GREAT MARSH COASTAL ADAPTATION PLAN

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Great Marsh Coastal Adaptation Plan

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Great Marsh Coastal Adaptation Plan available online at **www.nwf.org/GreatMarshAdaptation**

Cover: The Great Marsh, Parker River National Wildlife Refuge, Massachusetts. Photo: Kelly Fike/USFWS.

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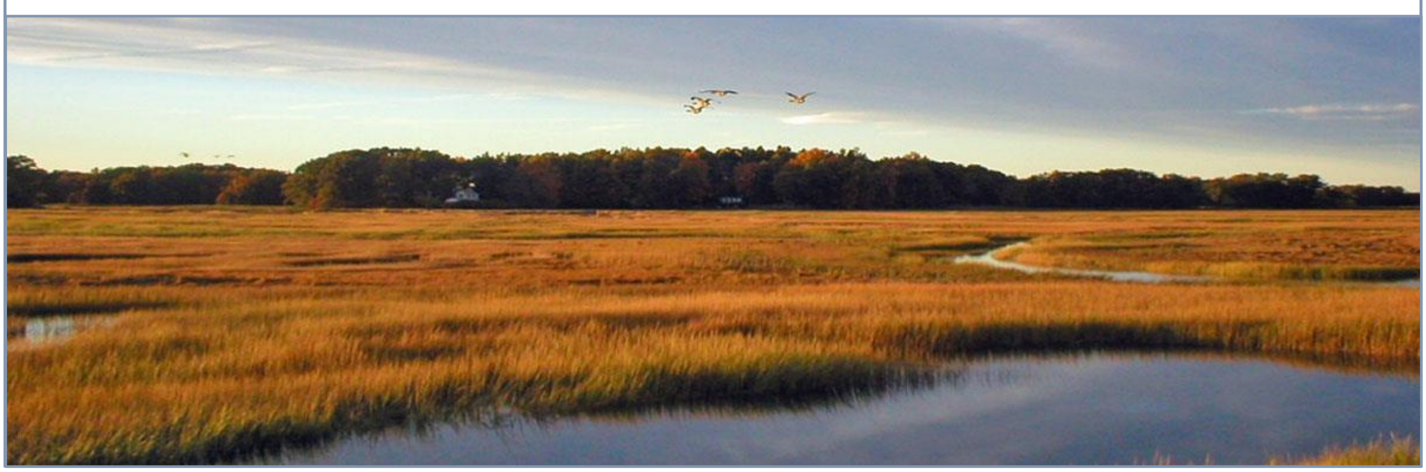

Matthew Kirwan/USGS

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CHAPTER 1
Introduction

Climate-driven threats are accelerating, and it is becoming abundantly clear that adaptation planning is no longer a luxury. Rather it is a necessity required to ensure public safety and well-being, strengthen economies and communities, and protect critical natural areas that support a wide variety of wildlife. While the impacts of climate change can be seen anywhere in the United States, and in the world, nowhere are the effects more obvious and perhaps more devastating than in low-lying coastal areas. Global sea levels are predicted to rise 0.3m – 1.2m (1 to 4 feet) by 2100 and potentially as much as 2m (6.6 feet) under certain worse case scenarios that are becoming more and more likely.[1,2] In addition, as warming temperatures fuel larger and more frequent storms, storm surge will combine with sea level rise to push ocean flooding even further inland. Unfortunately, as storm surge and sea level rise accelerate, the added stress to coastlines will lead to accelerating erosion rates and loss of coastline. In addition, the combined impacts of freshwater flooding and sea level rise pose the greatest risk to coastal areas.

As coastlines come under threat from increasingly severe impacts driven by a rapidly changing climate, it is important to acknowledge that the most vulnerable areas are also often the most heavily populated.

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[1] IPCC, *Climate Change 2014: Synthesis Report*. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, Switzerland, 2014), 59

[2] Walsh, J.D. et al., "Ch. 2: Our Changing Climate," in *Climate Change Impacts in the United States: The Third National Climate Assessment*, ed. J.M. Melillo, T.C. Richmond, and G.W. Yohe (Washington, DC: U.S. Global Change Research Program, 2014), 44

Here in the United States, 39 percent of our population live in coastal counties,[3] often concentrated in particularly low-lying areas vulnerable to even moderate amounts of sea level rise and storm surge. The US economy is also disproportionately reliant on coastal areas. In 2010, 58 percent of our nation's Gross Domestic Product (GDP) was generated in coastal watershed counties (this includes the Great Lakes region, which faces its own significant challenges from climate change).[4]

"All coasts share one simple fact: no other region concentrates so many people and so much economic activity on so little land, while also being so relentlessly affected by the sometimes violent interactions of land, sea, and air."[5]

The undeveloped portions of coastline, though relatively few and far between, are also of significant value and importance for both humans and wildlife. Coastal habitats provide a wide range of ecosystem services that directly benefit human communities. For instance, barrier beaches act as a first line of defense against the open ocean, absorbing wave energy and reducing penetrating storm surge. Similarly, healthy coastal marshes act as a sponge, soaking up flood waters before they reach dry land and human infrastructure. These coastal habitats are even more important for a variety of wildlife whose existence may depend on the preservation of such areas. Numerous rare, threatened, and endangered species rely on marshes and beaches for breeding, during migration, or as wintering habitat. As these habitats degrade or even disappear, many species will be put on a fast track towards extinction. The saltmarsh sparrow (*Ammodramus caudacutus*) is a prime example: This species nests exclusively in salt marshes along the east coast, and research indicates that because of sea level rise and human development, within the next 25 years the species' population may crash from 53,000 to 5,000. By 2070 the species may be extinct.[6]

Our climate is simply changing too rapidly for coastal ecosystems and coastal communities to thrive without direct and thoughtful intervention. From town planners and emergency management personnel to conservation biologists, there is a growing awareness that business as usual will not adequately protect our valued coastal areas. For coastal communities to flourish, stakeholders must act with intentionality and explicitly acknowledge and plan for change. Municipal planning must take into account that in 20 to 50 years coastlines will likely look noticeably different than they do today. Present day hazards like flooding and erosion will become much worse in the near future.

Philip R. Brown/www.nebirdsplus.com

Even in the face of uncertainty, communities should begin to take practicable steps to reduce their vulnerability to climate change. The primary goal of this Adaptation Plan is to guide communities within the Great Marsh towards a more vibrant and resilient future.

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[3] "What percentage of the American population lives near the coast?" NOAA, last updated July 6, 2017, http://oceanservice.noaa.gov/facts/population.html

[4] NOAA, *The Economic Value of Resilient Coastal Communities* (Silver Spring, MD, 2012), http://www.performance.noaa.gov/wp-content/uploads/EconomicValueofResilientCoastalCommunities.pdf

[5] Moser, S.C. et al., "Ch. 25: Coastal Zone Development and Ecosystems," in *Climate Change Impacts in the United States: The Third National Climate Assessment*, ed. J.M. Melillo, T.C. Richmond, and G.W. Yohe (Washington, DC: U.S. Global Change Research Program, 2014), 581

[6] Furfaro, Hannah, "The Saltmarsh Sparrow is Creeping Dangerously Close to Extinction," Audubon, posted August 23, 2016, http://www.audubon.org/news/the-saltmarsh-sparrow-creeping-dangerously-close-extinction

Complexities of Coastal Adaptation Planning

Adaptation planning, while incredibly necessary, is not an easy undertaking. Successful coastal adaptation planning, in the Great Marsh and elsewhere, must navigate a complex web of (1) interconnected human stressors, (2) competing stakeholder interests, and (3) dynamic ecosystems:

(1) Interconnected human stressors: Climate change, the focus of this Adaptation Plan, is far from the only stressor affecting our coastline. Human stressors include poor land-use planning that allows for overdevelopment along or in priority natural areas, increased runoff due to impervious surfaces, nutrient and bacterial pollution in stormwater runoff that degrades the freshwater and saltwater ecosystems, tidal and freshwater restrictions that contribute to habitat fragmentation, and increased water withdrawals that alter streams and aquifers. It is critical to pay attention to the range of human stressors when developing an adaptation plan as each stressor interacts with, and exacerbates, climate-driven threats.

(2) Competing stakeholder interests: The number of stakeholders with a vested interest in coastal management can present both an opportunity and a challenge. From federal, state, and local officials to recreation groups, industry, chambers of commerce, scientists, and others – each group has its own priorities and mandates. At times, the priorities can be seemingly at odds with one another. Some stakeholders may be inclined to prioritize short-term economic gains while others focus on long-term sustainability. Finding common ground to coalesce around can be challenging but is critical for successful coastal adaptation planning.

(3) Dynamic ecosystems: Lastly, coastal ecosystems are incredibly complex and dynamic. Tidal waterways, wetlands, beaches, barrier islands, and other coastal habitats are shaped by the interaction of a variety of biotic and physical processes. Over time, fluctuations in the climate, tidal ranges, salinity levels, and sediment transport can alter the location, distribution, and makeup of coastal ecosystems. For example, barrier islands naturally shift and reform after storms, waves, and currents erode sediment from one area of the island and deposit it elsewhere. These fluctuations are natural and even necessary to maintain the health of our coastline. However, the complexities and ever-changing nature can present

David Stone

challenges to coastal management. It is important to understand these natural processes and the site-specific conditions that ultimately shape our coastline. Understanding the natural processes and then working with them—not against them—is critical for enhancing the resilience of our coastline and coastal communities.

