MOVING FROM VULNERABILITY TO RESILIENCE: A CLIMATE CHANGE ADAPTATION PLAN FOR THE TAUNTON RIVER WATERSHED

A thesis

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ABSTRACT

Ecosystems generate a variety of goods and services, collectively called ecosystem services, that sustain and fulfill 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 climate and non-climate stressors, vulnerabilities and equity and environmental justice issues. Economic data, where readily available, are also presented in order to contextualize the value of the selected ecosystem services and the impact, in terms of financial gains and losses, of healthy and impaired ecosystems in the watershed. Adaptation recommendations are included in order to increase the resilience of the river, and the physical resources that are connected to it, in light of the changing social, physical and environmental conditions in the watershed.

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The Taunton River Watershed has long been recognized for its rich cultural, ecological, agricultural and recreational resources. The river itself is directly tied to early contact between Native People and English settlers; many examples of early industrial, water-based innovation, such as weirs, millworks and transportation, can still be seen along the river and its tributaries today. The Taunton River is also extraordinarily wild; its corridor contains a mix of large woodland areas filled with predominantly native and some globally rare species, vast tidal and non-tidal wetlands and just over 77 square miles of prime farmland (Massachusetts Office of Geographic Information 2010*a*). These features contribute to the scenic quality of a variety of recreational opportunities that are available throughout the watershed, including hiking, bird watching, paddling, swimming and fishing.

There are three major challenges facing the Taunton River Watershed in the 21st century. The first two, population growth and the associated development, have received increased attention in recent years. The population of southeastern Massachusetts, including the Taunton River Watershed, continues to grow at almost twice the rate of the state average according to the 2010 U.S. Census and all indications are that trend will continue (Commonwealth of Massachusetts 2011*a*). As a result of this growth, approximately 40% of the agricultural lands in the region have been lost since 1971 (Woods Hole Research Center 2011). There has also been more than a 60% increase in residential, industrial and commercial properties since that time (Woods Hole Research Center 2011). Adding to this growth pressure on southeastern Massachusetts are a series of multi-million dollar transportation improvement projects, including rail line extensions and the expansion of Routes 3, 24 and 44.

The third major challenge facing the Taunton River Watershed is climate change. In Massachusetts, changes in climate are already being observed. Ambient temperatures have increased by approximately 1.8°F since 1970 and sea surface temperatures have increased by 2.3°F between 1970 and 2002 (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 1). These warming trends are linked to other observed changes, including a rise in sea level of nearly nine inches between 1921 and 2006, more frequent days with temperatures above 90°F, reduced snowpack and earlier snow melt and spring peak flows (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 1). By the end of the 21st century, Massachusetts is predicted to experience even more drastic seasonal changes in both temperature and precipitation.

In order to avoid the most severe effects of climate change over the long-term, greenhouse gas emissions must be reduced. Any delay of action in the form of mitigation strategies (e.g., regulatory standards and tradable permits) not only makes reducing emissions more costly and disruptive, it also increases the need to plan and implement measures to limit the adverse impacts of climate change. These measures, or adaptation strategies, can take many forms, such as updating infrastructure to accommodate larger, more severe storms; restoring forests and wetlands to improve resiliency; and modifying agricultural practices to accommodate warmer temperatures and changing precipitation patterns. The goal of this plan is develop adaptation strategies for the Taunton River Watershed that increase the resilience of the river, and the physical resources that are connected to it, in light of the changing social, physical and environmental conditions in the region.

The Taunton River is one of the most diverse and intact coastal riverine ecosystems in New England. It is home to a wide variety of flora and fauna, including several globally rare species and habitats. The river is also the longest, undammed coastal waterway in the region and was recently designated as a National Wild & Scenic River (Taunton Wild & Scenic River Study Committee 2005, 4; Taunton River Stewardship Council 2011). 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 (Taunton Wild & Scenic River Study Committee 2005, 4). The Taunton River is tidally influenced for 18 miles from this point; saltwater intrusion ends at or near the Dighton-Taunton line (Taunton Wild & Scenic River Study Committee 2005, 4).

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 Figure 1; Taunton Wild & Scenic River Study Committee 2005, 4; Horsley Witten Group, Inc. 2008, 1-3). 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 (Commonwealth of Massachusetts 2011*b*). Together, these three ACECs represent the second largest contiguous area to receive this special state designation (Commonwealth of Massachusetts 2011*c*). 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 (Massachusetts Office of Geographic Information 2009*a*). Current commodities include fruits and vegetables, nursery products, milk and other dairy products, as well as fish and

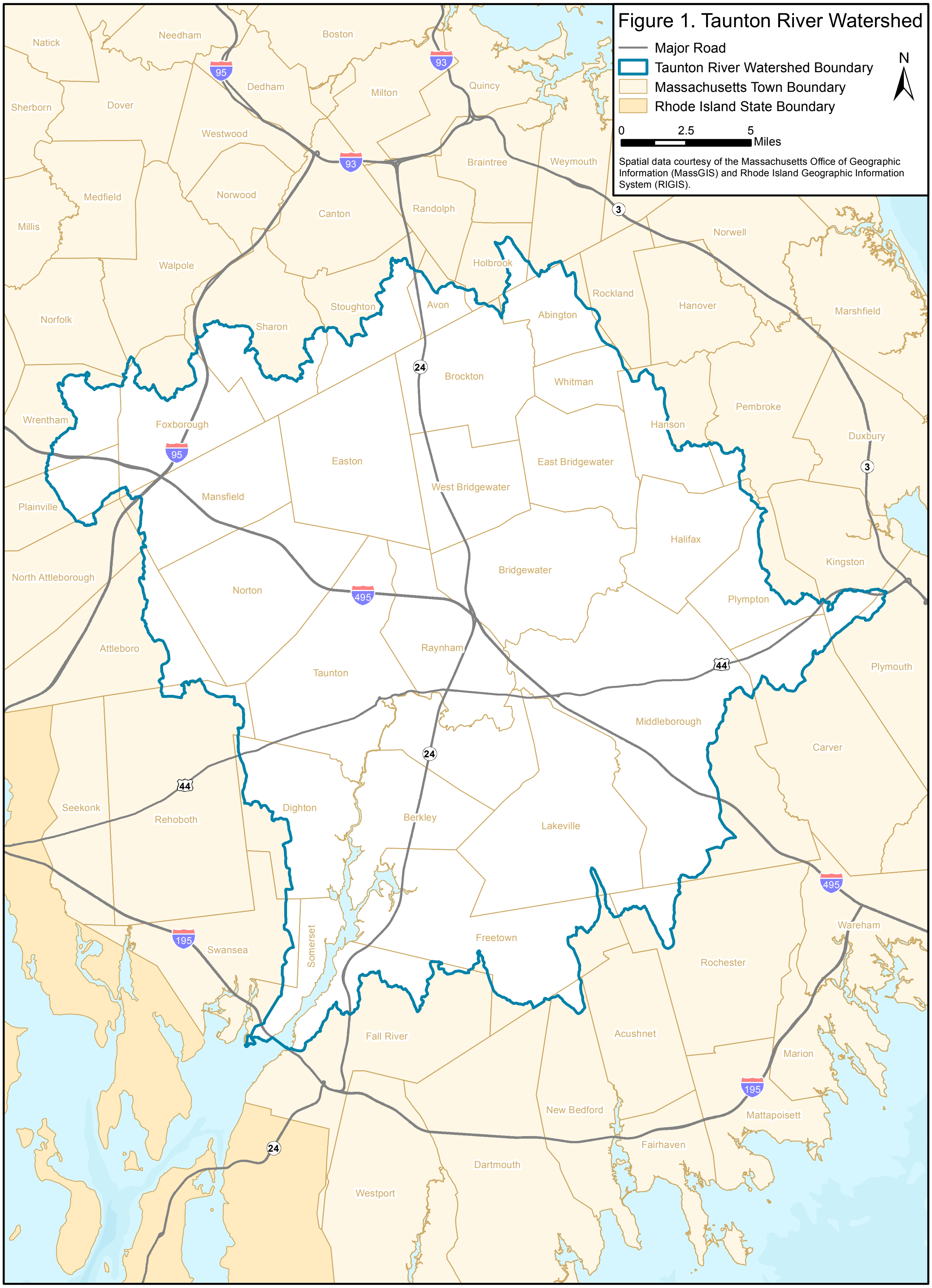


Figure 1. Taunton River Watershed
Major Road
Taunton River Watershed Boundary
Massachusetts Town Boundary
Rhode Island State Boundary
N
0
2.5
5
Miles
Spatial data courtesy of the Massachusetts Office of Geographic Information (MassGIS) and Rhode Island Geographic Information System (RIGIS).
Natick
Needham
Boston
Quincy
Sherborn
Dover
Dedham
Milton
Westwood
Braintree
Weymouth
Medfield
Norwood
Millis
Canton
Randolph
Norwell
Walpole
Holbrook
Rockland
Hanover
Marshfield
Stoughton
Avon
Abington
Norfolk
Sharon
Brockton
Whitman
Pembroke
Wrentham
Foxborough
Hanson
Duxbury
Easton
East Bridgewater
West Bridgewater
Mansfield
Plainville
Halifax
Kingston
Bridgewater
North Attleborough
Norton
Plympton
Raynham
Attleboro
Plymouth
Taunton
Middleborough
Carver
Seekonk
Dighton
Rehoboth
Berkley
Lakeville
Wareham
Freetown
Swansea
Somerset
Rochester
Fall River
Acushnet
Marion
New Bedford
Mattapoisett
Fairhaven
Dartmouth
Westport
95
93
3
24
495
44
195

shellfish (United States Department of Agriculture 2011*a*; United States Department of Agriculture 2011*b*).

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 (Taunton Wild & Scenic River Study Committee 2005, 5). The river also contributes greatly to the rural character and 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" (Taunton Wild & Scenic River Study Committee 2005, 43).

Throughout history, the Taunton River Watershed has supported an ever-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 (Taunton Wild & Scenic River Study Committee 2005, 44). By the 17th century, bog iron was discovered in the watershed and local metal industries prospered as a result (Taunton Wild & Scenic River Study Committee 2005, 45). 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 (Taunton Wild & Scenic River Study Committee 2005, 47). 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 (Taunton Wild & Scenic River Study Committee 2005, 47).

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 strict 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 (Taunton Wild & Scenic River Study Committee 2005, 71). 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, excessive plant growth and low 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 (Taunton Wild & Scenic River Study Committee 2005, 59).

The primary source of nutrients and pathogens in the Taunton River is effluent from the area's six wastewater treatment plants (Taunton Wild & Scenic River Study Committee 2005, 60; GeoSyntec Consultants 2006, 32). 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 (Taunton Wild & Scenic River Study Committee 2005, 60). 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. In addition, stormwater runoff from the impervious surfaces in the watershed (e.g., roads, parking lots and rooftops) contributes to high flows during storm events and reduces the amount of groundwater recharge, which can lead to low flows, especially during the warmest months of the year when flows are naturally lowest and most vulnerable to depletion (Taunton Wild & Scenic River Study Committee 2005, 60).

