Taunton River Watershed

Climate Change Adaptation Plan

Manomet Center for Conservation Sciences

Loni Plocinski, William VanDoren, Eric Walberg

May 2013

Contents

Suggested citation: Polcinski, L., Walberg, E., VanDoren, B. 2013. Climate Change Adaptation Plan for the Taunton River Watershed, MA. Manomet Center for Conservation Sciences, Plymouth, MA.

Support for this project was provided by The Kresge Foundation.

This report is available for download at: http://www.manomet.org/climate_solutions/Taunton_Watershed_Adaptation Plan.pdf

Tables

Maps

Figures

MANOMET
Center for Conservation Sciences

Executive Summary

The Taunton River Watershed has long been recognized for its rich cultural, ecological, agricultural and recreational resources. The river is directly tied to early contact between Native People and English settlers; evidence of early industrial, water-based innovation such as weirs and millworks, can still be seen along the river and its tributaries today. The Taunton River is a natural treasure in southeastern Massachusetts; it is the longest undammed river in the region and recently received a National Wild & Scenic River designation. A broad range of recreational opportunities are available throughout the watershed, including hiking, bird watching, paddling, swimming and fishing.

Climate change is already affecting the Taunton River Watershed and is threatening many of the attributes that make the River and the surrounding lands special to citizens and visitors. The climate has become significantly warmer and wetter over the last 100 years and the rate of change is projected to accelerate over the next 100 years. This rapid change is impacting natural systems and the built environment. Heavy precipitation events have increased 67% over the last 50 years in New England. These changes are increasing the threat of fresh water flooding in the Taunton watershed, particularly in urban areas with extensive impervious surface cover. Sea level rise is also impacting the tidal portion of the river and surrounding shoreline. Sea level has risen approximately ¾ of a foot in the last 100 years in Narragansett Bay and the rate of rise if projected to increase over the next 100 years.

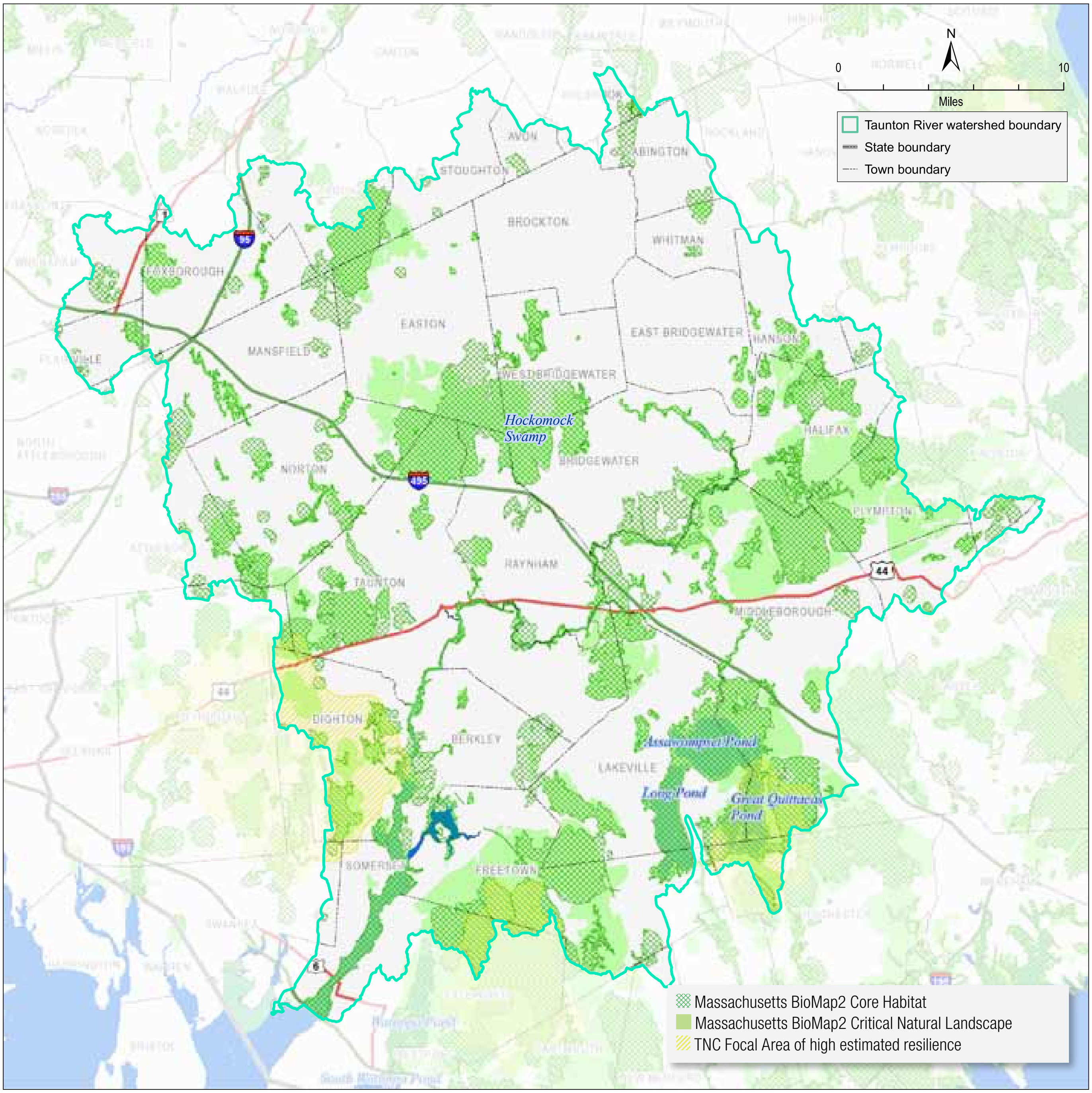
Intact ecosystems generate a variety of goods and services, collectively called ecosystem services, which sustain and enhance the quality of human life. Climate change will affect the quality, abundance, distribution, productivity and value of ecosystem services throughout the Taunton River Watershed. This plan focuses on a subset of the watershed's ecosystem services and examines each through the lens of both climate and non-climate stressors. The recommended adaptation strategies are intended to maximize the benefits of the natural services provided by a healthy, intact watershed against the backdrop of a rapidly changing climate.

While many responses to climate-related threats are possible, capitalizing on the services provided by intact natural systems is among the most cost effective and efficient approaches available. This type of management approach, known as green infrastructure, can provide multiple benefits, including minimizing the threat of flooding, protecting water quality, improving air quality and cooling urban environments. On a watershed scale, green infrastructure is a network of conserved and working lands that provide essential environmental functions such as support of biodiversity and water resource protection. In urban settings, green infrastructure also includes small scale features such as urban forest, grassed swales and riparian buffers that contribute to swormwater management, improve air quality and minimize heat island effects. Managing climate impacts using a green infrastructure approach emphasizes the natural resiliency of the watershed while minimizes risks to citizens and limiting taxpayer costs.

Maps 1 and 2 illustrate a green infrastructure network for the Taunton River Watershed that addresses many of the projected impacts of climate change. Map 1 identifies management areas that are important for maintaining biodiversity. Map 2 identifies management areas that are important for maintaining a balanced water budget, water quality and flood protection. Specific management recommendations include the following:

› Protecting and restoring large, contiguous habitat blocks and the corridors that connect them is an important strategy to maximize watershed resilience. The areas shown in green on Map 1 include significant habitat and areas anticipated to be important in maintaining ecosystem resiliency in response to climate change. The areas shown in yellow have geophysical properties that support high levels of biodiversity. These areas will be important refuges as the climate changes and existing species distribution patterns are disrupted. Maintaining and restoring natural landscapes in these areas will contribute significantly to the long-term ecosystem health of the watershed.

Map 1. Green Infrastructure Habitat Synopsis for the Taunton River Watershed



› Maintaining and enhancing the natural ability of the watershed to control and withstand flooding is among the most cost effective adaptation strategies available. Map 2 highlights areas in blue that are both vulnerable to flooding and of importance in maintaining healthy riparian systems. Maintaining and restoring natural vegetation in these areas supports biodiversity, flood control and water quality benefits. Minimizing development in riparian buffers, and utilizing low impact development features when development does take place, will contribute to maximizing watershed resiliency and minimizing the tax burden associated with engineered approaches to stormwater management and flood control.

- Urban areas are particularly vulnerable to increased flooding due to the more frequent and severe precipitation events that are occurring in conjunction with climate change. Extensive impervious surface cover combined with ageing stormwater infrastructure and combined sewer overflow issues underscore the need for stormwater management strategies that are responsive to the projected continued increase in rainfall intensity. Redevelopment opportunities should be utilized to install modern approaches to stormwater management. Map 2 includes the planned transit stops associated with the South Coast Rail project. Retrofitting these areas with a green infrastructure upgrades as redevelopment occurs is recommended as a cost effective method of both minimizing flood threat and nonpoint source water pollution.
- Climate change will likely exacerbate existing water budget problems in the Taunton River Watershed. Areas shown in yellow on Map 2 are sub-watersheds that have a water deficit as compared to natural conditions. Instituting water efficiency and reuse measures, minimizing new impervious surfaces and maximizing groundwater recharge are recommended in these areas.
- Sea level rise and storm surge flooding will be significant threats for the area that surrounds the tidal portion of the Taunton River. Map 2 highlights areas of low elevation that are subject to sea level rise and storm surge in red. Minimizing new development, flood proofing existing structures and protecting and enhancing riparian buffers in these areas are recommended.
- Sea level rise will also cause the water table to rise and lessen the suitability of septic tanks in areas that already have a high water table. This phenomenon will be most pronounced in and around the areas shown in red on Map 2. Alternatives, including the establishment of public sewer systems where not currently available, should be explored.
- The climate change-related consequences for public health in the Taunton River Watershed are likely to be significant, especially for populations that are more vulnerable because of their age, socioeconomic status or pre-existing health conditions. The changing public health threat and the projected impacts on vulnerable populations should be included in state, regional and local public health and hazard mitigation planning. A green infrastructure-based approach to adaptation, including features such as urban forests will lessen urban heat island effects and air quality issues associated with climate change.

MAP 1

Ecosystems and associated wildlife populations in the Taunton River Watershed will be impacted by a mix of stressors associated with both climate change and continued urbanization of the watershed. The Massachusetts BioMap2 project incorporates climate change vulnerability considerations by incorporating strategies to improve resistance and resilience of significant ecosystems and species.

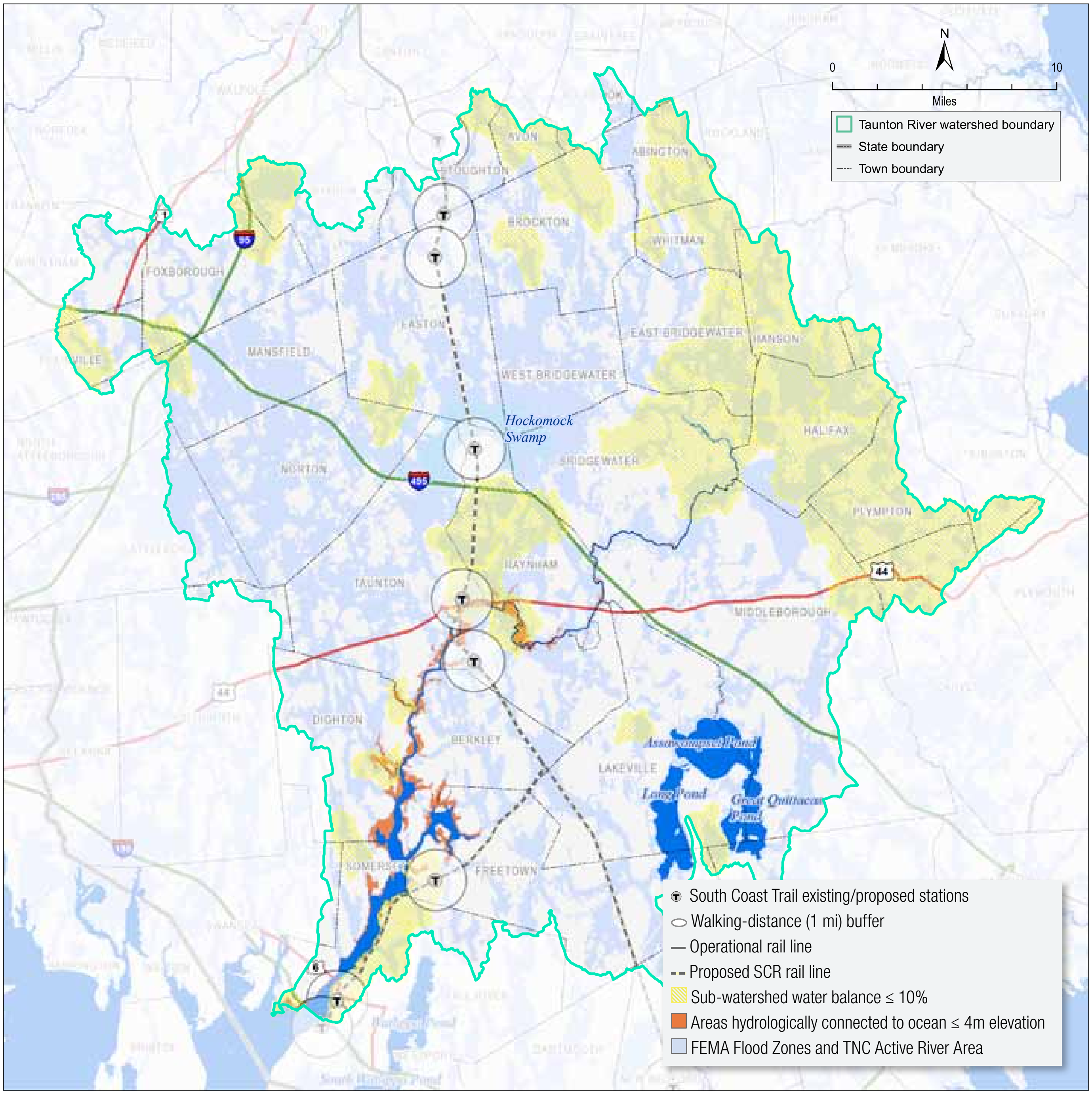
BioMap2 Core Habitat comprises interior forest; habitat for species of conservation concern; priority natural communities; and the best examples of wetland, aquatic, and vernal pool habitats across Massachusetts. BioMap 2 Critical Natural Landscape includes large areas of predominantly intact blocks of natural vegetation (landscape blocks), upland buffers of aquatic and wetland core habitat, tern habitat, and undeveloped coastal areas that will support salt marsh migration. These areas provide habitat for wide-ranging species and support and maintain ecological processes, connectivity, and ecological resilience. Data from MassGIS (2011).

A different approach was taken in a recent analysis of resilient sites by The Nature Conservancy (TNC) that identifies areas with geophysical features that are inherently supportive of high biodiversity. Areas of high estimated resiliency are likely to have characteristics (microclimatic buffering and connectedness) that maintain ecological functions and sustain an array of specialist and generalist wildlife species in the face of climate change, anthropogenic disruption, and other disturbances. Three focal areas that intersect the Taunton River Watershed were identified in the study. Data from TNC (2012).

Massachusetts BioMap2 Core Habitat
Massachusetts BioMap2 Critical Natural Landscape
TNC Focal Area of high estimated resilience

MANOMET Center for Conservation Sciences

Map 2. Green Infrastructure Hydrology Synopsis for the Taunton River Watershed



› Climate change will both open new opportunities for agriculture in the watershed and challenge existing operations with changing conditions. New England will likely become an increasingly important region of the United States for agriculture due to warming temperatures, continued water availability and the degradation of agricultural conditions in some other regions of the country. Protecting prime agricultural soils from development and employing adaptation methods, such as improving shading and cooling for livestock, installing irrigation systems and exploring opportunities for new crops, are recommended.

› The South Coast Rail project has the potential to be an important driver of land use patterns and economic development in the Taunton River Watershed. The utilization of transit oriented development approaches fits well with the recommended green infrastructure network for the watershed and could be an important element of both climate change mitigation and adaptation.

Introduction

The Taunton River is one of the most diverse and intact coastal riverine ecosystems in New England. Its corridor contains a mix of large woodland areas that include globally rare species and habitats, vast tidal and non-tidal wetlands and just over 77 square miles of prime farmland.[1] The Taunton River is also the longest, undammed coastal waterway in the region and was recently designated as a National Wild & Scenic River.[2,3] From its headwaters in Bridgewater, the river winds through ten communities, over 40 miles, to Mount Hope Bay on the southern coasts of Massachusetts and Rhode Island.[4] The Taunton River is tidally influenced for 18 miles from this point, as far north as Route 44, and saltwater mixing ends at or near the Dighton-Taunton line, approximately 12 miles upstream.[5,6]

The Taunton River and its extensive network of tributaries drain an area of 562 square miles, which encompasses all or part of 43 cities and towns (see Map 3).[7,8] The watershed also contains three Areas of Critical Environmental Concern (ACEC): the 14,280 acre Three Mile River ACEC, the 16,950 acre Hockomock Swamp ACEC, which is the largest vegetated freshwater wetland in Massachusetts, and the 17,200 acre Canoe River Aquifer ACEC.[9] Together, these three ACECs represent the second largest area to receive this special state designation.[10] (Map 4 includes Landsat imagery for the watershed and the recent BioMap2 analysis of important habitat areas in Massachusetts.) More than half (63%) of the Taunton River Watershed is characterized as forested or open land; over 65,000 acres, or approximately 19%, is residential land; and nearly 17,000 acres (5%) is agricultural land (see Map 5).[11] Current commodities include fruits and vegetables, nursery products, milk and other dairy products, as well as fish and shellfish.[12,13]

In addition to these exceptional natural resources, the Taunton River provides noteworthy recreational opportunities, such as hiking, swimming and fishing. The fact that the river drops approximately 20 feet in elevation over its entire course makes it particularly appealing to canoe and kayak enthusiasts.[14] The River also contributes greatly to the scenic beauty of the cities and towns through which it flows. The remaining undeveloped areas along the river's corridor help to preserve the watershed's sensitive archaeological resources. Some of the most important resources are in Bridgewater and Middleborough, "where a number of large, multi-component [archaeological] sites containing a high volume of artifacts and a diversity of features have been found."[15]

Throughout history, the Taunton River Watershed has supported a growing and industrious population. Historical records indicate that the first English settlers were taught how to use stone and wooden fish weirs by Native People; both herring and shad were harvested in large quantities from the beginning of colonial settlement.[16] By the 17th century, bog iron was discovered in the watershed and local metal industries prospered as a result.[17]

MAP 2

The redevelopment that will take place surrounding the transit stops associated with the South Coast Rail project will provide an opportunity for the incorporation of green infrastructure features to limit heat island effects, maximize the infiltration of stormwater and limit nonpoint source water pollution. Data from MassGIS (2008) and MassEOT (2009).

The estimated water balance of some parts of the Taunton River Watershed is already negative relative to natural conditions. That is, withdrawals in some sub-watersheds result in a deficit of groundwater recharge relative to undeveloped conditions. As climate change alters precipitation patterns and development increases impervious surface area alteration to the area's natural hydrology will be exacerbated. These sub-watershed areas should be targeted for measures that maximize groundwater recharge. Data from Horsley Witten Group, Inc. (2008).

Storm surge and sea level rise have the potential to affect low-lying areas along the mainstem of the Taunton River. LiDAR data was used to identify areas adjacent to the Taunton River that may be vulnerable. Flood proofing of existing structures, minimizing new development and increasing the width of riparian buffers are recommended for this area. LiDAR data from MassGIS (2012); analysis follows Hamann et al. (2008).

Riparian areas and associated flood zones will be increasingly vulnerable to flooding due to climate change. Maintaing and restoring forest and natural vegetative cover in these areas can help to maintain natural stream processes and attenuate flooding from all but the most severe precipitation events. Data from MassGIS and FEMA (1997) and TNC Active River Area (2009).

- South Coast Trail existing/proposed stations
- Walking-distance (1 mi) buffer
- Operational rail line
- Proposed SCR rail line
- Sub-watershed water balance ≤ 10%
- Areas hydrologically connected to ocean ≤ 4m elevation
- FEMA Flood Zones and TNC Active River Area

The Taunton River also played a role in the success of the textile industry, specifically in Fall River, where it was convenient to both send goods to cloth markets in New York and receive coal deliveries, by water, directly to the mills. By the middle of the 19th century, shipping and shipbuilding peaked in the watershed.[18] Between 1850 and 1900, nearly 300 vessels were registered in Taunton and Somerset and so much trade occurred on the river that Dighton established its own customs house.[19]

Water Quality

Once considered toxic as a result of these industrial and commercial uses, the water quality of the Taunton River has improved greatly in the past 30 years. Much of this improvement can be attributed to the passage of environmental regulations, most notably the Clean Water and Wetlands Protection acts, and an overall decrease in the quantity of pollutants entering the river, primarily due to the closing of shoreline mills.[20] While the return of harbor seals, bald eagles and robust macroinvertebrate communities signals the renewed health of the Taunton River, several significant water quality issues are still present in the watershed today. High levels of nutrients and pathogens and low levels of dissolved oxygen have placed several sections of the river and its tributaries on Massachusetts' list of impaired waters under section 303(d) of the Clean Water Act.[21]

The primary source of nutrients and pathogens in the Taunton River is effluent from the area's six wastewater treatment plants.[22,23] The largest treatment plant is located in Brockton and discharges an average of 21 million gallons per day of treated wastewater to the Salisbury Plain River, a tributary of the Taunton River.[24] Non-point source pollution is a second major source of sediment, nutrients and pathogens in the Taunton River and can be attributed to both the urbanized (e.g., Brockton, Fall River and Taunton) and more rural landscapes in the watershed. Stormwater runoff from the impervious surfaces in the watershed (e.g., roads, parking lots and rooftops) contributes to the river's pollutant load and freashwater flooding during heavy precipitation events.[25] Impervious surface cover also reduces groundwater recharge and exacerbates problems with reduced streamflow, especially during the warmest months of the year when flows are naturally lowest and most vulnerable to depletion.[26]

Water Quantity

The quantity of water in the Taunton River and its tributary systems is of particular concern when the future of the watershed is considered. Over the last few decades, the watershed has experienced significant growth, both in terms of population and development. For example, the City of Taunton experienced a 24% increase in its population between 1980 and 2000.[27] According to the 2010 U.S. Census, the population of southeastern Massachusetts, as a whole, grew at almost twice the rate of the state average.[28] As a result of this growth, approximately 40% of the agricultural lands in the region have been lost since 1971.[29] In fact, the amount of developed land within the watershed increased from 56,800 acres in 1971 to 92,340 acres in 1999, a 62% increase in just under 30 years.[30] Adding to the growth and development pressure on the region are several ongoing, multi-million dollar transportation improvement projects, including rail line extensions and the expansion of routes 3, 24 and 44.

It is no surprise that the demand for water in the Taunton River Watershed has increased in parallel with these trends. A recent report by the Massachusetts Water Resources Commission indicated that 63% of the watershed is classified as medium-stressed or high-stressed, which means "the quantity of streamflow has been significantly reduced, or the quality of the streamflow is degraded, or the key habitat factors are impaired."[31] With respect to the quantity of streamflow, the report identified the rivers with the lowest flows per square mile of drainage area by comparing multiple years' worth of low flow statistics for 72 stream gages across the state. The statistics chosen were: median of annual seven-day flow, median of annual 30-day flow and median of low pulse duration.[32] The values for each stream gage were sorted, ranked and assigned a corresponding "low," "medium" or "high" label, indicating the stress level. Three gages within the Taunton River Watershed identified the Segreganset, Taunton and Three Mile rivers as being medium-stressed or high-stressed (see Table 1).

Table 1. Low Flow Statistics for Three Stream Gages within the Taunton River Watershed

LOCATION OF STREAM GAGE	DRAINAGE AREA (mi^2)	DATA RECORD (Years)	MEDIAN OF ANNUAL 7-DAY LOW FLOW (cfsm)	MEDIAN OF ANNUAL 30-DAY LOW FLOW (cfsm)	MEDIAN OF ANNUAL LOW PULSE (Days)
Segreganset River, Dighton	10.6	13	0.01 – "High"	0.04 – "High"	13.8 – "High"
Taunton River, Bridgewater	258	68	0.19 – "Medium"	0.26 – "Medium"	10.29 – "Medium"
Three Mile River, North Dighton	84.3	33	0.16 – "Medium"	0.26 – "Medium"	13.9 – "High"

Source: Massachusetts Water Resources Commission, 6-13.

Environmental Justice Issues

It is worth noting a few specific trends and characteristics related to the growing population of southeastern Massachusetts, including the Taunton River Watershed. Historically, the region has always lagged behind the state in indicators of economic strength, such as employment, income, education and new investment.[33] For example, the recent downturn in the economy has hit several cities in the region particularly hard; as of June 2012, New Bedford and Fall River ranked as the third and fourth highest unemployment rates in the state (11.7% and 11.6%, respectively).[34] Southeastern Massachusetts is also very diverse. In 2009, approximately 25% of the region's population reported Portuguese as their primary ancestry and nearly 3% reported Cape Verdean heritage.[35] Other fast growing racial and ethnic minority groups include African Americans and Hispanics, which increased 60% and 72%, respectively, between 2000 and 2009.[36]

Studies conducted throughout the U.S. have determined that lower-income and minority communities suffer from a disproportionately high share of environmental burdens and, at the same time, lack environmental assets in their neighborhoods; a pattern that holds true in Massachusetts. Fortunately, the environmental justice (EJ) movement, which is "based on the principle that all people have a right to be protected from environmental pollution and to live in and enjoy a clean and healthful environment," has made significant progress towards reversing this pattern.[37] On a national, state and local level, EJ policies and programs have been developed to proactively address environmental equity concerns and ensure that EJ populations are meaningfully involved in the development, implementation and enforcement of environmental laws, regulations and policies, and the equitable distribution of environmental benefits.[38]

Massachusetts established its own EJ policy in 2002.[39] Within the policy, EJ populations are defined as neighborhoods that meet one or more of the following criteria: 1) the median annual household income is at or below 65% of the statewide median income or; 2) 25% of the residents are minority or; 3) 25% of the residents are foreign born or; 4) 25% of the residents are lacking English language proficiency.[40] According to the state, these characteristics place a population more at risk of "being unaware of or unable to participate in environmental decision-making or to gain access to state environmental resources."[41] EJ populations reside in 108 cities and towns across the state; twenty of these communities meet all four of the EJ population criteria (based on the 2000 U.S. Census).[42] Within the Taunton River Watershed, there are nine communities that meet at least two of the four EJ population criteria; Brockton, Fall River and New Bedford meet all four criteria (based on the 2000 U.S. Census).[43]

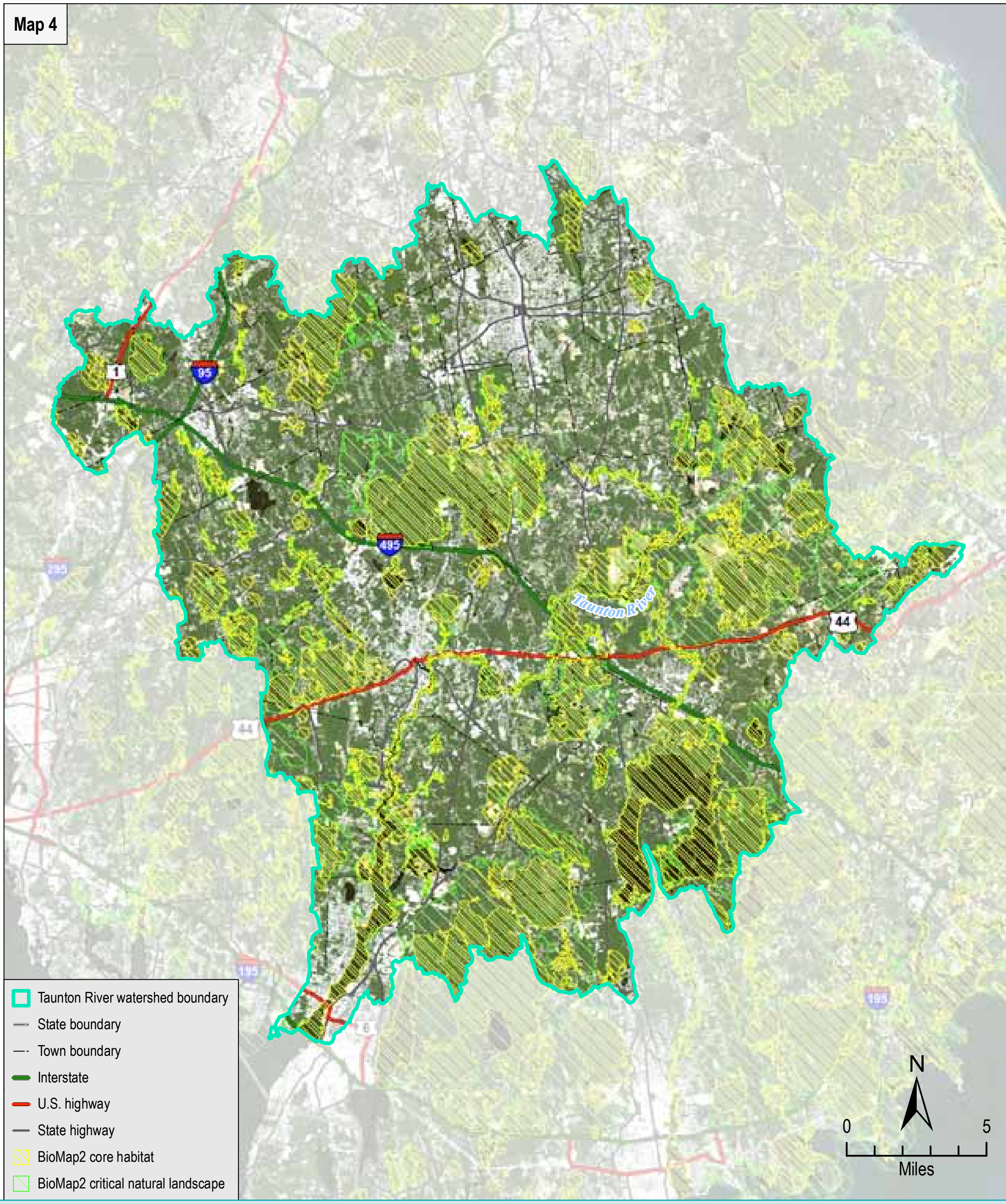
In terms of an opportunity to participate in environmental decision-making and access environmental resources within the watershed, residents are fortunate to be able to rely on and join a number of active organizations dedicated to protecting, managing and restoring the river's natural resources. For example, the Taunton River Watershed Alliance, which was founded in 1988, coordinates land conservation efforts, water quality monitoring and policy advocacy within the watershed. In addition, the Taunton River Watershed Campaign is working to protect the landscapes, natural communities and quality of life in the watershed. The Campaign's goals include protecting critical land and water resources; linking environmental groups and municipalities working to protect natural resources; and identifying environmental priorities to help ensure a balance between growth and the preservation of biodiversity, water quality and community character. Finally, the Taunton River Stewardship Council serves as the facilitating body for the implementation of the Taunton River Stewardship Plan, which was developed as part of the 2005 Taunton River Wild & Scenic River Study.