Project Geography

The Great Marsh is described by many as the coastal jewel of the Northeast. It's the largest salt marsh in New England, spanning over 20,000 acres of salt marsh, barrier beaches, and tidal estuaries. Extending from northeastern Massachusetts to southeastern New Hampshire, this sprawling complex of interconnected ecosystems encompass historic, quintessential coastal communities and major tourist destinations alike. To the north, the New Hampshire and Maine coastline becomes increasingly rocky with fewer large salt marsh blocks. To the south, the coastline becomes more developed and increasingly armored with revetments, bulkheads, and other engineered features that provide little or no wildlife habitat.

The Great Marsh has received numerous designations from federal, state, and non-profit entities recognizing it as "one of the most important coastal ecosystems in northeastern North America."[7] It has been designated a Critical Natural Landscape, Long Term Ecological Research Network site, Important Bird Area of Global Significance, Western Hemisphere Shorebird Reserve Network site (1 of only 2 in New England), and an Area of Critical Environmental Concern. Put simply: the fish and wildlife habitat in the Great Marsh is of unparalleled importance in the Northeast (for more information on the habitat and species found in the Great Marsh, see the natural resource portions of the town-specific vulnerability chapters in Sections 3.2-3.7).

The Great Marsh's ecological importance is matched only by its importance to human communities. Seven coastal Massachusetts communities are located within the Great Marsh: Salisbury, Newbury, Newburyport, Rowley, Ipswich, Essex, and Gloucester. Over 55,000 residents live in these communities and an additional 3.5 million people live and/or recreate in and around the north shore of Massachusetts. These communities rely on the Great Marsh to buffer storm damages, reduce coastal erosion, and dampen flooding. The marsh directly supports a thriving coastal tourism and commercial fishing economy, supporting more than 1,000 families.

Matt Poole/USFWS

The marsh, and the communities behind it, are protected by three major barrier beaches. Salisbury Beach stretches from the mouth of the Merrimack River north into New

[7] "The Great Marsh," Western Hemisphere Shorebird Reserve Network, http://www.whsrn.org/site-profile/great-marsh

Hampshire. Plum Island Beach also begins at the mouth of the Merrimack River and runs south through portions of Newbury, Newburyport, Rowley, and Ipswich. Crane Beach (Castle Neck) is located in Ipswich. The northern portion of Salisbury Beach is highly developed compared to the southern portion, which is owned by the MA Department of Conservation & Recreation. Meanwhile, the northern portion of Plum Island is highly developed while the southern portion is undeveloped and owned by the Parker River National Wildlife Refuge. Crane Beach is completely undeveloped and owned by the Trustees of Reservations.

Project Context

In October of 2012, communities witnessed one of the most devastating hurricanes to ever hit the United States. Formed in the Caribbean Sea, Hurricane Sandy became a monstrous storm as it tracked northward, wreaking havoc upon everything in its path. On October 29th, it slammed into the heavily populated Mid-Atlantic coastline of the United States. The impacts of the storm were felt as far south as the Carolinas and as far north as Maine and even Canada. According to the National Oceanic and Atmospheric Administration (NOAA), the storm was responsible for 147 deaths, destroyed at least 650,000 homes, and left approximately 8.5 million customers without power.[8] After the flood waters receded, officials began assessing the damage. Ultimately they determined that the storm resulted in over 71 billion in damage, making Hurricane Sandy the second most costly hurricane to impact the United States.[9]

As the storm passed and the magnitude of Hurricane Sandy's destruction became evident, the United States Congress passed the Disaster Relief Appropriations Act of 2013 and the Sandy Recovery Improvement Act of 2013, providing over $50 billion dollars in support to the states, communities, and individuals affected. Most of the appropriated funds went to the Federal Emergency Management Agency, the Department of Transportation, and the Department of Housing and Urban Development to provide immediate disaster relief. However $287 million went to the Department of the Interior which in turn created a grants program with a forward looking vision: to restore and improve coastal habitats to reduce communities' vulnerability to future storms. Named the "Hurricane Sandy Coastal Resiliency Competitive Grant Program" and administered by the National Fish and Wildlife Foundation (NFWF), the stated goal was to fund "projects that assess, restore, enhance or create wetlands, beaches and other natural systems to help better protect communities and to mitigate the impacts of future storms and naturally occurring events [such as sea level rise and erosion]."[10]

United States Air Force

Building off a long history of work by the Great Marsh Revitalization Task Force, the Great Marsh Coalition, and the Parker-Ipswich-Essex (PIE) Rivers Restoration Partnership, The National Wildlife Federation (NWF), in

[8] Blake, E.S. et al., *Tropical Cyclone Report Hurricane Sandy (AL182012)*, National Hurricane Center, February 12, 2013, http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf
[9] "The thirty costliest mainland United States tropical cyclones 1900-2013," NOAA Hurricane Research Division, http://www.aoml.noaa.gov/hrd/tcfaq/costliesttable.html
[10] "Hurricane Sandy Coastal Resiliency Competitive Grant Program," National Fish and Wildlife Foundation, http://www.nfwf.org/hurricanesandy/Pages/home.aspx

collaboration with the newly formed Great Marsh Resiliency Partnership, submitted a proposal to this grants program. The submittal was the culmination of a facilitated process where NWF convened relevant local, state, and federal agencies, not for profit organizations, and municipalities engaged in Great Marsh activities, the majority of geographically-oriented technical/research experts, as well as a number of educational institutions.

With these relevant stakeholders at the table, the Partnership worked together to identify all on-going work in the Great Marsh and then identified five project components (both new and ongoing) that would work together synergistically to reduce community vulnerability and increase the resiliency of the coastal ecosystems. The five project components included (1) marsh restoration, (2) dune restoration, (3) hydrodynamic sediment transport and salinity modeling, (4) hydro-barrier assessments, and (5) community adaptation planning. Below is a brief summary of each project component.

1. **Marsh Restoration:** The marsh restoration team was led by the Merrimack Valley Planning Commission (MVPC). Over 10,000 acres of marsh were assessed and treated where necessary to remove non-native, invasive Common Reed (*Phragmites australis*) and Perennial Pepperweed (*Lepidium latifolium*). In addition, a team from Boston University (BU) reestablished 2 acres of submerged aquatic vegetation (SAV), specifically eelgrass (*Zostera marina*), in the Essex Bay of the Great Marsh. This eelgrass restoration was supported by a concurrent program to catch and remove invasive European Green Crabs across 1,280 acres of habitat. To learn more about this effort, see "Perennial Pepperweed Control Project,"[11] "Eelgrass Restoration in Plum Island Sound and Essex Bay,"[12] and "Invasive Green Crab Removal."[13]

2. **Dune Restoration:** The University of New Hampshire and the Massachusetts Department of Conservation and Recreation (DCR), in close collaboration with local Conservation Commissions and other stakeholders, restored over 20 acres of priority dunes in Salisbury, Newbury, and Newburyport. DCR added over 9,500 cubic yards of sand along a roughly one-mile stretch of particularly degraded dunes. Scientists at the University of New Hampshire led the dune revegetation effort. Plantings were combined with various fencing techniques to promote dune stabilization, accretion, and resilience. These efforts also included extensive stakeholder outreach and education; in particular, dune planting served as an opportunity to engage schools and provided a "living classroom" where over 350 students participated in the restoration work. To learn more about this effort, see "Beach Dune Restoration: Newbury, Newburyport, & Salisbury."[14]

3. **Hydrodynamic Sediment Transport & Salinity Modeling:** The hydrodynamic model provides a detailed understanding of existing hydrologic and salinity conditions in the Great Marsh system, along with additional detail in priority sub-system estuaries to identify opportunities for restoration and evaluation of potential alternatives. Using this model, alternatives were assessed for their ability to restore salt marsh, mitigate potential negative flooding impacts to adjacent properties/infrastructure, and improve water quality for shellfishing, finfish, and wildlife habitat. Wave and sediment transport

[11] "Perennial Pepperweed Control Project," Mass Audubon, http://www.massaudubon.org/learn/nature-wildlife/invasive-plants/pepperweed/project
[12] "Eelgrass Restoration in Plum Island Sound and Essex Bay," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_32/
[13] "Invasive Green Crab Removal," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_31/
[14] "Beach Dune Restoration: Newbury, Newburyport, & Salisbury," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_26/

models were also developed for the coastal barrier island to better understand the regional sediment transport trends, identify patterns of erosion and accretion, and advise future shoreline management strategies. The modeling team included technical experts from Boston University, US Geological Survey, U.S. Fish and Wildlife Service, Woods Hole Group, Merrimack Valley Planning Commission and many others. To learn more about this effort, see "Great Marsh Hydrodynamic Modeling."[15]

In 2014, NWF was awarded $2.9 million dollars for the project titled "Community Risk Reduction through Comprehensive Coastal Resiliency Enhancement for the Great Marsh." This project offered a holistic and integrated approach to reducing the growing vulnerability of communities within the Great Marsh to coastal hazards by strengthening the resiliency of the ecological systems upon which those communities depend. Upon receipt of the award, this investment was leveraged by project partners to provide an additional $1.3 million dollars in research and conservation efforts in this priority coastal area.