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 alone experienced a 24% increase in its population between 1980 and 2000 (GeoSyntec Consultants 2006, 12). And 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 (Horsley Witten Group, Inc. 2008, 1-3). It is no surprise that the demand for water in the Taunton River Watershed has increased in parallel with this growth and development. A recent report by the Massachusetts Water Resources Commission indicated that 60% of the watershed is classified as "medium-stressed" or "high-stressed," which means that "the quantity of streamflow has been significantly reduced, or the quality of the streamflow is degraded, or the key habitat factors are impaired" (Horsley Witten Group, Inc. 2008, 7-2; Commonwealth of Massachusetts 2011*d*).

While the information presented above related to the quality and quantity of water in the Taunton River Watershed may seem daunting, it is important to remember that there are a number of active organizations within the watershed focused on restoring and properly managing the water and related natural resources of the Taunton River. A brief summary of the three most prominent Taunton River Watershed organizations is presented below.

> The *Taunton River Watershed Alliance* was founded in 1988 to unite individuals, businesses and organizations that both appreciate the Taunton River and its tributaries and are concerned about the

watershed's future. The Alliance coordinates land conservation efforts, water quality monitoring and policy advocacy within the watershed.

The *Taunton River Watershed Campaign* is a partnership of ten organizations working to protect the landscapes, natural communities and quality of life in the Taunton River 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.

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. The purpose of the Council is to promote the long-term protection of the river by uniting and coordinating various groups working on river management; discussing and making recommendations regarding issues of concern; and implementing the Stewardship Plan.

In addition, the Taunton River Watershed has also been the focus of a variety of reports and planning documents in the last 20 years. A brief summary of the most recent planning efforts is presented below.

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.

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.

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.

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.

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" (Bridgewater State University 2011).

Since the start of the Industrial Revolution, greenhouse gas emissions from human activity have accumulated, beyond natural levels, in the earth's atmosphere. There is "broad agreement and high confidence" within the scientific community that this increase in greenhouse gas concentrations is changing the earth's climate, not only raising average global temperatures, but more importantly, altering regional and local climates and weather patterns (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 12). The observed effects of climate change, on a global scale, include increased ambient and ocean temperatures, heat waves, increased evapotranspiration and precipitation, a greater frequency and intensity of storms, floods and droughts and a rise in sea level. These changes are expected to persist for many decades, even if greenhouse gas emissions are reduced or eliminated today.

By the end of the 21st century, under the high emissions scenario of the Intergovernmental Panel on Climate Change, Massachusetts is predicted to experience up to a 10°F increase in average ambient temperatures, with several more days of extreme heat during the summer months (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 1). On an annual basis, days with temperatures greater than 90°F are predicted to increase from 5-20 days to 30-60 days and up to 28 days are predicted to reach above 100°F, compared to the one or two days at present (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 1). Sea surface temperatures are also predicted to increase by 8°F, while winter precipitation, mostly in the form of rain, is expected to increase by 12-30% (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 1). Finally, the number of snow events is predicted to decrease from five each month to between one and three each month (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 1). These changes will have very real and potentially profound effects on Massachusetts' economy, public health, water resources, infrastructure, coastal resources, energy demand, natural features and recreational resources.

Ecosystems generate a variety of goods and services, collectively called ecosystem services, that 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 can be provisional (e.g., food, timber, medicines, water and fuels), 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) in nature (Millennium Ecosystem Assessment 2005, 39). Ecosystem services are utilized both directly by people and indirectly, when they support the production and quality of other things people enjoy. Today, more than ever, the nature and value of the planet's ecosystems is primarily realized through their disruption and loss.

The awareness of ecosystem services, expressed in terms of their loss, dates back at least to Plato, who connected the deforestation of Attica to soil erosion and the drying of springs:

> "What now remains of the formerly rich land is like the skeleton of a sick man with all the fat and soft earth having wasted away and only the bare framework remaining. …Once the land was enriched by yearly rains, which were not lost, as they are now, by flowing from the bare land into the sea. The soil was deep, it absorbed and kept the water…, and the water that soaked into the hills fed springs and running streams everywhere. Now the abandoned shrines at spots where formerly there were springs attest that our description of the land is true" (Daily 1997, 5-6).

In more recent history, George Perkins Marsh, a lawyer, politician and scholar, was the first to argue against the idea that America's resources were infinite in his book entitled *Man and Nature* (1864). Marsh, who served as ambassador in Turkey and Italy, used examples from the once-fertile Roman Empire to describe the deterioration of ecosystems due to human activities (Daily 1997, 11). Nearly a century later, renowned environmentalist Aldo Leopold touched upon the impact of human activities on species populations, using deer herds as an example: "The cowman who cleans his range of wolves does not realize he is taking over the wolf's job of trimming the herd to fit the range" (Daily 1997, 12). Around the same time as Leopold, another fairly well-known environmentalist, Fairfield Osborn, identified "...four major elements that make possible not only our life, but to a large degree, the industrial economy upon which civilization rests: water; soil; plant life, from bacteria to forests; animal life, from protozoa to mammals" in his book *Our Plundered Planet* (1948; Daily 1997, 13). By 1962, Rachel Carson's book, *Silent Spring*, had sparked the environmental movement and concern for preserving ecosystems was expressed in more mainstream publications. For example, in the first widely used environmental science textbook, a chapter entitled "Ecosystems in Jeopardy" included the following statement: "The most subtle and dangerous threat to man's existence…is the potential destruction, by man's own activities, of those ecological systems upon which the very existence of the human species depends" (Daily 1997, 14).

It is widely believed that the modern day concept of ecosystems delivering services to humanity was first explicitly described in a report entitled *Man's Impact on the Global Environment* (1970). The report, which was compiled over the course of one month by experts in the field of meteorology, ecology, physics, engineering and social sciences, among others, "listed the following 'environmental services' that would decline if there were also a 'decline in ecosystem function:' pest control, insect pollination, fisheries, climate regulation, soil retention, flood control, soil formation, cycling of matter and composition of the atmosphere" (Daily 1997, 14). Several years later, Holdren and Ehrlich (1974), expanded this list to include "public-service functions," which included the maintenance of soil fertility and a genetic library (Daily 1997, 14). With these additions, the traditionally cited list of ecosystem services was essentially complete.

In more recent years, researchers in the fields of ecology and economics have begun to bridge the gap between identifying and assigning value to ecosystem services. Walter Westman was the first to attempt to assign numbers to what he called "nature's services" in 1977; he relied on estimates for replacing or repairing impaired ecosystem functions (Ruhl et al. 2007, 6). Several years later, Farnworth et al. (1981) described "one of the earliest comprehensive frameworks for considering the value of services provided by natural ecosystems" (Ruhl et al. 2007, 6). By 1989, a new discipline, ecological economics, emerged; a journal by the same name was first published that year and a full-length book on the subject, entitled *Ecological Economics: The Science and Management of Sustainability*, followed in 1991 (Ruhl et al. 2007, 6). More recently, ecological economics made national headlines when a research team led by Robert Costanza estimated that global ecosystem service values were over 30 trillion dollars (Ruhl et al. 2007, 6). And with their publication of *Ecological Economics* in 2004, Herman Daly and Joshua Farley "firmly planted the discipline, including its focus on ecosystem service values, on the university curriculum landscape" (Ruhl et al. 2007, 6).

While economic measures of value are particularly useful, because most societies have some intuitive notion of economic value and the sources of human impacts on natural systems are frequently economic, such as the construction of a dam or harvesting timber, they represent just one approach to quantifying the importance of ecosystems. Ecological, socio-cultural and intrinsic measures of value are also worth consideration in order to make more informed decisions regarding the sustainable use and management of ecosystem services. Natural scientists express ecological value through indicators, such as species diversity, rarity, ecosystem integrity and resilience; these values can help set priorities regarding the conservation of biodiversity and ecosystem services in light of the ever increasing pressures on the planet's ecosystems and typically limited financial resources (Millennium Ecosystem Assessment 2003, 129). Socio-cultural values are "based on different worldviews or conceptions of nature and society that are ethical, religious, cultural and philosophical" (Millennium Ecosystem Assessment 2003, 129). Socio-cultural values are often determined through group discussion and consensus building and can be expressed through the designation of sacred species and places, or development of social rules concerning ecosystem use (Millennium Ecosystem Assessment 2003, 140). Finally, intrinsic values are based on the general concept that ecosystems have value in and of themselves without regard to what they do for people. Intrinsic values, by definition, are impossible to quantify and much scientific and philosophical debate has focused on what role, if any, intrinsic values should play in conservation decision-making.

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 climate and non-climate stressors, vulnerabilities and equity and environmental justice issues. Economic data, where readily available, are also presented in order to contextualize the value of ecosystem services and the impact, in terms of financial gains and losses, of healthy and impaired ecosystems in the Taunton River Watershed. Adaptation recommendations follow in a separate section of this plan.

From the supply of water for household use to the mitigation of flood damages, people rely on ecosystems to provide many water-related services. These services generally fit into one of three categories: the supply of water for drinking, irrigation and other purposes; the supply of goods other than water, such as fish and waterfowl; and the supply of in-stream benefits, such as recreation, transportation and flood control (Daily 1997, 196). Each of these categories is defined by attributes of quality, quantity, location and timing of flow, all of which are impacted by climate change. 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 ambient temperature will lead to warmer water temperatures, which will affect certain elements of water quality, such as dissolved oxygen, and species of fish and other aquatic organisms. As winter temperatures rise, more precipitation in the form of rain, instead of snow, will alter hydrologic cycles (e.g., earlier peak flows in the spring and extended low flows in the summer), which will impact water resources, including increased flooding and polluted overflows from stormwater and wastewater systems and increased stress on drinking water sources. While it sounds counterintuitive, droughts will also become more common as regional and seasonal precipitation patterns change; rainfall will be concentrated into heavy storm events with longer and hotter dry periods in between. Finally, the current projections for 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 also have the potential to limit drinking water options for many communities and private homeowners due to saltwater entering fresh water supplies located in permeable sands and gravels.

Adding to these climate-based stressors are several non-climate factors that will further challenge the Taunton River Watershed. First, a significant portion of the water resource infrastructure in the watershed is old and requires updating and rebuilding; this is both a tremendous physical and financial burden on cities and towns (Massachusetts Department of Environmental Protection 2011, 41-43). For example, recent federal and state mandates to eliminate all combined sewer overflows into the Taunton River have significantly impacted Taunton and Fall River. To date, the cities have invested over 320 million dollars in order to upgrade their stormwater and wastewater infrastructure (Holtzman 2010; Massachusetts Department of Environmental Protection 2011, 41). Second, regardless of whether climate change has an effect on water supply, the rapidly developing portions of the Taunton River Watershed will face increasing water demands. In particular, the fastest growing communities will be challenged by more extensive regulations, fewer undeveloped areas to claim for their use and competition from neighboring cities and towns that may also be experiencing rapid growth. Finally, extensive development along the coast and within or adjacent to floodplains increases the susceptibility of critical infrastructure to be inundated and, in a majority of cases, inhibits the natural migration of wetlands.