MAP 3

Location of the Taunton River Watershed and surrounding towns in eastern Massachusetts.

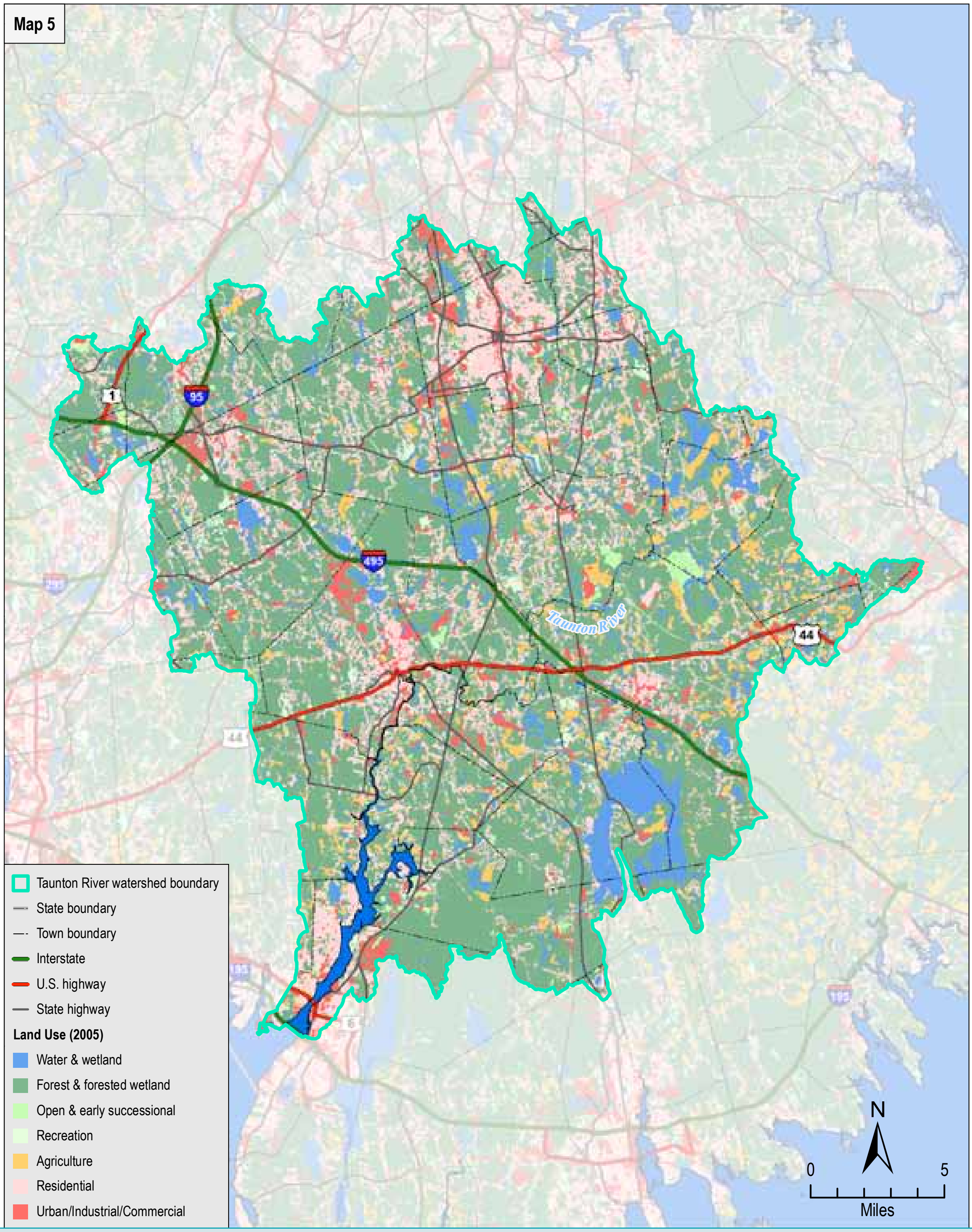
MANOMET Center for Conservation Sciences

Map 4. Important Habitat in and around the Taunton River Watershed



Map showing important habitat in and around the Taunton River Watershed. BioMap2 data produced by the Massachusetts Natural Heritage and Endangered Species Program (NHESP) and The Nature Conservancy (TNC). Core Habitat is critical to the long-term persistance of rare, threatened, and endangered species, diverse natural communities, and intact ecosystems. Critical Natural Landcape complements core habitat to ensure its long-term integrity. Landsat 5 TM scene path 12 row 31 acquired August 2010 and displayed using bands 3, 2, 1 (R, G, B). Data acquired from USGS Global Visualization Viewer (GLOVIS) website. Town and state boundaries from MassGIS and RIGIS; road data from the National Highway Planning Network.

MAP 4



MAP 5

Map showing land use (2005) in and around the Taunton River Watershed. Land use data from MassGIS (2005) and RIGIS (2003-04). Town and state boundaries from MassGIS and RIGIS; road data from the National Highway Planning Network.

MANOMET Center for Conservation Sciences

Previous Studies and Associated Management Goals

The Taunton River Watershed has been the focus of a variety of reports and planning documents in the last 20 years, many of which serve as a valuable source of baseline information for this plan. These resources also identify a number of management goals that support the primary goal of this plan. Below is a brief summary of the most recent planning efforts for the watershed, along with a list of supporting management goals, as identified within each document and applicable to the primary goal of this plan.

- *An Action Plan for the Taunton River Watershed: Assessment and Recommendations (1992)* – The University of Massachusetts, Boston, compiled this report on the water quality of the Mount Hope Bay Estuary. Included in the document is a discussion of the pollutant and nutrient inputs to the estuary as well as recommendations for the control of non-point source pollution, additional research and monitoring initiatives.
    - **GOAL:** Collaborate at the local, regional and state levels to plan for and establish comparable methods of controlling pollution sources within the watershed.
- *Natural Resource Inventory and Conservation Plan for the Taunton River Corridor (1998)* – The Wildlands Trust of Southeastern Massachusetts assembled this plan, which catalogs the significant natural resources of the river corridor and identifies the priority areas for conservation protection along the Taunton River.
- *Taunton River Watershed Water Quality Assessment Report (2001)* – This document was assembled by the Massachusetts Department of Environmental Protection. It presents a summary of the water quality data and other resources used to assess the status of the designated uses for the Taunton River Watershed. The designated uses include aquatic life, fish consumption, shellfish harvesting, primary and secondary contact recreation and aesthetics; each designated use is classified as supported or impaired.

» **GOAL:** Monitor the water quality and other physical attributes (e.g., the shoreline) of the Taunton River to build on the existing baseline information for the river and evaluate the effectiveness of pollution reduction strategies.

› *The Taunton River Stewardship Plan (2005)* was assembled as part of the *Taunton Wild & Scenic River Study* through a partnership between the Taunton Wild & Scenic River Study Committee, the Southeastern Regional Planning & Economic Development District and the National Park Service. The plan presents a vision and action strategy for the cooperative management and protection of approximately 40 miles of the Taunton River, the major tributaries of the river and the upper reaches of Mount Hope Bay.

» **GOAL:** Protect and promote the agricultural, ecological, cultural and recreational resources within the river's corridor.

› *Five-Year Watershed Action Plan for the Taunton River Watershed (2006)* – The goals of this planning effort were to promote watershed-wide planning, cooperation and consistency; synthesize and prioritize the information presented in seven watershed plans and reports; and develop a relevant, focused and achievable plan. A "Watershed Advisory Committee," comprised of municipal officials, watershed organizations, regional planning agencies, state agencies and other stakeholders, met to develop a complete list of action items and then voted to establish 16 "high priority" action items for the watershed. The plan was prepared for the Massachusetts Executive Office of Environmental Affairs by GeoSyntec Consultants, Inc.

» **GOAL:** Research and promote innovative, low impact design technologies that can be applied to the watershed's stormwater and wastewater infrastructure.

› *Final Pathogen TMDL for the Taunton River Watershed (2011)* – The Massachusetts Department of Environmental Protection assembled this document to provide a framework for addressing bacterial and other fecal-related pollution in the surface waters of the Taunton River Watershed. Specific parameters for meeting water quality standards and prioritized recommendations, or best management practices, are identified.

› The *Taunton River Watershed Management Plan Phase I (Data and Assessment, 2008)* and *Phase II (Example Code Reform and Demonstration Projects, 2011)* were developed by the Horsley Witten Group, Inc., in partnership with the Commonwealth of Massachusetts, Bridgewater State University and the Taunton River Watershed Steering Committee. The plan was "designed to assist the communities, organizations, and individuals throughout the Taunton River [W]atershed to evaluate the current conditions in the watershed, develop a watershed model reflecting inputs and withdrawals in the basin, understand options and tools for managing the human impacts on the vital water resources within the watershed and implement appropriate tools at the local level."[44]

» **GOAL:** Educate local officials on watershed science and management techniques to significantly reduce the impact of land development projects and to optimize opportunities for restoration.

» **GOAL:** Develop regulatory revisions at the local level to encourage or require sustainable development.

» **GOAL:** Develop strategies to restore, and ultimately preserve, a water balance throughout the watershed.

» **GOAL:** Establish economic incentives to encourage progressive watershed management and restoration.

Stakeholder Involvement

Manomet Center for Conservation Sciences (Manomet) hosted a Taunton River Watershed Workshop on November 10, 2010 at Middleboro Town Hall. The overall workshop goal was to solicit input from a group of experts on the prioritization of ecosystem services provided by the Watershed, the threat posed by climate change, and the recommended adaptation response.

The workshop brought together more than 30 individuals from non-government organizations (land trusts, watershed associations, conservation-based), municipal government (conservation commissions and planning departments), regional planning agencies, state and federal government, as well as individuals involved with grassroots efforts in the watershed. The key points from the workshop are as follows:

Education – Regulatory Change/Enforcement – Additional flood data needed

INFRASTRUCTURE UPDATES –LAND PROTECTION

- The majority of participants felt strongly that public education regarding climate change adaptation/issues is needed – from individual to municipality and state agencies. A visual tool and/or map is needed ASAP that is specific to the Taunton River watershed to facilitate education. The map should have explicit information for decision making on the issues of: water quality, quantity and flow as they are impacted by climate change. This will hopefully connect the urgency with financial resource need.
- Regulatory change and enforcement is critical:
  - Pass stream flow regulations that protect sustainable flows.
  - Recognition of climate change in current regulations and state enabling legislation, implement to full extent possible – wetlands regulations, water management act, stream flow, etc.
  - Regionally consistent zoning and regulations are needed to prevent "development hopping." These need to be incorporated into state planning lexicon.
  - Wetland protection! Ways to protect migrating wetland areas are needed. Strengthen local and state regulations on wetlands and obtain new data on 100 year flood events. All must be communicated to planners.
  - Enforcement of current regulations pertaining to stormwater and flooding issues is lacking. Need to put pressure for compliance on MADEP.
  - Better and more flexible planning integrating adaptive future uses; legal constraints on permitting procedures.
- More data is needed:
  - Cornell University has produced rainfall curves that take climate change into account. But has to be DEP required or engineers will not use it, mapping in communities to show potential impact areas, encourage infiltration.
  - Urbanization has resulted in a net decrease in groundwater recharge of -6.2%. However, this deficit is to some extent counterbalanced on a watershed-wide basis by surface discharge of treated wastewater. Unfortunately, on a sub-watershed basis significant imbalances exist that threaten the ecological vitality of those areas

- Ecosystems in the watershed will be impaired due to climate change along with water quality, quantity and flow. Especially need to prepare for wetland migration.
- Planning and communication to planners critical:
  - Infrastructure updates are necessary to remove "functionally obsolete, structurally deficient" structures (dams, update culverts, un-develop floodplains, especially wastewater plants, etc) for multiple benefits. TNC and others have identified priority dams.
  - Get development out of flood plains; identify places where salt and freshwater wetlands will need to migrate.
  - Acquire land to protect food and farms, support local agriculture and CSAs, species, riparian zones, wetlands/cranberries – carbon sink.
  - Revisit the Taunton River Priority Opportunity Acquisition list and overlay climate change impacts. Priorities for acquisition may change as a result.

Recent and Projected Climate Change in New England

Climate has changed significantly in New England during the period 1900 through 1999. Average annual temperatures have increased by 0.08 degrees Celsius per decade and average winter temperatures have increased by 0.12. The rate of average temperature increase accelerated significantly during the period of 1970-2000 with average annual temperatures increasing by 0.25 degrees Celsius per decade and average winter temperatures increasing by 0.70. Driven by these changes growing seasons have lengthened, the number of days with snow on the ground has decreased for many locations and the timing of peak spring stream flow has shifted to earlier in the year.[45]

The continued increase in atmospheric greenhouse gas levels is also driving associated increases in extreme weather events. In 2008 the U.S. Climate Change Science Program found that:

- "Human-induced warming has likely caused much of the average temperature increase in North America over the past 50 years and in turn causing changes in temperature extremes.
- Heavy precipitation events in North America have increased over the past 50 years in conjunction with observed increases in atmospheric water vapor.
- Increasing greenhouse gas concentrations have contributed to the increase in sea surface temperatures in the hurricane formation regions. Over the past 50 years there has been a strong statistical connection between tropical Atlantic sea surface temperatures and Atlantic hurricane activity as measured by the Power Dissipation Index."[46]

The change in frequency and intensity of extreme precipitation events differs regionally within North America with the most pronounced increase taking place in New England. A recent study of the period of 1948-2007 found significant increases in both the occurrence and intensity of extreme precipitation with the most significant increases occurring most recently.[47]

Projections of future climate indicate a likely acceleration of the changes that have occurred during the last 100 years. Due to significant unknowns such as future greenhouse gas emission rates, the influence of various feedback loops and the likely existence of climate tipping points it is impossible to predict the exact timing and extent of climate change. That being said, over time climate modeling tools are becoming more sophisticated and for the most part different modeling approaches are yielding increasingly similar results. A 2006 study downscaled output from several global climate models and produced output specific to New England for three different possible future emission scenarios.[48] Nine atmosphere-ocean general circulation models where utilized in creating the projections that were downscaled. The three emission scenarios were the B1, A2 and A1FI scenarios developed by the IPCC. The B1 scenario assumes a stabilizing of atmospheric CO_2 levels at or above 550 ppm by year 2100. The A2 scenario assumes atmospheric CO_2 levels of 830 ppm by 2100 and the A1FI scenario assumes CO_2 levels of 970 ppm by 2100. Results for the B1 and A1FI scenarios for two of the modeled variables, temperature and precipitation are shown in the following table.

Table 2. Results for the B1 and A1FI scenarios for Temperature and Precipitation

	UNITS	2035-2064		2070-2099	
Temperature	Degrees C	B1	A1FI	B1	A1FI
Annual		+2.1	+2.9	+2.9	+5.3
Winter		+1.1	+3.1	+1.7	+5.4
Summer		+1.6	+3.1	+2.4	+5.9
Precipitation	% change				
Annual		+5%	+8%	+7%	+14%
Winter		+6%	+16%	+12%	+30%
Summer		-1%	+3%	-1%	0%

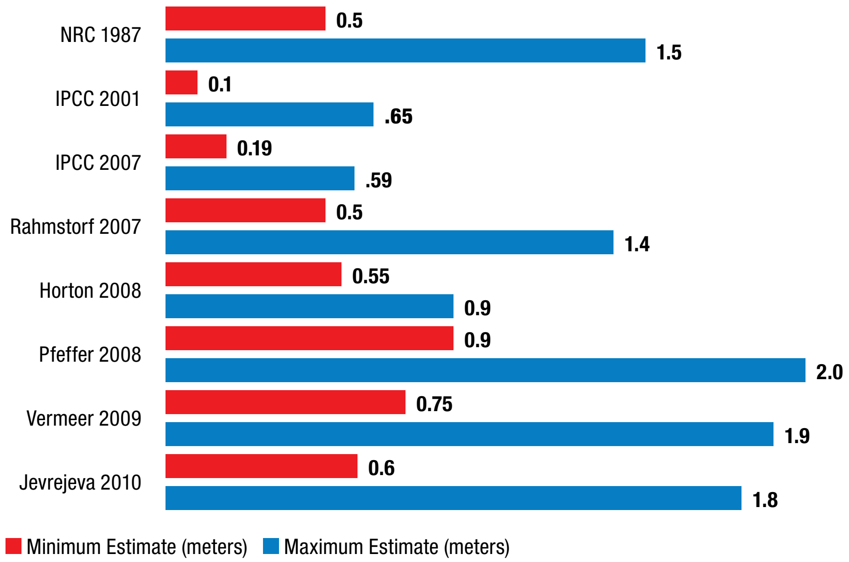
Source: (Reference number 45, Hayhoe)

Several other variables were modeled including stream flow and drought frequency. The projected changes in stream flow are mixed with low flow periods decreasing slightly for all but the A1FI scenario for the period 2070-2099, where the number of low flow days per year is projected to increase by 22 days. Drought is projected to increase for both scenarios and both time periods with the most significant increases for the A1FI scenario in the latter time period.[49]

Sea Level Rise

Sea level rise (SLR) projections through the year 2100 cover a broad range due to several factors including an uncertain trajectory for future greenhouse gas emissions and an incomplete understanding of future ice melt rates. Figure 1 provides a synopsis of sea level rise projections based on several different modeling approaches.[50]

Figure 1. Projected Sea Level Rise by 2100

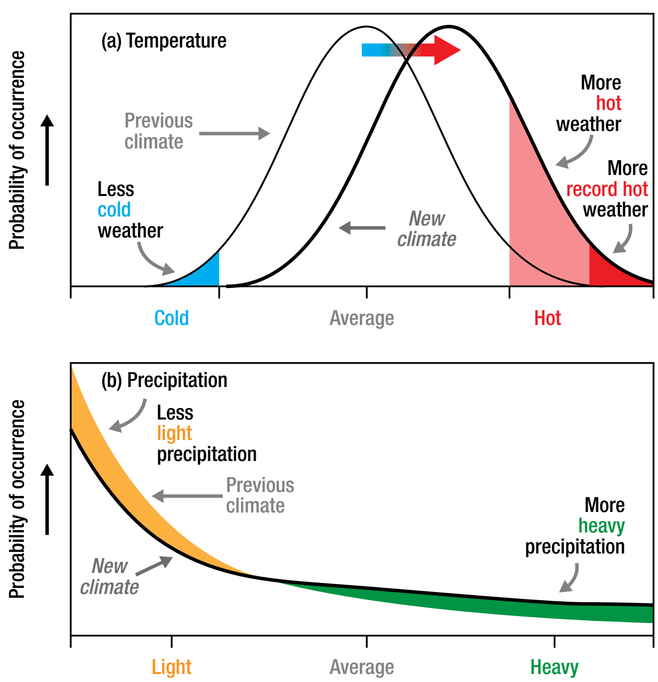


Source: (Reference number 46, Karl)

The most recent U.S. Army Corps of Engineers guidance indicates that two meters is the likely upper bound of SLR through 2100 but does not rule out higher maximum levels.[51] A recent study by the United States Geological Survey indicates that the section of the Atlantic coast from Cape Hatteras to Maine is subject an additional increment of sea level rise associated with a slowing of the Atlantic Meridional Overturning Current.[52]

Sea level rise will increase the severity of storm surge flooding. A recent study estimated the change in frequency in occurrence of today's 100-year flooding event through the year 2050. The projected changes include a recurrence frequency of every 5 years for Portland, ME, a 30 year return frequency for Boston, MA and a 10 year return frequency for Providence, RI.[53]

Figure 2. Projected Changes in Extreme Weather and Climate



Source: (Reference number 46, Karl)

As average temperature and precipitation continue to increase in North America the projections indicate related changes in extreme weather and climate. The U.S. Climate Science Program projects that:

- "Future changes in extreme temperatures will generally follow changes in average temperature: Abnormally hot days and nights and heat waves are very likely to become more frequent. Cold days and cold nights are very likely to become much less frequent. The number of days with frost is very likely to decrease."[54] (See Figure 2 [55])
- "Over most regions, precipitation is likely to be less frequent but more intense, and precipitation extremes are very likely to increase."[56]
- "It is likely that hurricane/typhoon wind speeds and core rainfall rates will increase in response to human-caused warming. Analyses of model simulations suggest that for each 1 degree C increase in tropical sea surface temperatures, hurricane surface wind speeds will increase by 1 to 8% and core rainfall rates by 6 to 18%."[57]
- "Storm surge levels are likely to increase due to projected sea level rise, though the degree of projected increase has not been adequately studied."[58]
- "There are likely to be more frequent deep low-pressure systems (strong storms) outside the tropics, with stronger winds and more extreme wave heights".[59]

Ecosystems and Ecosystem Services

Ecosystems generate a variety of goods and services, collectively called ecosystem services, which sustain and fulfill human life. The Millennium Ecosystem Assessment, which was initiated by the United Nations in 2001, highlights the enormous value of the goods and services people obtain from the planet's ecosystems and the crucial role these services play in sustaining economic prosperity. Ecosystem services are frequently categorized as provisioning (e.g., food and water), regulating (e.g., water purification and carbon sequestration), supporting (e.g., climate regulation and nutrient cycling) or cultural (e.g., aesthetic values and sense of place).[60] Ecosystem services are utilized both directly by people and indirectly, when they support the production and quality of other things people enjoy.

The Millennium Ecosystem Assessment also sheds light on the challenges that lie ahead, in terms of ecosystem health and human well-being. The demand for ecosystem services is growing rapidly, but at the same time, people are altering the capability of ecosystems to continue to provide these invaluable goods and services.[61] The ways in which ecosystems are affected by human activities will have serious consequences for the supply of ecosystem services, prevalence of diseases, frequency and magnitude of floods and droughts, as well as local and global climate.[62] There is also growing evidence that many ecosystems have been degraded to the point that their capacity to provide useful goods and services may be drastically reduced.[63] The vulnerabilities of the Taunton River Watershed's ecosystems and ecosystem services, with respect to climate change, are highlighted below in Table 3.

Table 3. Vulnerabilities of the Taunton River Watershed's Ecosystems and Ecosystem Services to Climate Change

ECOSYSTEMS AND ECOSYSTEM SERVICES	VULNERABLE TO CLIMATE CHANGE?	RATIONALE
Provisioning Services		
Food	Yes	Increasing heat stress, heavy precipitation, summer drought, volatility in water availability and risk of invasive plants, pests and diseases
Fresh water	Yes	Warmer water temperatures, increasing risk of floods and droughts, saltwater intrusion, increasing pollution from impervious surfaces and stormwater and wastewater overflows
Regulating Services		
Local climate and air quality regulation	Yes	Increasing frequency and severity of extreme heat, exacerbation of heat island effects, degrading air quality in urban areas
Carbon sequestration and storage	Perhaps	Potentially at risk due to development and deforestation, which will exacerbate climate change impacts
Moderation of extreme events	Yes	Loss of protective wetlands in the coastal zone, additional impervious surface cover over time enhancing flood risk
Wastewater treatment	Yes	Increasing risk of overflows for municipal systems due to more common extreme weather events; increasing risk of failure for private septic systems due to rising water table
Erosion prevention and maintenance of soil fertility	Perhaps	Impacts of increasing heavy precipitation events
Pollination	Perhaps	Warming climate may lead to disruption of pollinator synchronization; urbanization may lead to loss of pollinator habitat
Biological control	Yes	Warming temperatures and increasing levels of precipitation provide more suitable habitat for mosquitoes and ticks
Supporting Services		
Ecosystems and habitats for species	Yes	Warming temperatures and fluctuations in precipitation will degrade valuable habitat for aquatic and non-aquatic species
Cultural Services		
Recreation, mental and physical health	Yes	Warming temperatures and fluctuations in precipitation will impact landscapes and species favored for recreation; mental and physical health at risk due to vector-borne diseases
Tourism	Perhaps	Potentially negative impact on waterfront attractions, such as swimming beaches, and the agritourism industry due to poor weekend weather

Source: TEEB, 34.

MANOMET Center for Conservation Sciences

WATER-RELATED SERVICES AND ASSOCIATED CLIMATE CHANGE VULNERABILITIES: WATER SUPPLY, WASTEWATER TREATMENT, STORM WATER MANAGEMENT, FLOOD CONTROL AND ECOSYSTEM SUPPORT

The Taunton River watershed provides several water-related ecosystem services including water supply, wastewater treatment, stormwater management, flood control and ecosystem support. All of these services will be impacted by climate change. Future land use, infrastructure and management decisions will have a significant impact on the future viability of these services. The three most significant climate hazards facing the water-related services of the Taunton River Watershed are temperature, precipitation and sea level rise. Increases in atmospheric temperature will lead to warmer water temperatures, which will affect certain elements of water quality (e.g., dissolved oxygen), as well as change the species composition in both the Taunton River and Narragansett Bay. As winter temperatures rise, more precipitation in the form of rain and less in the form of snow will alter hydrologic cycles, causing earlier peak flows in the spring and extended low flows in the summer. While it sounds counterintuitive, summer droughts are projected to become more common as summer temperatures increase and seasonal precipitation patterns change. Rainfall is projected to be increasingly concentrated into heavy precipitation events, with longer and hotter dry periods during the summer months. Finally, sea level rise will increase the height of storm surges, frequency of coastal flooding and likelihood that low-lying coastal areas will be permanently inundated. Higher sea levels may also eventually cause saltwater to intrude into the groundwater system in and adjacent to the coastal zone, contaminating drinking water supplies.