4. **Assessment of Barriers to Flow:** The barrier team, led by the Ipswich River Watershed Association (IRWA), conducted a thorough infrastructure assessment of coastal and storm resilience of in-river structures throughout the coastal watersheds of the Great Marsh. They assessed approximately 1,000 potential barriers to natural flow as well as riverine and coastal processes using a combination of existing and field-collected data. The results of this analysis along with feedback from municipalities were used to prioritize high-risk and high-impact barriers in the region. The team developed preliminary design recommendations for upgrade of 100 of the highest priority structures. *See Appendix B for more information, including methodology and results.*

5. **Community Adaptation Planning:** The National Wildlife Federation and Ipswich River Watershed Association led a community-driven process to assess community vulnerability and develop operationally-feasible ecosystem-oriented adaptation strategies for the municipalities of Essex, Ipswich, Rowley, Salisbury, Newbury and Newburyport. The planning process resulted in the development and engagement of cross-sector municipal resiliency task forces, six town-specific summary vulnerability assessments, community engagement workshops focused on community vulnerability and resiliency strategy planning and development, task force prioritization of near-term and long-term risk-reduction strategies, and the development of this Great Marsh Coastal Adaptation Plan.

The proposal was supported by federal entities including: NOAA, US EPA (Region 1), USGS, and the Parker River National Wildlife Refuge (a project partner); several state entities including the Massachusetts Department of Conservation and Recreation, Division of Ecological Restoration, Division of Fisheries and Wildlife, Division of Marine Fisheries, and the Office of Coastal Zone Management (among others); and over 15 municipal entities and 20 non-governmental organizations, academic institutions, and community associations.

[15] "Great Marsh Hydrodynamic Modeling," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_25/

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CHAPTER 2

Community Adaptation Planning in the Great Marsh

This Great Marsh Coastal Adaptation Plan (hereinafter “Adaptation Plan”) is the product of the Community Adaptation Planning component of the project “Community Risk Reduction through Comprehensive Coastal Resiliency Enhancement for the Great Marsh,” further informed through the work achieved across all components of said project (see Chapter 1, page 7). The Community Adaptation Planning Team (hereinafter the “Project Team”), led by the National Wildlife Federation and Ipswich River Watershed Association, used the following approach and methodology to guide six communities (Salisbury, Newbury, Newburyport, Essex, Ipswich, and Rowley) through an adaptation planning process - with the overarching goal of identifying strategies to reduce community vulnerability to climate driven threats by increasing the resilience of the natural systems that the communities depend upon.

Approach: The Climate-smart Conservation Cycle

In 2014 the National Wildlife Federation published *Climate Smart Conservation: Putting Adaptation Principles into Practice.*[16] This formative report is a cornerstone for practitioners and technical experts in the climate adaptation field. The report offers a streamlined approach to designing and pursuing conservation in the face of a rapidly changing climate, based on several key characteristics of climate-smart conservation.

Box 2.1. Key characteristics of climate-smart conservation.[16]

Link Actions to climate impacts
Conservation strategies and actions are designed specifically to address the impact of climate change in concert with existing threats; actions are supported by an explicit scientific rationale.

Embrace forward-looking goals
Conservation goals focus on future, rather than past, climatic and ecological conditions; strategies take a long view (decades to centuries) but account for near-term conservation challenges and needed transition strategies.

Consider broader landscape context
On-the-ground actions are designed in the context of broader geographic scales to account for likely shifts in species distributions, to sustain ecological processes, and to promote cross-institutional collaboration.

Adopt strategies robust in an uncertain future
Strategies and actions ideally provide benefit across a range of possible future conditions (including extreme events) to account for uncertainties in climate, and in ecological and human responses to climatic shifts.

Employ agile and informed management
Planning and resource management is capable of continuous learning and dynamic adjustment to accommodate uncertainty, take advantage of new knowledge, and cope with rapid shifts in climatic, ecological, and socio-economic conditions.

Minimize carbon footprint
Strategies and projects minimize energy use and greenhouse gas emissions, and sustain the natural ability of ecosystems to cycle and sequester carbon and other greenhouse gases.

Account for climate influence on project success
Managers consider how climate impacts may compromise project success, and avoid investing in efforts likely to be undermined by climate-related changes unless part of an intentional strategy.

Safeguard people and wildlife
Strategies and actions enhance the capacity of ecosystems to protect human communities from climate change impacts in ways that also sustain and benefit fish, wildlife, and plants.

Avoid maladaptation
Actions to address climate impacts on human communities or natural systems do not exacerbate other climate-related vulnerabilities or undermine conservation goals and broader ecosystem sustainability.

[16] Stein, B.A., P. Glick, N. Edelson, and A. Staudt (eds.), *Climate-Smart Conservation: Putting Adaptation Principles into Practice* (Reston, VA: National Wildlife Federation, 2014)

In addition, *Climate Smart Conservation* lays out a 7-step process, or "climate-smart cycle," that can be followed to maximize the effectiveness of adaptation actions (Figure 2.1). While geared primarily towards natural resource adaptation planning, the process is equally applicable to community adaptation planning efforts. The climate-smart cycle directly informed the development of adaptation strategies and also directly guided the development of this adaptation plan.

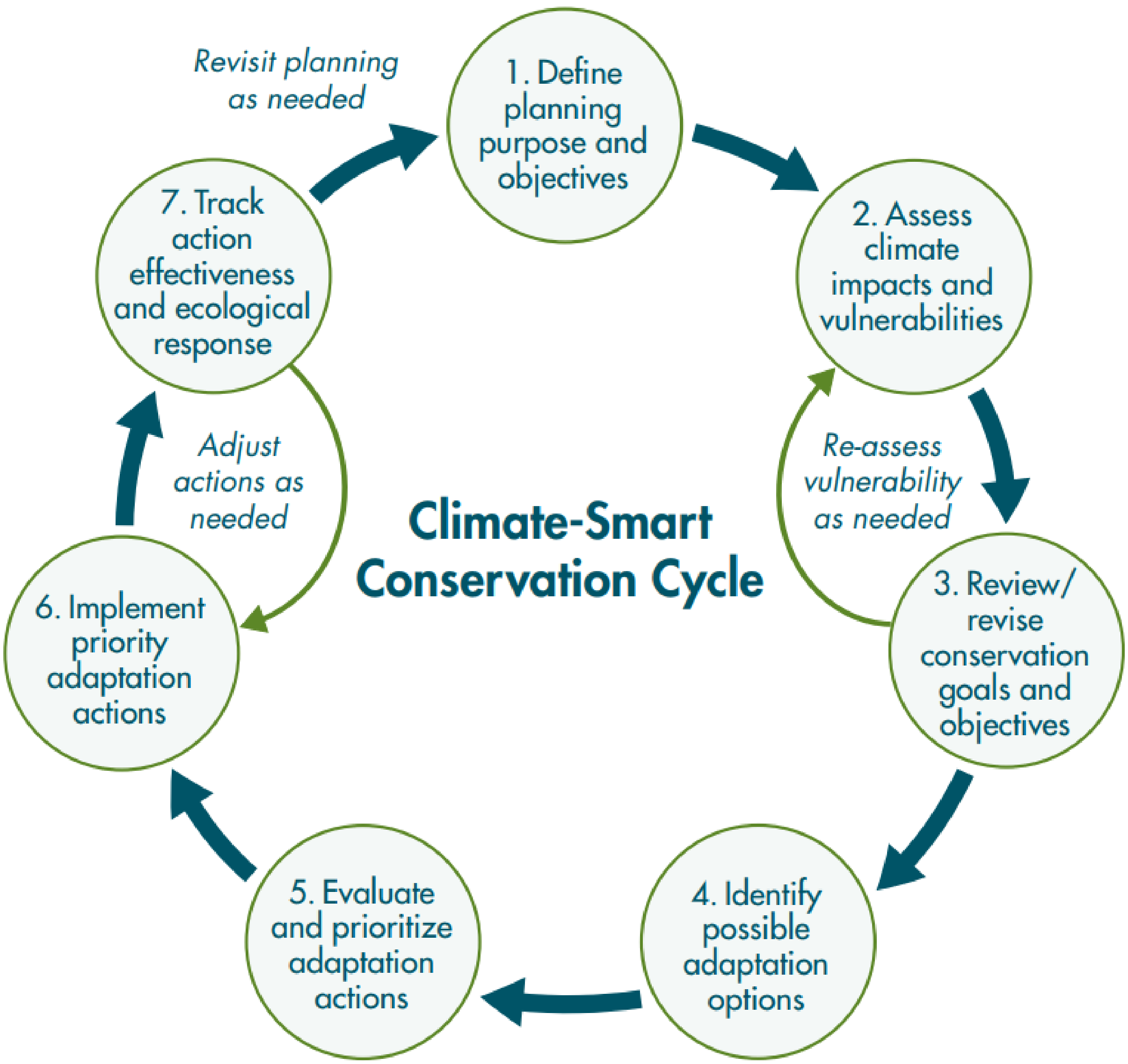

Figure 2.1. Climate-Smart Conservation Cycle. This cycle serves as the basis for this Community Adaptation Planning effort, and was used to help incorporate climate considerations throughout the planning process. *Source*: Stein, B.A., P. Glick, N. Edelson, and A. Staudt (eds.). 2014. *Climate-Smart Conservation: Putting Adaptation Principles into Practice*. National Wildlife Federation, Washington, D.C.

