Changes

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Executive Summary: Floodwall. Reprinted with permission of the Daily Hampshire Gazette. All rights reserved; Flood Resilient Building. Photo by: Jeffrey Tortaro, Design firm: Tsoi/Kobus & Associates in Cambridge, MA; Wetland Restoration; Woonasquatucket Wetland Restoration http://www.dem.ri.gov/programs/benviron/water/wetlands/wetplan.htm; Vegetated Waterways, Town of Barnstable School Street Bridge, Cotuit; Additional Reservoir. Wikicommons; Protected Shorelines. Town of Barnstable Ropes Beach, Cotuit.

Dock. Town of Barnstable Long Beach, Centerville

Adaptation Options for Flooding: Restored Wetland. Three Bridges Foundation; Floodwall. Reprinted with permission of the Daily Hampshire Gazette. All rights reserved. Fox Point Hurricane Barrier. FEMA; Pervious Pavement. USDA; Flood Resilient Building. Photo by: Jeffrey Tortaro, Design firm: Tsoi/Kobus & Associates in Cambridge, MA; Low Impact Development, Southeast Michigan Council of Governments.

Adaptation Options for Drought: Additional Reservoirs. Wikicommons; Water Efficiency. Wikicommons; Irrigation Efficiency. Wikicommons.

Heat Wave Adaptation Options: Building Retrofits. RafterTales; Cooling Center. NYC Urbanlife Blogspot; Urban Canopy. The Sanguine Root.

Adaptation Options for Ecosystems Changes: Protect Beach Habitat. Town of Barnstable Sandy Neck; Vegetated Waterway. Town of Barnstable School Street Bridge, Cotuit

Appendix 1: Methodology for Downscaled Projections and Sea Level Rise

The Barnstable downscaled projections were generated as output from four different global circulation models (GCMs) that have been well-established and evaluated in the peer-reviewed scientific literature: 1) the US National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1; 2) the United Kingdom Meteorological Office's Hadley Centre Climate Model version 3 (HadCM3); 3) the National Center for Atmospheric Research's Parallel Climate Model (PCM) and 4) Community Climate System Model Version 3 (CCSM3). These models have different climate sensitivities, where sensitivity refers to the amount of temperature change resulting from a doubling of atmospheric CO_2 concentrations relative to pre-industrial times. GFDL, CCSM3, and HadCM3 have medium sensitivity, and PCM has a low sensitivity.

Each global model produces output in the form of geographic grid-based projections of daily, monthly, and annual temperatures, precipitation, and other climate variables. GCMs operate on the scale of hundreds of miles, which is too coarse a resolution to distinguish changes across different towns and cities in a given region, such as New England. However, scientists used state-of-the-art statistical downscaling models to capture historical relationships between large-scale weather features and local climate, and use these to translate future projections down to the scale of local weather station observations. In this project we used a relatively new statistical downscaling model, the Asynchronous Regional Regression Model[4]. This report averages the projections downscaled to the meteorological stations of Hyannis, East Wareham, New Bedford, Rochester, and Edgartown, MA to forecast changes for Barnstable, MA.

Two different climate change scenarios drove the projections from the GCMs: a high emissions scenario (A1fi) and a low emissions scenario (B1). The high emissions scenario assumes that the world will experience economic growth dependent primarily on fossil fuels and that atmospheric concentrations of CO_2 will reach 940 parts per million by 2100. The low emissions scenario assumes that economies will shift to cleaner, less fossil-fuel intensive technologies, and that atmospheric concentrations of CO_2 will reach 550 parts per million by 2100[5]. The purpose of choosing a high emissions and a low emissions scenario is to create a likely range of future climatic change that Barnstable may experience during the 21st century.

4 More information on the statistical downscaling method used is provided in: Stoner, AMK, K Hayhoe, X Yang and DJ Wuebbles (2012) An asynchronous regional regression model for statistical downscaling of daily climate variables. Int. J. Climatol. DOI: 10.1002/joc.3603.

5 The emissions scenarios and GCM simulations used in this report consist of models that contributed to phase 3 of the Coupled Model Intercomparison Project (CMIP3). These are the results presented in the Intergovernmental Panel on Climate Change (IPCC) Third (2001) and Fourth (2007) Assessment Reports. More recent scenarios combined with CMIP5 climate projections were recently released (September 2013) in the IPCC Fifth Assessment Report.

The projections are also presented in three time frames: short term, medium term, and long term. The short term refers to the time period between 2010 and 2039, the medium term refers to the time period between 2040 and 2069, and the long term refers to the time period between 2070 and 2099. The historical baseline refers to the time period between 1980 and 2009. We averaged the results of the historical baseline and climate projections over their respective 30-year timeframes. This period is long enough to filter out any inter-annual variation or anomalies and short enough to show longer climatic trends.

Table A1. Global Circulation Models

Origin	Model	Scenarios	Equilibrium Climate Sensitivity (°C)*
National Center for Atmospheric Research, USA	CCSM3	A1fi, B1	2.7
National Center for Atmospheric Research, USA	PCM	A1fi, B1	2.1
Geophysical Fluid Dynamics Laboratory, US	GFDL CM2.1	A1fi, B2	3.4
UK Meteorological Office Hadley Centre	HadCM3	A1fi, B3	3.3
* data from IPCC 2007 Fourth Assessment Report, Chapter 8.			