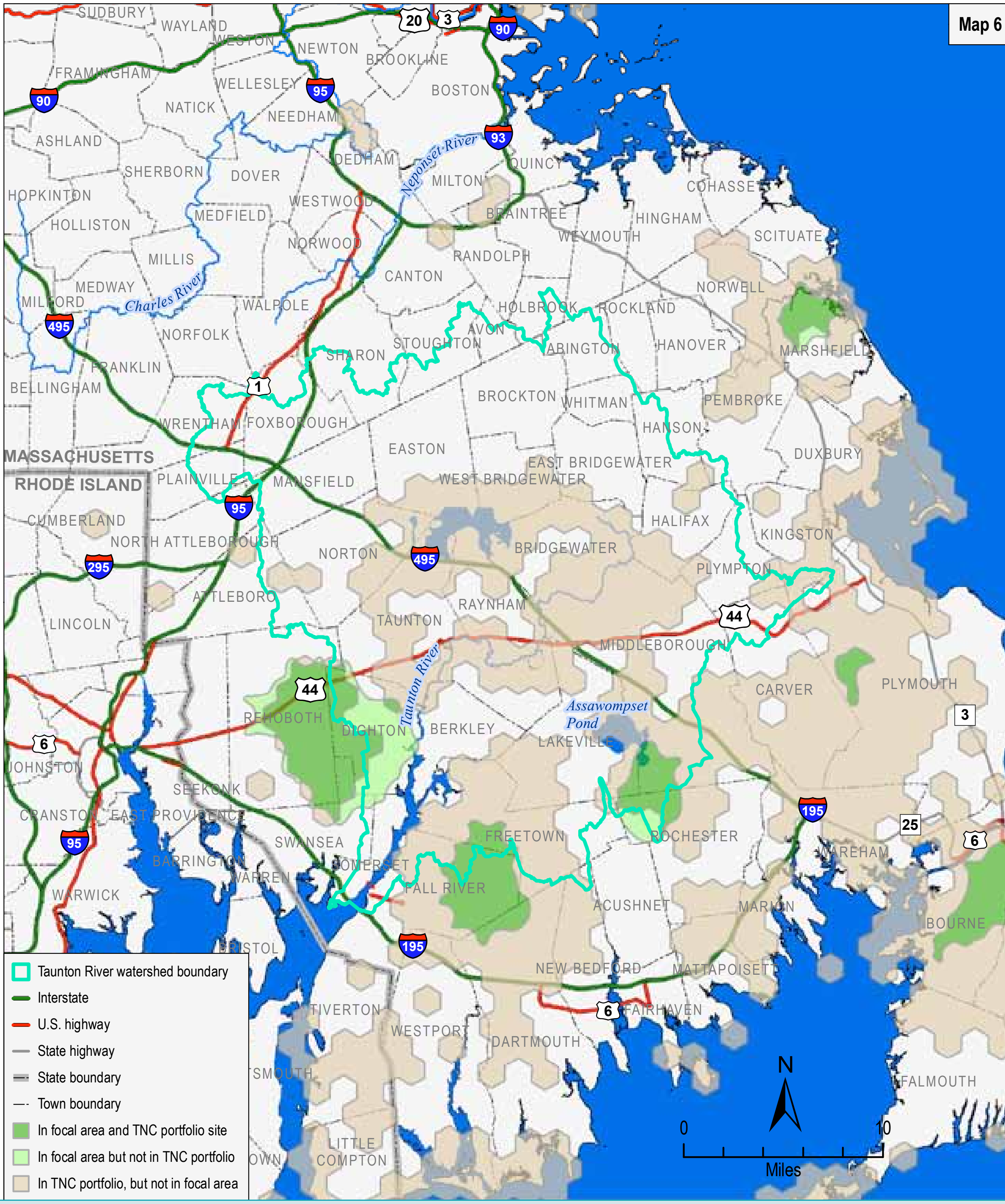
Flood Control and Stormwater Management

Non-climate stressors will work in conjunction with climate stressors to exacerbate impacts on the water-related services of the Taunton River Watershed. First, a significant portion of the storm water and sewer infrastructure in the watershed is old and requires updating; this is a tremendous financial burden on cities and towns. For example, federal and state mandates to eliminate all combined sewer overflows into the Taunton River have significantly impacted Fall River. To date, the city has invested nearly 200 million dollars in order to upgrade their stormwater and wastewater infrastructure to withstand a three-month storm, or 1.76 inches of rain over a 12-hour period.[64] However, as recently as August 15, 2012, the city's new infrastructure was overwhelmed with 1.38 inches of rain in roughly 45 minutes, leading the water department director to admit that, "some storm events are so strong that we might need to increase some capacities in some areas."[65]

Cities and towns within the watershed are familiar with how expensive and disruptive flooding can be. In 2010, heavy spring rains, which featured three intense storms in March alone, caused record or near record flooding in central and eastern Massachusetts. A number of rivers, including the Taunton River, were at their highest flows since record keeping began (see Table 4). When the Taunton River spilled over its banks, nearby infrastructure suffered the brunt of the damage, physically and financially. For example, Route 44 was shut down for more than four days and as a result, an estimated 26,000 cars per day were re-routed through local neighborhoods.[66] Fall River's upgraded stormwater and wastewater infrastructure also made headlines after five vehicles became trapped on Mount Hope Avenue due to "a colossal river of sewage" that erupted from under the roadway.[67] And in Bridgewater, Raynham and Lakeville, the Federal Emergency Management Agency assisted 1,250 families, including 121 displaced households, with over 2.5 million dollars in disaster relief as a result of the flooding.[68]

Map 7 highlights the areas within the watershed that are both vulnerable to flooding and important for riverine processes. Ideally, these areas would remain largely free of development in order to reduce the costly impacts of flooding and enhance the natural ability of the watershed to withstand flooding.

Map 6. TNC Focal Areas and Portfolio Sites within the Taunton River Watershed



MAP 6

Map showing focal areas of high estimated resilience, and their coincidence with TNC portfolio sites, as indicated by Anderson, Clark, and Sheldon (2012) around the Taunton River Watershed. The Nature Conservancy's Eastern Conservation Science office combined a variety of metrics to estimate resiliency at a coarse scale (1,000 ac. hexagons) for the northeastern United States. This map groups adjacent, high resiliency hexagons into sites appropriate for conservation focus. TNC portfolio sites contain the best known occurrence of a particular community. Town and state boundaries from MassGIS and Rhode Island GIS. Hydrologic data from the National Hydrography Dataset (1:100k). Road data from the National Highway Planning Network.

Table 4. Recent Record High Spring Flows in Select Massachusetts Rivers

STATION NAME	MARCH-APRIL 2010 PEAK FLOWS		HISTORIC PEAK FLOW		START OF ANALYSIS PERIOD
	DATE	GAGE HEIGHT (m/ft)	DATE	GAGE HEIGHT (m/ft)	
Charles River at Waltham	3/15/2010	2.30 / 7.56	2/3/1976	1.99 / 6.54	1932
Indian Head River at Hanover	3/15/2010	2.23 / 7.32	3/18/1968	2.17 / 7.13	1967
Taunton River near Bridgewater	4/1/2010	4.56 / 14.97	3/20/1968	4.41 / 14.48	1930
Segreganset River near Dighton	3/15/2010	2.64 / 8.66	3/18/1968	2.34 / 7.69	1967

Source: Massachusetts Executive Office of Energy and Environmental Affairs, Massachusetts Climate Change Adaptation Report, 19; Phillip J. Zarriello and Gardner C. Bent.

Several factors will influence the extent to which climate change will enhance flooding in the Taunton watershed. Significant freshwater flooding events in New England often occur during periods when soils are saturated and snowmelt or rainfall cannot be readily absorbed. Many variables will factor into future flooding in rural portions of the watershed including precipitation volumes and intensities, growing season length and soil wetness. Urban areas with extensive impervious surface cover and highly compacted soils will experience a much more predictable increase in flood threat due to the increase in heavy precipitation caused by climate change. In urban areas enhanced flooding vulnerability will not be limited to floodplains; urban infrastructure and drainage facilities that are not designed for the increasing rainfall intensity will be increasingly problematic.

In-stream infrastructure, such as dams and culverts, can contribute to flash flooding, especially in the cases of improper design and maintenance. Map 9 highlights the location of dams and culverts in the Taunton River Watershed. The associated Critical Linkages project was intended to identify impediments to aquatic habitat connectivity and is not an assessment of the role of that infrastructure in enhancing flooding. However, the map provides a good starting point for identifying situations where infrastructure upgrades could address both habitat connectivity and future flood threat. [69]

Runoff from impervious surfaces also negatively affects water quality through its typical velocity (fast), temperature (warm) and pollutant load (e.g., heavy metals and chemicals). This is especially true for impervious surfaces that are adjacent to a waterbody or connected to a drainage network that empties directly into a waterbody. A summary of the amount of impervious surface cover and potential for adverse water quality impacts in the Taunton River Watershed is presented below, in Table 5.

Table 5. Impervious Surface Cover and Potential for Adverse Water Quality Impacts in the Taunton River Watershed, by Sub-watershed

SUB-WATERSHED	LOCATION WITHIN THE TAUNTON RIVER WATERSHED	IMPERVIOUS SURFACE COVER	POTENTIAL FOR ADVERSE WATER QUALITY IMPACTS[A]
Matfield River	Northeast	West = >25% Central and east = <12.8%	High Low to moderate
Town River	North central	Most = <10% South (Town River) = 11% South (Coweeset Brook) = 12.9%	Low Low to moderate Low to moderate
Mill River	North central	<10%	Low
Three Mile River	West	Most = <10% East (Robinson Brook) = 13.6% East (Rumford River) = 23.7%	Low Low to moderate High
Nemasket River	East	<10%	Low
Assonet River	Southeast	<10%	Low

a. Based on the amount of impervious surface cover.

Source: GeoSyntec Consultants, 7-10.

Warmer temperatures, increased evaporation rates, a growing population and other factors will cause rivers and streams in the summer and fall to become drier, with extended periods of low flow. And when water levels are low, pollutant concentrations are much higher, due to less dilution. For water quality-based National Pollutant Discharge Elimination System (NPDES) permits, the in-stream concentration of a permitted pollutant is determined from the dilution capacity of the lowest consecutive seven-day streamflow that is likely to occur in a ten-year period.[70] In other words, NPDES permit holders are prohibited from discharging pollutants that would cause in-stream concentrations to exceed permit limits, even at very low flows. Further decreases in low flows due to climate change may require reconsideration of these NPDES permit guidelines as well as which facilities should still receive NPDES permits. A summary of the facilities within the Taunton River Watershed that currently hold, or have recently held, a NPDES permit is presented below, in Table 6. In general, NPDES permits are valid for five years from the date of issuance.

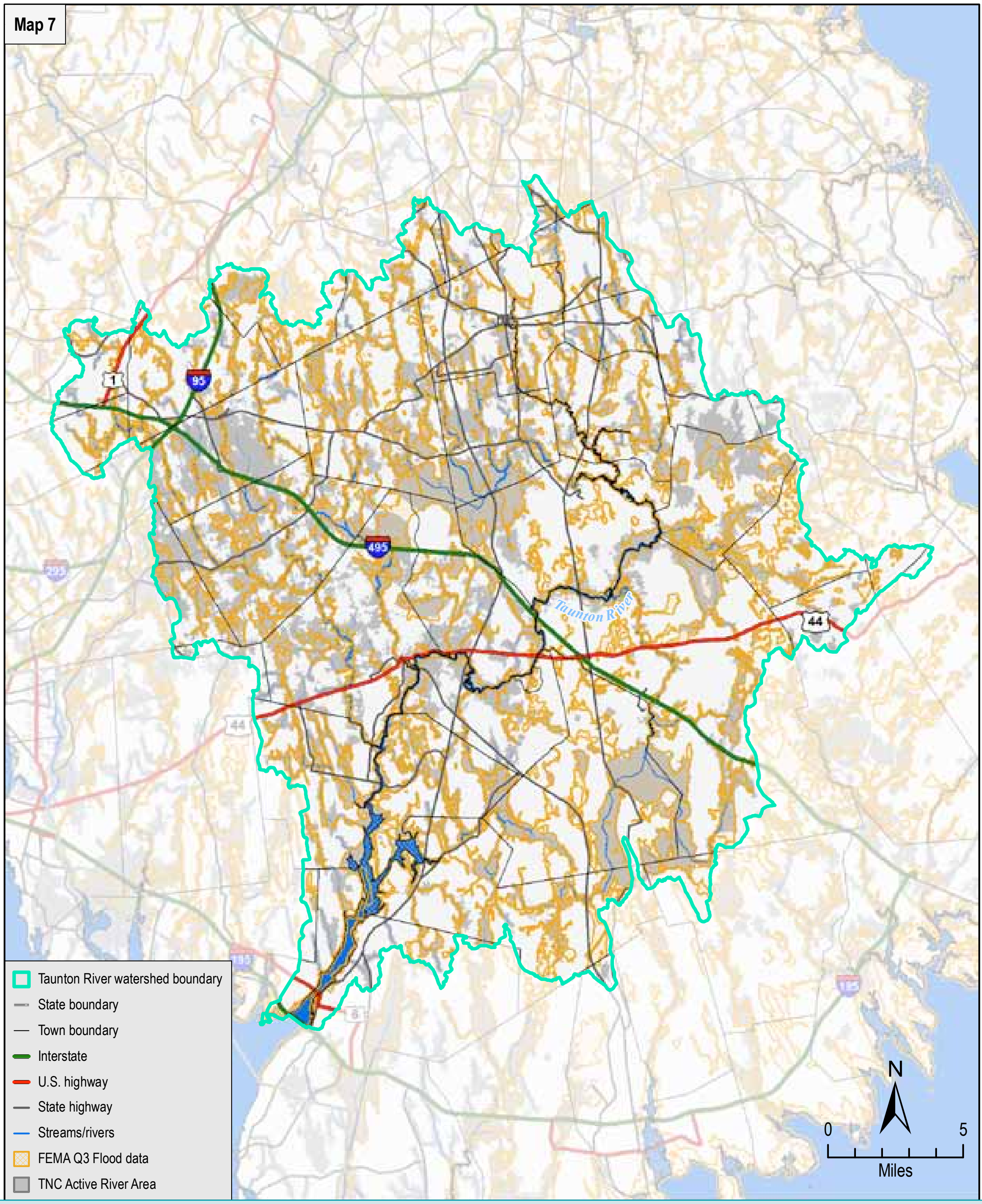
Table 6. Facilities within the Taunton River Watershed with a NPDES Permit, by City/Town

CITY/TOWN	FACILITY NAME[A]	PERMIT NUMBER	DATE OF ISSUANCE	STATUS[C]
Bridgewater	Bridgewater POTW	MA0100641	12/30/2003	AC
Brockton	Brockton Advanced Water Reclamation Facility	MA0101010	5/11/2005	AP
Dighton	INIMA USA, Co.	MA0040193	11/30/2006[b]	A
E. Bridgewater	East Bridgewater High School	MA0022446	4/7/2004	AC
Fall River	Fall River POTW	MA0100382	12/7/2000	AC
Middleborough	Middleborough POTW	MA0101591	9/26/2003	AC
Middleborough	Oak Point Property	MA0032433	8/3/2004	AC
Somerset	Somerset POTW	MA0100676	5/14/2004	AC
Taunton	Draka Cableteq USA	MA0028649	10/19/2011	A
Taunton	Taunton Municipal Lighting Plant	MA0002241	9/13/2006	AC
Taunton	Taunton POTW	MA0100897	9/19/2001	AP
W. Bridgewater	Howard School	MA0101753	11/21/2003	D
W. Bridgewater	MacDonald School	MA0102061	11/21/2003	D

a. POTW = Publicly owned treatment works facility.
b. NPDES permit does not expire until 2013.
c. A = Active; AC = Administratively continued (awaiting the assignment of a permit writer from the United States Environmental Protection Agency); AP = Assigned to a permit writer from the United States Environmental Protection Agency; D = Discontinued.

Source: United States Environmental Protection Agency; Vergara.

Map 7. Areas Vulnerable to Flooding and Important for Riverine Processes in and around the Taunton River Watershed



Map showing areas vulnerable to flooding and important for riverine processes in and around the Taunton River Watershed. FEMA Q3 Flood data acquired from MassGIS, not showing areas of undesignated flood hazard. The Nature Conservancy (TNC) Active River Area (ARA) data (Olivero, 2009) shows areas within which important physical and ecological processes of the river or stream occur. Town and state boundaries from MassGIS and RIGIS; road data from the National Highway Planning Network.

MAP 7

Sea Level Rise and Storm Surge

The Taunton River Watershed has not suffered a direct hit by a hurricane in many years. Hurricane Bob, a Category 2 storm, brought sustained hurricane force winds to southern New England in the summer of 1991.[71] Wind damage to trees and utility infrastructure was common; over 60% of residents lost power as a result of the storm.[72] While the Massachusetts coastline from Buzzards Bay east to Cape Cod was the hardest hit in terms of storm surge (10-15 feet), Hurricane Bob caused a surge of 5-8 feet along the Rhode Island shore.[73] The total damage in Connecticut, Rhode Island and Massachusetts was approximately 680 million dollars.[74]

As sea levels continue to rise the Taunton River will be increasingly vulnerable to storm surge flooding. Map 8 highlights the areas within the watershed that are most vulnerable to coastal flooding due to a Category 1 through Category 4 hurricane striking the coast of Massachusetts or New Hampshire. It is important to note that the storm surge data displayed in Map 8 do not take sea level rise into account; the current rates of sea level rise and projections for accelerated trends all but guarantee an increase in the height of future storm surges and frequency of coastal flooding. Maps 10 and 11 delineate areas of low elevation in and around the mouth of the Taunton River that are most vulnerable to sea level rise and enhanced storm surge.

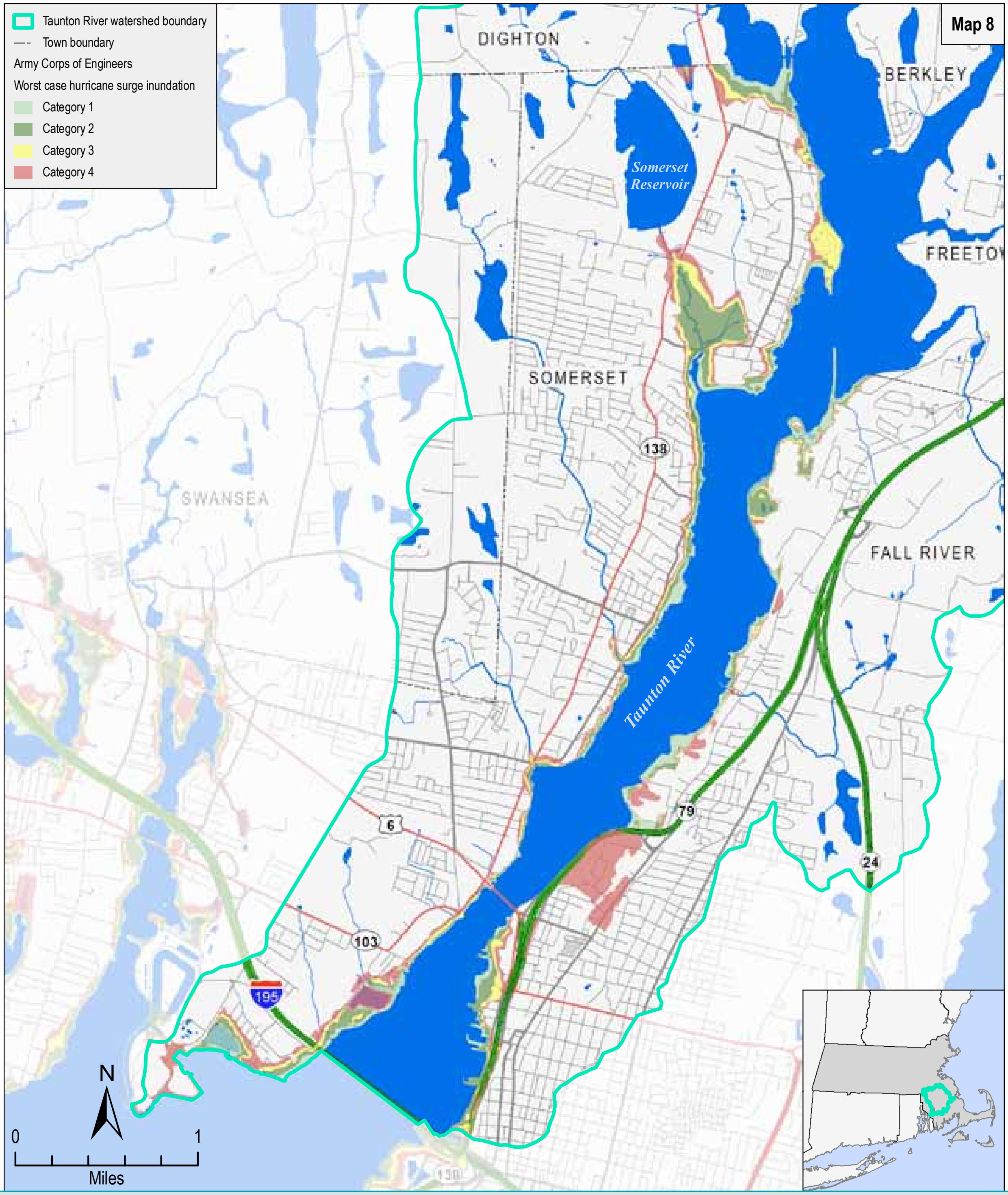
Water Supply

As for vulnerabilities related to water supply, it is useful to consider both surface water and groundwater supplies in terms of sensitivity to drought. More specifically, supplies will fall into one of three categories: 1) relatively insensitive to any droughts; 2) sensitive to short droughts (two months); and 3) sensitive to moderate droughts (six months). Only two cities within the Taunton River Watershed, Brockton and Taunton, rely on surface water for their drinking water needs.[75] The remaining watershed communities rely almost exclusively on groundwater resources (Map 12).[76]

The City of Brockton withdraws most of its water from Silver Lake, in Halifax, Kingston, Pembroke and Plympton, and a much smaller quantity from Brockton Reservoir, in Avon.[77] Brockton is one of five cities and towns within the Taunton River Watershed with the highest demand for water; together with Attleboro, Fall River, New Bedford and Taunton, the five-year average daily demand (1998-2002) for these communities was 45.89 million gallons per day (MGD) or 61% of the watershed-wide total demand of 75.26 MGD.[78] A portion of Brockton's demand can be attributed to the fact that the city sells its water to neighboring public water suppliers; in 2002, Brockton sold nearly 400 million gallons of water to Hanson and Whitman.[79] The city's withdrawals from Silver Lake, in particular, have been characterized as excessive due to low water levels in the lake itself and low streamflow in the headwaters of the Jones River, which reportedly does not flow for eight months of the year.[80] In the fall of 2007, Brockton's main water supply was challenged by six months of drought and, as a result, the lake level fell to 72 inches; its lowest level since another drought in 2002.[81] Given this information, it is fair to assess the city's primary water supply as being sensitive to moderate droughts.

It should be noted that the City of Brockton recently (2002) signed a 20-year contract with Aquaria, a newly constructed (2008) desalination plant located in North Dighton, on the banks of the Taunton River.[82] The primary drivers for the city making this expensive, long-term commitment were a "water crisis" in 2002 and the potential for the water in Silver Lake to drop to alarmingly low levels in the future.[83] Under the terms of the contract, the city must pay over five million dollars a year in fixed costs to Aquaria, whether it buys water or not.[84] The city initially planned to use 1.9 million to 4.07 million gallons of desalinated Taunton River water each day.[85] While Brockton has not purchased water from Aquaria since May 2011, the city's fiscal year 2012 budget includes $546,850 for desalinated water, should the level of Silver Lake trigger the need.[86]

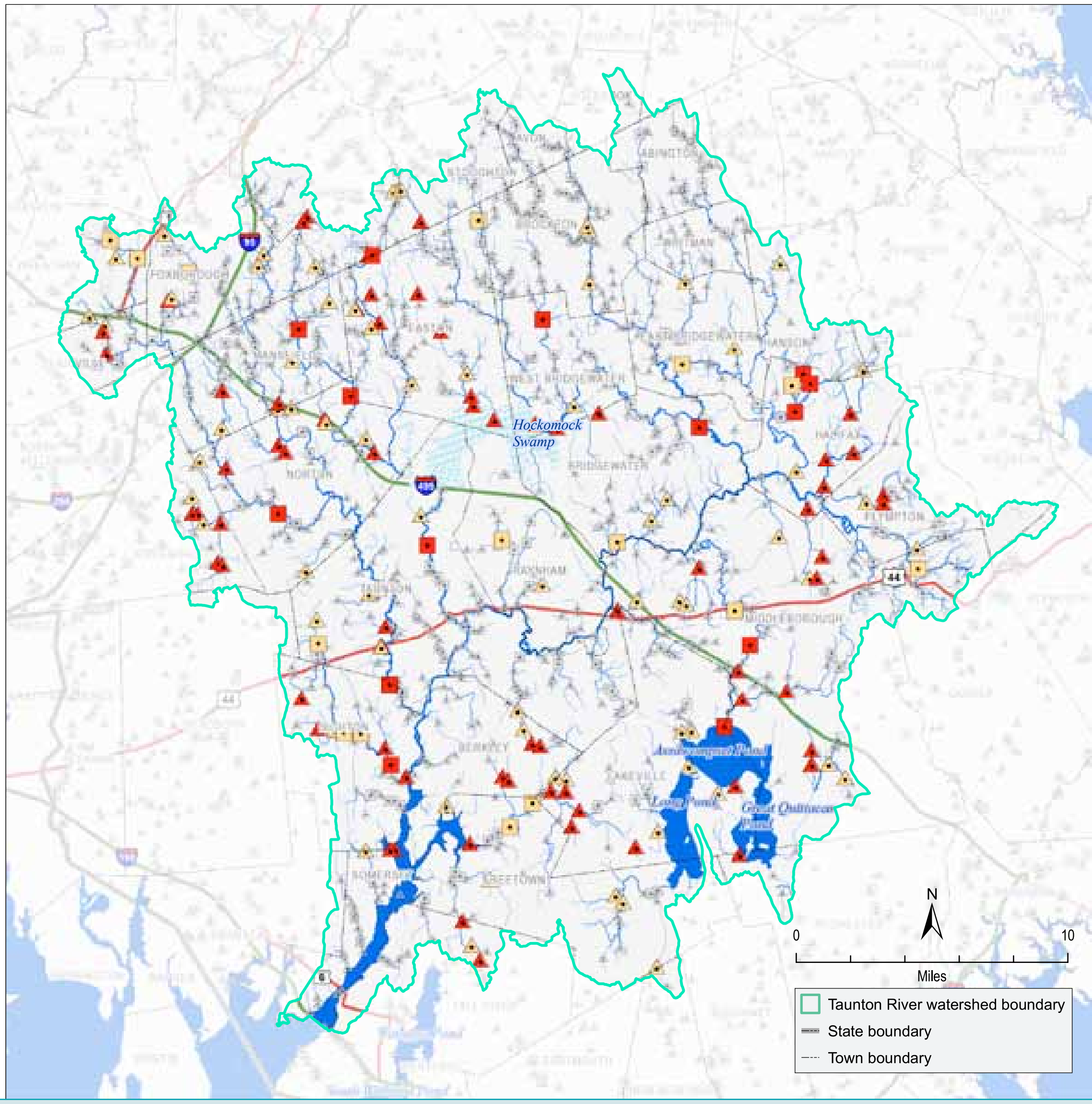
Map 8. Worst Case Hurricane Surge Inundation within the Taunton River Watershed



Map showing worst case hurricane surge inundation within the Taunton River Watershed for category one through four hurricanes striking the coast of Massachusetts or New Hampshire. Hurricane surge values were developed by the National Hurricane Center using the Sea, Lake, and Overland Surge from Hurricances (SURGE) Model, and were developed into this inundation data by the U.S. Army Corps of Engineers by subtracting land elevation from the expected surge values. Note that this data does not take into account sea level rise and was designed primarily to assist emergency management officials. Road, town boundary, and hydrologic data from MassGIS, National Hydrography Dataset, and the National Highway Planning Network.