Methodology

The Project Team guided all six communities through the following planning process comprised of multiple steps and milestones (Table 2.1). Laying out the linear process is helpful to local stakeholders in understanding what this report offers, but it's also helpful for other adaptation practitioners who may want to use this project as a model for other geographies.

Table 2.1. Great Marsh Community Adaptation Planning Process Outline.

Step	Milestones
1. Established formal stakeholder engagement process for the duration of the project	Convened resiliency task forces with diverse local and regional representation
	Identified avenues for public outreach, public meetings, and information dissemination to be carried out throughout the project
2. Identified and prioritized potentially vulnerable community assets	Synthesized relevant information from hazard mitigation plans and other existing documents
	Convened resiliency task force meetings to identify stakeholder priority assets
3. Assessed both asset and overall community vulnerability to present and future climate impacts	Mapped projected coastal inundation for present, 2030, and 2070
	Conducted geospatial hazard analysis
	Convened resiliency task force meetings to gather local input on vulnerabilities
4. Identified co-benefit ecosystem-oriented adaptation strategies that reduce risk and increase resiliency	Compiled and synthesized coastal adaptation strategies from best-available scientific literature
	Convened resiliency task forces to identify current adaption projects and locally-informed strategies
5. Evaluated and prioritized adaption strategies	Categorized and prioritized strategies based on input from technical experts, review of site-specific considerations, implementation feasibility and co-benefits provided
6. Developed Regional Coastal Adaptation Plan	Combined town-specific vulnerability assessments and adaptation strategies into one document
	Peer reviewed the report and solicited input from the local and regional resiliency task force members
	Conducted outreach and hosted public events to disseminate the findings in the report

Step 1. Established formal stakeholder engagement process for the duration of the project.
Community engagement and participation is critical in coastal adaptation planning because local knowledge can often play a key role in understanding the nuances and implications of existing and future hazards. Similarly, local stakeholders are often most familiar with site-specific considerations that must be addressed when developing adaptation strategies. Most importantly, community engagement lays the

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framework, and builds support, for future implementation of on-the-ground adaptation strategies. Recognizing these factors, at the beginning of the project, Municipal Resiliency Task Forces were established in each of the six communities. The makeup of each task force varied, but generally included town planners, conservation agents, emergency management personnel, members of the select board, and city engineers, among others. Over 40 individuals served on these task forces and an additional 9 members served as regional representatives. Regional representatives included state and federal agency personnel, regional planners, and local NGO representatives. These task force members provided critical local representation throughout the vulnerability assessment and adaptation planning process. During the course of the project, task force members convened at five meetings and collaborated regularly across monthly conference calls. Task force members reviewed and edited this document (see Chapters 3 and 4 on vulnerability assessments and adaptation planning to learn more about how these task forces engaged in this process).

While the task forces were the backbone of the planning process, additional and extensive outreach was also conducted throughout the project. The Project Team designed and printed town-specific outreach brochures[17] for each community involved in the planning process. These brochures highlighted the threats facing each community, an overview of the work occurring in each town to address those threats, and directions on how to engage and further participate in adaptation efforts. More than 1,000 hard copies of the brochures were distributed throughout the six communities. In addition, the brochures were made available on the Great Marsh Resiliency website[18] and were emailed in electronic newsletters sent by the Ipswich River Watershed Association, the PIE-Rivers Partnership, and the Storm Surge citizens group. Community meetings were also held during both the vulnerability assessment and adaptation planning phase of the project. Task force meetings and public meetings together directly engaged close to 500 individuals. Meetings were held during the day and the evenings to reach a maximum number of local residents. The meetings were designed to inform attendees of the planning project, the risks each community is facing, the range of strategies to reduce those threats, and why certain strategies may be more effective than others. Furthermore, at each meeting, local residents were given the opportunity to provide input, share information, raise concerns, and ask questions. These meetings were an outreach tool and served as a useful opportunity to learn more about the concerns of local residents.

Step 2: Identified and prioritized potentially vulnerable community assets. In close coordination with the task forces, the Project Team identified and inventoried community assets deemed vulnerable to present and future climate-driven threats. These assets were located in close proximity to areas that suffer from freshwater flooding, coastal inundation, and erosion. Initial assets identified were wide-ranging and included roads, public facilities, critical infrastructure, open space and natural areas, natural resources, discreet neighborhoods, dams, and other areas, sites, and facilities considered important to the overall community. After the initial list of assets was compiled, the Project Team led task force

[17] "Great Marsh Resiliency Planning Project: Preparing Communities for the Future," PIE-Rivers, http://www.pie-rivers.org/new-outreach-materials/
[18] "Great Marsh Resiliency Project," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_21/

members through a facilitated process of categorizing and prioritizing these assets based on current vulnerability and perceived overall importance to the communities' wellbeing.

Box 2.2. Defining vulnerability.

According to the Intergovernmental Panel on Climate Change (IPCC), vulnerability to climate change is defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity."[19]In other words, something is vulnerable if it is *exposed* and *sensitive* to the impacts of climate change and at the same time has only limited capacity to *adapt*.

To better understand this concept, imagine a building that is being assessed for flood vulnerability resulting from sea level rise and storm surge. *Exposure* would refer to the likelihood of the climate hazards occurring in the vicinity of the building. Is the building located near the ocean? Does the area regularly flood? Are there erosion issues? *Sensitivity* refers to the intrinsic nature of the asset and how it will be impacted if it is exposed to a climate hazard. Is the building constructed out of wood? Is the building showing signs of deteriorating and in need of structural repairs? *Adaptive capacity* refers to the ability of an asset or system to accommodate or cope with climate hazards with minimal disruption.[20]Is the building flood proofed? Is it raised on stilts?

Step 3: Assessed both asset and overall community vulnerability to present and future climate impacts. Once the communities' current priorities were identified, the Project Team initiated a comprehensive geospatial analysis to assess overall community vulnerability, identify additional vulnerable assets, and assess the future vulnerability of the priority areas of concern identified by the task force. Using cutting edge inundation modeling from the Woods Hole Group, the US Geological Survey (USGS) integrated the geospatial inundation data with various economic, demographic, land use, and infrastructure data to estimate the amount and relative percentage of specific societal assets likely to be inundated by coastal flooding. The analysis looked at projected inundation for the present day, 2030, and 2070. USGS grouped the probability of inundation into "high", "medium", "low", and "very low" hazard zones, allowing the community to bracket results based on the level of risk they wanted to analyze. *To learn more about the methodology used by the USGS for their analysis, see Appendix A or see Abdollahian, N. et al. (2016).*

Results from the geospatial analysis, inundation modeling, and local input were combined into town-specific vulnerability assessments (see Section 3.2-3.7). In addition, a wealth of pertinent information contained in previous reports, hazard mitigation plans, and other planning documents was also incorporated. Town-specific vulnerability assessments were reviewed by task force members and their input was incorporated through multiple rounds of revisions.

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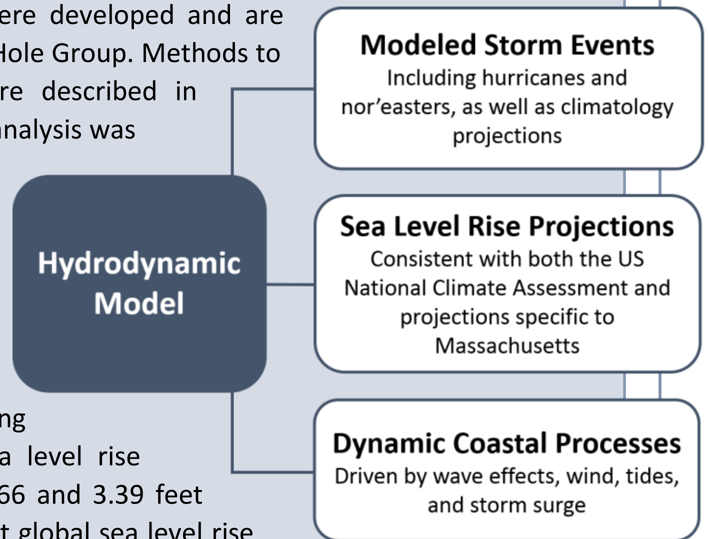
[19] IPCC, *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E.Hanson (Cambridge, UK: Cambridge University Press, 2007), 6

[20] Glick, P., B.A. Stein, and N.A. Edelson, eds., *Scanning the Conservation Horizon – A guide to Climate Change Vulnerability Assessment* (Washington, DC: National Wildlife Federation, 2011), 20