Vulnerabilities

Given the characteristics of the Taunton River Watershed and likely consequences of climate change, it is clear that water-related services will be most vulnerable in terms of flooding, water quality and water quantity. Cities and towns within the watershed are all too 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 1). When the Taunton River spilled over its banks, nearby infrastructure – roads, bridges, homes and business – suffered the brunt of the damage, physically and financially. For example, Route 44, a major throughway in the watershed, 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 (Littlefield 2010*a*). In addition, the Federal Emergency Management Agency assisted 1,250 families, including 121 displaced households, in Bridgewater, Raynham and Lakeville alone with over 2.5 million dollars in disaster relief as a result of the flooding (Hyman 2011).

Table 1. 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	2.3 / 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 2011, 19; Zarriello, Phillip J. and Gardner C. Bent 2011.

In order to reflect on a significant coastal storm that affected the Taunton River Watershed, one must turn the calendar back 20 years. Hurricane Bob, a Category 2 storm, brought sustained hurricane force winds to southern New England in the summer of 1991 (National Oceanic and Atmospheric Administration 2012). Wind damage to trees and utility infrastructure was common; over 60% of residents lost power as a result of the storm (National Oceanic and Atmospheric Administration 2012). 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 (National Oceanic and Atmospheric Administration 2012). The total damage in Connecticut, Rhode Island and Massachusetts was approximately 680 million dollars (National Oceanic and Atmospheric Administration 2012). Even though the Taunton River Watershed has not felt the impact of a major coastal storm since Hurricane Bob, the threat of an equivalent or stronger storm making landfall in the area is greater than ever before. The current rates of sea level rise and projections for accelerated trends guarantee an increase in the height of future storm surges and frequency of coastal flooding.

Most scientists and policy makers agree with the conventional wisdom that any increase in the frequency and intensity of rainfall will result in an increased likelihood of flooding. However, predicting the extent to which storms like those described above will reoccur and produce similar or worse outcomes in the Taunton River Watershed is challenging. In order to appropriately assess whether flooding in the watershed will increase as a result of climate change, it is important to focus on region-specific studies. For example, one study by Pielke and Downton (2000) suggests that different flooding factors dominate in different regions of the United States, thus raising the "possibility that what might be damaging precipitation in one region could be innocuous or even beneficial in another region" (3636). Another more recent study of sea level rise (Yin et al. 2009) concludes, based on a series of ten different models, that the northeast coast of the United States will experience "considerably faster and larger [rise] than the global mean" during the 21st century (262). Further supporting the authors' conclusion is the fact that all ten models agreed in projecting a significant increase in sea level for the region.

It is important to note that there are a few scenarios in which flooding, as a result of climate change, can be predicted with more certainty. More frequent and severe flooding will occur in areas where floods are directly linked to the intensity and amount of rainfall, such as urban areas and steep basins. More urban and densely populated areas, of which there are few in the Taunton River Watershed, tend to have impervious surfaces, reduced vegetative cover and compacted soils that minimize the ability of soil to store water. These characteristics increase the chances that heavy rainfall events will result in flash flooding. 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 2.

Table 2. 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
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
Threemile 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

Source: GeoSyntec Consultants 2006, 7-10.

Additional threats to water quality in the Taunton River Watershed, which will be exacerbated by climate change, include non-point and point sources of pollution, increased water temperatures and decreased streamflow. In the areas of the watershed that have less impervious surface, such as active farmlands, increased runoff from intense rainfall events could contain elevated levels of sediment, nutrients (e.g., nitrogen and phosphorus) and chemicals (e.g., herbicides and insecticides). More frequent and severe storms will also challenge the capacity of municipal stormwater and wastewater treatment facilities, some of which already discharge partially treated or untreated sanitary sewage and stormwater into the Taunton River or its tributaries during a heavy rainstorm. As would be expected, these discharges contain pathogens (disease-causing agents), excess nutrients, heavy metals and large debris. While some cities and towns are in the process of updating their stormwater and wastewater infrastructure, it will take several years before the repaired and rebuilt systems are complete. Illegal sewer connections (i.e., private wastewater connections to municipal stormwater pipes) and non-conforming or failing septic systems, which are relatively common, further complicate the identification and elimination of "wet weather" sources of pollution in the watershed (Massachusetts Department of Environmental Protection 2011, 34).

Increased water temperatures will also degrade water quality within the Taunton River Watershed. In addition to directly stressing aquatic species, especially coldwater fish species like the Taunton River's native brook trout, warmer water temperatures are associated with greater pathogen survivability in water. However, it should be noted that the type of organism as well as other environmental conditions, such as ice cover and wave intensity, influence this physical and microbiological connection. For example, a study of the occurrence of *Vibrio cholerae* (the cause of cholera) in Chesapeake Bay found that the pathogen was four times more frequently detected in the northern portion of the Bay, where water temperatures were above 66°F and salinity was lower (Louis et al. 2003, 2773). The study also found that in sub-optimal conditions (freshwater or high salinity), the occurrence of *Vibrio cholerae* could be linked to the presence of zooplankton (Louis et al. 2003, 2784). Finally, the combination of more nutrient-rich and warmer waters will lead to an increase in algae growth and even harmful algal blooms, which have the potential to kill fish, mammals and birds and cause human illness.

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 (Commonwealth of Massachusetts 2012*a*). 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 3. In general, NPDES permits are valid for five years from the date of issuance.

Table 3. 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 an EPA permit writer); AP = Assigned to an EPA permit writer; D = Discontinued.
Source: United States Environmental Protection Agency 2012; Vergara 2012.

As for vulnerabilities related to water quantity, 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 (Massachusetts Department of Environmental Protection 2001, 13). The remaining watershed communities rely almost exclusively on groundwater resources (Massachusetts Department of Environmental Protection 2001, 13).

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 (Massachusetts Executive Office of Environmental Affairs 2006, 11-21). 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 (Massachusetts Executive Office of Environmental Affairs 2006, 11-12). 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 (Massachusetts Executive Office of Environmental Affairs 2006, 11-35). 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 (Colby 2008). 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 (Downing 2007). 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 (Downing 2011). 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 (Littlefield 2010*b*). 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 (Downing 2011). The city initially planned to use 1.9 million to 4.07 million gallons of desalinated

Taunton River water each day (Littlefield 2010*b*). 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 (Downing 2011).

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 (Massachusetts Executive Office of Environmental Affairs 2006, 11-2). Taunton and New Bedford share this water supply, which contains the largest natural body of water in the state, Assawompset Pond (2,404 acres; Tuoti 2011). Under Massachusetts' Water Management Act, Taunton is authorized to withdraw a total of 7.29 MGD, on average, from the Assawompset Pond Complex (Massachusetts Executive Office of Environmental Affairs 2006, 11-16). 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 (Massachusetts Executive Office of Environmental Affairs 2006, 11-16). 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 (Massachusetts Executive Office of Environmental Affairs 2006, 11-16).

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 (Wagner 2010). According to officials, the ideal water level is closer to

53 feet above sea level (Wagner 2010). 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 (Tuoti 2011). 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 (Wagner 2010). In the long-term, the management team hopes to secure federal funding for a more thorough study of the complex and permanent action plan (Wagner 2010).

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* (2008), 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. 2008). 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 (Horsley Witten Group, Inc. 2008, 4-32). The sub-watersheds range from a surplus of 9% to a deficit of 231% in one small sub-watershed with several significant water withdrawals (see Appendix A; Horsley Witten Group, Inc. 2008, 4-32). 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 (Horsley Witten Group, Inc. 2008, 4-32).

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 (Horsley Witten Group, Inc. 2008, 4-32).

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 (see Appendix A; Horsley Witten Group, Inc. 2008, 4-32). 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 (Horsley Witten Group, Inc. 2008, 4-33).

Overall, based on these results, it is clear that "there is a need to balance the hydrologic budgets in the Taunton River Watershed" (Horsley Witten Group, Inc. 2008, 4-33). 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" (Horsley Witten Group, Inc. 2008, 4-33). 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 (Horsley Witten Group, Inc. 2008, 4-33). 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. Several additional climate change-related vulnerabilities to groundwater supplies in the Taunton River Watershed include saltwater intrusion, especially for near-shore wells that currently extend into fresh water resources, and the potential for the geographic extent of ponds and wetlands and the carrying capacity of rivers and streams to change, given sea level rise.

Equity and Environmental Justice

Equity and environmental justice issues are likely to occur with regard to flooding, water quality and water quantity too. As a result of increased flooding, some communities may consider developing or expanding flood control structures or moving homes and businesses, as well as public infrastructure, out of high risk areas. These options, and many others, have strong equity implications. For example, land use regulations that could alter private property rights or values, such as remapping floodplains or enacting new zoning codes, need to be carefully considered, especially in terms of the burden on property owners and whether or not compensations are being distributed fairly.

The water quality vulnerabilities discussed in the previous section also include a number of equity-related issues. 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 (2002) found that, nationwide, lower socioeconomic groups are "much more likely to swim in polluted beaches as well as consume fish from contaminated waters" (308). 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.

Finally, populations with stressed water supplies will be more vulnerable to an increase in the frequency and duration of droughts. Those who live in more rural areas may be impacted economically; while populations in more densely settled areas may experience water scarcity as increasing demands overwhelm local supplies. In order to mitigate these potential scenarios, cities and towns may consider water conservation programs (e.g., issuing rebates for low-flow fixtures) or pricing schedules (i.e., allocating a fixed quantity of water to households and imposing financial penalties for exceeding that amount), which encourage residents to limit their consumption of water through voluntary or mandatory measures. Lawmakers will need to consider the out-of-pocket costs associated with each of these options relative to the economic stability of the watershed communities.

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 4, below; United States Department of Agriculture 2011*a*; United States Department of Agriculture 2011*b*).

Table 4. 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	39,252 acres	49,612 acres
Average Size of Farm	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 USDA to avoid disclosing data for individual farms.
Source: United States Department of Agriculture 2011*a*; United States Department of Agriculture 2011*b*.

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 (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 91).

Several non-climate based stressors will also challenge the watershed's farming operations. First, the sale of productive farmland for development purposes will continue to threaten the agricultural industry. Climate change will exacerbate the current development trends in the watershed by pushing displaced populations, due to sea level rise and more frequent flooding, from the coast to undeveloped areas further inland. Increased development will also bring more non-agricultural water uses to the area, which will impact the water supply for farming operations. Next, growers and farmers will continue to face highly volatile and rising energy costs, which, in turn, affect the price of key products like fertilizers and livestock feed; farming operations will find business planning and maintaining profit margins even more difficult because of this stressor. 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 (Wolfe et al. 2008, 565).

Given the characteristics of the agriculture industry in the Taunton River Watershed and likely consequences of climate change, it is clear that farming operations will be most vulnerable in terms of increased ambient temperatures and fluctuations in precipitation. 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.