MAP 8

Map 9. Green Infrastructure Stream Connectivity Synopsis for the Taunton River Watershed



MAP 9

Green Infrastructure Stream Connectivity Synopsis for the Taunton River Watershed – Dams and road-stream crossings

The Critical Linkages project undertaken by researchers at UMass Amherst (Jackson, Compton, and McGarigal; 2011) in collaboration with The Nature Conservancy used a resistant kernel estimator to evaluate the functional connectivity of aquatic habitats across Massachusetts. Functional connectivity describes the response of organisms and ecological process to the physical landscape, and this project evaluated that connectivity in a non-species specific fashion.

This map displays the result of analyzing the effect of removing dams and replacing culverts and bridges with “ideal” crossing structures. Both culverts and dams act as barriers to aquatic connectivity. The analysis first used data collected on over 1,000 crossings to create a model to predict the aquatic barrier potential on crossings not assessed in the field. Then, the researchers predicted the increase in habitat connectivity by replacing the crossing with an ideal structure. The analysis assigned each dam a barrier rating with a more severe rating assigned as a function of increasing dam height. A relatively small number of dams and road-stream crossings (culverts or bridges) account for much of the restoration potential.

Dams (shown with squares) and road-stream crossings (shown with triangles) displayed in red represent the structures in the watershed which, if removed or replaced, show the greatest potential to improve connectivity. Those shown in orange represent additional structures which, if upgraded, would also improve connectivity though not as much. In some cases, information on fish passage structures, which may improve baseline connectedness, was unavailable.

Rank of change in aquatic connectedness:

Dams:	Road-stream crossings:
Top 10%	Top 5%
Top 10-20%	Top 5-10%
Other dams	Other crossings

The City of Taunton's primary water supply can be described with completely different terms, including its sensitivity to droughts (relatively insensitive). The majority of the surface water withdrawals (approximately seven billion gallons) that occurred within the Taunton River Watershed in 2002 came from the reservoir system known as the Assawompset Pond Complex, in Lakeville, Middleborough, Rochester and Freetown.[87] Taunton and New Bedford share this water supply, which contains the largest natural body of water in the state, Assawompset Pond (2,404 acres).[88] Under Massachusetts' Water Management Act, Taunton is authorized to withdraw a total of 7.29 MGD, on average, from the Assawompset Pond Complex.[89] This amount represents the city's share of the safe yield of 27.5 MGD for the complex, which was determined through an engineering analysis performed in 1988.[90] Because the complex is an environmentally sensitive area, Taunton (and New Bedford) must also abide by a fisheries plan, which provides guidance on minimizing the impacts of water withdrawals on the migration of alewife fry to the sea.[91]

An Assawompset Pond Complex Management Team was recently formed to coordinate management of the resource between local, state and federal officials. Specifically, the team plans to address the recent, but relatively persistent high water levels in Assawompset Pond. In July 2009, the water level in the pond reached 55 feet above sea level and after the heavy spring rains of 2010, the water level rose to 57 feet above sea level.[92] According to officials, the ideal water level is closer to 53 feet above sea level.[93] One issue affecting the water level of the pond, in addition to heavy rains and the associated high groundwater level, is the slow rate of flow in the Nemasket River.[94] Several dams in the area may also contribute to the pond's high water levels. The short-term goals of the management team are to balance water levels, in an environmentally-sensitive way, in order to meet the needs of nearby residents and those who rely on the complex for drinking water.[95] In the long-term, the management team hopes to secure federal funding for a more thorough study of the complex and permanent action plan.[96]

Water Balance

The results of a water balance analysis, conducted by the Horsley Witten Group, Inc. as part of the Taunton River Watershed Management Plan Phase I: Data and Assessment – Final Report, provide the most recent, comprehensive and accurate insight into the groundwater supplies for the Taunton River Watershed; details regarding the methodology for the water balance calculations can be found online (see Horsley Witten Group, Inc.). The water balance analysis found that of 108 sub-watersheds in the Taunton River Watershed, 29 (27%) have surplus water compared to natural conditions and 79 (73%) have water deficits, excluding surface water withdrawals and NPDES permit information.[97] The sub-watersheds range from a surplus of 9% to a deficit of 231% in one small sub-watershed with several significant water withdrawals.[98] Overall, this portion of the analysis, which, again, excluded surface water withdrawals and NPDES permit information, found a 6.2% water deficit throughout the entire watershed.[99]

When the information regarding surface water withdrawals and NPDES permit information was included in the calculations, the initial results were only slightly different. Of 108 sub-watersheds, 34 (31%) have surplus water compared to natural conditions and 74 (69%) have water deficits.[100] However, the net results were quite different. The sub-watersheds range from a surplus of 259% to a deficit of 1225% in one small sub-watershed with several significant water withdrawals.[101] And overall, this portion of the analysis, which again, included surface water withdrawals and NPDES permit information, found a 1.5% water surplus throughout the entire watershed.[102]

Based on these results, it is clear that "there is a need to balance the hydrologic budgets in the Taunton River Watershed."[103] The current land use and water resource infrastructure within the watershed have resulted in the shifting of water "from one sub-watershed to another, leaving many areas with water deficits and some with surpluses."[104] Since the results of the water balance analysis only reflect conditions over an annual timeframe and do not capture drought or wet conditions, it is difficult to assess how sensitive the watershed's groundwater resources are to drought.[105] However, it is likely that climate change, in addition to improperly sited future development, will exacerbate the current hydrologic imbalances in the watershed and make several areas sensitive to moderate droughts.

Groundwater supplies within the Taunton River Watershed are characteristic of the coastal aquifer systems that are situated throughout much of southeastern Massachusetts. The U.S. Geological Survey recently published several studies related to these invaluable resources and their susceptibility to saltwater intrusion (see Masterson, Masterson and Walter and Masterson et al.). While the studies are not conclusive, they indicate that the potential for adverse impacts on fresh water supplies, due to changes in sea level and aquifer recharge, certainly exists.[106] Saltwater may intrude into groundwater supplies due to the combined effects of aquifer drawdown and sea level rise. [107]

Equity and Environmental Justice Concerns

Equity and environmental justice issues are likely to occur with regard to flooding, water quality and water quantity too. In addition to geographic differences (e.g., one community versus another), decreased water quality can be associated with several demographic differences, such as socioeconomic status. For example, a recent study by Evans and Kantrowitz found that, nationwide, lower socioeconomic groups are "much more likely to swim in polluted beaches as well as consume fish from contaminated waters."[108] Non-English speaking populations may also be particularly vulnerable to water quality issues due to a lack of understanding or awareness of warnings and assistance programs. Any new policies related to climate change and water quality will need to consider certain demographic characteristics, like education, language and income, of the watershed communities in order to be implemented equitably and successfully.

AGRICULTURE-RELATED SERVICES

Food and Tourism

The agriculture industry is an important component of the Taunton River Watershed. It includes both large wholesale growers like Ocean Spray Cranberries, Inc., who sell their products nationally and internationally, as well as many small farms that provide the region with fresh, local produce and, arguably, represent the essence of the watershed's landscape. The most recent Census of Agriculture provides some valuable insight regarding the physical characteristics of farms and value of products sold in the watershed. Nearly 1,700 farms in Bristol and Plymouth counties produced over 122 million dollars worth of goods in 2007, the majority of which (89%) was dedicated to crops, such as hay and corn for livestock feed, vegetables and, of course, cranberries (see Table 7, below).[109,110] Map 13 shows the location and overall distribution of agricultural lands in the Taunton River Watershed.

Table 7. Physical Characteristics and Value of Sales for Farms in Bristol and Plymouth Counties, According to the 2007 Census of Agriculture

	BRISTOL COUNTY	PLYMOUTH COUNTY
Number of Farms	777	882
Land in Farms (Acres)	39,252 acres	49,612 acres
Average Size of Farm (Acres)	51 acres	56 acres
Market Value of Products Sold	$44,245,000	$78,440,000
Crop Sales (% of Total)	$36,559,000 (83%)	$73,082,000 (93%)
Livestock Sales (% of Total)	$7,686,000 (17%)	$5,358,000 (7%)
Top Crop Items (Acres, State Rank)	Forage (7,484 acres, #6) Vegetables (1,786 acres, #3) Corn for silage (1,708 acres, #4) Land in berries (930 acres, #3)	Land in berries (11,241 acres, #1) Forage (3,202 acres, #9) Vegetables (695 acres, #8) Sweet corn (369 acres, #7)
Top Livestock Items (Number, State Rank)	Egg-laying hens (8,542, #4) Cattle and calves (6,083, #4) Colonies of bees (X[a], #1) Horses and ponies (1,798, #5)	Egg-laying hens (2,433, #9) Horses and ponies (2,404, #3) Hogs and pigs (1,311, #4) Cattle and calves (827, #9)

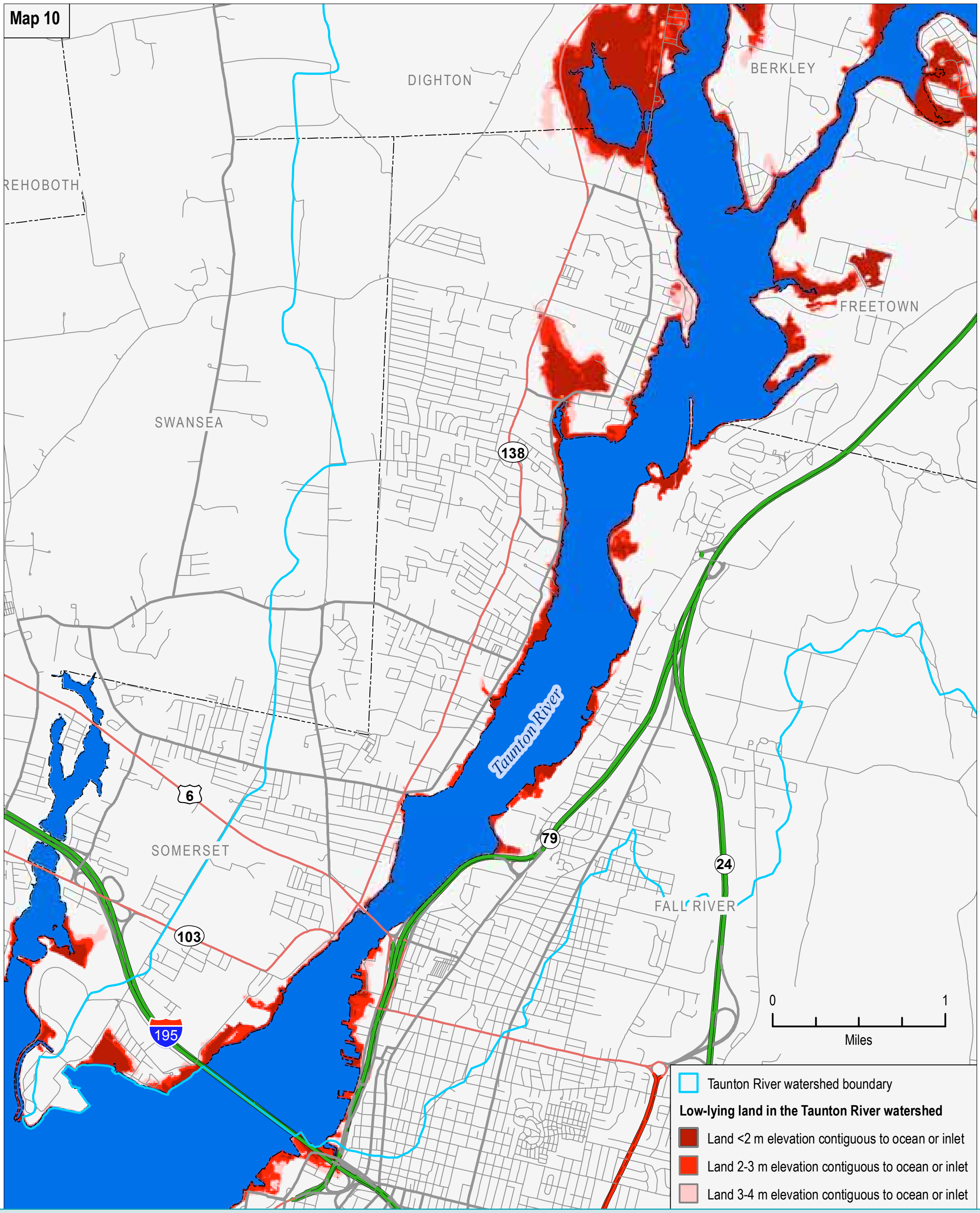
a. Number withheld by the United States Department of Agriculture to avoid disclosing data for individual farms.

Source: United States Department of Agriculture, 2007 Census of Agriculture: Bristol County Massachusetts; United States Department of Agriculture, 2007 Census of Agriculture: Plymouth County Massachusetts.

The agriculture industry is also extremely vulnerable to climate change, as most farming operations in the watershed have been optimized to fit a given climate niche. The direct impacts on crops and livestock will affect the livelihood of growers and farmers and cause ripple effects throughout the region's economy. Warmer temperatures will bring both longer growing seasons and new threats in the form of invasive plants and weeds as well as insect and disease pests. Heat stress will also negatively impact the quality and seasonal yield of many crops as well as the health and productivity of livestock. Changes in precipitation patterns, in combination with increased ambient temperatures, will challenge farming operations in terms of water usage; many growers and farmers may turn to increased irrigation and storage of water in order to provide a reliable source of water for their crops and livestock. Finally, extreme and unpredictable weather patterns will affect the growing agritourism industry. The greatest impact on most retail farm sales in the state is weekend weather because it influences the number of customers who visit individual farms and regional farmers' markets.[111] Finally, recent studies have shown that, aside from the predicted climate change-related impacts, higher levels of atmospheric carbon dioxide will benefit weeds more than crops and potentially make weeds more resistant to herbicides.[112]

Vulnerabilities

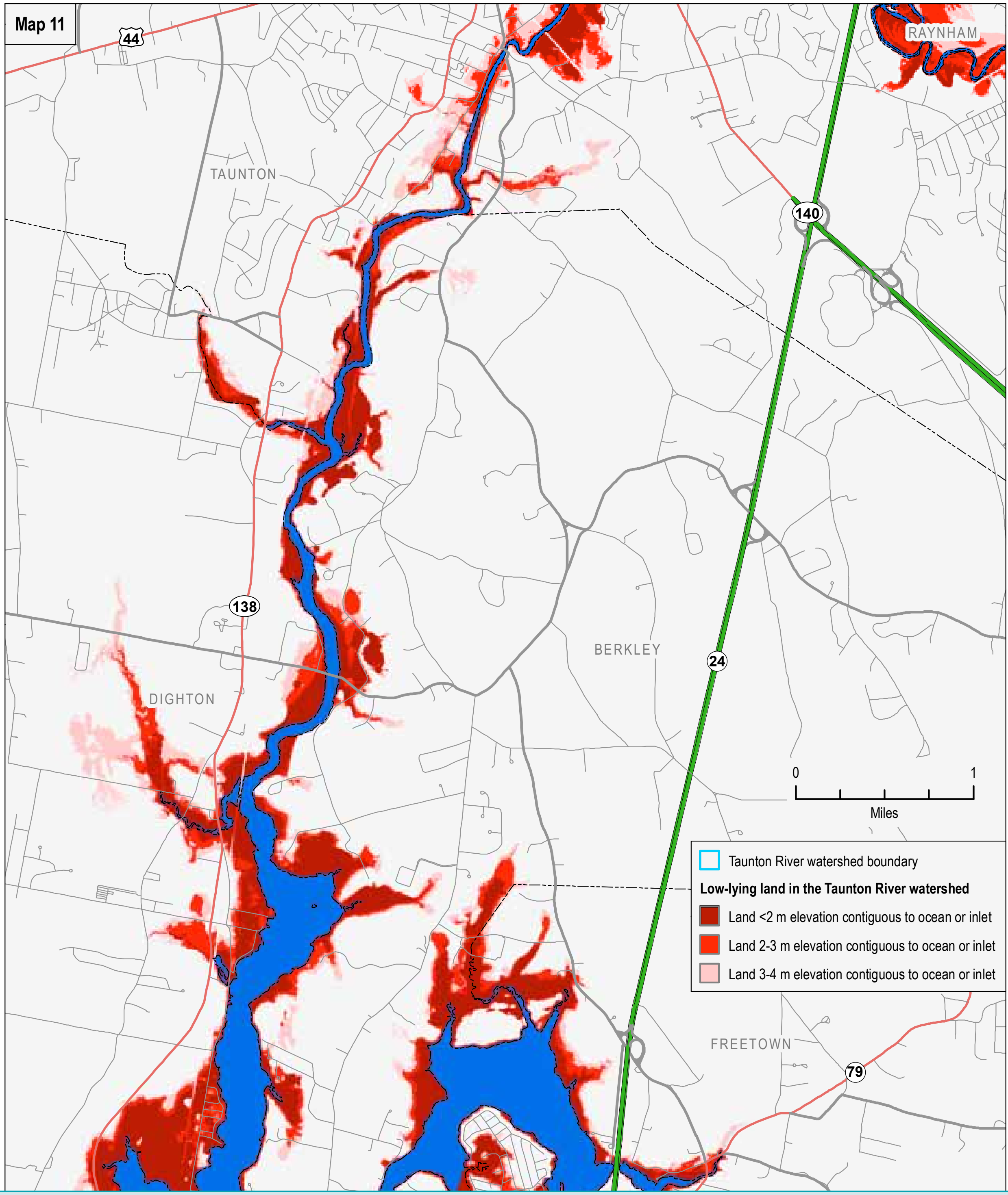
Given the characteristics of the agriculture industry in the Taunton River Watershed and likely consequences of climate change, it is likely that farming operations will be most vulnerable in terms of increasing average temperatures, increasing incidence of extreme heat, increase in very heavy precipitation and increasing threat of storm damage. Many of the valuable crops and livestock that support the watershed's population and economy benefit from the region's relatively cool climate. Historically, the region's climate has also kept the population of certain pests under control and prevented new species from becoming established in the area.



MAP 10

Map showing approximate areas of low elevations in and around the mouth of the Taunton River. 1 m resolution LiDAR data acquired from MassGIS and hydrologically processed using USGS NHD. Hydrography data combined from MassGIS DEP Wetlands and USGS NHD. Road data from MassGIS MassDOT roads. Watershed boundary from NRCS WBD dataset.

Map 11. Areas of Low Elevations in and around the Mouth of the Taunton River (2 of 2)



Map showing approximate areas of low elevations in and around the mouth of the Taunton River. 1 m resolution LiDAR data acquired from MassGIS and hydrologically processed using USGS NHD. Hydrography data combined from MassGIS DEP Wetlands and USGS NHD. Road data from MassGIS MassDOT roads. Watershed boundary from NRCS WBD dataset.

MAP 11

Temperature is likely the single most important environmental factor influencing the survival and distribution of weeds, insects and diseases. Scientists have long recognized the potential for weed species' ranges to expand northward as the climate changes. For example, the spread of kudzu, an aggressive invasive weed that covers over one million hectares in the southeastern U.S., is limited in part by low winter temperatures (5°F to -4°F).[113] Given the diminishing number of days with temperatures below -4°F and aggressive nature of the species, as well as its recent migration pattern, it is likely that kudzu will spread throughout the northeast this century.[114] Research also indicates that insects and diseases will persist in the absence of cooler weather. For example, given a 1.8°F, 3.6°F and 5.4°F temperature increase, insects may experience one to three, one to five and one to seven additional lifecycles per season, respectively.[115] In addition, it is well known that fungi that cause plant diseases generally grow best in moderate temperature ranges. As a result of climate change, the Taunton River Watershed will experience longer periods of temperatures more suitable for pathogen growth and reproduction.

An increase in winter temperatures will also directly impact the region's crops, especially those varieties that require a prolonged "winter chilling" period to flower; seasonal yields will decline "if the chilling requirement is not completely satisfied, even if spring and summer temperatures are optimum for growth."[116] Cranberries, in particular, have a winter chilling requirement of at least 1,700 cumulative hours within a narrow temperature range (32°F and 45°F) in order to break dormancy in the spring and initiate flowering for the new season.[117,118] Temperatures below or above this range do not meet the winter chilling requirement and can reset the cranberries' "internal 'cold counter' to zero, [forcing] the number of hours below 45°F to begin accumulating all over again."[119] In addition, warmer temperatures will prevent ice from forming on flooded cranberry bogs in the winter. Growers often flood their bogs during the winter and apply sand when the water freezes, so that the sand filters into the vines in the spring and encourages new plant growth as well as a small degree of pest control.[120]

As with temperature, changes in precipitation will affect the survival and distribution of weeds, insects and diseases. During wet periods, weeds will compete with, or in some cases outcompete, crops for water and nutrients. Weeds will pose less of a threat to crops during dry periods, but the potential seasonal yield will already be limited due to the lack of rainfall. More frequent and intense precipitation events will provide some benefit in terms of pest control, since some insects can be killed or removed from crops by heavy rains. However, depending on the timing of the storm, the potential for heavy rain to wash off chemical treatments also exists. Under the same wet conditions, fungal diseases that prefer high humidity will increase.

During the summer of 2009, the perfect combination of cool, wet weather spurred an early and devastating outbreak of late blight in New England. Late blight, the disease responsible for the Irish potato famine, is caused by a fungus-like pathogen that spreads through wind or wind-driven rain; it infects potatoes and tomatoes. Late blight spores can disperse from one to several miles from the point of origin during ideal conditions of high moisture and temperatures below 77°F.[121] According to plant disease specialists, the reach and pace of the 2009 outbreak was also aided by the sale of infected tomato plants to "thousands of home gardeners via major big box stores."[122] At least 400 farms in New England were impacted by late blight, with an estimated 100 to 200 farms in Massachusetts reporting the disease on their crops.[123] As a result of the outbreak, farmers were required to make numerous fungicide applications on a shortened timetable in order to harvest marketable produce; this was both an expensive and environmentally risky solution, but one that may be need to be repeated in the future as the climate changes.[124]

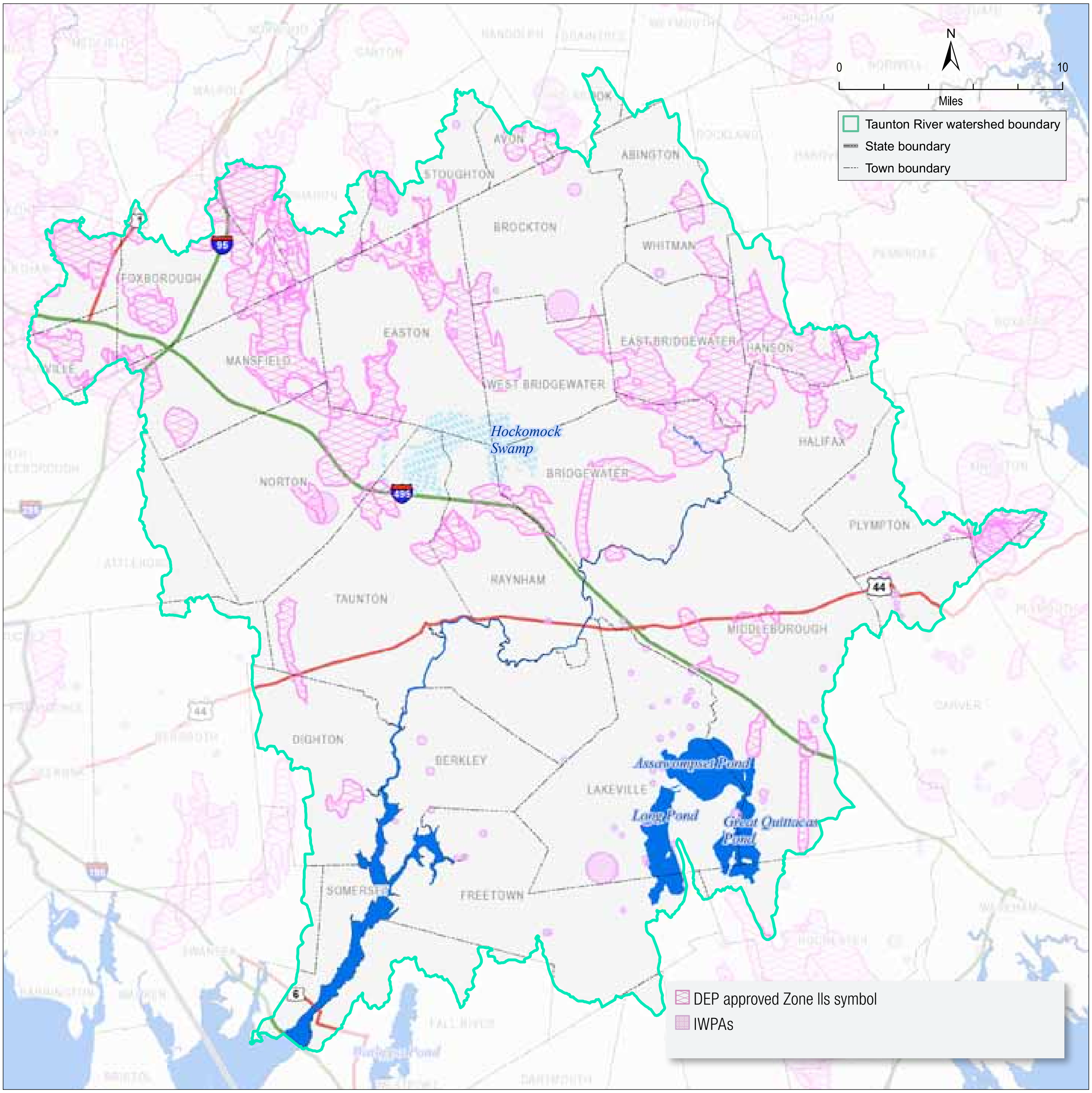
PUBLIC HEALTH-RELATED SERVICES: LOCAL CLIMATE AND AIR QUALITY REGULATION, BIOLOGICAL CONTROL AND MENTAL AND PHYSICAL HEALTH

The climate change-related consequences for public health in the Taunton River Watershed are likely to be significant, especially for populations that are more vulnerable because of their age, socioeconomic status or pre-existing health conditions. A range of potential health outcomes will occur in the watershed, including more heat-related illnesses; worsening air quality and related respiratory health impacts, due to increasing smog, pollens and molds; and changing patterns of vector-borne (i.e., carried by mosquitoes and ticks) and other infectious diseases. These health outcomes are especially sensitive to changes in climate, either because the physical burden of the illness or disease is especially high, or because climate change could directly impact the frequency or severity of an outbreak. The effects of climate change will also stress each component of the public health infrastructure in the watershed, from local boards of health to the network of hospitals, rehabilitation centers and nursing homes, among others.

Social Vulnerability Analysis

The goal of this section is to investigate vulnerability within the watershed, beyond the identification of EJ populations, in order to determine which neighborhoods are most socially vulnerable to climate change impacts. The concept of a social vulnerability analysis has its roots in social indicators research, which was a thriving topic within the social sciences in the 1960s and 70s.[125] The development of environmental indicators followed in later years, with quality-of-life studies emerging as a combination of the two areas of research.[126] Much of the contemporary work on quality-of-life studies can be found in popular rating places guides, such as The Places Rated Almanac and America's Top-Rated Cities, or comparative rankings of environmental quality, such as the Green Metro Index.[127] In 2003, researchers at the University of South Carolina opted to answer the call for a consistent set of metrics to assess social vulnerability to environmental hazards. The researchers identified the characteristics most often cited in literature as influencing social vulnerability (over 250) and through some robust statistical processing, narrowed their original list down to just 11 characteristics, including per capita income, median age, employment status and race, that differentiated populations according to their relative level of social vulnerability.[128]

In a practical application of some of these concepts and characteristics, Oxfam America recently released a study of social vulnerability and climate change in the southeastern U.S. The study focuses on eight characteristics that account for most of the variation in the social vulnerability of populations: wealth, age, race, gender, ethnicity, rural farm populations, special needs populations and employment status. It also includes shaded maps that depict social and climate change-related vulnerabilities, including drought, flooding, hurricane force winds and sea level rise. One of the main points of the study is that "while social variables such as income and age do not determine who will be hit by a natural disaster, they do determine a population's ability to prepare, respond, and recover when disaster does strike."[129] The study concludes that the most socially vulnerable communities will suffer disproportionately from climate change impacts, given the population characteristics examined. Among the recommendations featured in the study are strengthening preparedness and response plans at state, regional and local levels, as well as using early warning programs to help prepare and evacuate, if necessary, the most vulnerable populations during intense weather events.