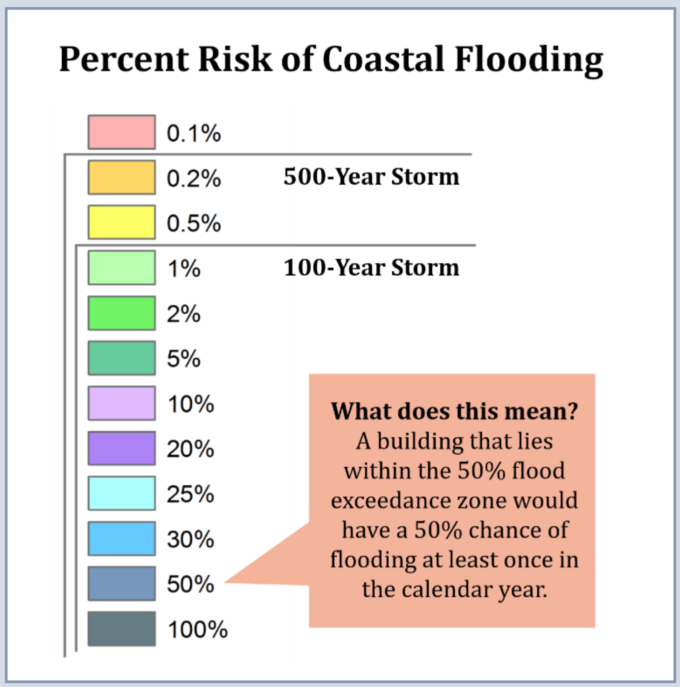
Box 2.3. Modeling future effects of coastal storms and sea level rise.

Coastal-inundation-hazard zones used in this study were developed and are summarized in geospatial data provided by the Woods Hole Group. Methods to develop the various scenario-based hazard zones are described in Kleinfelder (2015).[21] Water-elevation modeling in their analysis was based on a fully optimized Monte Carlo approach to simulate the influence of climate change on sea level, tides, waves, and the track and intensities of tropical (hurricanes) and extra-tropical (nor'easters) storms. This model does not take into account inland, freshwater flooding.



The spatial resolution of modeling efforts varied, ranging from 1 to 10 meters, based on data availability. Sea level rise assumptions for 2030 and 2070 hazard zones were 0.66 and 3.39 feet relative to mean sea level, respectively, which represent global sea level rise projections for the "highest" scenario by the Intergovernmental Panel on Climate Change[22] and Parris et al.[23]

Inundation modeling from Woods Hole Group include scenarios for 2013 (representing present day and hereafter referred to as "current" hazard zones), 2030, and 2070.[24] For each time scenario, mapped inundation-probability values ranged from 0.1% to 100% with 12 discrete classes. A percentage refers to the likelihood that coastal inundation will occur in a certain area during a 365 day period. Coastal inundation is defined as flood water (at a depth greater than or equal to 2 inches (5 cm)) encroaching on the surface at a particular location. USGS grouped the inundation probability values into four categories: high probability (100%), medium probability (25%, 30%, and 50%), low probability (1%, 2%, 5%, 10%, and 20%), and very low probability (0.1%, 0.2%. and 0.5%).



[21] Kleinfelder, *Coastal climate change vulnerability assessment and adaptation plan: City of Gloucester, MA* (Cambridge, MA, 2015) http://gloucester-ma.gov/DocumentCenter/View/3416

[22] IPCC, Climate Change 2014, 59

[23] Parris, A. et al., *Global Sea Level Rise Scenarios for the United States National Climate Assessment*, NOAA Tech Memo OAR CPO-1 (Silver Spring, MD: National Oceanic and Atmospheric Administration, 2012), 37

[24] Famely, J. et al., *Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA)*, Prepared by Woods Hole Group for National Wildlife Federation and U.S. Geological Survey (Falmouth, MA, 2016)

Step 4: Identified ecosystem-oriented adaptation strategies that reduce risk and increase resiliency. As the vulnerability assessments were finalized, phase two of the project began: identifying co-benefit adaptation strategies that reduce community vulnerability to current and future climate threats and improve the resilience of the natural ecosystems. To begin, the Project Team reviewed and synthesized over 50 documents, reports, and plans to identify a full array of possible adaptation strategies. Documents included local and regional adaptation plans, peer-reviewed journal articles, fact sheets, as well as government and NGO publications. While all documents were reviewed, particular attention was given to documents outlining strategies for the northeast and Massachusetts in particular; these documents generally outlined strategies that took into account site-specific considerations of the New England coastline and specific Massachusetts state policies. The Project Team also incorporated information gathered through a separate project where the National Wildlife Federation, in partnership with the Mid-Atlantic Regional Ocean Council (MARCO), conducted over 100 interviews with coastal adaptation experts and practitioners from the New York, New Jersey, Delaware, Maryland, and Virginia. The goal of these interviews was to identify the most pressing challenges and state of activity regarding the use and implementation of natural and nature-based features for enhancing coastal resilience in the Mid-Atlantic. This extensive review of literature and findings on relevant approaches was synthesized into an adaptation catalog containing approximately 90 coastal adaptation strategies.

The Project Team then expanded the list of strategies through a facilitated process**.** The Project Team convened task force meetings to engage local stakeholders on the coastal adaptation strategies identified in Step 1, and to expand this list of strategies even further. During in-person meetings, the Project Team met with local emergency management officials, planners, and others to inform them of the range of strategies available, but more importantly to get input and solicit ideas on additional strategies being considered at the local level.

Step 5: Evaluated and prioritized adaption strategies. The Project Team began categorizing and prioritizing coastal adaptation strategies based on site-specific considerations in each community, current state policies and regulations, and the overall practicality of each strategy to mitigate specific hazards in each community. Approximately 3-5 priority adaptation strategies were identified for each primary Area of Concern (see Section 4.2). To solicit feedback on the specific recommended strategies identified to reduce the vulnerabilities, the Project Team met with outside technical experts with expertise in the Great Marsh region, including three consulting and engineering firms (Horsley Witten Group, Chester Engineers, and Kleinfelder) and MA Coastal Zone Management. Input from these meetings was incorporated into the list of recommended strategies. Similar technical expert elicitation also occurred across a day-long workshop aimed at identifying specific strategies to improve overall ecosystem health and resilience. The workshop convened approximately 20 natural resource professionals representing numerous agencies and non-profits working in the Great Marsh, including US Fish and Wildlife Service, MA Dept. of Marine Fisheries, MA Division of Ecological Restoration, Mass Audubon and several others.

Step 6: Developed Great Marsh Coastal Adaptation Plan. The most relevant and useful information collected during the adaptation planning process was incorporated into an adaptation strategy summary document that addressed how to reduce the vulnerabilities of specific areas of concern as well as overall community vulnerability. That document was incorporated into this final plan and sent to local stakeholders and technical experts for review and input before being finalized.

Joe Teixeira

CHAPTER 3

Assessing Climate Impacts and Vulnerabilities

This section is a distillation of relevant information summarizing current and projected climate-driven threats and the associated vulnerability of six shorefront communities (Salisbury, Newbury, Newburyport, Essex, Ipswich, and Rowley) along the Great Marsh, as well as the natural resources they depend upon.

3.1. Summary of Threats

Climate change is easily one of the greatest challenges of this generation and the consequences associated with a rapidly changing climate are widely evident. Across the globe, patterns of precipitation are changing and surface temperatures are increasing. According to the IPCC, global surface temperatures, both land and ocean temperatures combined, have increased by 0.85 (0.65 – 1.06)^{o}C from 1880 to 2012 (an increase of 1.53⁰F).[25] The last three decades alone have been consecutively warmer than any decade prior to 1850, and 2014 was the second hottest year on record, only to be topped by 2015 which was even hotter.[26, 27] Global sea levels are also rising due to thermal expansion of our oceans and an influx of freshwater inputs from melting glaciers and ice sheets. Since 1880, sea levels have risen 0.2 meters (8 inches) and are predicted to rise another 0.3m – 1.2m (1 to 4 feet) by 2100 (Figure 3.1-1), and potentially as much as 2m (6.6 feet) under certain worse case scenarios.[28,29]