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; Wolfe et al. 2008, 564). 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 seems almost inevitable that kudzu will spread throughout the northeast this century (Wolfe et al. 2008, 564). 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 (Yamamura and Kiritani 1998, 295). 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" (Wolfe et al. 2008, 561). 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 (University of Maine 2012; University of Massachusetts Amherst 2012*a*). 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" (University of Maine 2012). 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 (University of Massachusetts Amherst 2012*a*).

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 be beneficial 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. However, two to six months of drought will decrease the amount of time that crop leaves are wet and, in turn, reduce some of the ways in which pathogens attack crops.

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 (University of Massachusetts Amherst 2012*b*). 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" (Venkataraman 2009). 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 (Venkataraman 2009). 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 (University of Massachusetts Amherst 2012*b*).

Equity and Environmental Justice

Within the Taunton River Watershed, there are a number of equity and environmental justice issues related to climate change and agriculture. Certain farming operations will be more at risk from exposure to climate change based on their physical location; growers and farmers with property close to or within flood-prone areas will face a disproportionate risk of crop damage from sea level rise, saltwater intrusion and flooding. Other farming operations may be more at risk due to their primary product. For example, it will be more expensive and risky for growers and farmers that raise perennial crops to introduce new, stress-tolerant varieties as an adaptation strategy. Finally, small farms will be the most vulnerable to climate change if adaptation requires significant capital investments, such as new infrastructure or increased chemical applications. Small farms are also less able to take advantage of the economies of scale (i.e., increasing the production of goods to decrease the overall cost of producing those goods) associated with most adaptation strategies.

Climate change also has the potential to negatively impact the demand for agricultural products through weather events that disrupt supply chains or limit consumer access to markets, with especially harsh effects on low income and disabled residents. Growers and farmers without sufficient information and training, or access to credit are also at risk under these conditions, which require flexibility and quick responses, such as arranging alternative supply lines and finding new locations to sell their products. In the face of decreasing demand and the high costs of adaptation, growers and farmers could also pursue ways to supplement their incomes or diversify their operations beyond agriculture, but once again, may lack the training or capital to carry out such strategies. Finally, decreasing demand will influence the local economy and job market. Low-wage, temporary and seasonal workers are especially vulnerable to fluctuations in demand for agricultural products.

For lower-income communities throughout the watershed, issues related to food justice are of particular concern. The lack of access to grocery stores in lower-income urban and rural communities, as well as the inability of low income residents to afford healthy, fresh produce, will be exacerbated by climate change. For example, heat stress will affect the quality, accessibility and affordability of local agricultural products. This will, in turn, impact food security for lower-income residents; households with pre-existing poor nutrition; and communities that have very few connections to grocery stores or markets offering nutritional selections. The frequency and duration of extreme heat events or droughts will also affect the cost structures and productivity of community gardens and other local food sources that serve lower-income urban areas.

Finally, there are a number of possible unintended outcomes or secondary consequences to consider that are related to adaptation within the agricultural industry. First, while some farming operations will be able to adapt to climate change, others will experience inequality in terms of profits and productivity as a result of not being able to adapt. Next, certain farming operations may be able to consolidate in ways that make it more difficult for smaller farms to survive or even enter the market. On a natural resource level, the increased use of fertilizers and pesticides will likely affect waterways and disproportionally impact communities that rely on water-based, outdoor recreation for revenue. In addition, the use of more chemicals may create or exacerbate inequitable distributions of human health-related illnesses. Together, these impacts could negatively impact property values and intensify geographic inequities in the watershed. Lastly, as water and energy consumption increases both within and outside of the agricultural industry, so too will utility prices; these increases will be more burdensome for low income families because, in general, a greater proportion of their budget is spent on basic goods than middle and upper-income families.

The climate change-related consequences for public health in the Taunton River Watershed are likely to be profound, 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. The increased demand for treatment of acute and chronic illnesses and diseases as well as mental health effects, such as anxiety resulting from losses or displacement due to more severe storms, will fall squarely on the shoulders of public and private health care systems.

Environmental Justice Populations

Article 97 of the Massachusetts Constitution states, “The people shall have the right to clean air and water, freedom from excessive and unnecessary noise, and the natural, scenic, historic, and aesthetic qualities of their environment; and the protection of the people in their right to the conservation, development and utilization of the agricultural, mineral, forest, water, air and other natural resources is hereby declared to be a public purpose” (Massachusetts Executive Office of Environmental Affairs 2002, 1). To realize the goals of Article 97 and advance environmental justice, Massachusetts established an environmental justice (EJ) policy to help ensure the protection of low income residents and communities of color from environmental pollution, as well as promote public participation by EJ populations in planning and development decision-making.

More specifically, EJ populations are defined as neighborhoods (Census Block Groups) 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 for the state 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 (Massachusetts Executive Office of Environmental Affairs 2002, 5). EJ populations reside in 108 cities and towns across the state; 20 of these communities meet all four of the EJ population criteria (based on 2000 U.S. Census data; Massachusetts Executive Office of Energy and Environmental Affairs 2012, 1). Within the Taunton River Watershed, there are nine communities that meet at least two of the four EJ population criteria; three of which meet all four criteria (Fall River, New Bedford and Brockton; Massachusetts Executive Office of Energy and Environmental Affairs 2012, 1-3).

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. 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 (Cutter et al. 2003, 244). The development of environmental indicators followed in later years, with quality-of-life studies emerging as a combination of the two areas of research (Cutter et al. 2003, 244). 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* (Cutter et al. 2003, 244). 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 (Cutter et al. 2003, 245-252).

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” (Oxfam America, Inc. 2009, 2). The study concludes that the most socially vulnerable communities will suffer disproportionately from climate change impacts, given the population characteristics examined. Among the recommendations 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.

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 in the labor force; 4) percent of population with at least 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. 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 2000 U.S. Census, 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 5 below, as an example. 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 5. Criteria of Interest for Cities and Towns in Bristol County and the Taunton River Watershed, Based on 2000 U.S. Census Data

Location	Per Capita Income[a]	% Families Below Poverty	% In Labor Force[b]	% H.S. Grad[c]	% Language Other Than English[d]	% Age ≥ 65
U.S.	$21,587	9.2	63.9	80.4	17.8	12.4
Massachusetts	$25,952	6.7	66.2	84.8	18.7	13.5
Bristol County	$20,978	7.8	65.8	73.2	21	14.2
Attleboro	$22,260	3.7	70.6	81.9	12.9	12.9
Berkley	$21,652	0.7	76.8	85.7	8.8	6.4
Dartmouth	$24,326	2.8	64.8	75.3	22.3	15.6
Dighton	$22,600	1	73.2	85.8	9.7	12.8
Easton	$30,732	0.7	73.5	93.9	7.1	9.4
Fall River	$16,118	14	59.1	56.6	34.6	17
Freetown	$24,237	2.7	75.5	82.4	9.7	9
Mansfield	$27,441	3	75	93.3	5.6	6.3
New Bedford	$15,602	17.3	57.7	57.6	37.8	16.7
Norton	$23,876	2.2	76.4	89.2	5.1	7.8
Raynham	$24,476	3.2	72.2	85.3	8.5	13
Rehoboth	$26,467	2.1	74.7	86.8	8.2	10
Somerset	$22,420	3.2	62.9	76	16.4	21.1
Swansea	$21,776	3.4	67.9	76.4	15.1	15.7
Taunton	$19,899	8	68.2	74.8	19.1	12.8

a. Average income in 1999 dollars.
b. For population ≥ 16 years.
c. Or higher for population ≥ 25 years.
d. Spoken at home for population ≥ 5 years.
Source: Social Explorer 2011.

In a similar table for the cities and towns located within Plymouth County and the Taunton River Watershed, Brockton stands out from the other Plymouth County communities in four of the six criteria of interest in this analysis. Given the fact that the majority of New Bedford, including the downtown area and associated waterfront, falls outside of the Taunton River Watershed, Fall River and Brockton represent the ideal communities within the watershed to pursue an in-depth, neighborhood level (Census Block Group) analysis. Table 6, below, identifies the cut-off values for this level of analysis in Fall River (Bristol County) and Brockton (Plymouth County). It is important to emphasize the fact that each county was evaluated separately in order to determine the most appropriate cut-off values for each of the six criteria of interest in this analysis. As a result, the cut-off value for the percent of population with at least a high school diploma is higher in Plymouth County than Bristol County.

Table 6. Cut-off Values for the Neighborhood Level (Census Block Group) Analysis for Fall River (Bristol County) and Brockton (Plymouth County)

Criteria	Fall River (Bristol County)	Brockton (Plymouth County)
Per Capita Income[a]	< \$19,000	< \$19,000
% Families Below Poverty	> 10%	>10%
% In Labor Force[b]	< 60%	< 60%
% H.S. Grad[c]	< 65%	< 80%
% Speak Language Other Than English[d]	> 25%	> 25%
% Age ≥ 65	≥ 17%	≥ 17%

a. Average income in 1999 dollars.
b. For population ≥ 16 years.
c. Or higher for population ≥ 25 years.
d. Spoken at home for population ≥ 5 years.

Figures 2 and 3 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 figure. In Fall River, there are 25 Census Block Groups that meet five of the six criteria and 16 that meet all six criteria. These neighborhoods are primarily situated along the western coast of Fall River, adjacent to the Taunton River and Mount Hope Bay, and within the Interstate 195 and Route 6 corridors. It is interesting to note that there is considerable 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 eight neighborhoods that meet five of the six criteria and two that meet all six criteria, all of which are situated in or near the center of the city. There is also considerable overlap between these Census Block Groups and the 10 neighborhoods that meet three or four of the four EJ population criteria.