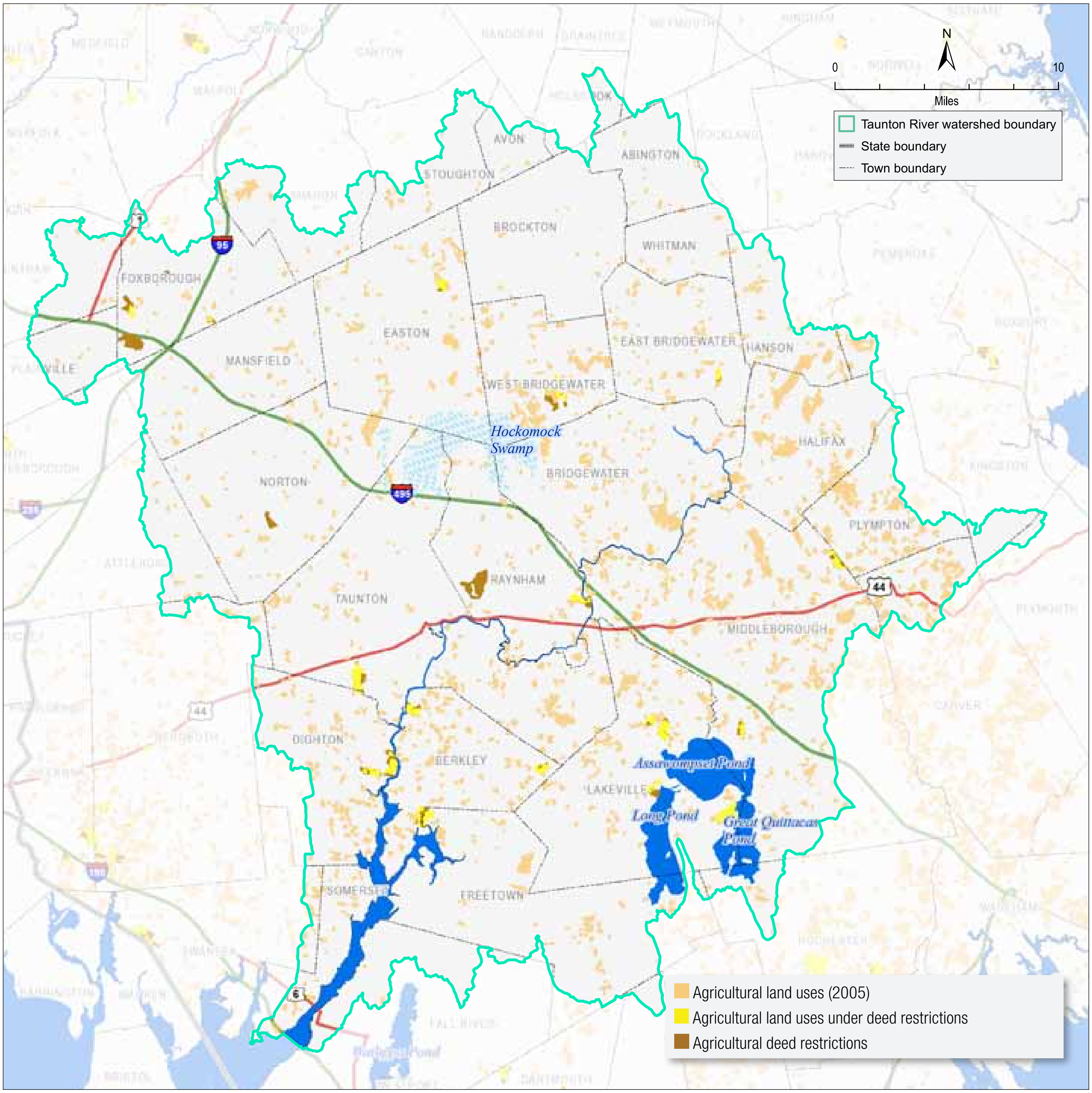
MAP 12

Approved Zone II Wellhead Protection Areas have been determined by hydrologic modeling and is the area of an aquifer that can be realistically anticipated to contribute water to a well under severe recharge and pumping conditions.

Interim Wellhead Protection Areas (IWPAs) are established as simple circles around public water supply wells. Radii range from a minimum of 400 feet and increase proportionally with the maximum approved pumping rate, metered data, or Title 5 flow rate.

Manomet Center for Conservation Sciences

Map 13. Agricultural Lands in and around the Taunton River Watershed



The MassGIS Land Use (2005) datalayer was used to identify land currently in agricultural production. Land and associated buildings identified as cropland, pasture, cranberry bogs, orchards, and nurseries are shows as agricultural uses on this map.

The MassGIS Open Space (2012) data was used to identify parcels of land on which an agriculture-related deed restriction has been placed. This primarily includes Agricultural Preservation Restrictions (APRs), a program unique to Massachusetts that helps to stabilize farmland values in areas of increasing development pressure and keep prime farmland, a limited resource, in active agricultural use.

MAP 13

MANOMET Center for Conservation Sciences

For the purpose of the Taunton River Watershed's social vulnerability analysis, characteristics that are fairly well accepted among sociologists as factors that make populations socially and economically vulnerable are used. Those characteristics are as follows: 1) per capita income; 2) percent of families below the poverty line; 3) percent of population not in the labor force; 4) percent of population with less than a high school diploma; 5) percent of population that speaks a language other than English at home; and 6) percent of population greater than or equal to age 65. The first four characteristics were selected because it is generally accepted that people of lower socioeconomic status and with less education tend to be more vulnerable, both because they are less likely to attend public meetings and more likely to be unaware of environmental issues, including climate change.[130,131] Populations who tend to speak a language other than English at home may need special outreach efforts in other languages, both for communicating risks in general and in terms of specific warnings about pending severe weather events. In addition, these populations, as well as the elderly, may need special considerations during an emergency, especially if the need to evacuate arises. Finally, age is also a consideration for vulnerability to vector-borne diseases, because the elderly have weakened immune systems and may experience more serious consequences from exposure to these diseases.

By evaluating municipal level data from the 2006-2010 American Community Survey, it is possible to identify communities within the watershed that stand out from the others, based on the six criteria of interest in this analysis. The cities and towns located within Bristol County and the Taunton River Watershed are presented in Table 8; Fall River and New Bedford are highlighted because they stand out from the other Bristol County communities in all six of the criteria of interest in this analysis. Table 9 contains the same information for the cities and towns located within Plymouth County and the Taunton River Watershed; Brockton, Middleborough and West Bridgewater are highlighted because they stand out from the other Plymouth County communities in four of the six criteria of interest in this analysis.

Table 8. Criteria of Interest for Cities and Towns in Bristol County and the Taunton River Watershed, Based on 2006-2010 American Community Survey

LOCATION	PER CAPITA INCOME[A]	% FAMILIES BELOW POVERTY	% NOT IN LABOR FORCE[B]	% LESS THAN H.S.[C]	% LANGUAGE OTHER THAN ENGLISH[D]	% AGE ≥ 65
U.S.	$27,334	10.08	35.01	14.97	20.12	12.74
Massachusetts	$33,966	7.45	32.30	11.31	21.05	13.54
Bristol County	$27,736	8.77	32.29	19.90	20.77	13.85
Attleboro	$29,983	4.63	26.20	13.76	14.16	11.92
Berkley	$29,102	3.37	26.11	11.51	10.40	9.30
Dartmouth	$30,589	2.89	36.61	17.85	22.46	15.87
Dighton	$33,456	0.92	29.52	8.90	10.68	16.45
Easton	$37,504	2.12	31.41	5.10	7.42	10.41
Fall River	$20,337	17.78	38.59	32.45	33.47	15.3
Freetown	$31,339	1.79	24.16	11.28	11.77	9.31
Mansfield	$38,780	3.55	22.72	5.39	8.58	7.09
New Bedford	$20,447	19.7	38.24	34.14	38.05	14.62
North Attleborough	$33,870	3.23	23.48	6.74	7.30	9.84
Norton	$31,433	3.79	30.19	8.53	5.14	10.66
Raynham	$33,425	1.11	27.58	8.07	6.34	12.57
Rehoboth	$37,769	3.01	25.62	8.73	10.45	11.91
Somerset	$29,597	1.80	35.33	16.22	14.50	20.75
Swansea	$32,979	2.70	30.34	17.48	11.51	16.21
Taunton	$25,945	8.92	27.89	18.41	19.59	12.87

a. Average income in 2010 dollars. b. For population ≥ 16 years. c. For population ≥ 25 years. d. Spoken at home for population ≥ 5 years.
Source: Social Explorer; United States Census Bureau.

Table 9. Criteria of Interest for Cities and Towns in Plymouth County and the Taunton River Watershed, Based on 2006-2010 American Community Survey

LOCATION	PER CAPITA INCOME[A]	% FAMILIES BELOW POVERTY	% NOT IN LABOR FORCE[B]	% LESS THAN H.S.[C]	% LANGUAGE OTHER THAN ENGLISH[D]	% AGE ≥ 65
U.S.	$27,334	10.08	35.01	14.97	20.12	12.74
Massachusetts	$33,966	7.45	32.30	11.31	21.05	13.54
Plymouth County	$33,333	5.04	30.79	8.21	11.25	13.20
Abington	$32,208	4.17	26.22	5.55	7.54	12.41
Bridgewater	$27,645	4.06	37.48	9.35	8.78	9.39
Brockton	$22,254	11.52	29.80	17.48	34.53	11.05
Carver	$28,826	2.49	29.25	10.20	2.93	14.51
East Bridgewater	$30,965	2.50	26.30	6.76	4.87	12.24
Halifax	$33,839	5.20	26.02	5.68	1.08	14.22
Hanson	$31,040	3.19	24.30	6.43	5.71	9.93
Kingston	$37,369	4.60	31.90	5.97	3.78	16.23
Lakeville	$35,371	1.73	21.78	4.59	5.36	9.00
Middleborough	$27,746	5.14	34.28	9.14	6.66	12.94
Pembroke	$33,942	2.41	23.13	5.41	4.47	10.23
Plymouth	$33,163	4.88	32.29	6.98	6.76	13.50
Plympton	$33,265	0.00	33.11	11.63	1.47	13.08
Rochester	$33,358	2.45	26.49	8.01	9.47	11.43
Rockland	$29,696	5.04	29.58	8.74	9.98	12.75
West Bridgewater	$32,111	3.14	33.13	8.81	3.73	17.62
Whitman	$30,082	6.28	26.32	6.21	8.12	10.79

a. Average income in 2010 dollars. b. For population ≥ 16 years. c. For population ≥ 25 years. d. Spoken at home for population ≥ 5 years. Source: Social Explorer; United States Census Bureau.

Of the five cities and towns highlighted in Tables 8 and 9, only three (Fall River, New Bedford and Brockton) meet all four of Massachusetts' EJ population criteria (based on the 2000 U.S. Census).[132] These communities represent an opportunity to compare, via a more in-depth analysis, those neighborhoods identified as having EJ challenges to those at risk of being socially vulnerable. The results of the in-depth, neighborhood level analysis will provide some insight regarding the need for additional outreach and assistance, in response to climate change impacts, within those neighborhoods that are socially vulnerable alone or both socially vulnerable and challenged by EJ concerns. Since Fall River and New Bedford are both a part of Bristol County, Fall River was used for the in-depth, neighborhood level analysis because a larger portion of the city is part of the Taunton River Watershed. Table 10, below, summarizes the six criteria of interest for Fall River and Brockton; these values determine which neighborhoods within each community exceed, or fall below in the case of per capita income, the values for that community and, as a result, are socially vulnerable.

Table 10. Criteria of Interest for Fall River and Brockton, Based on 2006-2010 American Community Survey

LOCATION	PER CAPITA INCOME[A]	% FAMILIES BELOW POVERTY	% NOT IN LABOR FORCE[B]	% LESS THAN H.S.[C]	% LANGUAGE OTHER THAN ENGLISH[D]	% AGE ≥ 65
Fall River	$20,337	17.78	38.59	32.45	33.47	15.30
Brockton	$22,254	11.52	29.80	17.48	34.53	11.05

a. Average income in 2010 dollars. b. For population ≥ 16 years. c. For population ≥ 25 years. d. Spoken at home for population ≥ 5 years. Source: Social Explorer; United States Census Bureau.

Maps 14 and 15 identify the neighborhoods (Census Block Groups) within Fall River and Brockton that are the most socially vulnerable, based on the six criteria of interest in this analysis. Census Block Groups that meet five or six of the six criteria are shaded in red; the specific criteria that each neighborhood meets are provided in the legend of each map. In Fall River, there are 14 Census Block Groups that meet five of the six criteria and four that meet all six criteria. These neighborhoods are primarily situated along the coast of Fall River, adjacent to the Taunton River and Mount Hope Bay, and within the Interstate 195 and Route 81 corridors. While the majority of these Census Block Groups fall outside of the Taunton River Watershed, it is important to recognize that they will still be impacted by many of the climate change vulnerabilities identified in this plan. It is also interesting to note that there is no overlap between these neighborhoods and three Census Block Groups that meet three of the four EJ population criteria; there are no Census Block Groups in Fall River that meet all four EJ population criteria. In Brockton, there are 17 neighborhoods that meet five of the six criteria and three that meet all six criteria, all of which are situated in or near the center of the city and within the Route 28 corridor. There is also very little overlap between these Census Block Groups and the eight neighborhoods that meet three or four of the four EJ population criteria; only three neighborhoods overlap.

Combining this information with 100-year and 500-year flood zone data, as well as storm surge data, provides some insight into the potentially challenging combination of socially vulnerable populations and severe climate change impacts (see Maps 16, 17 and 18). It is important to note that the flood zone and storm surge data used in this analysis do not take climate change into account. As a result, there will most certainly be more neighborhoods impacted by flooding and storm surges as the climate changes. In Fall River, there are six Census Block Groups that meet five or six of the six criteria and fall within an area identified as being prone to flooding. In addition, four Census Block Groups meeting five or six of the six criteria are situated along the western coast and as a result, are at risk to storm surge from a Category 1 through Category 4 hurricane. In Brockton, 16 of the neighborhoods that meet five of the six criteria fall within a flood-prone area; one of the three Census Block Groups that meet all six criteria does not fall within a 100-year or 500-year flood zone.

Vector-borne Diseases

One important topic that should be addressed with respect to vulnerable populations in the Taunton River Watershed, but ultimately cannot be evaluated in-depth due to confidentiality (human health records) and security (location of mosquito traps) concerns, is the occurrence of vector-borne diseases, specifically those that are transmitted by mosquitoes. The ecology, development, behavior and survival of mosquitoes, and the diseases they carry, are strongly influenced by climactic factors, such as temperature, rainfall and humidity.[133] Climate change will undoubtedly bring more favorable conditions for mosquitoes to Massachusetts, intensifying the vulnerability of certain areas of the state and making new areas more vulnerable to mosquito-spread diseases. The principle mosquito-borne viruses in Massachusetts that cause human and non-human disease are Eastern Equine Encephalitis (EEE) and West Nile Virus (WNV).

The early symptoms of the EEE virus are flu-like, including chills, headache and fever; however, as the disease progresses, mental confusion and coma usually result. The populations most susceptible to becoming severely ill are those over 50 and under 15 years of age.[134] While only a small percentage (4-5%) of humans infected with the EEE virus become severely ill, the full onset of EEE is far more severe than WNV, with a mortality rate of 30-50% and survivors often having permanent neurological problems, such as brain damage, deafness and other forms of disabilities.[135,136] Between 1964 and 2011, nearly 300 human cases of EEE were documented in the U.S.[137,138] Remarkably, Massachusetts had the second largest number of human EEE cases (38) during this time period, behind Florida, which had 70 cases.[139,140]

Most human cases of EEE in Massachusetts occur in Norfolk, Bristol and Plymouth counties, most likely because of the prevalence of wetlands in these areas, which are ideal for mosquito breeding.[141] The Massachusetts Department of Public Health routinely tests mosquitoes for EEE during the warmest months of the year. As of October 11, 2012, 260 EEE-positive mosquito pools (a collection of 10-50 mosquitoes) were detected in the state, a dramatic increase over the 80 EEE-positive mosquito pools detected in 2011.[142,143] Of the 260 EEE-positive mosquito pools, 219 (84%) were located in the Taunton River Watershed, nearly the same percentage as in 2011 (88%).[144,145] At the same point in time in 2012, seven human cases of EEE were reported, up from one human case in 2011.[146,147] The 2012 human cases were more widely distributed across the state than usual; the individuals lived in Essex (2), Franklin (1), Middlesex (1), Plymouth (2) and Worcester (1) counties.[148]

The first human case of WNV was identified in Massachusetts in 2001.[149] About 80% of human cases show no symptoms, with approximately 20% showing mild, generic symptoms like fever, fatigue and stiff neck.[150] Less than 1% of humans infected with WNV become severely ill, including encephalitis or meningitis; populations over 50 years of age are, again, at higher risk for these health outcomes and possible fatality.[151] WNV is more often fatal in some species of birds, particularly the American crow and blue jay.[152] Confirmation of WNV in dead birds frequently provides sentinel information for assessing the risk of human WNV infections.[153]

The WNV transmission cycle varies in severity from year to year; however, surveillance information indicates that WNV is established in the U.S. and virus activity is likely to occur, on some level, in Massachusetts on an annual basis.[154] WNV-positive mosquito pools are more widely distributed than EEE-positive mosquito pools across the state. As of October 11, 2012, the Massachusetts Department of Public Health detected 264 WNV-positive mosquito pools, a slight decrease over those WNV-positive mosquito pools detected in 2011 (275).[155,156] Of the 264 WNV-positive mosquito pools, 78 (30%) were located in the Taunton River Watershed, an increase over the number detected in 2011 (46 or 17%).[157,158] Also in 2012, 22 human cases of WNV were reported, a dramatic increase over the six cases reported during 2011.[159,160] None of the individuals lived in the Taunton River Watershed.[161]

A number of actions, ranging from preventative to reactive, are taken each year in order to reduce the number of human EEE and WNV cases in Massachusetts. On the preventative end of the scale, residents in high risk areas are encouraged to empty standing water from around their homes, wear long clothing, apply insect repellent containing DEET and avoid outdoor activities from dusk to dawn. Local mosquito control projects (MCPs), of which there are nine across the state, also take preventative actions, such as monitoring mosquito breeding sites and applying larvicide on an as needed basis. In addition, the MCPs maintain drainage ditches, culverts and man-made ponds to improve water quality and increase water flow, reducing the potential for mosquito breeding. On the reactive end of the scale, the MCPs spray adulticide, via hand-held or truck-mounted units, when adult mosquito populations reach intolerable levels. If the risk of an EEE or WNV outbreak becomes widespread, a state-funded aerial application of adulticide is also used to reduce the number of adult mosquitoes. In 2012, the state conducted two separate aerial sprayings, primarily over the Taunton River Watershed, in response to one of the worst threats of EEE the state has seen in three decades.[162]

"One of the main points of the study is that 'while social variables such as income and age do not determine who will be hit by a natural disaster, they do determine a population's ability to prepare, respond, and recover when disaster does strike.'"[128]

Overarching Climate Change Adaptation Strategies

In response to climate change, adaptation is a complementary approach to mitigation. While mitigation strategies generally focus on actions to reduce greenhouse gas emissions and the extent of climate change, adaptation strategies focus on actions to lessen the impact of climate change and take advantage of the changes caused by a shifting climate. Due to the uncertainties in projected climate change impacts, as well as how ecosystem services will be affected by those impacts, adaptation strategies have varying degrees of uncertainty too. So called "no regrets" strategies for climate change adaptation have evolved in response to this uncertainty. No regrets approaches to adaptation are designed to provide benefit regardless of the rate and extent of climate change. These approaches typically provide multiple benefits by addressing climate change in conjunction with other ecosystem service stressors. The following overarching adaptation recommendations for the Taunton River Watershed fit in the category of no regret strategies.

Avoid Creating Additional Adaptation Need:

- Adaptation decisions must be made within the broader framework of climate change mitigation. Failure to mitigate climate change will likely result in multiple barriers to successful adaptation, including higher costs of adaptation; more situations in which incremental adaptation measures become insufficient, requiring more extreme and disruptive adaptation measures; and, in some instances, particularly in the natural resource sector and coastal zone, all viable adaptation options could be lost.
- In landscapes that are not yet significantly developed, applying a green infrastructure approach to land use planning can reduce long-term infrastructure costs, enhance ecosystem service delivery and support transit oriented development patterns.
- Intelligently planning and siting new infrastructure in light of climate change will minimize life-cycle costs and the inadvertent creation of health and safety risks. In particular, minimizing new development in areas of increasing flood hazard will limit the extent to which tax dollars must be used to maintain the viability of poorly sited communities and infrastructure.

Keep Options Open:

- While climate models provide good, general guidance on the rate and extent of climate change, it is impossible to know how complicated social-ecological systems will respond. Therefore, it is important to keep future options open, particularly in regard to basic human needs, such as food production and water supply. For example, New England will likely become an increasingly important geographic area for food production under climate change, due to projected continued water availability and a longer growing season. Minimizing the loss of agricultural soils to development and protecting the integrity of surface and groundwater supplies will be important as climate change progresses.

Employ a Multiple Benefits Approach to Adaptation:

- Extreme limitations in fiscal and staffing resources make it possible to address only a small fraction of adaptation needs. This fact, combined with the need to simultaneously address both climate and non-climate stressors, make it necessary to prioritize adaptation actions based on the extent to which multiple management objectives can be addressed.
- Linking adaptation to pre-existing lines of work and identifying situations where adaptation will result in cost savings are important elements in transitioning from adaptation planning to implementation.

Recommended Adaptation Actions for the Taunton River Watershed

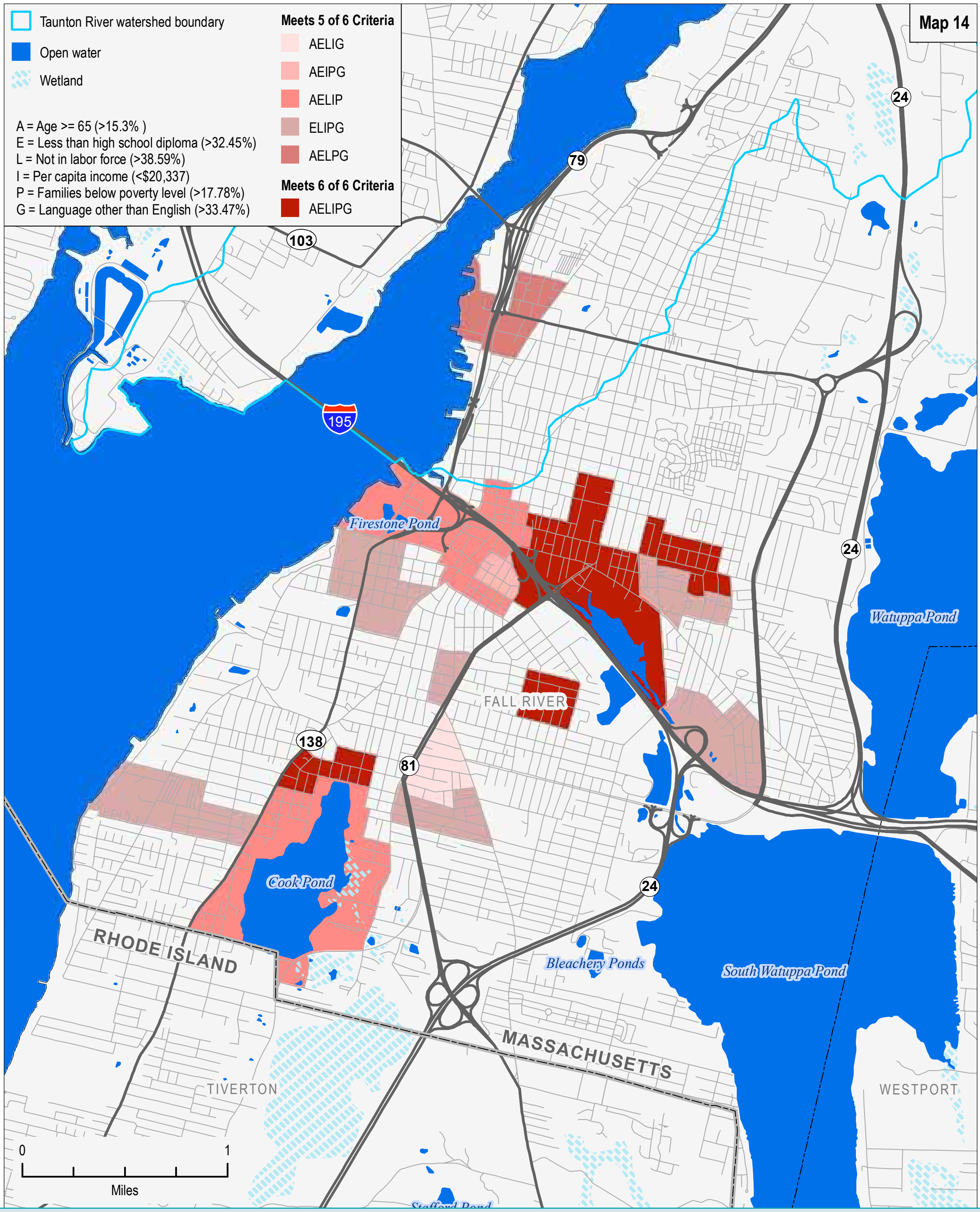
Regional and Local Green Infrastructure

- Maps 1 and 2 illustrate a green infrastructure network for the Taunton River Watershed that addresses many of the projected impacts of climate change. Map 1 identifies management areas that are important for maintaining biodiversity. Map 2 identifies management areas that are important for maintaining a balanced water budget, water quality and flood protection. Specific management recommendations include the following:

- Protecting and restoring large, contiguous habitat blocks and the corridors that connect them is an important strategy to maximize watershed resilience. The areas shown in green on Map 1 include significant habitat and areas anticipated to be important in maintaining ecosystem resiliency in response to climate change. The areas shown in yellow have geophysical properties that support high levels of biodiversity. These areas will be important refuges as the climate changes and existing species distribution patterns are disrupted. Given that much is unknown about how ecosystems will respond to rapid climate change an approach that has merit is protection of areas of high geophysical diversity. Areas of geologic and topographic diversity offer a range of habitat niches and therefore are likely to support high biodiversity as species assemblages reorganize in response to climate change. The TNC Resilient Sites approach to conservation planning is focused on the identification of areas of high geophysical diversity that will provide "the full spectrum of physical arenas that create and support species diversity".[163] The analysis, which includes both the Mid-Atlantic and New England, involved three stages. The first was the insuring that all geophysical settings present in the region are represented, the second was selecting sites that maximize resiliency, and the third was insuring connectivity among the sites.[164] The resilient sites approach is intended as a complement to more traditional methods of identifying high priority conservation areas based on existing species composition.[165] As a component of a regional green infrastructure network, areas of high geophysical diversity complement the protection of areas of important habitat under current conditions. Three of the geographic areas identified in the resilient sites study intersect the Taunton River watershed. Obviously, to have maximum benefit from a biodiversity perspective, conservation efforts within the Taunton River watershed will need to be coordinated with conservation efforts in the surrounding landscape. Maintaining and restoring natural landscapes in these areas will contribute significantly to the long-term ecosystem health of the watershed.