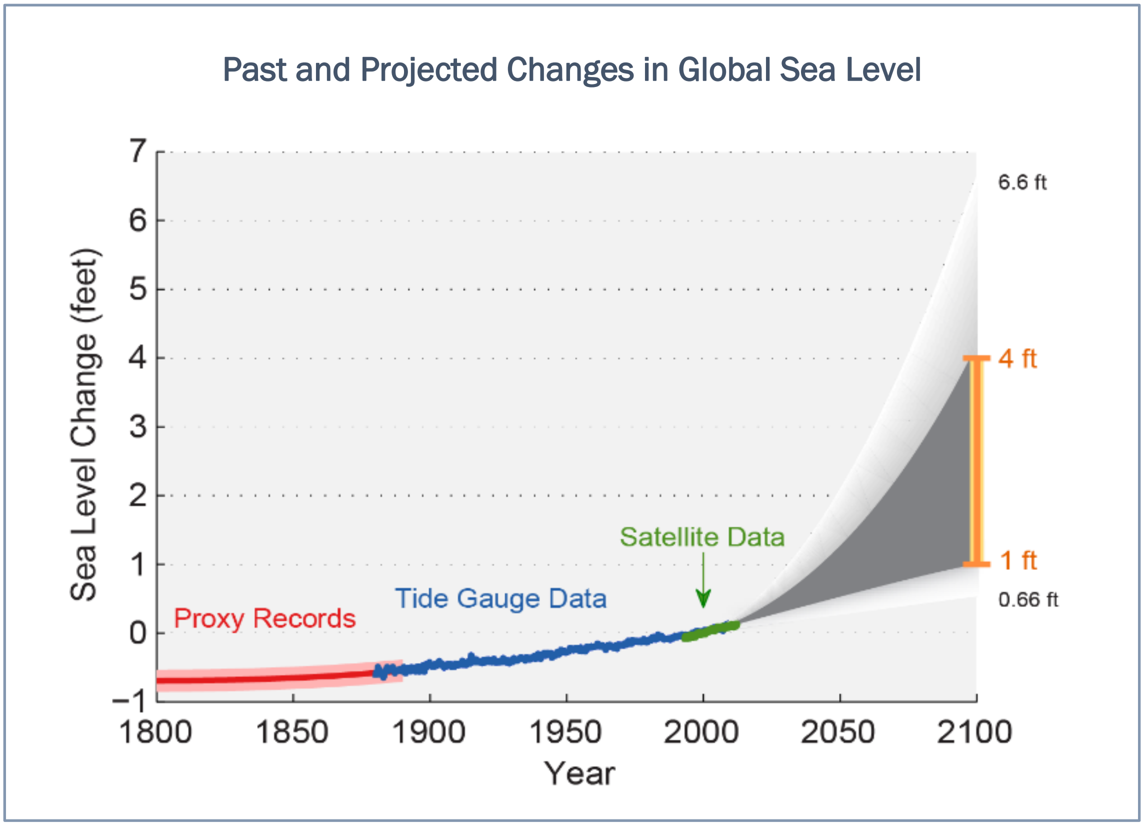


Figure 3.1-1. Estimated, observed, and possible future amounts of global sea level rise from 1800 to 2100, relative to the year 2000.[29]

Worldwide, the trends are clear – temperatures and sea levels are rising, droughts are becoming more frequent and severe, and large storms such as Hurricane Sandy are becoming more common. However the threats posed by climate change will not be uniform across the globe. Where some regions are experiencing more frequent drought, others will experience an increase in extreme precipitation events.[30] For example, between 1958 and 2010, the northeastern United States experienced a 70% increase in the

[25] IPCC, *Climate Change 2014,* 2
[26] "NASA, NOAA Find 2014 Warmest Year in Modern Record," NASA, January 16, 2015, https://www.nasa.gov/press/2015/january/nasa-determines-2014-warmest-year-in-modern-record
[27] "Climate Monitoring Summary Information," NOAA, accessed March 3, 2016, http://www.ncdc.noaa.gov/sotc/summary-info/global/201512
[28] IPCC, *Climate Change 2014,* 59
[29] Walsh, J.D. et al., "Ch. 2: Our Changing Climate," 44
[30] Ibid 33

amount of precipitation occurring during heavy rainfall events – an increase far greater than any other region in the U.S.[31]

In Massachusetts, the climate is already changing and the impacts have been widespread. Since 1895, the average annual temperature for the state has increased significantly, particularly since 1970. As shown in Figure 3.1-2, from 1970 to 2015, the average temperature has increased 0.28^{o}C (0.5^{o}F) every decade – with most recent years showing the steepest rise in temperatures above the historical average.[32]

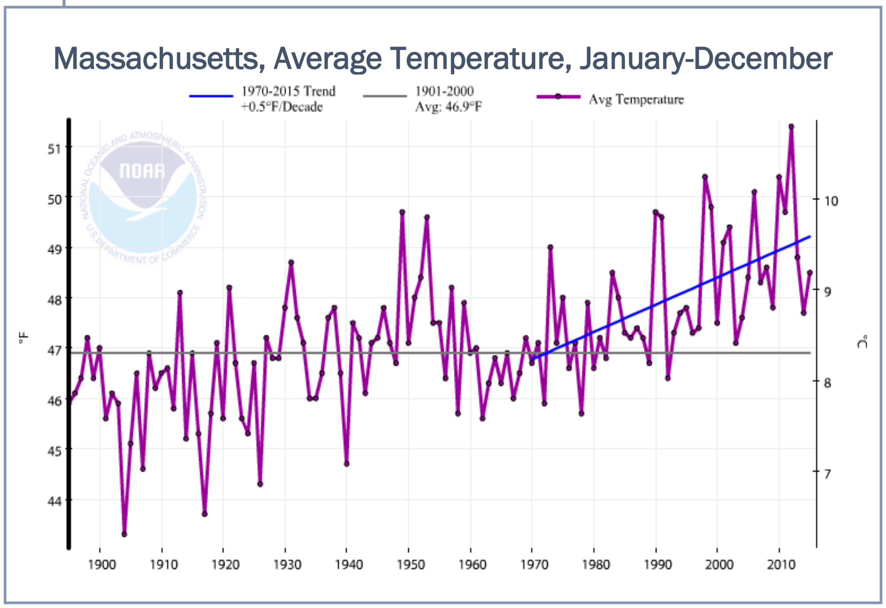


Figure 3.1-2. Average annual temperature in Massachusetts from 1895 to 2015. Trend line shows 0.5^{0}F increase in temperature per decade from 1970-2015.[32]

The Massachusetts coast is also experiencing significant sea level rise. Due to land subsidence and ocean currents, the state has a slightly higher rate of sea level rise than the global average.[33] Based on data collected from 1921 to 2015, Massachusetts has experienced a relative sea level rise of 0.28 centimeters annually (0.11 inches/year), which is equivalent to a rise of 0.28 meters (0.92 ft) in 100 years.[34] Sea level rise is expected to accelerate, perhaps drastically, over the next century (Table 3.1-1).[35] Three sea level rise scenarios are presented in accordance with the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: highest, intermediate, and lowest. The highest, or worst case, scenario is based on estimated rise in ocean temperatures leading to thermal expansion combined with maximum melting of glacier and ice sheets. The lowest scenario assumes a historical rate of sea level rise with no increase due to climate change. For more information on these scenarios, see the Boston Research Advisory Group's 2016 report on *Climate Change and Sea Level Rise Projections for Boston."*[36] Sea level rise associated with any but the lowest scenario will lead to significantly higher mean high tides and will contribute to an increase in storm surge height and the frequency of associated coastal flooding.

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[31] Horton, R.G. et al., "Ch. 16: Northeast," in *Climate Change Impacts in the United States: The Third National Climate Assessment,* ed. J.M. Melillo, T.C. Richmond, and G.W. Yohe (Washington, DC: U.S. Global Change Research Program, 2014), 373

[32] "Climate at a Glance," NOAA, accessed April 1, 2016, http://www.ncdc.noaa.gov/cag/

[33] Massachusetts Executive Office of Energy and Environmental Affairs (MA EEA), *Massachusetts Climate Change Adaptation Report* (Boston, MA, 2011), 16

[34] "Mean Sea Level Trend 8443970 Boston, Massachusetts," NOAA, accessed March 6, 2016, http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8443970

[35] Boston Research Advisory Group (BRAG), *Climate Change and Sea Level Rise Projections for Boston: The Boston Research Advisory Group Report,* prepared for the Climate Ready Boston project (Boston, MA, 2016), 6

[36] Ibid 9-14

Table 3.1-1. Sea level rise projections for Boston, MA (measurements in feet, relative to 2000) categorized by likely range (0.833-0.167 exceedance probabilities) and estimates of the maximum physically plausible (0.001 exceedance probability).[37]

	2030		2050		2070		2100		2200	
Scenario	**Likely Range**	**Max**	**Likely Range**	**Max**	**Likely Range**	**Max**	**Likely Range**	**Max**	**Likely Range**	**Max**
Highest	0.3-0.7'	1.2'	0.7-1.5'	2.4'	1.5-3.1'	4.8'	3.2-7.4	10.5'	21.4-32.8'	36.9'
Intermediate	0.3-0.7'	1.2'	0.7-1.4'	2.3'	1.3-2.6'	4.1'	2.4-5.1'	8.0'	7.2-16.5'	20.9'
Lowest	0.3-0.7'	1.2'	0.6-1.4'	2.3'	1.1-2.3'	3.6'	1.8-3.8'	6.2'	5.2-7.7'	11.8'

Although ocean temperature increases are not typically considered a major threat to coastal Massachusetts, it is still pertinent to note that the annual mean sea surface temperature in Massachusetts has increased annually by 0.04°C (0.07°F) and overall by 1.3°C (2.3°F) (from 1970-2002).[38] By 2050, sea surface temperature is projected to warm by an additional 1.7°C (3°F) and by the end of the century could increase 2.2°C to 4.4°C (4° to 8°F) depending on the level of greenhouse gas emissions.[39] Such a rise in sea temperature may significantly impact many coastal and marine animals, including commercially important species. The impacts are already being felt in the state with many formally "southern" marine species becoming increasingly common along the North Shore.[40]