Combining this information with 100-year and 500-year flood zone data, as well as storm surge data, provides some insight into the potentially devastating combination of socially vulnerable populations and severe climate change impacts (see Figures 4, 5 and 6). It is important to note that the flood zone and storm surge data used in this analysis do

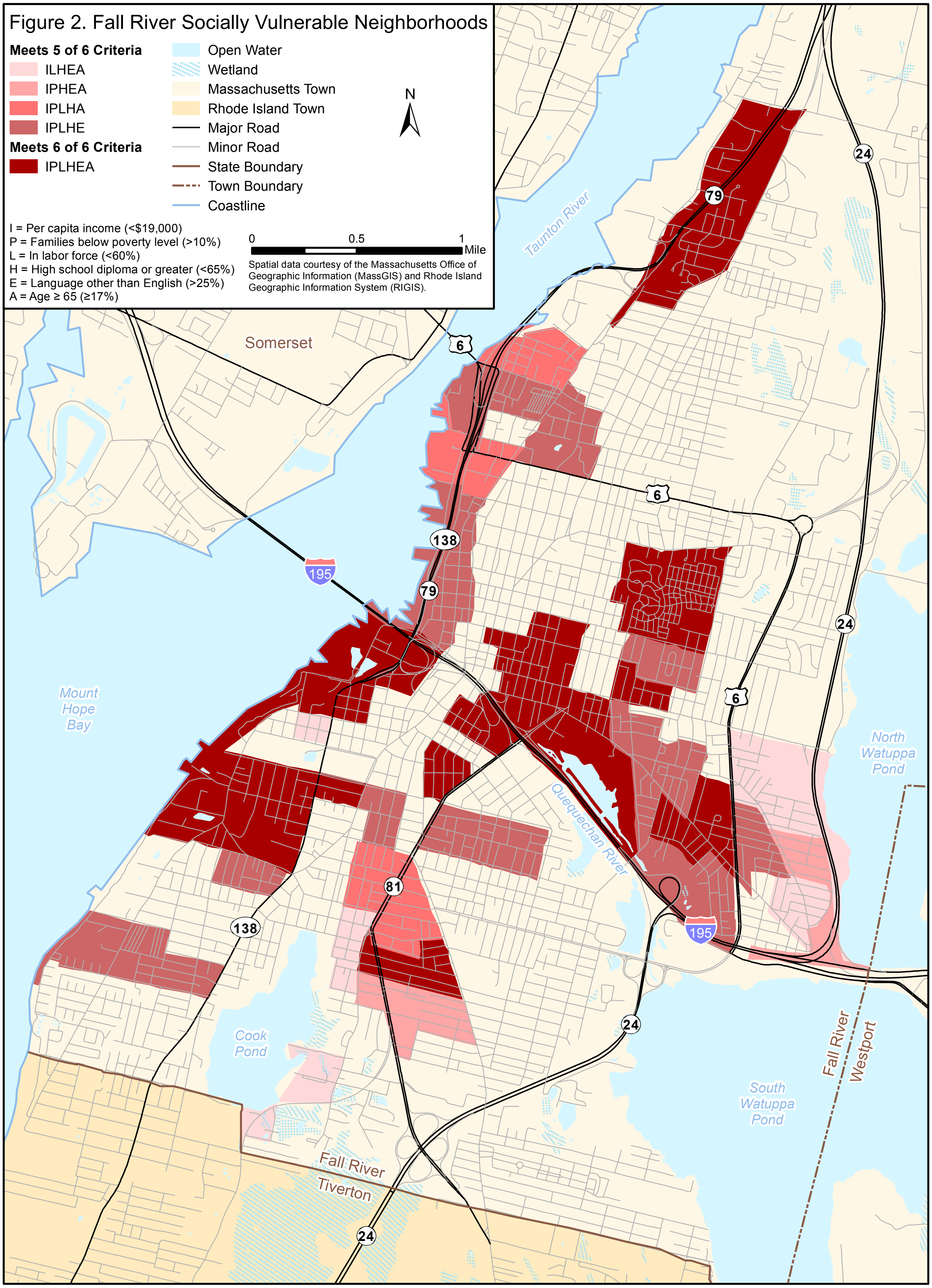


Figure 2. Fall River Socially Vulnerable Neighborhoods
Meets 5 of 6 Criteria
ILHEA
IPHEA
IPLHA
IPLHE
Meets 6 of 6 Criteria
IPLHEA
Open Water
Wetland
Massachusetts Town
Rhode Island Town
Major Road
Minor Road
State Boundary
Town Boundary
Coastline
N
I = Per capita income (<$19,000)
P = Families below poverty level (>10%)
L = In labor force (<60%)
H = High school diploma or greater (<65%)
E = Language other than English (>25%)
A = Age ≥ 65 (≥17%)
0
0.5
1
Mile
Spatial data courtesy of the Massachusetts Office of Geographic Information (MassGIS) and Rhode Island Geographic Information System (RIGIS).
Somerset
Taunton River
Mount Hope Bay
Quequechan River
North Watuppa Pond
South Watuppa Pond
Cook Pond
Fall River
Tiverton
Westport
195
138
79
6
24
81

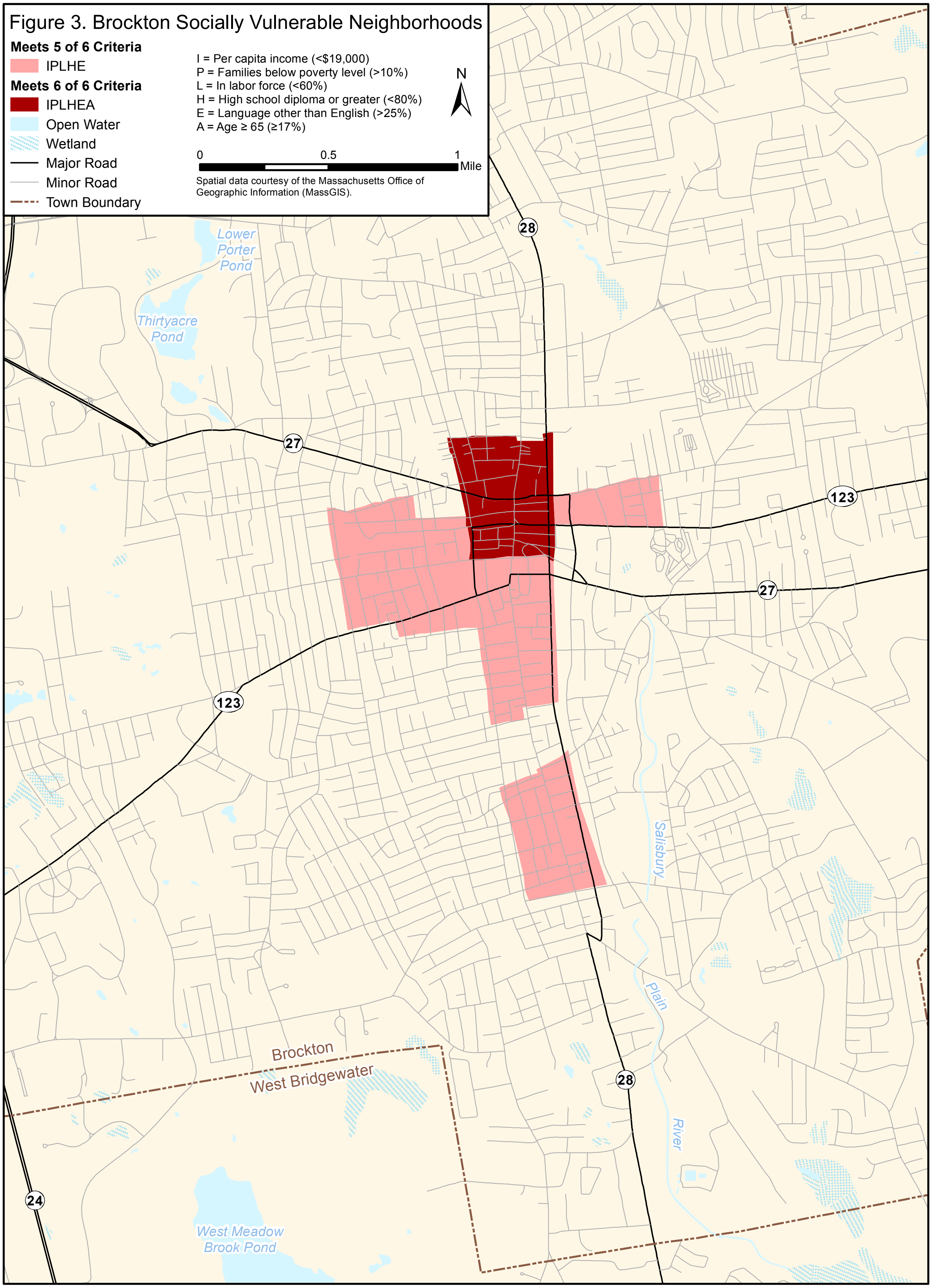


Figure 3. Brockton Socially Vulnerable Neighborhoods
Meets 5 of 6 Criteria
IPLHE
Meets 6 of 6 Criteria
IPLHEA
Open Water
Wetland
Major Road
Minor Road
Town Boundary
I = Per capita income (<$19,000)
P = Families below poverty level (>10%)
L = In labor force (<60%)
H = High school diploma or greater (<80%)
E = Language other than English (>25%)
A = Age ≥ 65 (≥17%)
N
0
0.5
1
Mile
Spatial data courtesy of the Massachusetts Office of Geographic Information (MassGIS).
Lower Porter Pond
Thirtyacre Pond
28
27
123
27
123
Salisbury
Plain
River
Brockton
West Bridgewater
28
24
West Meadow Brook Pond

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 nine 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, eight 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, only four of the neighborhoods that meet five of the six criteria fall within a flood-prone area; the two Census Block Groups that meet all six criteria do not fall within a 100-year or 500-year flood zone.

It is important to note that while the watershed's social vulnerability analysis focuses on data from the 2000 U.S. Census, five-year estimate data from the U.S. Census 2005-2009 American Community Survey is also available and can provide valuable insight into potential demographic trends leading up to the release of the 2010 U.S. Census data. For example, in Fall River, one of the most significant differences between the census and estimate data is an increase in the percent of high school graduates, from 56.6% in 2000 to approximately 67.1% between 2005 and 2009 (Social Explorer 2011). In Brockton, the criterion with the greatest change is the percent of population who do not speak English at home, from 28.4% in 2000 U.S. Census to an estimated 34.4% in the 2005-2009 American Community Survey (Social Explorer 2011). These estimated changes emphasize the importance of continually evaluating and monitoring socially vulnerable populations. When the 2010 U.S. Census data is released in the coming months, it will be critical to determine whether the socially vulnerable neighborhoods identified here remain the same or change and to respond accordingly, both in terms of planning for potentially vulnerable populations and identifying appropriate climate change adaptation efforts.