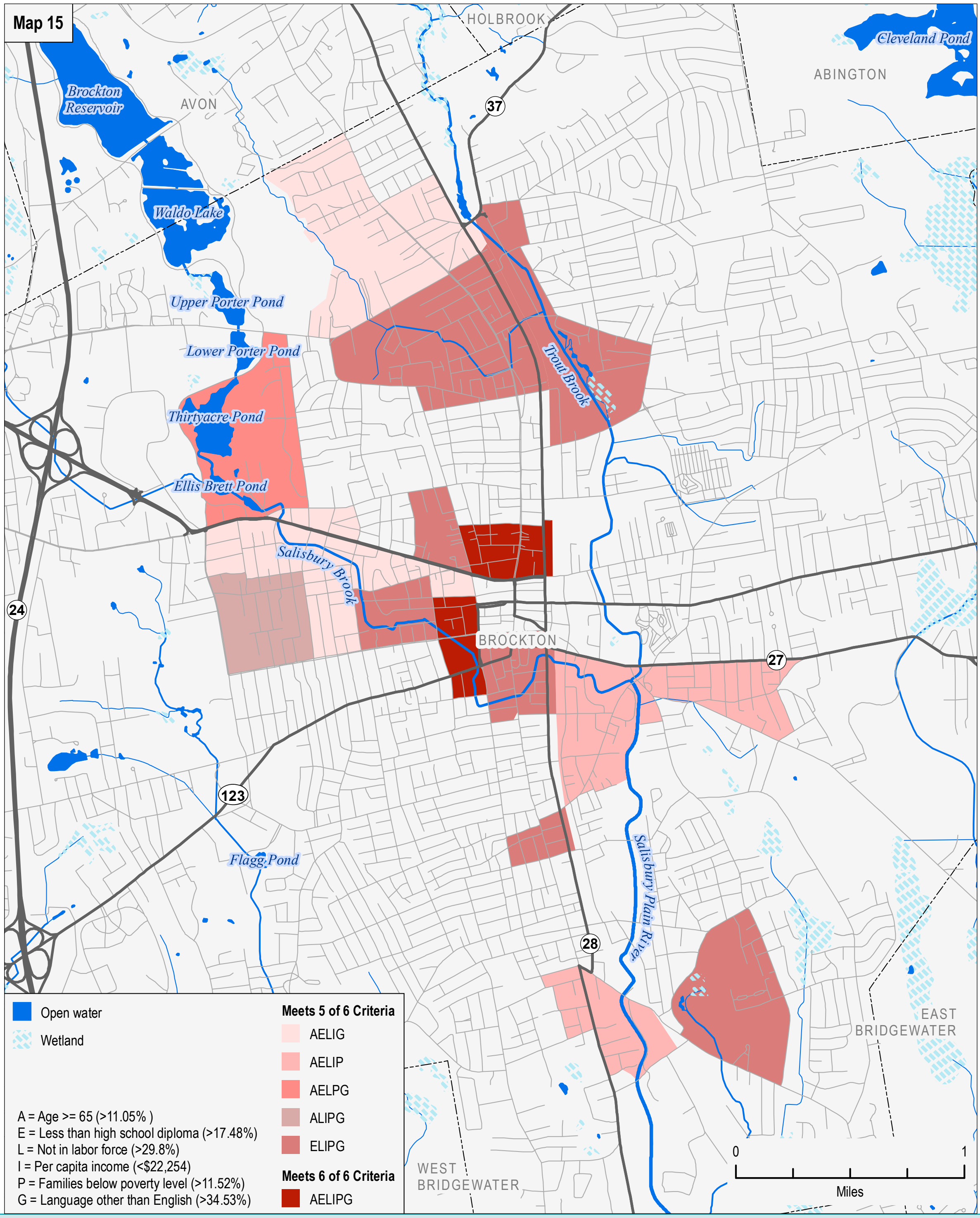
- Maintaining and enhancing the natural ability of the watershed to control and withstand flooding is among the most cost effective adaptation strategies available. Map 2 highlights areas in blue that are both vulnerable to flooding and of importance in maintaining healthy riparian systems. Maintaining and restoring natural vegetation in these areas supports biodiversity, flood control and water quality benefits. Forested riparian buffers provide multiple climate change benefits including slowing and absorbing stormwater runoff, enhancing groundwater recharge, reducing nonpoint source pollution and shading and cooling streams. On average 200 foot riparian buffers in the Taunton River watershed contain only 6.3% impervious cover, indicating a significant opportunity to keep an important green infrastructure feature in place. 43% of the sub-watersheds have 0-10% protected land in the 200 buffer indicating a significant need for protective measures.[166] Minimizing development in riparian buffers, and utilizing low impact development features when development does take place, will contribute to maximizing watershed resiliency and minimizing the tax burden associated with engineered approaches to stormwater management and flood control.

Map 14. Socially Vulnerable Neighborhoods in Fall River



Map showing socially vulnerable neighborhoods in Fall River. Vulnerability data from Plocinski (2012) combined with 2010 U.S. Census Bureau Block Groups from U.S. Census Bureau TIGER/Line dataset. Hydrography data combined from MassGIS DEP Wetlands and USGS NHD. Road and political boundary data from U.S. Census Bureau 2012 TIGER/Line dataset. Watershed boundary from NRCS WBD dataset.

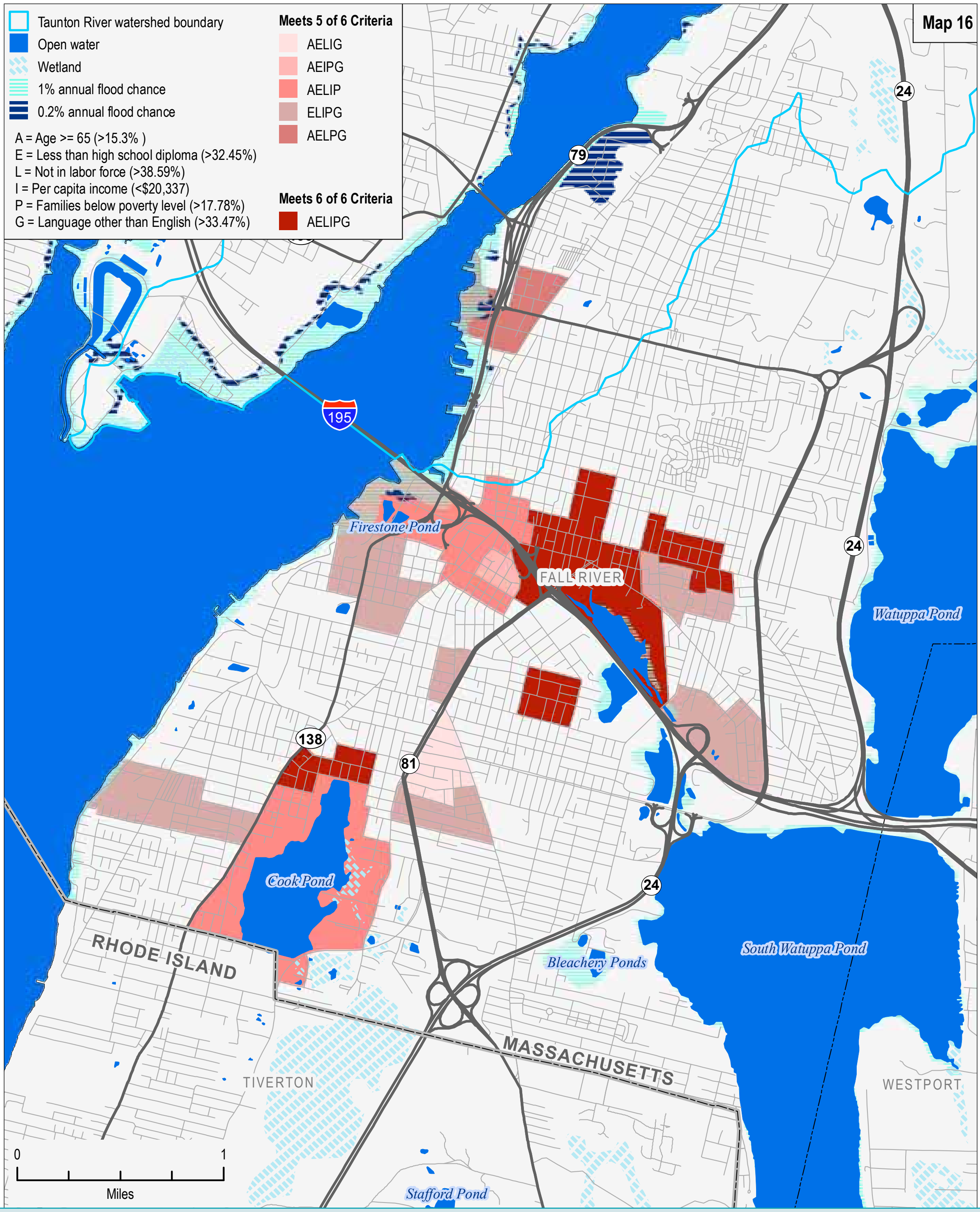
MAP 14



MAP 15

Map showing socially vulnerable neighborhoods in Brockton. Vulnerability data from Plocinski (2012) combined with 2010 U.S. Census Bureau Block Groups from U.S. Census Bureau TIGER/Line dataset. Hydrography data combined from MassGIS DEP Wetlands and USGS NHD. Road and political boundary data from U.S. Census Bureau 2012 TIGER/Line dataset. Watershed boundary from NRCS WBD dataset.

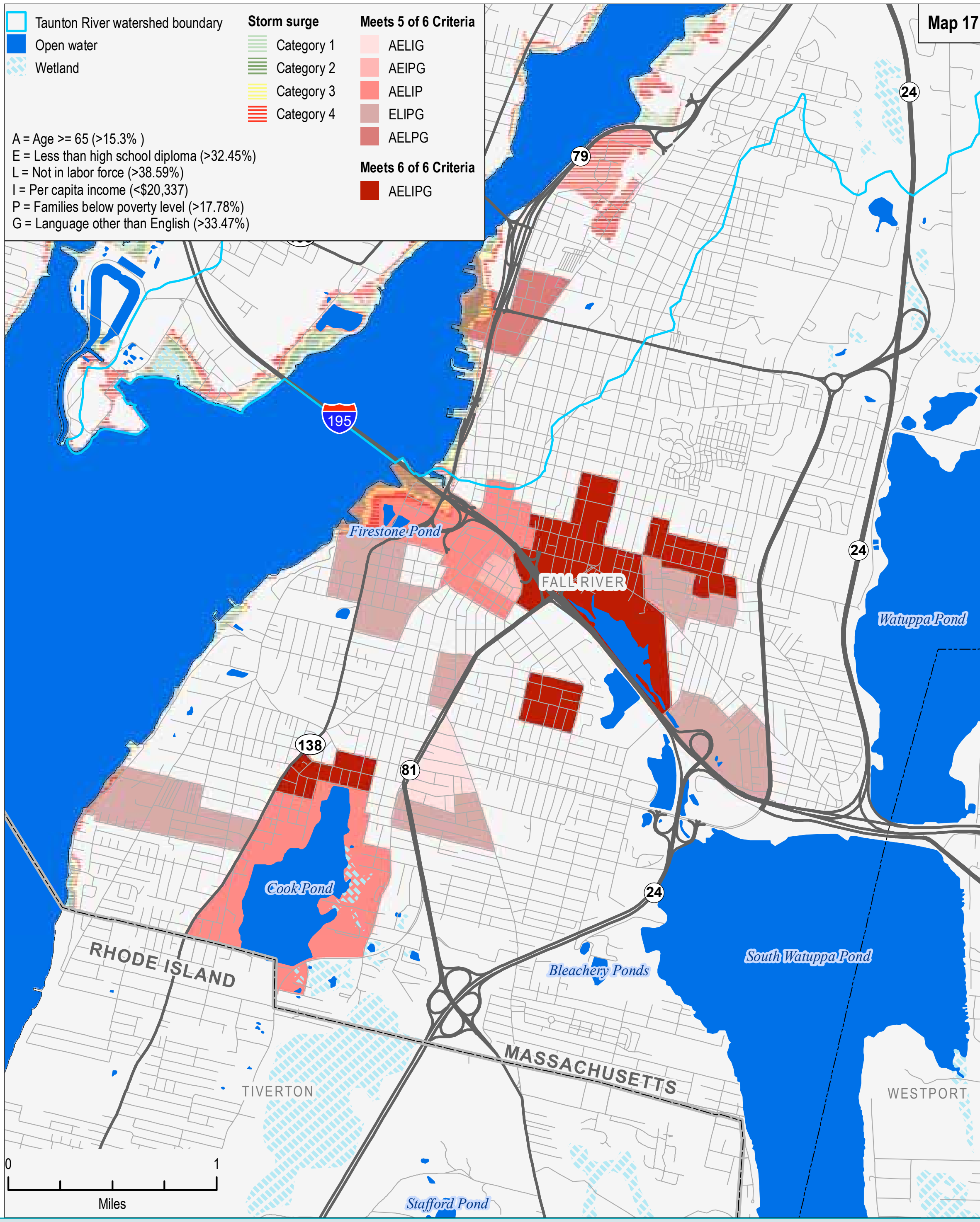
Map 16. Socially Vulnerable Neighborhoods and Annual Flood Risk in Fall River



Map showing socially vulnerable neighborhoods and annual flood risk in Fall River. Vulnerability data from Plocinski (2012) combined with 2010 U.S. Census Bureau Block Groups from U.S. Census Bureau TIGER/Line dataset. Flood risk data from MassGIS (FEMA Q3 data, updated 1997). Hydrography data combined from MassGIS DEP Wetlands and USGS NHD. Road and political boundary data from U.S. Census Bureau 2012 TIGER/Line dataset. Watershed boundary from NRCS WBD dataset.

MAP 16

Map 17. Socially Vulnerable Neighborhoods and Worst Case Storm Surge in Fall River

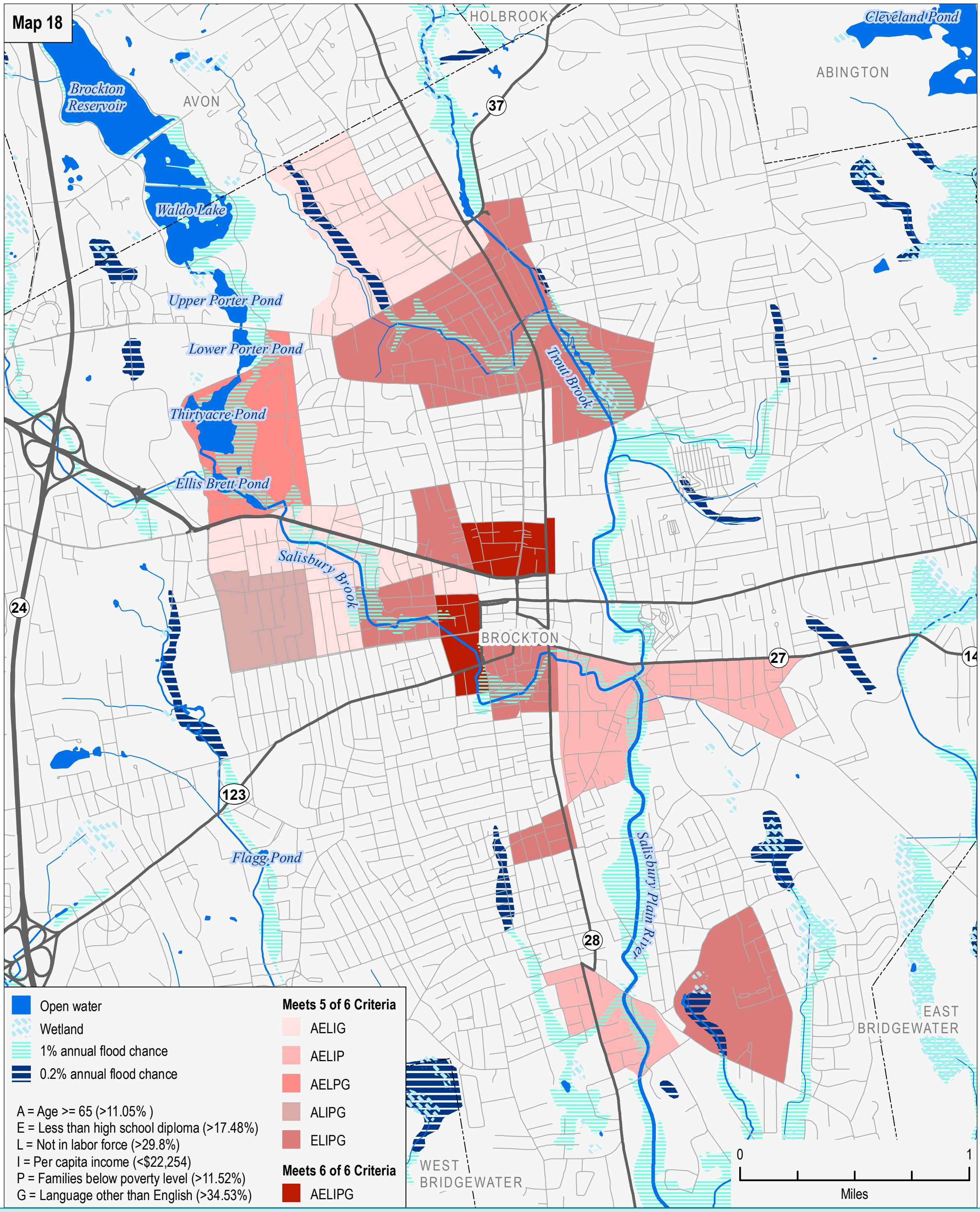


MAP 17

Map showing socially vulnerable neighborhoods and worst case storm surge in Fall River. Vulnerability data from Plocinski (2012) combined with 2010 U.S. Census Bureau Block Groups from U.S. Census Bureau TIGER/Line dataset. Hurricane surge inundation data from U.S. Army Corps of Engineers (2002). Hydrography data combined from MassGIS DEP Wetlands nd USGS NHD. Road and political boundary data from U.S. Census Bureau 2012 TIGER/Line dataset. Watershed boundary from NRCS WBD dataset.

MANOMET Center for Conservation Sciences

Map 18. Socially Vulnerable Neighborhoods and Annual Flood Risk in Brockton



Map showing socially vulnerable neighborhoods and annual flood risk in Brockton. Vulnerability data from Plocinski (2012) combined with 2010 U.S. Census Bureau Block Groups from U.S. Census Bureau TIGER/Line dataset. Flood risk data from MassGIS (FEMA Q3 data, updated 1997). Hydrography data combined from MassGIS DEP Wetlands and USGS NHD. Road and political boundary data from U.S. Census Bureau 2012 TIGER/Line dataset. Watershed boundary from NRCS WBD dataset.

MAP 18

- Urban areas are particularly vulnerable to increased flooding due to the more frequent and severe precipitation events that are occurring in conjunction with climate change. Extensive impervious surface cover combined with ageing stormwater infrastructure and combined sewer overflow issues underscore the need for stormwater management strategies that are responsive to the projected continued increase in rainfall intensity. Redevelopment opportunities should be utilized to install modern approaches to stormwater management. Map 2 includes the planned transit stops associated with the South Coast Rail project. Retrofitting these areas with a green infrastructure upgrades as redevelopment occurs is recommended as a cost effective method of both minimizing flood threat and nonpoint source water pollution.

- Climate change will likely exacerbate existing water budget problems in the Taunton River Watershed. Areas shown in yellow on Map 2 are sub-watersheds that have a water deficit as compared to natural conditions. Instituting water efficiency and reuse measures, minimizing new impervious surfaces and maximizing groundwater recharge are recommended in these areas.

- Sea level rise and storm surge flooding will be significant threats for the area that surrounds the tidal portion of the Taunton River. Map 2 highlights areas of low elevation that are subject to sea level rise and storm surge in red. Minimizing new development, flood proofing existing structures and protecting and enhancing riparian buffers in these areas are recommended.

- Climate change will further limit the viability of septic systems in the Taunton River watershed. The majority of the watershed is currently served by on-site septic systems in soils that have "severe limitations" for sewage disposal.[167] Rising water tables associated with sea level rise and increasing total precipitation limit the effectiveness of septic systems in areas with unsuitable soils and/or limited depth to water table. This phenomenon will be most pronounced in and around the areas shown in red on Map 2. Replacing existing systems that are located in unsuitable areas and updating ordinances to require systems that will remain functional in projected future conditions is recommended. Alternatives, including the establishment of public sewer systems where not currently available, should be explored.

- The climate change-related consequences for public health in the Taunton River Watershed are likely to be significant, especially for populations that are more vulnerable because of their age, socioeconomic status or pre-existing health conditions. The changing public health threat and the projected impacts on vulnerable populations should be included in state, regional and local public health and hazard mitigation planning. A green infrastructure-based approach to adaptation, including features such as urban forests will lessen urban heat island effects and air quality issues associated with climate change.

- Climate change will both open new opportunities for agriculture in the watershed and challenge existing operations with changing conditions. New England will likely become an increasingly important region of the United States for agriculture due to warming temperatures, continued water availability and the degradation of agricultural conditions in some other regions of the country. Protecting prime agricultural soils from development and employing adaptation methods, such as improving shading and cooling for livestock, installing irrigation systems and exploring opportunities for new crops, are recommended.

- The South Coast Rail project has the potential to be an important driver of land use patterns and economic development in the Taunton River Watershed. The utilization of transit oriented development approaches fits well with the recommended green infrastructure network for the watershed and could be an important element of both climate change mitigation and adaptation if new development is focused around transit stops rather than the surrounding countryside.

Agriculture

DAIRY AND LIVESTOCK

A variety of adaptation options are recommended for dairy farms in the Taunton River watershed that together can help reduce heat stress and its impacts through infrastructure changes, and alterations in diet and water supply management.[168]

- Increase the cooling capacity of existing indoor livestock areas (e.g., barns) and utilize modeled temperature projections when planning new structures - On hot days, indoor barn temperatures can be higher than ambient air temperatures in poorly ventilated structures, a more significant problem with the warming climate. Improved ventilation is a first-step adaptation strategy to address heat stress. Other potential cooling measures include the increased use of fans to improve air flow, sprinklers or misters to improve evaporative cooling; and ensuring all cows have shade in the facility.[169,170]
- Ensure adequate water availability for livestock - Check the water management system to ensure adequate water is available for livestock, especially dairy cattle, under heat stress conditions, in the barn and also while grazing. Consider the use of "nose pumps" for cattle farther away from farm facilities to essentially self-water without using additional energy or committing to new energy infrastructure. Consider increasing irrigation capacity on the farm to prepare for growing water needs of livestock as well as crops.
- Ensure adequate livestock shading in farm areas by developing a shading plan in tandem with regional agricultural support services. For example, simple structures can be built in pasture areas to provide shade.[171]
- Adjust diet and feed strategies - Changing diet and feeding management can alleviate some heat stress impacts on livestock without incurring high costs. Explore available options, which include adjusting the cattle's diet to include more easily digestible forages, or adding minerals to reduce those lost through increased sweating and respiration. Also consider techniques such as shifting feeding times to cooler parts of the day.[172,173]

CROPS

- Explore different crop varieties – Consider varieties better suited to the changing environment, and that provide higher yield with lower maintenance if possible. Over the longer term, some farms may consider diversifying with other perennial crops better suited to the changing environment.[174]
- Consider updating water management techniques – To prepare for increasing water needs of crops, farms may consider further water conservation measures for efficient water use.[175] Make appropriate investments on an as needed basis, including maintenance of current irrigation systems and addition or expansion of irrigation capacity.
- Alter harvesting schedule - Investigate benefits of altering planting or harvesting dates to take advantage of a longer growing season or avoid adverse weather affecting crops (e.g., heat stress), keeping in mind timing of market demands to maintain profitability.[176]
- Monitor for pest pressures - Farms should monitor for changing pests pressure (e.g., fungi, insects) and incorporate associated management techniques as necessary. If herbicide or pesticide use is necessary, follow best management practices and select the least harmful methods to decrease associated environmental, wildlife, and human health effects.

- Incorporate new technology and techniques to address climate change affects - This varies greatly based on the type of farming. Cranberry growers may want to update bog designs and management to accommodate increasingly heavy precipitation. Already the region has had a 67% increase in very heavy precipitation events in the last 50 years.
- Seek opportunities - The changing weather may hold some new opportunities for the region. A warmer growing season may give access to new crops that are currently not viable, and to a broader genetic base for current crops. Also, changes in national and international market structure may provide new opportunities.

CRANBERRY PRODUCTION

- Chilling Requirements: Cranberry chilling requirements will likely be met in Massachusetts during the next 50 years even under higher emission scenarios. Beyond 50 years out the A1FI emission scenario may result in insufficient chilling hours. Investigation of cranberry verities that have been developed to thrive in warmer climates is recommended.
- Frost damage: Currently in Massachusetts the chilling requirements are typically met by February. Once the chilling requirements are met a late winter/early spring warm period can cause plants to come out of dormancy ahead of the typical schedule. Once this happens the period when frost damage can occur begins. The typical approach is to irrigate the bogs and form a layer of protective ice on the plants. This approach will still be viable under climate change but the labor and costs associated with starting this process earlier in the spring season will place an additional burden on growers. Automated irrigation systems have been used successfully to both lower labor costs and save water while providing effective frost protection. Continued development and implementation of automated and remotely operated systems that are capable of monitoring and responding to temperature fluctuations is recommended.
- Scald: Cranberry Scald is a heat stress injury that occurs when plants can't transpire quickly enough to keep the fruit cool. Scald can damage the fruit on its own and can make the fruit more vulnerable to rot (fungus) damage. Preliminary studies by the UMASS Cranberry Research Station indicate that the hot, dry summer conditions that are projected to occur more frequently under climate change are a factor in scald damage. The primary adaptive response is to insure that soil moisture is sufficient prior to the onset of heat stress conditions. An additional finding is that scald damage is more prevalent in bogs with relatively young plants due to sparse vegetation that provides less shading than more mature plants.[177]
- Flooding: An increasing percentage of precipitation is projected to come in heavy downpours under climate change. Significant changes are already underway in New England with a 67% increase in very heavy precipitation events in the last 50 years. In addition total annual precipitation is projected to increase. In combination these factors will create changing water management requirements to avoid damage to crops. As bog infrastructure is updated design features to accommodate increasingly heavy precipitation events should be incorporated.
- Rot: Increasing stress associated with both scald and flooding will likely set the stage for increasing incidence of fungal damage of cranberries. Increased monitoring and herbicide use may be required to compensate.

› Changing insect pressure: Warming temperatures will increase the northern extent of some insects that are not currently a major threat in Massachusetts. For example the Gypsy Moth is currently a problem for cranberry producers in New Jersey. New England winters have historically been cold enough to kill overwintering eggs.[178] As average winter temperatures increase Gypsy Moth may become more of a problem for Massachusetts producers. Increasing total precipitation could suppress those insects such as cranberry fruitworm that are typically controlled through flooding of bogs.[179] Monitoring for changing insect pressure and incorporation of management techniques from those areas that currently have those pests is recommended.

› Productivity: Higher average summer temperatures are associated with a decrease in cranberry productivity in Massachusetts. Optimal productivity occurs when temperatures remain between 60 – 86 degrees in July and August. As previously mentioned Massachusetts growers will eventually need to investigate verities of cranberries that have been developed for warmer climates such as New Jersey.

Residential Development

Overarching Issues: New residential development in the Taunton River Watershed should be designed to anticipate warmer and wetter conditions. Specific adaptation recommendations include:

» Building Envelope: Inclusion of interior and exterior shading devices, high performance windows and insulating beyond building codes will all extend the comfort range of new homes and minimize the need for air condition use as New England warms.[180]

» Siting and Landscaping: Avoiding new construction in flood hazard areas will become increasingly important as total precipitation in New England increases. Storm water management systems should be sized for increasingly large design storms. Inclusion of low impact development features has proven to a cost effective approach to responding to heavy precipitation events in Massachusetts. Minimizing new impervious surface area and avoiding direct linkage between impervious surfaces and receiving waters will minimize nonpoint source pollution and thermal pollution of rivers and streams.

» Heating, Cooling and Lighting: Inclusion of cross ventilation and stack ventilation features will minimize air condition use and expense. Inclusion of daylighting in building design will both lessen cooling demand and increase energy efficiency.[181]

Coastal Zone: If available, utilize modeling of changing flood threat due to sea level rise. Most coastal zone areas in New England now have mapping of areas that will be inundated at different increments of sea level rise. Unfortunately, few areas have modeled the combined impacts of sea level rise and storm surge. As more sophisticated, dynamic modeling of changing storm surge threat becomes available that information should be utilized in coastal zone permitting decisions. Requiring freeboard levels that anticipate sea level rise and other flood-proofing design features such as elevating HVAC systems and designing wastewater systems to withstand flooding will minimize cost and damage associated with costal storms.

Riparian Areas: As total precipitation and extreme precipitation continue to increase the threat of freshwater flooding will grow. The development site selection process should anticipate an increasingly large floodplain and an increasing likelihood of flash flooding in riparian areas. Flood-proofing measures similar to those for the coastal zone are recommended. Maintaining riparian forest as development takes place will help to minimize flood threat, provide shade for rivers and streams and preserve the viability of cold water fish habitat.

The following tables present a variety of adaptation strategies that are appropriate for the Taunton River Watershed; they are organized by ecosystem service and identify a lead or responsible entity and additional benefits, where applicable, for each strategy.