Table A2. Downscaled Projections for Barnstable: Temperature Anomalies

Temperature Anomaly (°F)							
	Historical	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
	1980-2009	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Annual TMIN	43.0	44.3	44.1	45.2	46.6	45.8	49.2
Annual TMAX	59.2	60.6	60.5	61.6	63	62.1	65.6
Winter TMIN	24.5	26	25.9	27.1	28.1	27.6	30.8
Winter TMAX	40.4	41.5	41.3	42.3	43	42.5	44.7
Summer TMIN	61.4	62.6	62.6	63.7	65.3	64.2	67.6
Summer TMAX	77.9	79.4	79.6	80.8	82.6	81.4	85.6

Table A3. Downscaled Projections for Barnstable: Temperature Extremes

Temperature Extreme (days per year)							
	Historical	**Short Term (2010-2039)**		**Medium Term (2040-2069)**		**Long Term (2070-2099)**	
	1980-2009	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
<32°F	103	92	93	87	77	82	61
>90°F	2	5	4	7	12	9	27

Table A4. Downscaled Projections for Barnstable: Precipitation

Precipitation (inches)							
	Historical	**Short Term (2010-2039)**		**Medium Term (2040-2069)**		**Long Term (2070-2099)**	
	1980-2009	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
Annual mean	47.7	47.7	47.8	48.4	48.5	50.6	50.5
Winter mean	11.6	12.3	12.8	13	12.7	13.4	13.8
Summer mean	11.2	11.2	10.3	10.9	10.5	11.4	10.7

Table A5. Downscaled Projections for Barnstable: Extreme Precipitation Events

Extreme Precipitation (events per year)							
	Historical	**Short Term (2010-2039)**		**Medium Term (2040-2069)**		**Long Term (2070-2099)**	
	1980-2009	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
1" in 24 hrs	12.9	13.6	13.8	14.1	14.4	15.3	15.7
2" in 48 hours	5.6	6.9	6.6	7.5	7.6	8.5	9.5

Extreme Precipitation (events per decade)							
	Historical	**Short Term (2010-2039)**		**Medium Term (2040-2069)**		**Long Term (2070-2099)**	
	1980-2009	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
4" in 48 hrs	1.8	3	1.7	3.1	2.7	2.6	4.1

Relative sea level rise (SLR) at a site is considered to be the sum of global climate change and local subsidence. Other factors such as circulation changes are not considered. For global climate change, the estimates of sea level rise can be taken from Vermeer and Rahmstort (2009), similar to the later projections of Parrish et al. (2002) used for the US National Climate Assessment (Figure A1). For any particular time period, we suggest using the upper and lower values in the gray areas in the curve. Thus the SLR is approximately 1 to 2 feet by 2050, 3 to 6 feet by 2100. To address subsidence, Kirshen et al (2008) found a local rate of SLR of 1.0 mm/year at Woods Hole, the closest gauge to the Town of Barnstable. This is approximately the same value as Engelhart et al (2009) estimated. Therefore, 1.0 mm/year can be considered the local rate such that over a 50 year period, 50mm (2 inches) can be added to the global sea level rise projections noted above.

Table A6. Downscaled Projections for Barnstable: Sea Level Rise

Sea Level Rise (feet)						
	Short Term (2025)		Medium Term (2050)		Long Term (2085)	
	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Sea Level Rise	0.6	0.9	1.1	1.8	2.2	4.9

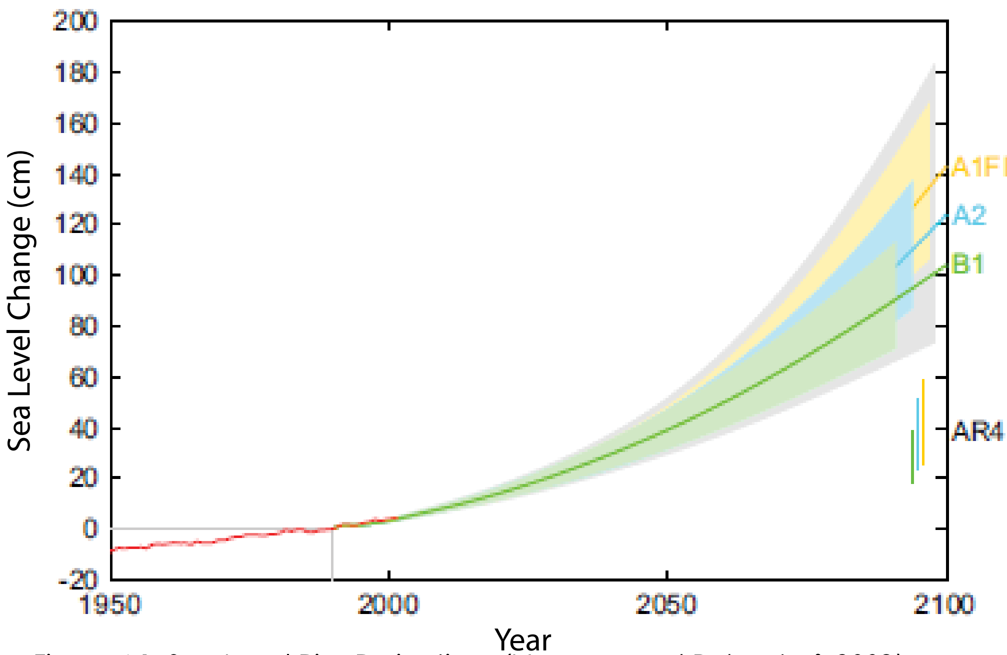

Figure A1. Sea Level Rise Projections *(Vermeer and Rahmstorf, 2009)*

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Appendix 2: Additional Resources

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