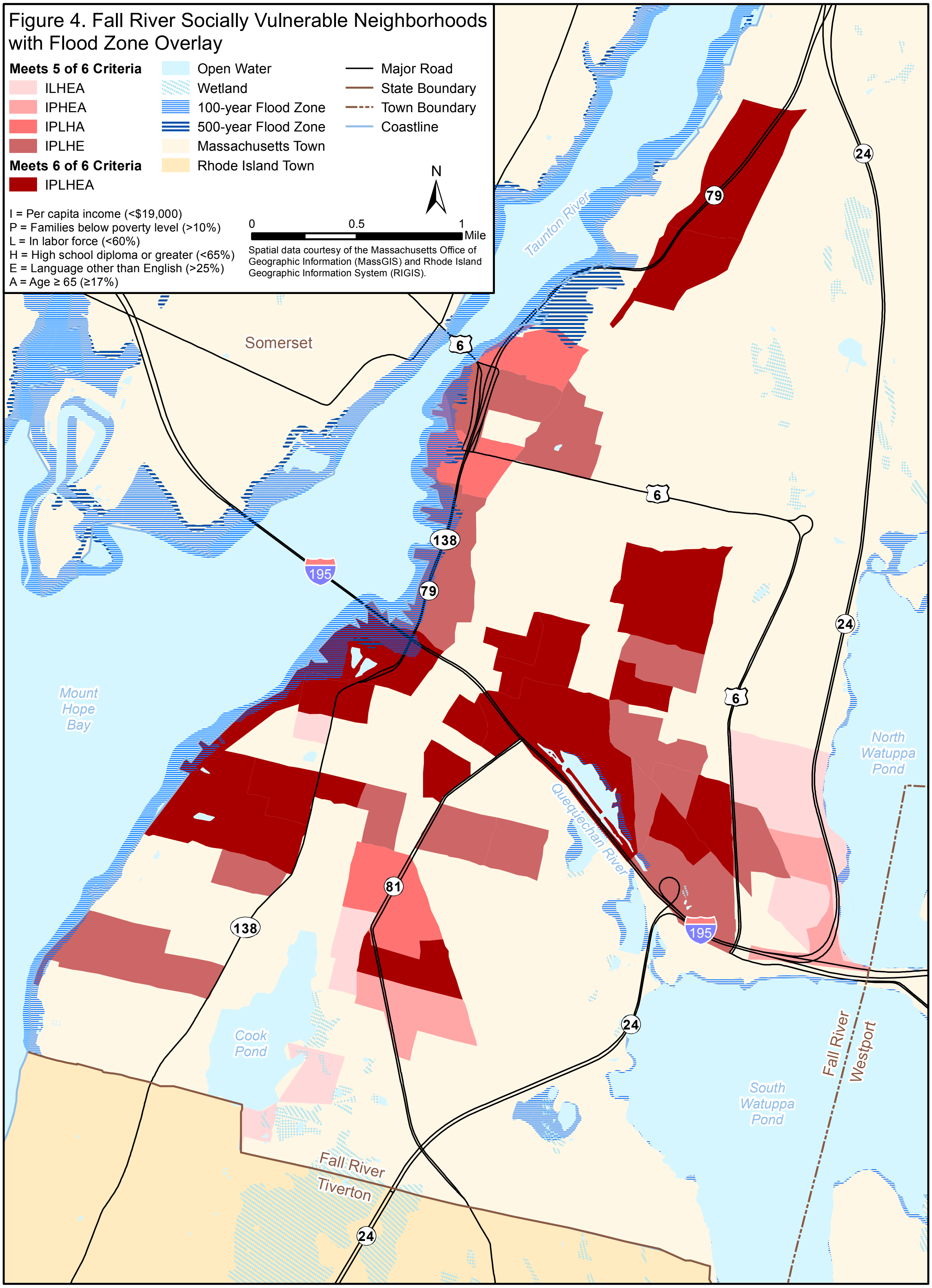


Figure 4. Fall River Socially Vulnerable Neighborhoods with Flood Zone Overlay
Meets 5 of 6 Criteria
ILHEA
IPHEA
IPLHA
IPLHE
Meets 6 of 6 Criteria
IPLHEA
Open Water
Wetland
100-year Flood Zone
500-year Flood Zone
Massachusetts Town
Rhode Island Town
Major Road
State Boundary
Town Boundary
Coastline
I = Per capita income (<$19,000)
P = Families below poverty level (>10%)
L = In labor force (<60%)
H = High school diploma or greater (<65%)
E = Language other than English (>25%)
A = Age ≥ 65 (≥17%)
0
0.5
1
Mile
Spatial data courtesy of the Massachusetts Office of Geographic Information (MassGIS) and Rhode Island Geographic Information System (RIGIS).
N
Somerset
Taunton River
Mount Hope Bay
Quequechan River
North Watuppa Pond
South Watuppa Pond
Cook Pond
Fall River
Tiverton
Westport
24
79
6
138
195
81

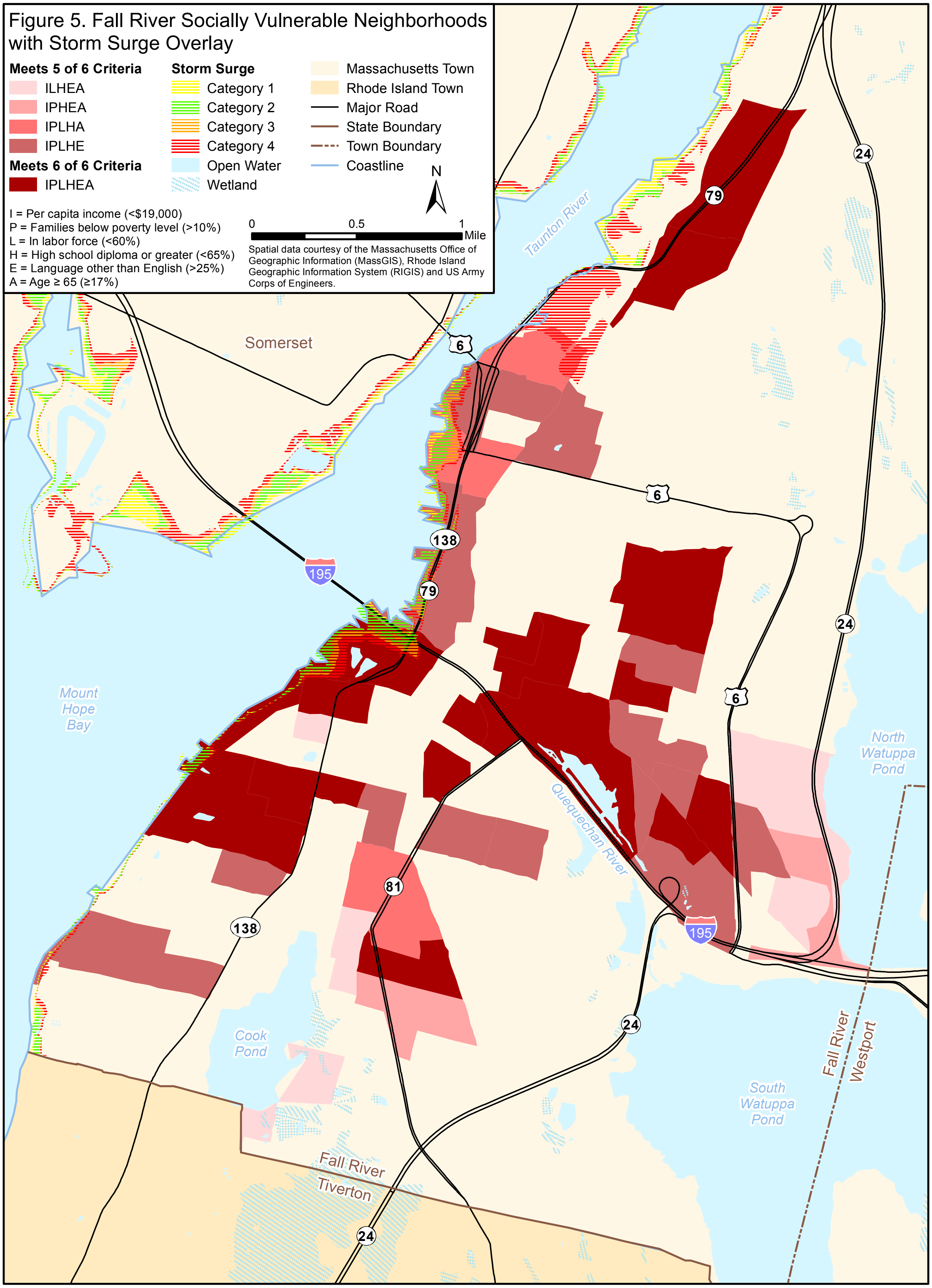


Figure 5. Fall River Socially Vulnerable Neighborhoods with Storm Surge Overlay
Meets 5 of 6 Criteria
ILHEA
IPHEA
IPLHA
IPLHE
Meets 6 of 6 Criteria
IPLHEA
Storm Surge
Category 1
Category 2
Category 3
Category 4
Open Water
Wetland
Massachusetts Town
Rhode Island Town
Major Road
State Boundary
Town Boundary
Coastline
N
I = Per capita income (<$19,000)
P = Families below poverty level (>10%)
L = In labor force (<60%)
H = High school diploma or greater (<65%)
E = Language other than English (>25%)
A = Age ≥ 65 (≥17%)
0
0.5
1
Mile
Spatial data courtesy of the Massachusetts Office of Geographic Information (MassGIS), Rhode Island Geographic Information System (RIGIS) and US Army Corps of Engineers.
Somerset
Taunton River
Mount Hope Bay
Quequechan River
North Watuppa Pond
South Watuppa Pond
Cook Pond
Fall River
Tiverton
Westport
79
24
6
138
195
81