Table 11. Adaptation Strategies for Water-related Services in the Taunton River Watershed

STRATEGY	LEAD ENTITY[A]	ADDITIONAL BENEFIT[B]
Include regional green infrastructure components in local planning and land use decisions.	Regional; Local	✓ ☺ $
Update emergency response plans to reflect projections of increasing precipitation, flooding and extreme storm events.	Regional; Local	☺ $
Integrate adaptation strategies into master, open space and other local plans to ensure long-term preparedness for climate change.	Local	☺
Continue efforts to locate and repair illegal sewer connections and non-conforming or failing septic systems.	State; Local; Private	
Modify NPDES permit guidelines, taking into consideration the most updated estimates of low streamflow.	Federal	☺
Implement water conservation strategies that minimize the need for building reservoirs and water treatment infrastructure.	Local; Non-profit; Private	✓ ☺ $
Improve communication of water demand data to the public to enhance water conservation efforts.	Local; Non-profit	☺
Update rule curves for surface water supplies to reflect climate change projections.	Local	$
Utilize climate change projections in design of new infrastructure projects. Protect existing infrastructure from increased flooding and extreme storm events; options include elevating, armoring or modifying critical infrastructure, including drinking water, wastewater and stormwater facilities and structures, with watertight doors and windows, submersible pumps, etc.	Local; Private	$
Amend zoning and building codes to account for projected climate change impacts.	Local	☺ $
Implement cost-effective stormwater management systems that use low-impact design technology and restored natural hydrology to keep stormwater on-site and, in turn, increase groundwater recharge, reduce polluted runoff and decrease flooding.	Regional; Local; Non-profit	✓ ☺ $
Take advantage of redevelopment opportunities to relocate infrastructure out of flood-prone areas.	Local; Private	☺ $
Maintain a supply of emergency equipment (e.g., mobile pumps, water tanks and filters) that can be used to temporarily supplement critically low water supplies.	Regional; Local	☺

a. Federal = United States Environmental Protection Agency; State = Massachusetts Department of Environmental Protection; Regional = regional planning agency(s); Local = Municipal government; Non-profit = Organization within the Taunton River Watershed; Private = Business or resident.

b. Adaptation strategies that also mitigate climate change (✓), are regret-free (☺) and/or offer a cost savings ($) are identified.

Table 12. Adaptation Strategies for Agriculture-related Services in the Taunton River Watershed

STRATEGY	LEAD ENTITY[A]	ADDITIONAL BENEFIT[B]
Strengthen efforts to protect active farmlands from being developed for non-agricultural purposes; include agricultural lands in a watershed-wide green infrastructure and/or transfer of development rights program as a means to this end.	State; Local; Non-profit	✓ ☺
Enhance programs and informational materials to keep the agricultural community informed about the impacts of climate change and how to adapt to the changing conditions; a cost-benefit analysis of adaptation options would be particularly valuable.	State; Educational institution; Non-profit	☺
Adopt best management practices that control pesticide, nutrient and soil runoff, which contribute to poor water quality.	Private	☺ $
Assess the major crops and livestock that are likely to be affected by climate change as well as practices that may mitigate these effects.	Federal; State; Educational institution	☺ $
Increase pest and disease monitoring efforts; by closely monitoring the occurrence of pests and diseases, and keeping records of the severity, frequency and cost of managing them over time, it will be easier to decide whether it remains economical to continue to grow a particular crop or use a certain pest-management strategy.	State; Regional; Local; Private	☺ $
Implement water conservation practices to reduce the vulnerability of crops and livestock to water supply fluctuations.	Local; Non-profit; Private	☺ $
Provide small farms with technical and financial (e.g., low- or no-cost loans) support to implement adaptation strategies, such as modifying existing infrastructure and transitioning to new crops.	Federal; State	☺
Ensure vulnerable populations have access to healthy, fresh produce; options include increasing food subsidies for lower-income residents, assisting small farms with selling produce at new markets in urban and rural areas, etc.	State; Regional	☺
Adjust planting or harvest dates to take advantage of a longer growing season or to avoid crop exposure to adverse climate impacts (e.g., heat stress and drought).	Private	$
Evaluate opportunities to alter farming practices and shift crop preferences to products better suited to greenhouse cultivation or new climate conditions; a more diversified farm will be buffered from negative climate change effects.	Educational institution; Private	☺ $

a. Federal = United States Department of Agriculture; State = Massachusetts Department of Agricultural Resources; Regional = Regional planning agency(s); Local = Municipal government; Educational institution = Agricultural extension affiliated with a public or private college or university; Non-profit = Organization within the Taunton River Watershed; Private = Grower or farmer.

b. Adaptation strategies that also mitigate climate change (✓), are regret-free (☺) and/or offer a cost savings ($) are identified.

The Economic Case for Proactive Adaptation

Strong economic arguments can be made for a proactive approach to adapting to climate change. A recent study of the potential costs and benefits of adaptation in New York found that the state's dairy and crop losses, due to climate change, are projected to range from 140 to 289 million dollars by the year 2050.[182] However, the state's agriculture-related adaptation measures are projected to cost 78 million dollars and result in benefits of 347 million dollars.[183] The study identified seven other sectors within the state, including ecosystems, transportation and public health, where the projected benefits of adaptation also far outweigh the costs.

The economic benefits of proactive adaptation efforts are further underscored when the value of ecosystem services that are not commonly represented in economic transactions are considered. The Manomet Center for Conservation Sciences recently published the results of an effort to estimate the yearly flow of ecosystem service values for Maine, a state that is both ecologically diverse and "tremendously important for its recreational and aesthetic resources."[184] On a county-level, the report estimates the total ecosystem service value to be between one million and nearly three billion dollars annually.[185] At the state-level, the yearly flow of services that stem from Maine's ecosystems is estimated to be nearly 15 billion dollars.[186] The fact that many of these services are vulnerable to climate change further tips the economic ledger in favor of a proactive response.

In recent years, the concept of green infrastructure has also emerged as an economically valuable approach to adapting to climate change. The benefits of green infrastructure range from reducing urban heat island effects and improving management of stormwater runoff, to lowering energy demand and even increasing land values by up to 30%.[187] These benefits have motivated several U.S. cities to adopt local green infrastructure solutions, regardless of the timing, extent and rate of climate change. For example, New York City recently released a Green Infrastructure Plan with the goal of reducing the city's sewer management costs by $2.4 billion over 20 years.[188] The plan estimates that every fully vegetated acre of green infrastructure within the city will provide total annual benefits of $8,522 in reduced energy demand, $166 in reduced CO2 emissions, $1,044 in improved air quality and $4,725 in increased property value.[189]

Implementation Challenges and Opportunities

Adapting to the impacts of climate change is an ongoing process. It cannot be thought of simply as a set of actions to be taken right now, although this plan does identify a several effective, short-term strategies for the Taunton River Watershed. In this sense, climate change adaptation poses enormous challenges across many areas of expertise and levels of authority. Successful adaptation involves a variety of interested partners and decision-makers: federal, state and local governments, the private sector, non-governmental organizations and community groups, as well as others.

Until recently, the federal government has focused very little on climate change adaptation. However, on October 5, 2009, President Obama signed Executive Order 13514, Federal Leadership in Environmental, Energy and Economic Performance, which requires each federal agency to "develop, implement and annually update an integrated Strategic Sustainability Performance Plan (SSPP)."[190] By June 2012, agencies must address climate change adaptation in their SSPP and be prepared to implement the related actions in fiscal year 2013.[191] Executive Order 13514 also "requires agencies to actively participate in the Interagency Climate Change Adaptation Task Force."[192] The task force has recently published the results of several initiatives, such as the National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate (October 2011) and National Fish, Wildlife and Plants Climate Adaptation Strategy (January 2012).[193]

Aside from Executive Order 13514 and the efforts of the Interagency Climate Change Adaptation Task Force, there is no clear federal coordination or national strategy for climate change adaptation. For a problem that applies to every state and community in the country and requires significant public and private investments, national coordination is essential to leveraging limited resources; avoiding redundancies and conflicts; fully understanding the changing conditions; and sharing information, ideas and lessons learned. As a result, there is a clear need for increased federal engagement in adaptation efforts. However, in the absence of federal legislation, and recognizing the importance of regional and local action, states and communities are beginning to plan and act in order to address the climate change-related impacts that will occur in the decades to come.

A number of adaptation planning and implementation activities have been initiated by states across the country, including Massachusetts. On August 7, 2008, Governor Patrick signed the Global Warming Solutions Act, which in part, created the Adaptation Advisory Committee in order to analyze strategies for adapting to climate change on a statewide scale.[194] In September 2011, Massachusetts released its Climate Change Adaptation Report, which includes climate change predictions and trends, potential impacts, vulnerabilities and adaptation strategies to increase resilience and preparedness across five broad subject areas (natural resources, infrastructure, human health, local economy and coastal zones). The report also identifies opportunities for state-based funding to support climate change adaptation at the local level, including tax-based incentives, low-interest loans and grants for communities and private landowners alike. Continued recognition of and funding for adaptation at the state level will enhance activities at the regional and local scales, further strengthening Massachusetts' ability to address climate change.

There are two regional planning agencies (RPAs) in the Taunton River Watershed: the Old Colony Planning Council and the Southeastern Regional Planning and Economic Development District. While these RPAs are sure to collaborate on specific issues within the watershed, by design, they largely function independently of one another. For example, each RPA has prepared, or is in the process of updating, its own pre-disaster mitigation plan. These plans assess the natural hazards (e.g., hurricanes, floods, blizzards, wildfires, etc.) that are likely to occur in each region and the associated vulnerabilities of residents and infrastructure. Recommendations are mitigation-based and primarily focus on reducing the number of lives lost and properties damaged, as well as minimizing disruptions to essential utilities. By having these federally approved plans in place, the communities within each region are eligible for federal grants under the Hazard Mitigation Grant Program, Flood Mitigation Assistance Program, Pre-Disaster Mitigation Grant Program and Severe Repetitive Loss Grant Program.

It is clear that pre-disaster mitigation plans are a benefit to the cities and towns in the Taunton River Watershed, especially in light of the changing climate; however, a parallel focus, at the regional level, on climate change adaptation would be of benefit. The RPAs serve as a critical, and often underutilized, link between state and local political entities. In this sense, the RPAs are often more aware of opportunities for leveraging resources and collaborating in order to make certain initiatives more cost-effective. In terms of climate change adaptation, there is a real opportunity for the RPAs to work with and provide incentives for communities to integrate adaptation strategies into their master, open space and other local plans in order to ensure that they are prepared for climate change in the long-term.

Although federal, state and regional action is essential, many important decisions about how to best manage the ecosystem services that will be impacted by climate change are made at the local level. For example, cities and towns are empowered, via the “Home Rule Amendment” of the Massachusetts Constitution, to adopt certain statutes like the Right to Farm By-Law, which promotes local agriculture and agriculture-based economic opportunities.[195] In addition, the Right to Farm By-Law “protects farmlands within a [community] by allowing agricultural uses and related activities to function with minimal conflict with abutters and [local] agencies.”[196] Cities and towns also have authority over land use planning decisions, including zoning and building codes, as well as some transportation infrastructure. In 2005, the Taunton Wild & Scenic River Study Committee identified several local zoning tools, such as wetlands and historic districts, and zoning by-laws, such as transfer of development rights, that appear to be underutilized among a sample of ten watershed communities.[197] The presence of a lead-by-example community, ideally one that has adopted a variety of tools and by-laws, can play a key role in mobilizing adaptation efforts in the watershed by providing leadership in education, outreach, best management practices and fundraising.

Conclusion

Adapting to a changing climate will be challenging in the Taunton River Watershed due to the diversity of its natural resources and residents. The main drivers of climate change impacts, higher temperatures, changes in precipitation and sea level rise, will have a wide variety of effects on the watershed’s ecosystem services. Climate change will bring both opportunities and constraints, while other stressors, such as population growth, will create new challenges. The adaptation strategies presented in this plan offer an opportunity to implement cost effective solutions in order to protect ecosystem service delivery in the watershed. By drawing on the relevant experience, know-how and other valuable resources at the regional and local levels, including collaborative opportunities to establish watershed-wide planning and regulatory tools, there is considerable hope that the necessary actions will be implemented, creating a more resilient watershed.

Notes

1. Massachusetts Office of Geographic Information, *NRCS SSURGO-Certified Soils* (2010), accessed December 10, 2011, http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/soi.html.
2. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan: Taunton River Wild & Scenic River Study* (2005), 4, accessed September 28, 2011, http://www.tauntonriver.org/stewarshipplan.htm.
3. "Taunton River Receives National Designation," Taunton River Stewardship Council, accessed December 17, 2011, http://tauntonriver.org/taunton%20gazette.pdf.
4. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 4.
5. Ibid.
6. "Ecology," Taunton River Stewardship Council, accessed June 23, 2012, http://www.tauntonriver.org/ecology.htm.
7. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 4.
8. Horsley Witten Group, Inc., *Taunton River Watershed Management Plan Phase I: Data and Assessment – Final Report* (2008), 1-3, accessed September 28, 2011, http://www.horsleywitten.com/tauntonwatershed/TauntonRiver-WS-finalreport.html.
9. "ACEC Designations," Commonwealth of Massachusetts, accessed December 17, 2011, http://www.mass.gov/dcr/stewardship/acec/acecs.htm.
10. "ACEC Designations – Three Mile River Watershed," Commonwealth of Massachusetts, accessed December 17, 2011, http://www.mass.gov/dcr/stewardship/acec/acecs/l-thrmil.htm.
11. Massachusetts Office of Geographic Information, *Land Use (2005)* (2009), accessed December 17, 2011, http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/lus2005.html.
12. United States Department of Agriculture, *2007 Census of Agriculture: Plymouth County Massachusetts* (2011), accessed December 17, 2011, http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/Massachusetts/cp25023.pdf.
13. United States Department of Agriculture, *2007 Census of Agriculture: Bristol County Massachusetts* (2011), accessed December 17, 2011, http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/Massachusetts/cp25005.pdf.
14. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 5.
15. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 43.
16. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 44.
17. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 45.
18. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 47.
19. Ibid.
20. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 71.
21. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 59.
22. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 60.
23. GeoSyntec Consultants, *Five-Year Watershed Action Plan for the Taunton River Watershed* (2006), 32, accessed September 28, 2011, http://www.horsleywitten.com/tauntonwatershed/Documents/Taunton%20River%20Watershed%205-Year%20Action%20Plan%20FINAL%20DRAFT.pdf.
24. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 60.
25. Ibid.
26. Ibid.
27. GeoSyntec Consultants, *Five-Year Watershed Action Plan*, 12.
28. "Housing and Economic Development – Southeast," Commonwealth of Massachusetts, accessed December 10, 2011, http://www.mass.gov/hed/economic/profiles/southeast.html.
29. "Mapping & Monitoring – Landcover Change in SE Massachusetts," Woods Hole Research Center, accessed December 10, 2011, http://www.whrc.org/mapping/semass/landcover.html.
30. Horsley Witten Group, Inc., *Taunton River Watershed Management Plan Phase I*, 1-3.
31. Massachusetts Water Resources Commission, *Stressed Basins in Massachusetts* (2001), 2, accessed December 18, 2011, http://www.mass.gov/eea/docs/eea/wrc/stressed-basins.pdf.
32. Massachusetts Water Resources Commission, *Stressed Basins in Massachusetts*, 4.
33. Southeastern Regional Planning & Economic Development District, *Towards a More Competitive Southeastern Massachusetts: Comprehensive Economic Development Strategy* (2011), 1, accessed July 14, 2012, http://www.srpedd.org/econ_devel/documents/CEDSFinalReport.pdf.
34. "Labor Force Statistics and Unemployment Rates for each City or Town by Area," Commonwealth of Massachusetts, accessed July 14, 2012, http://lmi2.detma.org/lmi/LAUS_town_index.asp.
35. Southeastern Regional Planning & Economic Development District, *Towards a More Competitive Southeastern Massachusetts*, 4.

36. Ibid.

37. Massachusetts Executive Office of Environmental Affairs, *Environmental Justice Policy of the Executive Office of Environmental Affairs* (2002), 2, accessed March 24, 2012, http://www.mass.gov/eea/docs/eea/ej/ej-policy-english.pdf.

38. Ibid.

39. Massachusetts Executive Office of Environmental Affairs, *Environmental Justice Policy*, 12.

40. Massachusetts Executive Office of Environmental Affairs, *Environmental Justice Policy*, 5.

41. Ibid.

42. Massachusetts Executive Office of Energy and Environmental Affairs, *Cities and Towns that Include Environmental Justice Communities* (2012), 1, accessed July 14, 2012, http://www.mass.gov/anf/docs/itd/services/massgis/ej-cities-towns.pdf.

43. Massachusetts Executive Office of Energy and Environmental Affairs, *Cities and Towns that Include Environmental Justice Communities*, 1-3.

44. "Taunton River Watershed Project," Bridgewater State University, accessed December 17, 2011, http://vc.bridgew.edu/taunton_riv.

45. Katharine Hayhoe et al., "Past and Future Changes in Climate and Hydrological Indicators in the U.S. Northeast," *Climate Dynamics* (2007), http://www.northeastclimateimpacts.org/pdf/tech/hayhoe_et_al_climate_dynamics_2006.pdf.

46. Thomas Karl et al., *Weather and climate extremes in a changing climate, Regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*, 2008, http://purl.access.gpo.gov/GPO/LPS110676.

47. Susan Spierre and Camron Wake, *Trends in Extreme Precipitation Events for the Northeastern United States 1948-2007* (Carbon Solutions New England, 2010), http://www.cleanair- coolplanet.org/cpc/documents/2010neprecip.pdf.

48. Hayhoe et al., "Past and Future Changes in Climate and Hydrological Indicators in the U.S. Northeast."

49. Ibid.

50. *Sea-Level Change Considerations for Civil Works Programs* (U.S Army Corps of Engineers, October 2011).

51. Ibid.

52. Asbury Sallenger, Kara S. Doran, and Peter A. Howd, "Hotspot of Accelerated Sea-level Rise on the Atlantic Coast of North America," *Nature Climate Change* (2012), doi:10.1038/nclimate1597.

53. Tebaldi C, Strauss B.H, and Zervas C.E, "Modelling sea level rise impacts on storm surges along US coasts," *Environ.Res.Lett. Environmental Research Letters 7*, no. 1 (2012).

54. Karl et al., *Weather and climate extremes in a changing climate regions of focus*.

55. Ibid.

56. Ibid.

57. Ibid.

58. Ibid.

59. Ibid.

60. Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: A Framework for Assessment* (Washington, DC: Island Press, 2003), 57, accessed January 2, 2012, http://www.maweb.org/en/Framework.aspx.

61. Millennium Ecosystem Assessment, *Ecosystems and Human Well-being*, 27.

62. Millennium Ecosystem Assessment, *Ecosystems and Human Well-being*, 26-27.

63. TEEB, *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB* (2010), 7, accessed September 8, 2012, http://www.teebweb.org/Portals/25/TEEB%20 Synthesis/TEEB_SynthReport_09_2010_online.pdf.

64. Michael Holtzman, "Combined Sewer Overflow System Not Designed to Handle 'Intense' Storms," *The Herald News,* August 16, 2012, accessed August 29, 2012, http://www.heraldnews.com/news/x2038877250/Combined-Sewer-Overflow-system-not-designed-to-handle-intense-storms.

65. Ibid.

66. Amy Littlefield, "Taunton River Still Causing Trouble," *Enterprise News*, March 23, 2010, accessed January 21, 2012, http://www.enterprisenews.com/news/x126578423/Taunton-River-still-causing-trouble.

67. Peter Howe, "Crews Begin to Repair Mount Hope Avenue in Fall River, Mass.," *NECN*, March 31, 2010, accessed August 4, 2012, http://www.necn.com/03/31/10/Crews-begin-to-repair-Mount-Hope-Avenue-/landing.html?blockID=207710&feedID=4215.

68. Rebecca Hyman, "Flood of Memories One Year Later in a Still Recovering Raynham," *Taunton Daily Gazette*, April 27, 2011, accessed January 21, 2012, http://www.tauntongazette.com/news/x655243099/Flood-of-memories-one-year-later-in-a-still-recovering-Raynham.

69. Kevin McGarigal et al., *Critical Linkages Phase 1: Assessing Connectivity Restoration Potential for Culvert Replacement, Dam Removal and Construction of Wildlife Passage Structures in Massachusetts* (Amherst, MA: University of Massachusetts Amherst, 2012), accessed November 12, 2012, http://masscaps.org/pdf/Critical-Linkages-Phase-1-Report-Final.pdf.

70. "Riverways Program – RIFLS – 7Q10 Factsheet," Commonwealth of Massachusetts, accessed January 29, 2012, http://www.mass.gov/dfwele/der/riverways/programs/rifls/lf_7q10.htm.

MANOMET Center for Conservation Sciences

71. "Hurricane Bob," National Oceanic and Atmospheric Administration, accessed January 21, 2012, http://www.erh.noaa.gov/box/hurricane/hurricaneBob.shtml.

72. Ibid.

73. Ibid.

74. Ibid.

75. Massachusetts Department of Environmental Protection, *Taunton River Watershed 2001 Water Quality Assessment Report* (2001), 13, accessed February 4, 2012, http://www.mass.gov/dep/water/resources/62wqar1.pdf.

76. Ibid.

77. Massachusetts Executive Office of Environmental Affairs, *Water Assets Study: Regional Summary Report for the Taunton River Watershed* (2006), 11-21, accessed February 4, 2012, http://www.mass.gov/mgis/waterassetsBasins/Water_Assets_Regional_Report_Taunton.pdf.

78. Massachusetts Executive Office of Environmental Affairs, *Water Assets Study*, 11-12.

79. Massachusetts Executive Office of Environmental Affairs, *Water Assets Study*, 11-35.

80. Edward B. Colby, "Brockton Accused of Killing Kingston's Water Wildlife," *Enterprise News*, July 17, 2008, accessed February 4, 2012, http://www.enterprisenews.com/homepage/x1816442166/Environmental-groups-to-sue-over-Brockton-water-use.

81. Vicki-Ann Downing, "Brockton's Main Water Supply Down 72 Inches," *Enterprise News*, December 7, 2007, accessed February 4, 2012, http://www.enterprisenews.com/news/x919867707.

82. Vicki-Ann Downing, "Brockton Councilor Brophy Seeking Answers about Desalination Plant," *Patriot Ledger,* August 23, 2011, accessed February 4, 2012, http://www.patriotledger.com/news/x865769381/Brockton-Councilor-Brophy-seeking-answers-about-Aquaria-plant.

83. Amy Littlefield, "Brockton Pays $4 Million for Mostly Unused Water," Patriot Ledger, May 21, 2010, accessed February 4, 2012, http://www.patriotledger.com/news/x258108000/Brockton-pays-4-million-for-mostly-unused-water.

84. Downing, "Brockton Councilor Brophy."

85. Littlefield, "Brockton Pays $4 Million."

86. Downing, "Brockton Councilor Brophy."

87. Massachusetts Executive Office of Environmental Affairs, *Water Assets Study*, 11-2.

88. Gerry Tuoti, "Assawompset Pond Dams to Remain Open as Long as Possible," *Taunton Daily Gazette*, December 7, 2011, accessed February 4, 2012, http://www.tauntongazette.com/dcover/x1626871956/Assawompset-Pond-dams-to-remain-open-as-long-as-possible.

89. Massachusetts Executive Office of Environmental Affairs, *Water Assets Study*, 11-16.

90. Ibid.

91. Ibid.

92. Jeffrey D. Wagner, "Interim Plan will be Devised to Lesson Pond Flooding Risk in Freetown," *The Herald News*, July 21, 2010, accessed February 4, 2012, http://www.heraldnews.com/news/x1882860601/Interim-plan-will-be-devised-to-lessen-pond-flooding-risk-in-Freetown.

93. Ibid.

94. Tuoti, "Assawompset Pond Dams."

95. Wagner, "Interim Plan."

96. bid.

97. Horsley Witten Group, Inc., *Taunton River Watershed Management Plan Phase I*, 4-32.

98. Ibid.

99. Ibid.

100. Ibid.

101. Ibid.

102. Horsley Witten Group, Inc., *Taunton River Watershed Management Plan Phase I,* 4-33.

103. Ibid.

104. Ibid.

105. Ibid.

106. John P. Masterson and Donald A. Walter, *Hydrogeology and Groundwater Resources of the Coastal Aquifers of Southeastern Massachusetts – U.S. Geological Survey Circular 1338* (Reston, VA: U.S. Geological Survey, 2009), accessed October 15, 2012, http://pubs.usgs.gov/circ/circ1338/pdf/circular%202009-1338_508.pdf.

107. Masterson and Walter, *Hydrogeology and Groundwater Resources*.

108. Gary W. Evans and Elyse Kantrowitz, "Socioeconomic Status and Health: the Potential Role of Environmental Risk Exposure," *Annual Review of Public Health 23* (2002): 308.

109. United States Department of Agriculture, *2007 Census of Agriculture: Plymouth County Massachusetts*.

110. United States Department of Agriculture, *2007 Census of Agriculture: Bristol County Massachusetts*.

111. Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts Climate Change Adaptation Report* (2011), 91, accessed September 28, 2011, http://www.mass.gov/eea/air-water-climate-change/climate-change/climate-change-adaptation-report.html.

112. David W. Wolfe et al., "Projected Change in Climate Thresholds in the Northeastern U.S.: Implications for Crops, Pests, Livestock, and Farmers," *Mitigation and Adaptation Strategies for Global Change* 13 (2008): 565.

113. Wolfe et al., "Projected Change in Climate Thresholds," 564.

114. Ibid.

115. Kohji Yamamura and Keizi Kiritani, "A Simple Method to Estimate the Potential Increase in the Number of Generations under Global Warming in Temperate Zones," *Applied Entomology and Zoology* 33, no. 2 (1998): 295.

116. Wolfe et al., "Projected Change in Climate Thresholds," 561.

117. "Cooperative Extension: Cranberries – Grower Services: Umbrella Bloom," University of Maine, accessed February 25, 2012, http://umaine.edu/cranberries/grower-services/umbrella-bloom.

118. "UMass Cranberry Station – How Cranberries Grow," University of Massachusetts Amherst, accessed February 25, 2012, http://www.umass.edu/cranberry/cropinfo/howgrow.html.

119. "Cooperative Extension: Cranberries – Grower Services: Umbrella Bloom."

120. "UMass Cranberry Station – How Cranberries Grow."

121. "Vegetable Program – Late Blight," University of Massachusetts Amherst, accessed February 25, 2012, http://extension.umass.edu/vegetable/diseases/tomato-late-blight.

122. Bina Venkataraman, "Late Blight Yields Bitter Harvest," *The Boston Globe*, July 31, 2009, accessed February 25, 2012, http://www.boston.com/news/local/massachusetts/articles/2009/07/31/disease_that_spawned_irelands_potato_famine_hits_new_england.

123. Ibid.

124. "Vegetable Program – Late Blight."

125. Susan L. Cutter, Bryan J. Boruff and W. Lynn Shirley, "Social Vulnerability to Environmental Hazards," *Social Science Quarterly* 84, no. 2 (2003): 244.

126. Ibid.

127. Ibid.

128. Cutter et al., "Social Vulnerability," 245-252.

129. Oxfam America, Inc., *Exposed: Social Vulnerability and Climate Change in the US Southeast* (2009), 2, accessed March 24, 2012, http://adapt.oxfamamerica.org/resources/Exposed_Report.pdf.

130. Kathleen G. Gundry and Thomas A. Heberlein, "Research Report: Do Public Meetings Represent the Public?," Journal of the American Planning Association 50, no. 2 (1984): 175.

131. Massachusetts Executive Office of Environmental Affairs, *Environmental Justice Policy,* 5.

132. Massachusetts Executive Office of Energy and Environmental Affairs, *Cities and Towns that Include Environmental Justice Communities*, 1-3.

133. Paul Reiter, "Climate Change and Mosquito-Borne Disease," *Environmental Health Perspectives* 109, no. 1 (2001): 142.

134. "Eastern Equine Encephalitis," Centers for Disease Control and Prevention, accessed March 24, 2012, http://www.cdc.gov/EasternEquineEncephalitis/tech/epi.html.