Other significant changes observed in the state's climate include reduced snowpack, earlier snow melt and spring peak flows, and an increase in the occurrence of days with temperatures above 32°C (90°F).[41] Based on data collected from 1958 to 2012, the amount of rain falling during extreme precipitation events has also increased by 71% in the Northeast – more than anywhere else in the country.[42] Increasing storm frequency and severity is often considered one of the biggest climate-driven hazards in the Northeast. Compared to historical levels, the North Shore, along with all of eastern Massachusetts, has already seen an increase in extreme precipitation events – defined as a storm dropping more than two inches of rain.[43] These downpours often lead to damaging floods. During the famous Mother's Day flood in 2006, flood waters wreaked havoc upon many coastal communities; 38.1 cm (15 in) of rain fell over the course of about four days, overwhelming drainage systems, culverts, and bridges. These extreme precipitation events are predicted to increase by an additional 8% by 2050 and up to 13% by the end of the century.[44] Due to projected increases in precipitation, by 2050, areas like Boston could experience the present-day "100-year" riverine flood as frequently as every two to three years and possibly once a year by 2100.[45,46]

[37] Boston Research Advisory Group (BRAG), *Climate Change and Sea Level Rise Projections for Boston,* 12
[38] MA EEA, *Massachusetts Climate Change Adaptation Report*, 15
[39] Ibid
[40] Wayne Castonguay (Executive Director of the Ipswich River Watershed Association), personal communication with authors, September 15, 2015
[41] MA EEA, *Massachusetts Climate Change Adaptation Report*, 1
[42] Walsh, J.D. et al., "Ch. 2: Our Changing Climate," 37
[43] MA EEA, *Massachusetts Climate Change Adaptation Report*, 19
[44] Ibid
[45] Ibid
[46] BRAG, *Climate Change and Sea Level Rise Projections for Boston,* 17

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3.2. Town of Salisbury Vulnerability Assessment

Community Exposure to Climate Hazards

Salisbury is the northernmost coastal community in Massachusetts. It is nestled between the Merrimack River to the south and New Hampshire to the north. It is a relatively small community with a land mass of 15.4 square miles, of which approximately 38% is forested.[47] The Great Marsh, the largest contiguous salt marsh in New England, makes up 27% of the landmass in Salisbury, while residential and commercial, and industrial development combined make up about 10%.[48]

According to the 2010 Federal Census, there were approximately 8,283 year-round residents living Salisbury. However in the summer, according to some estimates, the population can increase to as many as 24,000. The majority of the town's infrastructure is located in two sections: Salisbury Beach and Salisbury Square. Salisbury Beach is a 3.8 mile long barrier beach with dense residential and commercial development. This area of the community is especially vibrant during summer months. Salisbury Square, located approximately two miles inland, is the town center and consists of municipal buildings, stores, and residences.[49]

[47] MVPC, "Town of Salisbury Natural Hazard Risk Assessment," in the *Draft Merrimack Valley Multi-Hazard Mitigation Plan* (Haverhill, MA, 2015), 232

[48] Ibid

[49] Ibid

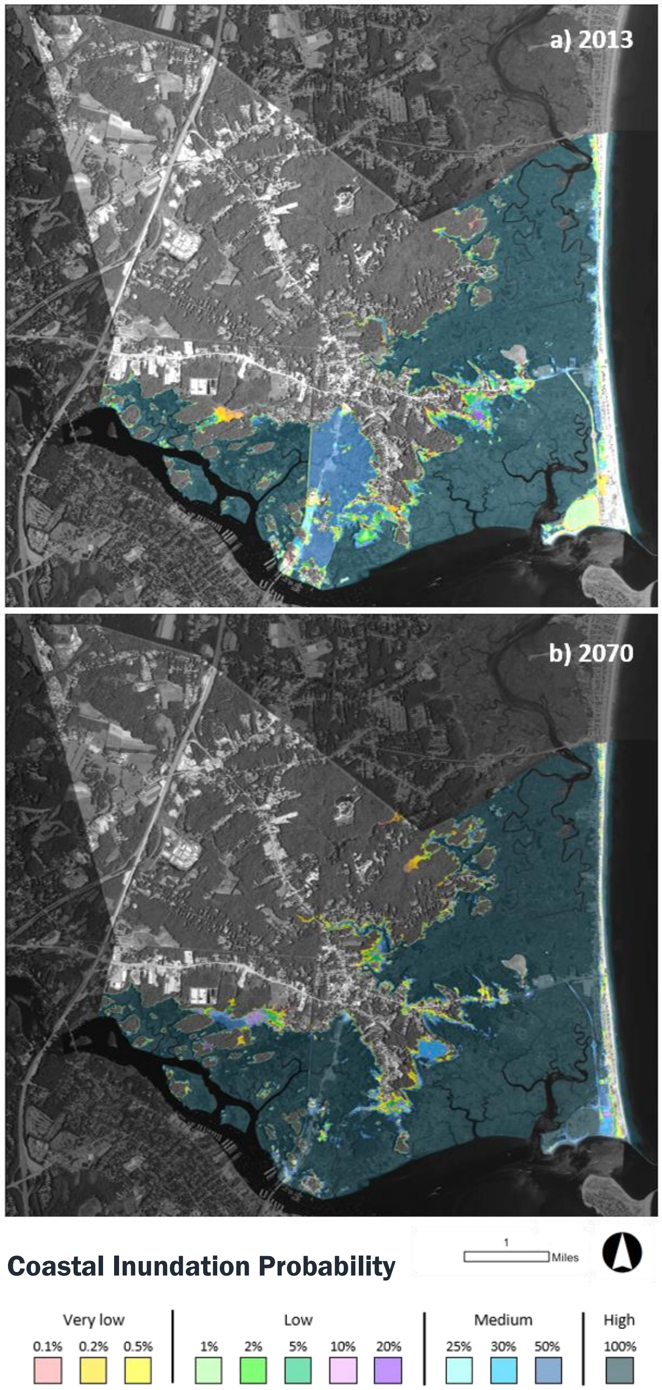

Figure 3.2-1. Salisbury, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

Salisbury spans two major watersheds – the Merrimack River and the Blackwater River Watersheds. The Merrimack River separates Salisbury from Newburyport and is the largest river in northeastern Massachusetts. The Blackwater River separates Salisbury Beach from the mainland and runs south to north, draining approximately nine miles of tidal estuary into Hampton Harbor, New Hampshire.[50] Like many North Shore communities, much of Salisbury is low-lying, leading to high exposure to sea level rise and flooding hazards. During storms and abnormally high-tides, water courses through tidal channels, carrying flood waters inland. Improperly sized culverts and bridges create hydro-barriers that often act as choke points causing tidal creeks to spill out of the marsh into surrounding areas. The natural topography combined with erosion and tidal restrictions lead to chronic coastal and riverine flooding.

Salisbury Beach has particularly high exposure to erosion. With almost four miles of sandy beach and dunes facing the open Atlantic Ocean, this barrier beach is the first line of defense against storm surge and sea level rise. The continuous onslaught of waves and wind have led to beach erosion. Large storms can also cause acute erosion events where large sections of beach are completely swept away. Largely due to its high exposure and significant coastal development, Salisbury experiences the highest level of erosion of any of the North Shore communities.[51]

A detailed analysis of coastal inundation, conducted by the Woods Hole Group and USGS, confirms that the Town of Salisbury has extremely high exposure to sea level rise and storm surge. Present day estimates (which are for the year 2013) indicate approximately 40% of the town is vulnerable to coastal inundation – depending on the severity of the storm. That number climbs to 45% in 2070 (Figure 3.2-1).[52] It is apparent that in a worst case storm scenario, much of the town would be under water from penetrating storm surge.

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[50] USACE, *Draft Detailed Project Report and Environmental Assessment: Local Flood Protection Blackwater River Salisbury, Massachusetts* (Concord, MA: U.S. Army Corps of Engineers, New England District, 2006), 4

[51] MA EEA, *Shoreline Characterization and Change Analyses: North Shore Region* (Gloucester, MA, 2014) http://www.mass.gov/eea/docs/czm/erosion-commission/shoreline-profile-north-shore.pdf

[52] Abdollahian, N. et al., *Community exposure to potential climate-driven changes to coastal-inundation hazards for six communities in Essex County, Massachusetts*, U.S. Geological Survey open-file report (Reston, VA: USGS, 2016), 6-7

Additionally, the community's high exposure to coastal flooding is evidenced by the large amount (19%) of developed land that is currently vulnerable to coastal inundation under a worst case storm scenario. However even more telling is the fact that of the 19%, much of the developed land is in areas likely to flood on an annual or near semi-annual basis, especially by 2070. Undeveloped land has even higher exposure to inundation, now and in 2070 (Figure 3.2-2).