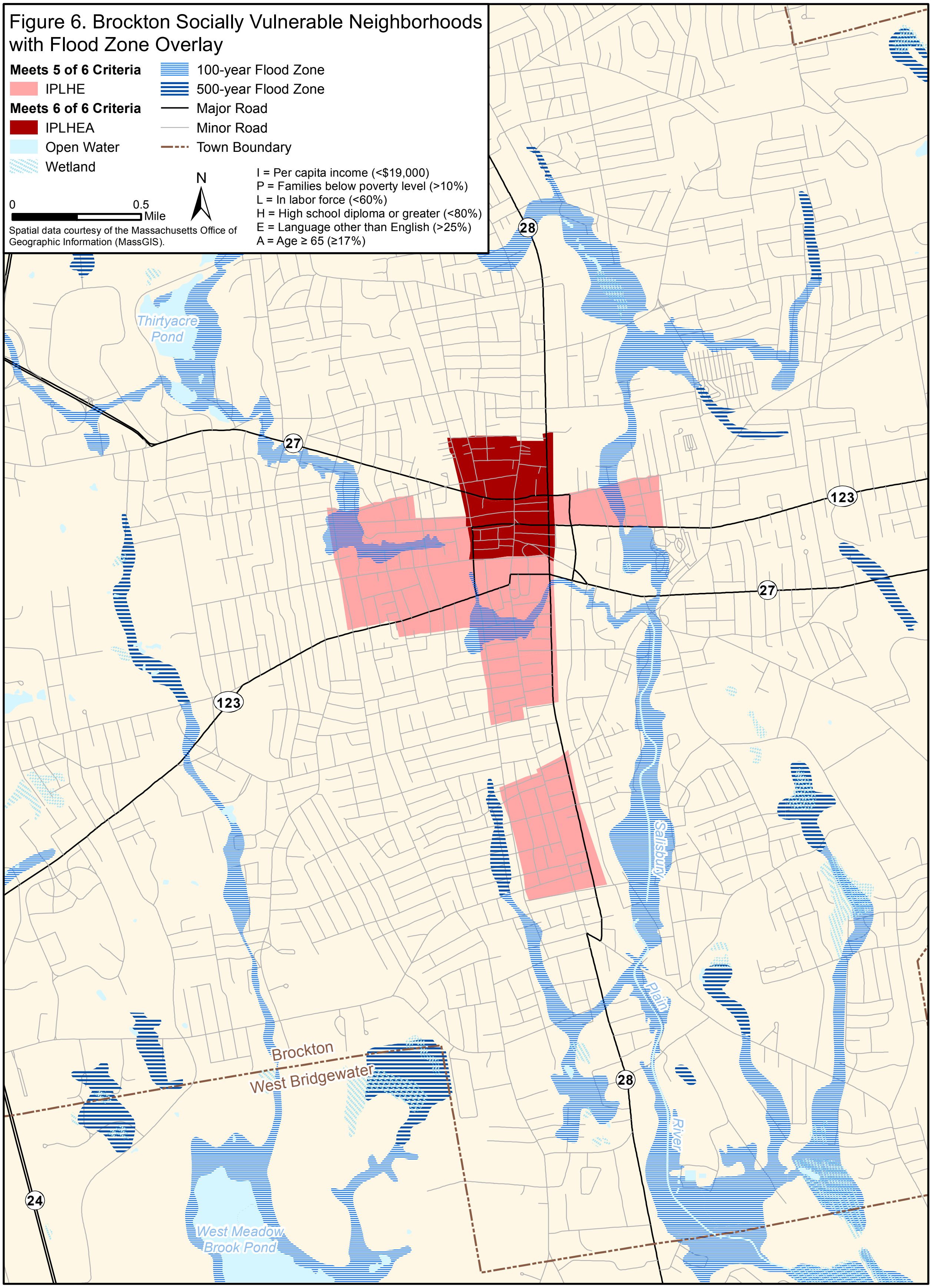


Figure 6. Brockton Socially Vulnerable Neighborhoods with Flood Zone Overlay
Meets 5 of 6 Criteria
IPLHE
Meets 6 of 6 Criteria
IPLHEA
Open Water
Wetland
100-year Flood Zone
500-year Flood Zone
Major Road
Minor Road
Town Boundary
N
0
0.5
Mile
Spatial data courtesy of the Massachusetts Office of Geographic Information (MassGIS).
I = Per capita income (<$19,000)
P = Families below poverty level (>10%)
L = In labor force (<60%)
H = High school diploma or greater (<80%)
E = Language other than English (>25%)
A = Age ≥ 65 (≥17%)
Thirtyacre Pond
28
27
123
27
123
Salisbury
Plain
River
28
Brockton
West Bridgewater
24
West Meadow Brook Pond

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 (Reiter 2001, 142). 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 first human case of EEE was identified in Massachusetts in 1938 (Massachusetts Department of Public Health 2011*a*, 3). 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 (Centers for Disease Control and Prevention 2012). 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 (Centers for Disease Control and Prevention 2012; Massachusetts Department of Public Health 2011*a*, 3).

Human cases of EEE tend to occur episodically in 2-3 year cycles, with gaps of 10-20 years in between each cycle (Massachusetts Department of Public Health 2011*a*, 3). Between 1964 and 2010, nearly 300 human cases of EEE were documented in the U.S. (Centers for Disease Control and Prevention 2012). Remarkably, Massachusetts had the second largest number of human EEE cases (37) during this time period, behind Florida, which had 70 cases (Centers for Disease Control and Prevention 2012). 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 (Massachusetts Department of Public Health 2011*a*, 4). The Massachusetts Department of Public Health routinely tests mosquitoes for EEE during the warmest months of the year. In 2011, 80 EEE-positive mosquito pools (a collection of 10-50 mosquitoes) were detected in the state, 70 (88%) of which were located in the Taunton River Watershed (Massachusetts Department of Public Health 2011*b*, 2-8). Also in 2011, one human case of EEE was reported; the individual lived in Bristol County (United States Geological Survey 2012*a*).

The first human case of WNV was identified in Massachusetts in 2001 (Massachusetts Department of Public Health 2011*a*, 3). About 80% of human cases show no symptoms, with approximately 20% showing mild, generic symptoms like fever, fatigue and stiff neck (Massachusetts Department of Public Health 2011*a*, 5). 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 (Massachusetts Department of Public Health 2011*a*, 5). WNV is more often fatal in some species of birds, particularly the American crow and blue jay (Massachusetts Department of Public Health 2011*a*, 5). Confirmation of WNV in dead birds frequently provides sentinel information for assessing the risk of human WNV infections (Massachusetts Department of Public Health 2011*a*, 5).

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 (Massachusetts Department of Public Health 2011*a*, 6). WNV-positive mosquito pools are more widely distributed than EEE-positive mosquito pools across the state. In 2011, the Massachusetts Department of Public Health detected 275 WNV-positive pools, 46 (17%) of which were located in the Taunton River Watershed (Massachusetts Department of Public Health 2011*b*, 2-8). Also in 2011, five human cases of WNV were reported; none of the individuals lived in Bristol or Plymouth counties (United States Geological Survey 2012*b*).

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 response to climate change, adaptation is a complementary approach to mitigation. While mitigation strategies generally focus on actions to reduce the magnitude 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. Adaptation strategies are not free of cost or foolproof. 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. As a result, it is worthwhile to consider the economic and political costs associated with any adaptive action, as well as the availability of resources, anticipated effectiveness of the action and expected value of the avoided damages, before moving forward with implementation. A fairly wide range of adaptation strategies exist, including, but not limited to (Pew Center on Global Climate Change 2011, 8):

> *No-regret strategies* – Actions that make sense or are worthwhile regardless of additional or exacerbated impacts from climate change, e.g., protecting or restoring ecosystems that are already vulnerable or of urgent concern for other reasons.
>
> *Opportunity-based strategies* – Actions that capitalize on observed or projected climatic changes, e.g., a farmer is able to shift to different crops that are better suited to changing climatic conditions.
>
> *Win-win strategies* – Actions that provide adaptation benefits while meeting other social, environmental or economic objectives, including climate change mitigation, e.g., improving the cooling capacity of buildings through improved shading or other low-energy cooling solutions.

Low-regret strategies – Measures with relatively low costs for which benefits under climate change scenarios are high, e.g., incorporating climate change into forestry, water and other public land management practices and policies, or long-term capital investment planning.

Sustainable investment strategies – Policies or other measures that prevent new investment in areas already at high risk from current climatic events, where climate change is projected to exacerbate the impacts, e.g., prohibiting new development in flood-prone areas where sea level rise is increasing and protective measures are not cost effective.

Catastrophic risk prevention strategies – Policies or measures intended to avert potential or eventual catastrophic events, e.g., relocating development in areas at or near sea level, given the projections for sea level rise and increasing severe weather events.

The following tables present adaptation recommendations that are appropriate for the Taunton River Watershed. The tables are organized first by ecosystem service and then by the type of strategy. A lead or responsible entity is also identified for each recommendation.

Table 7. Adaptation Recommendations for Water-related Services in the Taunton River Watershed

Recommendation	**Lead Entity[a]**	**Strategy**
Prepare or revisit emergency response plans; take into consideration the most updated estimates of levels of precipitation, flooding and extreme storm events in addition to vulnerable populations.	Regional; Local	No-regret
Integrate adaptation strategies into master, open space and other local plans to ensure long-term preparedness for climate change.	Local	No-regret
Continue or, where applicable, improve the maintenance of existing critical infrastructure to minimize the chances of flooding or other damage that might occur before more permanent adaptation strategies can be implemented.	Local; Private	Win-win
Continue or, where applicable, initiate or strengthen efforts to locate and repair illegal sewer connections and non-conforming or failing septic systems.	State; Local; Private	Win-win

Continued on next page.

Table 7. Adaptation Recommendations for Water-related Services in the Taunton River Watershed (continued)

Re-examine and modify, as appropriate, the NPDES permit guidelines, taking into consideration the most updated estimates of low streamflow.	Federal	Win-win
Implement water conservation strategies that guarantee a sufficient water supply without building reservoirs or other new infrastructure; measures often include the use of low-flow showerheads, toilets and washing machines; limited car washing and lawn watering; and increased use of rain barrels for gardens.	Local; Non-profit; Private	Win-win
Report water demand data to the public, even during non-drought periods, to help break the mentality that water supplies should provide 100% of demand at all times and to promote attitudes and behaviors that appreciate years when water is plentiful and conserve it in years when it is scarce.	Local; Non-profit	Win-win
Establish a set of target water levels or “rule curves” for surface water supplies that vary seasonally and balance the multiple interests around each waterbody in order to provide a systematic, unbiased protocol for managing the supplies under current and future drought.	Local	Win-win
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	Low-regret
Explore amendments to existing zoning and building codes to account for expected climate change impacts, particularly in terms of rainfall, when designing and constructing new infrastructure, repairing and upgrading existing infrastructure and evaluating sites and areas suitable for infrastructure development.	Local	Sustainable investment
Develop and employ 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	Sustainable investment
Take advantage of opportunities to relocate, reconstruct or remove existing infrastructure out of flood-prone areas as buildings and flood-protection structures age and it becomes time to rebuild.	Local; Private	Catastrophic risk prevention
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	Catastrophic risk prevention

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.

Table 8. Adaptation Recommendations for Agriculture-related Services in the Taunton River Watershed

Recommendation	**Lead Entity**[a]	**Strategy**
Continue or, where applicable, strengthen efforts to protect active farmlands from being developed for non-agricultural purposes.	State; Local; Non-profit	No-regret
Develop programs to keep the agricultural community informed about the impacts of climate change and how to adapt to the changing conditions.	State; Educational institution; Non-profit	No-regret
Adopt best management practices that control pesticide, nutrient and soil runoff, which contribute to poor water quality.	Private	No-regret
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	No-regret
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	Win-win
Conduct research and investigate the use of pest and disease controls, including organic strategies, for changing conditions; training in new pest and disease controls may be needed to increase familiarity of best practices and alternative solutions to new insects, weeds and diseases before they become widespread.	Federal; State; Educational institution	Win-win
Implement water conservation practices to reduce the vulnerability of crops and livestock to water supply fluctuations.	Local; Non-profit; Private	Win-win
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	Win-win
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	Win-win
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	Opportunity-based
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	Opportunity-based

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.

Table 9. Adaptation Recommendations for Public Health-related Services in the Taunton River Watershed

Recommendation	Lead Entity[a]	Strategy
Prepare or revisit emergency response plans; take into consideration the most updated estimates of levels of precipitation, flooding and extreme storm events in addition to vulnerable populations.	Regional; Local	No-regret
Assess the capacity of health care facilities and providers to accommodate changing physical and mental health demands.	State; Regional; Local	No-regret
Conduct a social vulnerability analysis using 2010 U.S. Census data.	Regional; Local	No-regret
Design and promote an educational campaign targeted towards vulnerable populations, which could include support for a network of notification procedures for vulnerable communities, cooling centers (gathering places for people to get relief during heat waves) and check on your neighbor programs.	State; Regional; Local; Non-profit	No-regret
Continue or, where applicable, expand preventative actions related to mosquito populations, including public outreach, general monitoring, control and infrastructure maintenance.	State; Regional; Local; Non-profit	No-regret
Expand on-going surveillance of climate-sensitive environmental and health indicators; surveillance is a central public health function that can identify emerging risks and anticipated future impacts and help to guide ongoing adaptation planning.	State; Local	Win-win
Develop strategies for large-scale use of integrated pest management control to reduce pesticide use in response to an EEE or WNV outbreak.	State; Regional	Win-win

a. State = Massachusetts Department of Public Health; Regional = Regional planning agency(s) or mosquito control project(s); Local = Municipal government; Non-profit = Organization within the Taunton River Watershed.