135. Massachusetts Department of Public Health, *2012 Massachusetts Arbovirus Surveillance and Response Plan* (2012), 3, accessed October 13, 2012, http://www.mass.gov/eohhs/docs/dph/cdc/arbovirus/arbovirus-surveillance-plan.pdf.

136. "Eastern Equine Encephalitis."

137. Ibid.

138. "Eastern Equine Encephalitis – Human – 2011," United States Geological Survey, accessed October 13, 2012, http://diseasemaps.usgs.gov/2011/eee_us_human.html.

139. "Eastern Equine Encephalitis."

140. "Eastern Equine Encephalitis – Human – 2011."

141. Massachusetts Department of Public Health, *2012 Massachusetts Arbovirus Surveillance and Response Plan*, 4.

Manomet Center for Conservation Sciences

142. Massachusetts Department of Public Health, *Arbovirus Mosquito Surveillance Program 2011 Test Report* (2011), 2-8, accessed October 13, 2012, http://www.mass.gov/eohhs/provider/reporting-to-state/state-lab/infectious-disease/arbovirus.

143. "Massachusetts Arbovirus Surveillance – Mosquitoes," Massachusetts Department of Public Health, accessed October 13, 2012, http://westnile.ashtonweb.com/index2.asp.

144. Massachusetts Department of Public Health, *Arbovirus Mosquito Surveillance Program 2011 Test Report*, 2-8.

145. "Massachusetts Arbovirus Surveillance – Mosquitoes."

146. Ibid.

147. "Eastern Equine Encephalitis – Human – 2011."

148. "Massachusetts Arbovirus Surveillance – Mosquitoes."

149. Massachusetts Department of Public Health, *2012 Massachusetts Arbovirus Surveillance and Response Plan*, 3.

150. Massachusetts Department of Public Health, *2012 Massachusetts Arbovirus Surveillance and Response Plan*, 5.

151. Ibid.

152. Ibid.

153. Ibid.

154. Massachusetts Department of Public Health, *2012 Massachusetts Arbovirus Surveillance and Response Plan*, 6.

155. Massachusetts Department of Public Health, *Arbovirus Mosquito Surveillance Program 2011 Test Report,* 2-8.

156. "Massachusetts Arbovirus Surveillance – Mosquitoes."

157. Massachusetts Department of Public Health, *Arbovirus Mosquito Surveillance Program 2011 Test Report*, 2-8.

158. "Massachusetts Arbovirus Surveillance – Mosquitoes."

159. Ibid.

160. "West Nile Virus – Human – 2011," United States Geological Survey, accessed October 13, 2012, http://diseasemaps.usgs.gov/2011/wnv_us_human.html.

161. "Massachusetts Arbovirus Surveillance – Mosquitoes."

162. Marc Larocque, "Greater Taunton Prepares for Second Aerial Spraying to Combat EEE," *Taunton Daily Gazette*, August 10, 2012, accessed October 13, 2012, http://www.tauntongazette.com/news/x442234538/Greater-Taunton-prepares-for-second-aerial-spraying-to-combat-EEE.

163. Mark Anderson, Mellissa Clark, and Arlene Sheldon, *Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region* (The Nature Conservancy, January 2012).

164. Ibid.

165. Ibid.

166. *Taunton River Watershed Management Plan, Phase I: Data and Assessment* (Horsley Witten Group, Inc., December 2008).

167. *Taunton River Watershed Management Plan, Phase I: Data and Assessment* (Horsley Witten Group, Inc., December 2008).

168. Wolfe, D.W., et al. 2008. "Projected change in climate thresholds in the Northeastern U.S.: Implications for crops, pests, livestock, and farmers." Mitigation and Adaptation Strategies for Global Change13:555–575.

169. Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.). 2011. Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York. www.nyserda.ny.gov.

170. Chase, L. (2005). Climate Change Impacts on Dairy Cattle. Department of Animal Science, Cornell University. Climate Change of Agriculture: Promoting Practical and Profitable Responses. Fact Sheet. Accessed at www.climateandfarming.org/pdfs/FactSheets/III.3Cattle.pdf on 03.27.13.

171. Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.). 2011. Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York. www.nyserda.ny.gov.

172. Chase, L. (2005). Climate Change Impacts on Dairy Cattle. Department of Animal Science, Cornell University. Climate Change of Agriculture: Promoting Practical and Profitable Responses. Fact Sheet. Accessed at www.climateandfarming.org/pdfs/FactSheets/III.3Cattle.pdf on 03.27.13.

173. Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.). 2011. Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York. www.nyserda.ny.gov.

174. Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.). 2011. Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York. www.nyserda.ny.gov.

MANOMET Center for Conservation Sciences

175. Jacobson, G.L., I.J. Fernandez, P.A. Mayewski, and C.V. Schmitt (editors). 2009. Maine's Climate Future: An Initial Assessment. Orono, ME: University of Maine. http://www.climatechange.umaine.edu/mainesclimatefuture.

176. Wolfe, D.W., L. Ziska, C. Petzoldt, A. Seaman, L. Chase and K. Hayhoe. 2008. "Projected change in climate thresholds in the Northeastern U.S.: Implications for crops, pests, livestock, and farmers." Mitigation and Adaptation Strategies for Global Change 13:555–575.

177. Ibid.

178. *Crop Profile for Cranberries in New Jersey* (NSF Center for IPM, November 2003), http://www.ipmcenters.org/cropprofiles/docs/njcranberries.html.

179. Curtis Petzoldt and Abby Seaman, *Climate Change and Agriculture: Promiting Practical and Profitable Responses. Climate Change Effects on Insects and Pathogens* (New York State IPM Program, n.d.).

180. Larissa Larsen, *Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions* (University of Michigan and U.S. Green Building Conucil, 2011).

181. Ibid.

182. Cynthia Rosenzweig et al. eds., *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation – Technical Report* (Albany, NY: New York State Energy Research and Development Authority, 2011), Annex III 9, accessed December 21, 2011, http://nyserda.ny.gov/Publications/Research-and-Development/Environmental/EMEP-Publications/~/media/Files/Publications/Research/Environmental/EMEP/climaid/11-18-response-to-climate-change-in-nys.ashx.

183. Ibid.

184. Austin Troy, *Valuing Maine's Natural Capital* (2012), 4, accessed November 8, 2012, http://www.manomet.org/sites/manomet.org/files/reports/Troy_2012_Value_of_Maine.pdf.

185. Troy, *Valuing Maine's Natural Capital*, 20.

186. Troy, *Valuing Maine's Natural Capital*, 27.

187. Josh Foster, Ashley Lowe and Steve Winkelman, *The Value of Green Infrastructure for Urban Climate Adaptation* (Washington, D.C.: Center for Clean Air Policy, 2011), 4, accessed October 16, 2012, http://www.ccap.org/green_infrastructure.html.

188. Foster et al., *The Value of Green Infrastructure*, A5.

189. Ibid.

190. Center for Climate and Energy Solutions, *Climate Change Adaptation: What Federal Agencies Are Doing – February 2012 Update* (2012), 5, accessed March 17, 2012, http://www.c2es.org/docUploads/federal-agencies-adaptation.pdf.

191. Ibid.

192. Ibid.

193. Center for Climate and Energy Solutions, *Climate Change Adaptation*, 6.

194. Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts Climate Change Adaptation Report*, 1.

195. "Right to Farm By-Law," Commonwealth of Massachusetts, accessed March 17, 2012, http://www.mass.gov/agr/righttofarm/index.htm.

196. Ibid.

197. Taunton Wild & Scenic River Study Committee, *Taunton River Stewardship Plan*, 97-102.

MANOMET
Center for Conservation Sciences

Bibliography

A Anderson, Mark G. and Charles E. Ferree. "Conserving the Stage: Climate Change and the Geophysical Underpinnings of Species Diversity." *PLoS ONE* 5, no. 7 (2010): e11554. Accessed June 7, 2012. doi:10.1371/journal.pone.0011554.

B Bridgewater State University. "Taunton River Watershed Project." Accessed December 17, 2011. http://vc.bridgew.edu/taunton_riv.

C Center for Climate and Energy Solutions. *Climate Change Adaptation: What Federal Agencies Are Doing – February 2012 Update.* 2012. Accessed March 17, 2012. http://www.c2es.org/docUploads/federal-agencies-adaptation.pdf.

Centers for Disease Control and Prevention. "Eastern Equine Encephalitis." Accessed March 24, 2012. http://www.cdc.gov/EasternEquineEncephalitis/tech/epi.html.

Colby, Edward B. "Brockton Accused of Killing Kingston's Water Wildlife." *Enterprise News*, July 17, 2008. Accessed February 4, 2012. http://www.enterprisenews.com/homepage/x1816442166/Environmental-groups-to-sue-over-Brockton-water-use.

Commonwealth of Massachusetts. "ACEC Designations." Accessed December 17, 2011. http://www.mass.gov/dcr/stewardship/acec/acecs.htm.

Commonwealth of Massachusetts. "ACEC Designations – Three Mile River Watershed." Accessed December 17, 2011. http://www.mass.gov/dcr/stewardship/acec/acecs/l-thrmil.htm.

Commonwealth of Massachusetts. "Housing and Economic Development – Southeast." Accessed December 10, 2011. http://www.mass.gov/hed/economic/profiles/southeast.html.

Commonwealth of Massachusetts. "Labor Force Statistics and Unemployment Rates for each City or Town by Area." Accessed July 14, 2012. http://lmi2.detma.org/lmi/LAUS_town_index.asp.

Commonwealth of Massachusetts. "Right to Farm By-Law." Accessed March 17, 2012. http://www.mass.gov/agr/righttofarm/index.htm.

Commonwealth of Massachusetts. "Riverways Program – RIFLS – 7Q10 Factsheet." Accessed January 29, 2012. http://www.mass.gov/dfwele/der/riverways/programs/rifls/lf_7q10.htm.

Cutter, Susan L., Bryan J. Boruff and W. Lynn Shirley. "Social Vulnerability to Environmental Hazards." Social Science Quarterly 84, no. 2 (2003): 242-261.

D Downing, Vicki-Ann. "Brockton Councilor Brophy Seeking Answers about Desalination Plant." *Patriot Ledger*, August 23, 2011. Accessed February 4, 2012. http://www.patriotledger.com/news/x865769381/Brockton-Councilor-Brophy-seeking-answers-about-Aquaria-plant.

Downing, Vicki-Ann. "Brockton's Main Water Supply Down 72 Inches." *Enterprise News*, December 7, 2007. Accessed February 4, 2012. http://www.enterprisenews.com/news/x919867707.

E Evans, Gary W. and Elyse Kantrowitz. "Socioeconomic Status and Health: the Potential Role of Environmental Risk Exposure." *Annual Review of Public Health* 23 (2002): 303-331.

F Foster, Josh, Ashley Lowe and Steve Winkelman. *The Value of Green Infrastructure for Urban Climate Adaptation.* Washington, D.C.: Center for Clean Air Policy, 2011. Accessed October 16, 2012. http://www.ccap.org/green_infrastructure.html.

Frumhoff, Peter C., James J. McCarthy, Jerry M. Melillo, Susanne C. Moser and Donald J. Wuebbles. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions – A report of the Northeast Climate Impacts Assessment.* Cambridge, MA: Union of Concerned Scientists, 2007. Accessed September 28, 2011. http://www.climatechoices.org/assets/documents/climatechoices/confronting-climate-change-in-the-u-s-northeast.pdf.

G GeoSyntec Consultants. *Five-Year Watershed Action Plan for the Taunton River Watershed.* 2006. Accessed September 28, 2011. http://www.horsleywitten.com/tauntonwatershed/Documents/Taunton%20River%20Watershed%205-Year%20Action%20Plan%20FINAL%20DRAFT.pdf.

Gundry, Kathleen G. and Thomas A. Heberlein. "Research Report: Do Public Meetings Represent the Public?" *Journal of the American Planning Association* 50, no. 2 (1984): 175-182.

H Hayhoe, Katharine, Cameron P. Wake, Thomas G. Huntington, Lifeng Luo, Mark D. Schwartz, Justin Sheffield, Eric Wood, Bruce Anderson, James Bradbury, Art Degaetano, Tara J. Troy and David Wolfe. "Past and Future Changes in Climate and Hydrological Indicators in the U.S. Northeast." *Climate Dynamics* 28 (2006): 381-407.

Hayhoe, Katharine, Camron Wake, Thomas Huntington, L Luo, M Schwartz, J Sheffeild, E Wood, et al. "Past and Future Changes in Climate and Hydrological Indicators in the U.S. Northeast." *Climate Dynamics* (2007). http://www.northeastclimateimpacts.org/pdf/tech/hayhoe_et_al_climate_dynamics_2006.pdf.

Holtzman, Michael. "Combined Sewer Overflow System Not Designed to Handle 'Intense' Storms." *The Herald News*, August 16, 2012. Accessed August 29, 2012. http://www.heraldnews.com/news/x2038877250/Combined-Sewer-Overflow-system-not-designed-to-handle-intense-storms.

Horsley Witten Group, Inc. *Taunton River Watershed Management Plan Phase I: Data and Assessment – Final Report.* 2008. Accessed September 28, 2011. http://www.horsleywitten.com/tauntonwatershed/TauntonRiver-WS-finalreport.html.

Horsley Witten Group, Inc. *Taunton River Watershed Management Plan Phase II: Example Code Reform and Demonstration Projects. Final Report.* 2011. Accessed September 28, 2011. http://www.horsleywitten.com/tauntonwatershed/TauntonRiver-WS-finalreport-phase-2.html.

Howe, Peter. "Crews Begin to Repair Mount Hope Avenue in Fall River, Mass." NECN, March 31, 2010. Accessed August 4, 2012.

http://www.necn.com/03/31/10/Crews-begin-to-repair-Mount-Hope-Avenue-/landing.html?blockID=207710&feedID=4215.

Hyman, Rebecca. "Flood of Memories One Year Later in a Still Recovering Raynham." *Taunton Daily Gazette,* April 27, 2011. Accessed January 21, 2012. http://www.tauntongazette.com/news/x655243099/Flood-of-memories-one-year-later-in-a-still-recovering-Raynham.

I Intergovernmental Panel on Climate Change. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Susan Solomon, Dahe Qin, Martin Manning, Zhenlin Chen, Melinda Marquis, Kristen B. Averyt, Melinda M.B. Tignor and Henry LeRoy Miller, Jr. Cambridge, United Kingdom and New York, NY: Cambridge University Press, 2007. Accessed September 28, 2011. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html.

K Karl, Thomas, United States. National Oceanic and Atmospheric Administration, United States. Dept. of Energy, Climate Change Science Program (U.S.), and National Science and Technology Council (U.S.). Subcommittee on Global Change Research. *Weather and climate extremes in a changing climate, Regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*, 2008. http://purl.access.gpo.gov/GPO/LPS110676.

L Larocque, Marc. "Greater Taunton Prepares for Second Aerial Spraying to Combat EEE." *Taunton Daily Gazette*, August 10, 2012. Accessed October 13, 2012. http://www.tauntongazette.com/news/x442234538/Greater-Taunton-prepares-for-second-aerial-spraying-to-combat-EEE.

Littlefield, Amy. "Brockton Pays $4 Million for Mostly Unused Water." *Patriot Ledger*, May 21, 2010. Accessed February 4, 2012. http://www.patriotledger.com/news/x258108000/Brockton-pays-4-million-for-mostly-unused-water.

Littlefield, Amy. "Taunton River Still Causing Trouble." *Enterprise News,* March 23, 2010. Accessed January 21, 2012. http://www.enterprisenews.com/news/x126578423/Taunton-River-still-causing-trouble.

Louis, Valérie R., Estelle Russek-Cohen, Nipa Choopun, Irma N. G. Rivera, Brian Gangle, Sunny C. Jiang, Andrea Rubin, Jonathan A. Patz, Anwar Huq and Rita R. Colwell. "Predictability of Vibrio cholerae in Chesapeake Bay." *Applied and Environmental Microbiology* 69, no. 5 (2003): 2773-2785.

M Massachusetts Department of Environmental Protection. *Final Pathogen TMDL for the Taunton River Watershed June 2011*. 2011. Accessed September 28, 2011. http://www.mass.gov/dep/water/resources/taunton1.pdf.

Massachusetts Department of Environmental Protection. *Taunton River Watershed 2001 Water Quality Assessment Report.* 2001. Accessed February 4, 2012. http://www.mass.gov/dep/water/resources/62wqar1.pdf.

Massachusetts Department of Public Health. *2012 Massachusetts Arbovirus Surveillance and Response Plan.* 2012. Accessed October 13, 2012. http://www.mass.gov/eohhs/docs/dph/cdc/arbovirus/arbovirus-surveillance-plan.pdf.

Massachusetts Department of Public Health. *Arbovirus Mosquito Surveillance Program 2011 Test Report.* 2011. Accessed October 13, 2012. http://www.mass.gov/eohhs/provider/reporting-to-state/state-lab/infectious-disease/arbovirus.

Massachusetts Department of Public Health. "Massachusetts Arbovirus Surveillance – Mosquitoes." Accessed October 13, 2012. http://westnile.ashtonweb.com/index2.asp.

Massachusetts Executive Office of Energy and Environmental Affairs. *Cities and Towns that Include Environmental Justice Communities.* 2012. Accessed July 14, 2012. http://www.mass.gov/anf/docs/itd/services/massgis/ej-cities-towns.pdf.

Massachusetts Executive Office of Energy and Environmental Affairs. *Massachusetts Climate Change Adaptation Report.* 2011. Accessed September 28, 2011. http://www.mass.gov/eea/air-water-climate-change/climate-change/climate-change-adaptation-report.html.

Massachusetts Executive Office of Environmental Affairs. *Environmental Justice Policy of the Executive Office of Environmental Affairs.* 2002. Accessed March 24, 2012. http://www.mass.gov/eea/docs/eea/ej/ej-policy-english.pdf.

Massachusetts Executive Office of Environmental Affairs. *Water Assets Study: Regional Summary Report for the Taunton River Watershed.* 2006. Accessed February 4, 2012. http://www.mass.gov/mgis/waterassetsBasins/Water_Assets_Regional_Report_Taunton.pdf.

Massachusetts Office of Geographic Information. *Land Use (2005).* 2009. Accessed December 17, 2011. http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/lus2005.html.

Massachusetts Office of Geographic Information. *NRCS SSURGO-Certified Soils.* 2010. Accessed December 10, 2011. http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/soi.html.

Massachusetts Water Resources Commission. *Stressed Basins in Massachusetts.* 2001. Accessed December 18, 2011. http://www.mass.gov/eea/docs/eea/wrc/stressed-basins.pdf.

Masterson, John P. *Simulated Interaction between Freshwater and Saltwater and Effects of Ground-water Pumping and Sea-level Change, Lower Cape Cod Aquifer System, Massachusetts – U.S. Geological Survey Scientific Investigations Report 2004-5014.* Northborough, MA: U.S. Geological Survey, 2004. Accessed October 15, 2012. http://pubs.usgs.gov/sir/2004/5014.

Masterson, John P. and Donald A. Walter. *Hydrogeology and Groundwater Resources of the Coastal Aquifers of Southeastern Massachusetts – U.S. Geological Survey Circular 1338.* Reston, VA: U.S. Geological Survey, 2009. Accessed October 15, 2012. http://pubs.usgs.gov/circ/circ1338/pdf/circular%202009-1338_508.pdf.

Masterson, John P., Carl S. Carlson and Donald A. Walter. *Hydrogeology and Simulation of Groundwater Flow in the Plymouth-Carver-Kingston-Duxbury Aquifer System, Southeastern Massachusetts – U.S. Geological Survey Scientific Investigations Report 2009–5063.* Northborough, MA: U.S. Geological Survey, 2009. Accessed October 15, 2012. http://pubs.usgs.gov/sir/2009/5063.

McGarigal, Kevin, Bradley W. Compton, Scott D. Jackson, Ethan Plunkett and Eduard Ene. *Critical Linkages Phase 1: Assessing Connectivity Restoration Potential for Culvert Replacement, Dam Removal and Construction of Wildlife Passage Structures in Massachusetts.* Amherst, MA: University of Massachusetts Amherst, 2012. Accessed November 12, 2012. http://masscaps.org/pdf/Critical-Linkages-Phase-1-Report-Final.pdf.

Millennium Ecosystem Assessment. *Ecosystems and Human Well-being: A Framework for Assessment.* Washington, DC: Island Press, 2003. Accessed January 2, 2012. http://www.maweb.org/en/Framework.aspx.

N National Oceanic and Atmospheric Administration. "Hurricane Bob." Accessed January 21, 2012. http://www.erh.noaa.gov/box/hurricane/hurricaneBob.shtml.

O Oxfam America, Inc. Exposed: *Social Vulnerability and Climate Change in the US Southeast.* 2009. Accessed March 24, 2012. http://adapt.oxfamamerica.org/resources/Exposed_Report.pdf.

P Pielke, Roger A., Jr. and Mary W. Downton. "Precipitation and Damaging Floods: Trends in the United States, 1932-97." *Journal of Climate* 13 (2000): 3625-3637.

R Reiter, Paul. "Climate Change and Mosquito-Borne Disease." *Environmental Health Perspectives* 109, no. 1 (2001): 141-161.

Rosenzweig, Cynthia, William Solecki, Arthur DeGaetano, Megan O'Grady, Susan Hassol and Paul Grabhorn, eds. *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report.* Albany, NY: New York State Energy Research and Development Authority, 2011. Accessed December 21, 2011. http://nyserda.ny.gov/Publications/Research-and-Development/Environmental/EMEP-Publications/~/media/Files/Publications/Research/Environmental/EMEP/climaid/11-18-response-to-climate-change-in-nys.ashx.

S Sallenger, Asbury H., Jr., Kara S. Doran and Peter A. Howd. "Hotspot of Accelerated Sea-level Rise on the Atlantic Coast of North America." *Nature Climate Change* (2012). Accessed July 7, 2012. doi:10.1038/nclimate1597.

Sallenger, Asbury, Kara S. Doran, and Peter A. Howd. "Hotspot of Accelerated Sea-level Rise on the Atlantic Coast of North America." *Nature Climate Change* (2012). doi:10.1038/nclimate1597.

Social Explorer. "Demographic Reports of the United States 1790 to the Present." Accessed August 5, 2012. http://www.socialexplorer.com/pub/ReportData/home.aspx.

Southeastern Regional Planning & Economic Development District. *Towards a More Competitive Southeastern Massachusetts: Comprehensive Economic Development Strategy.* 2011. Accessed July 14, 2012. http://www.srpedd.org/econ_devel/documents/CEDSFinalReport.pdf.

Spierre, Susan, and Camron Wake. Trends in Extreme Precipitation Events for the Northeastern United States 1948- 2007. Carbon Solutions New England, 2010. http://www.cleanair- coolplanet.org/cpc/documents/2010neprecip.pdf.

T Taunton River Stewardship Council. "Taunton River Receives National Designation." Accessed December 17, 2011. http://tauntonriver.org/taunton%20gazette.pdf.

Taunton River Stewardship Council. "Ecology." Accessed June 23, 2012. http://www.tauntonriver.org/ecology.htm.

Taunton Wild & Scenic River Study Committee. *Taunton River Stewardship Plan: Taunton River Wild & Scenic River Study.* 2005. Accessed September 28, 2011. http://www.tauntonriver.org/stewarshipplan.htm.

Tebaldi C, Strauss B.H, and Zervas C.E. "Modelling sea level rise impacts on storm surges along US coasts." Environ.Res.Lett. Environmental Research Letters 7, no. 1 (2012). *Sea-Level Change Considerations for Civil Works Programs.* U.S Army Corps of Engineers, October 2011.

TEEB. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB.* 2010. Accessed September 8, 2012. http://www.teebweb.org/Portals/25/TEEB%20Synthesis/TEEB_SynthReport_09_2010_online.pdf.

Troy, Austin. *Valuing Maine's Natural Capital.* 2012. Accessed November 8, 2012. http://www.manomet.org/sites/manomet.org/files/reports/Troy_2012_Value_of_Maine.pdf.

Tuoti, Gerry. "Assawompset Pond Dams to Remain Open as Long as Possible." *Taunton Daily Gazette*, December 7, 2011. Accessed February 4, 2012. http://www.tauntongazette.com/dcover/x1626871956/Assawompset-Pond-dams-to-remain-open-as-long-as-possible.

U United States Census Bureau. *Labor Force Statistics.* 2012. Accessed August 5, 2012. http://www.census.gov/hhes/www/laborfor/acs_employ.html.

United States Department of Agriculture. *2007 Census of Agriculture: Bristol County Massachusetts.* 2011. Accessed December 17, 2011. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/Massachusetts/cp25005.pdf.

United States Department of Agriculture. *2007 Census of Agriculture: Plymouth County Massachusetts.* 2011. Accessed December 17, 2011. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/Massachusetts/cp25023.pdf.

United States Environmental Protection Agency. "Massachusetts Final-issuance Individual Facility Permits." Accessed January 29, 2012. http://www.epa.gov/region1/npdes/permits_listing_ma.html.

United States Geological Survey. "Eastern Equine Encephalitis – Human – 2011." Accessed October 13, 2012. http://diseasemaps.usgs.gov/2011/eee_us_human.html.

United States Geological Survey. "West Nile Virus – Human – 2011." Accessed October 13, 2012. http://diseasemaps.usgs.gov/2011/wnv_us_human.html.

University of Maine. "Cooperative Extension: Cranberries – Grower Services: Umbrella Bloom." Accessed February 25, 2012. http://umaine.edu/cranberries/grower-services/umbrella-bloom.

University of Massachusetts Amherst. "UMass Cranberry Station – How Cranberries Grow." Accessed February 25, 2012. http://www.umass.edu/cranberry/cropinfo/howgrow.html.

University of Massachusetts Amherst. "Vegetable Program – Late Blight." Accessed February 25, 2012. http://extension.umass.edu/vegetable/diseases/tomato-late-blight.

University of Massachusetts Boston. *An Action Plan for the Taunton River Watershed: Assessment and Recommendations.* 1992. Accessed September 28, 2011. http://www.horsleywitten.com/tauntonwatershed/Documents/An%20Action%20Plan%20for%20the%20Taunton%20River%20Watershed%201992.pdf.

V Venkataraman, Bina. "Late Blight Yields Bitter Harvest." *The Boston Globe*, July 31, 2009. Accessed February 25, 2012. http://www.boston.com/news/local/massachusetts/articles/2009/07/31/disease_that_spawned_irelands_potato_famine_hits_new_england.

Vergara, Olga (Environmental Protection Specialist, EPA). Interview by L. Plocinski. Telephone. Boston, MA, March 13, 2012.

W Wagner, Jeffrey D. "Interim Plan will be Devised to Lesson Pond Flooding Risk in Freetown." *The Herald News*, July 21, 2010. Accessed February 4, 2012. http://www.heraldnews.com/news/x1882860601/Interim-plan-will-be-devised-to-lessen-pond-flooding-risk-in-Freetown.

Wolfe, David W., Lewis Ziska, Curt Petzoldt, Abby Seaman, Larry Chase and Katharine Hayhoe. "Projected Change in Climate Thresholds in the Northeastern U.S.: Implications for Crops, Pests, Livestock, and Farmers." *Mitigation and Adaptation Strategies for Global Change* 13 (2008): 555-575.

Woods Hole Research Center. "Mapping & Monitoring – Landcover Change in SE Massachusetts." Accessed December 10, 2011. http://www.whrc.org/mapping/semass/landcover.html.

Y Yamamura, Kohji and Keizi Kiritani. "A Simple Method to Estimate the Potential Increase in the Number of Generations under Global Warming in Temperate Zones." *Applied Entomology and Zoology* 33, no. 2 (1998): 289-298.

Yin, Jianjun, Michael E. Schlesinger and Ronald J. Stouffer. "Model Projections of Rapid Sea-level Rise on the Northeast Coast of the United States." *Nature Geoscience* 2, no. 4 (2009): 262-266.

Z Zarriello, Phillip J. and Gardner C. Bent. *Elevation of the March-April 2010 Flood High Water in Selected River Reaches in Central and Eastern Massachusetts – U.S. Geological Survey Open-File Report 2010–1315.* Reston, VA: U.S. Geological Survey, 2011. http://pubs.usgs.gov/ofr/2010/1315 (accessed January 21, 2012).

125 Manomet Point Road
Plymouth, MA 02360
www.manomet.org

MANOMET
Center for Conservation Sciences