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 recommendations 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. The central issue is the lack of a framework in which these stakeholders can work together efficiently and effectively, building on each other's strengths and assuring that actions taken reinforce one another rather being counterproductive.

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)" (Center for Climate and Energy Solutions 2012, 5). By June 2012, agencies must address climate change adaptation in their SSPP and be prepared to implement the related actions in fiscal year 2013 (Center for Climate and Energy Solutions 2012, 5). Executive Order 13514 also "requires agencies to actively participate in the Interagency Climate Change Adaptation Task Force" (Center for Climate and Energy Solutions 2012, 5). The task force has recently published, or will soon publish, 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* (winter 2012; Center for Climate and Energy Solutions 2012, 6).

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 (Massachusetts Executive Office of Energy and Environmental Affairs 2011, 1). 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 even more beneficial. 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. By making a concerted effort to collaborate with each other and facilitate collaboration between the communities in the watershed, the RPAs can ensure that many moving parts are working towards a common goal (adapting to the impacts of climate change) as efficiently and effectively as possible.

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 (Commonwealth of Massachusetts 2012*b*). 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" (Commonwealth of Massachusetts 2012*b*). Cities and towns also have authority over land use planning decisions, including zoning and building codes, as well as some transportation infrastructure. As a result, the presence of a lead-by-example community can play a key role in mobilizing adaptation efforts in the watershed by providing leadership in education, outreach, best management practices and fundraising.

Finally, one would be remiss to overlook the opportunity for non-profit organizations dedicated to the well-being of the Taunton River to support a "bottom-up" approach to adaptation planning and implementation efforts within the watershed. These organizations could take on a range of activities, from water quality monitoring and invasive species management; to communication and outreach efforts to inform residents about effects of climate change, including information on how to reduce their exposure to climate-related risks and become involved in community level efforts to prepare for climate change. By building on and supporting existing resources, such as these organizations, forward progress can be made in terms of improving the adaptive capacity of the watershed, implementing solutions to high priority climate change impacts and reducing vulnerabilities to ecosystem services.

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 recommendations presented in this plan will be useful in preparing for and responding to the watershed's climate change-related vulnerabilities now and in the future. By drawing on the relevant experience, know-how and other valuable resources at the regional and local levels, there is considerable hope that the necessary actions will be implemented, creating a more resilient watershed.

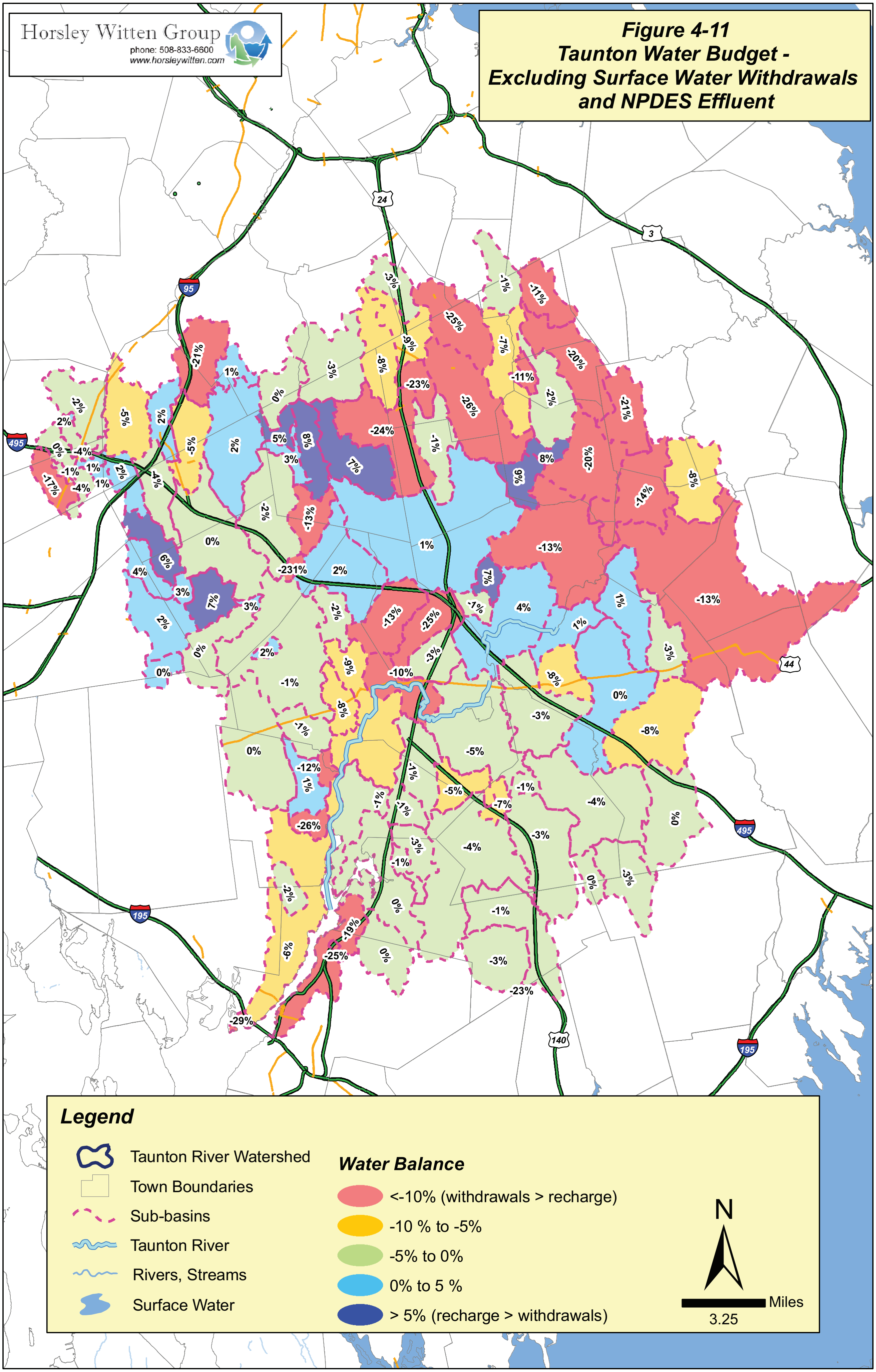
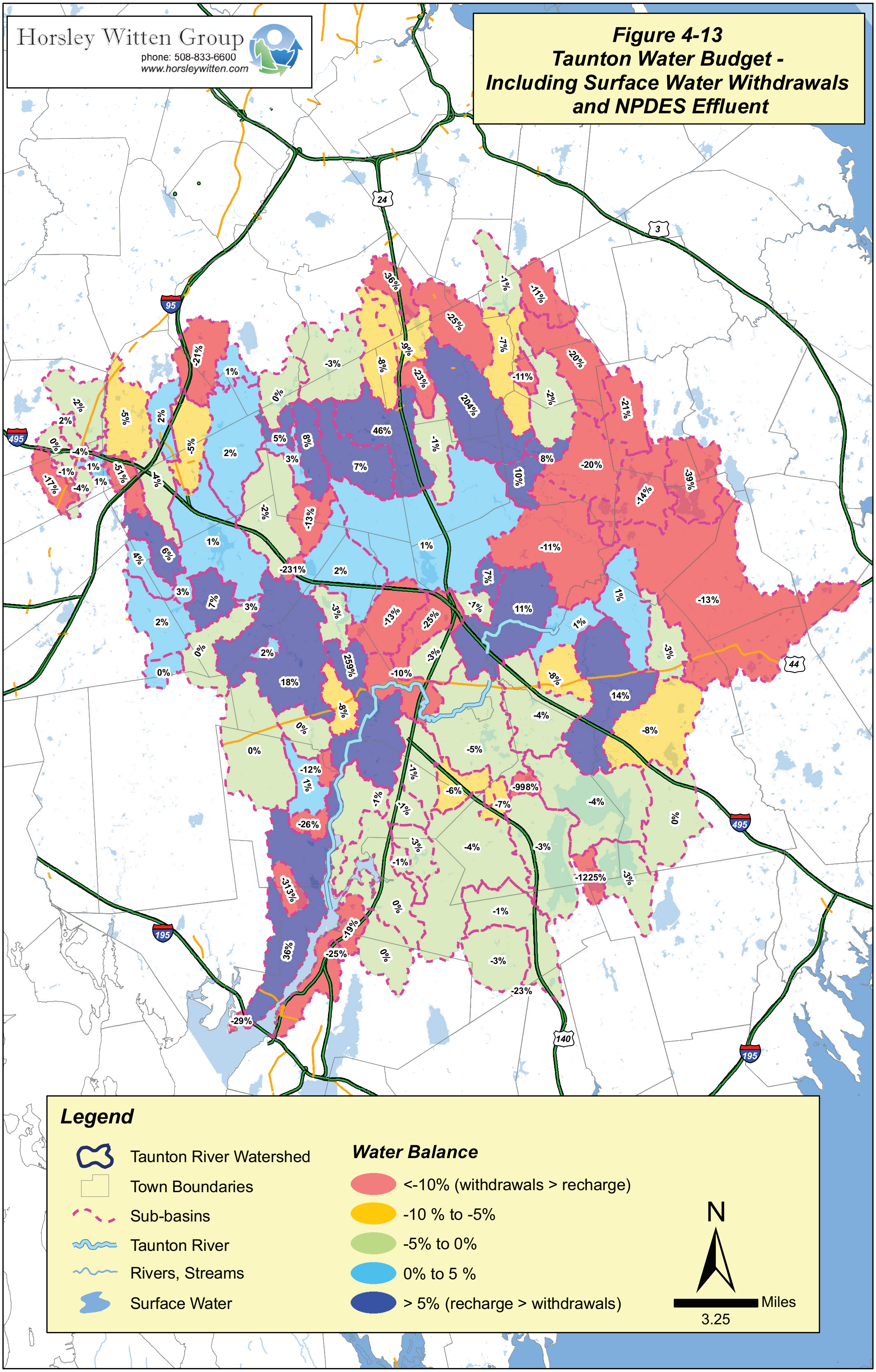


Figure 4-11
Taunton Water Budget - Excluding Surface Water Withdrawals and NPDES Effluent


Horsley Witten Group
phone: 508-833-6600
www.horsleywitten.com
Figure 4-13
Taunton Water Budget -
Including Surface Water Withdrawals
and NPDES Effluent
Legend
Taunton River Watershed
Town Boundaries
Sub-basins
Taunton River
Rivers, Streams
Surface Water
Water Balance
<-10% (withdrawals > recharge)
-10 % to -5%
-5% to 0%
0% to 5 %
> 5% (recharge > withdrawals)
N
Miles
3.25

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