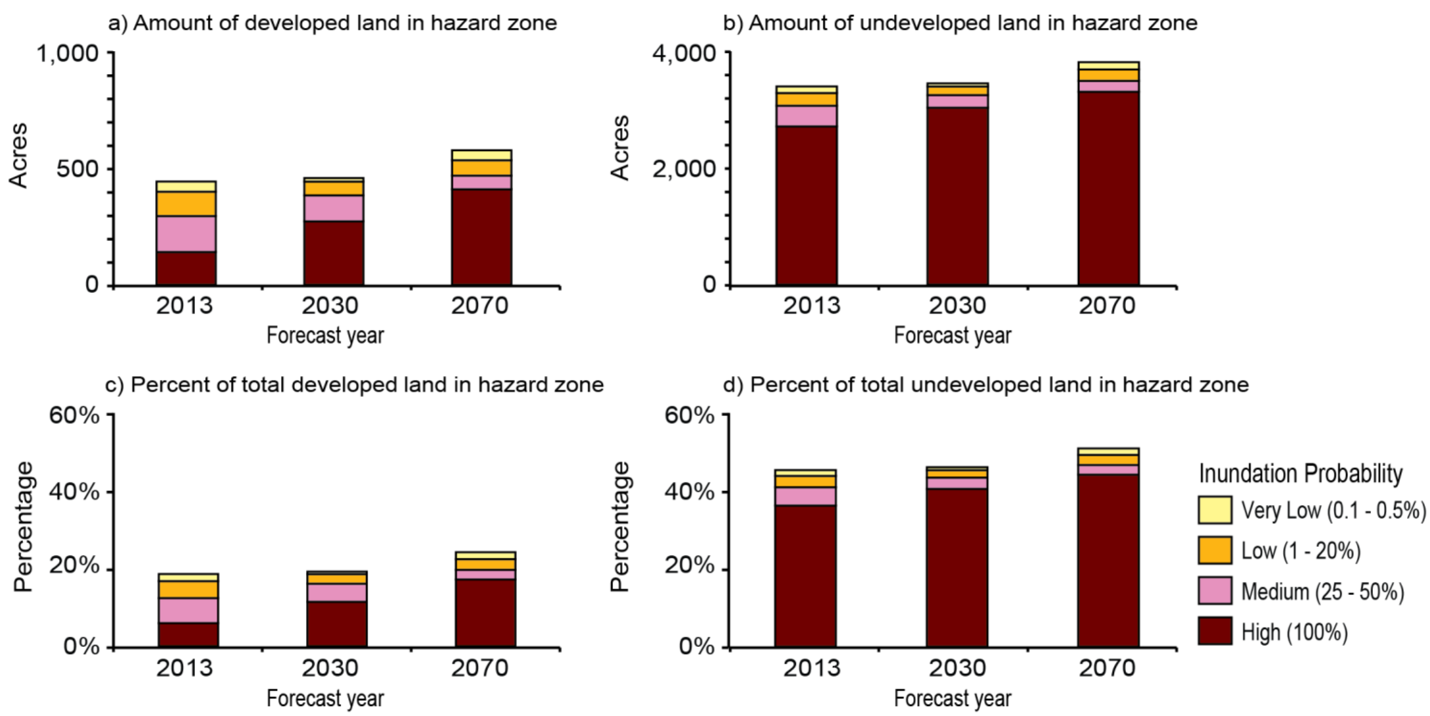

Figure 3.2-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Salisbury, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

In summary, Salisbury has high exposure to coastal flooding, riverine flooding, and erosion due to its topography, hydrology, and geographic location. The community's high exposure is best evidenced by the significant flooding and erosion that have occurred from recent storms such as Super Storm Sandy in 2011, the Patriots Day Storm of 2007, and smaller storms in the spring of 2005 and 2006, among others. Facing the open ocean, the Salisbury Beach area is exposed to wind, wave action, and increasing sea level rise – with no buffering landmass to diminish these hazards. The extensive number of tidal creeks and channels, combined with the overall low topography, can lead to widespread inland flooding during storms.

Community Sensitivity to Climate Hazards

Salisbury infrastructure appears to have a high level of exposure and sensitivity to climate-driven threats. Much of the infrastructure in Salisbury is located in low-lying areas that are susceptible to flooding from storm surge, sea level rise, and riverine flooding. Salisbury Beach in particular is an economic hub for the community, and it falls almost entirely within the 1% flood zone (often referred to as the "100-year" flood zone) and Coastal High Hazard Area as designated by FEMA.[53, 54] Overall 44% of the total community lies within either the 1% (100-year) or 0.2% (500-year) flood zone.[55] Based on a separate analysis by Climate Central, 43% of the population lives in areas less than six feet above sea level; virtually none of the population living in low-lying areas is protected or isolated from flooding by levees or natural topographic ridges.[56] Further analysis indicates that 46% of roads are located less than six feet above sea level (as defined by total road mileage).[57]

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In Salisbury, economic sensitivity to climate hazards is intrinsically linked to the sensitivity of the town's natural systems. Salisbury Beach State Reservation is the town's biggest tourist destination, and the barrier beach as a whole draws over 200,000 visitors annually.[58] Furthermore the Great Marsh, which covers 27% of the town, is designated an Important Bird Area of global significance. While exact estimates are unknown, large numbers of bird watchers from throughout the northeast, and throughout the country, travel to the area to witness the spectacular influx of birds during spring and fall migrations.

Marshes and barrier beaches are inherently sensitive to the impacts of climate change, and human activity can further increase their sensitivity. A healthy untouched marsh can attenuate storm surge by reducing wave height and heavily vegetated dunes are often resilient in the face of large storms.[59,60] Depending on topographic features, marshes and dunes can often migrate inland as sea levels rise. However, these natural systems are impacted by human development and management. Improperly-sized hydro barriers can disrupt marsh ecosystems by reducing flow of sediment and impacting salinity levels. Narrow, unvegetated dunes (typically found in heavily populated areas) can erode easily if they are exposed to waves. Salisbury Beach does appear to have high sensitivity to storm surge and erosion which is exacerbated by residential and commercial development on the beach front. The majority of the 37 repetitive loss sites in Salisbury occurred along Salisbury Beach and resulted in almost $3 million in

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53 MVPC, "Town of Salisbury Natural Hazard Risk Assessment," 217
54 "MORIS: CZM's Online Mapping Tool," CZM, last updated January 9, 2012, http://maps.massgis.state.ma.us/map_ol/moris.php
55 MVPC, "Town of Salisbury Natural Hazard Risk Assessment," 235
56 "Surging Seas: Risk Finder," Climate Central, last modified April 2014, http://sealevel.climatecentral.org/ssrf/massachusetts
57 Ibid
58 Town of Salisbury, *Open Space and Recreation Plan 2006-2007* (Salisbury, MA, 2010), 2
59 Shepard, C.C., et al., "The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis," *PLoS ONE* 6, no. 11 (November 2011): e27374. doi:10.1371/journal.pone.0027374
60 "In Defense of Dunes," ASBPA, January 13, 2015, http://www.asbpa.org/news/newsroom_14BN0113_in_defense_of_dunes.htm

payouts from the National Flood Insurance Program.[61] Sensitivity to erosion may be an even bigger area of concern. Based on a recent analyses completed by the Coastal Erosion Commission and presented by CZM, Salisbury public beach had some of highest erosion rates of any North Shore community. The public beach lost an average of almost four feet a year between 1978 and 2008, causing previously dry shoreline to become intertidal beach.[62, 63] Furthermore, 97% of locations surveyed showed at least some level of erosion and only 3% had any level of accretion (data collected between 1970 and 2009).[64] As noted previously, this is the highest level of erosion experienced by any of the North Shore communities.[65] Based on local observations, recent erosion rates appear to have declined, although more study is required to confirm these observations. With rising seas and increased storm activity, erosion and its associated impacts are likely to worsen for this community already sensitive to climate-driven impacts.

Community Vulnerability

An extensive amount of work has already been conducted in Salisbury to assess community vulnerability to natural hazards. The most comprehensive information to date is provided in *Salisbury's Hazard Mitigation Plan* prepared by the Merrimack Valley Planning Commission.[66] Information from this and other documents is synthesized below along with information from the Salisbury Resiliency Task Force, coastal inundation modeling conducted by the Woods Hole Group,[67] a comprehensive inventory and assessment to barriers to flow, and results from the 2016 USGS geospatial analysis[68] of potential impacts from coastal inundation.

Overall, Salisbury has a high level of vulnerability because it has both significant exposure and high sensitivity to climate hazards. Storm surge, riverine flooding of tidal creeks, and acute and long-term erosion pose the biggest threats to this community. MVPC's *Natural Hazard Risk Analysis* reached a similar conclusion. Based on their analysis, they identified nine areas of particular concern (Table 3.2-1) and assigned Salisbury a "high" risk rating for floods, winter storms, northeasters, and power outages caused by storms.[69, 70]

Table 3.2-1. Summary of "Special Flooding Problems/High Hazard Concerns listed in Salisbury's Hazard Mitigation Plan.[66] Order listed does not indicate priority or level of concern.

High Hazard Concerns	Type of Hazard
Salisbury Beach	Erosion
Salisbury Beach at Broadway	Storm over-wash during storms
Neighborhoods along Blackwater River	Flooding during extreme high tides and storms
US Route 1 North at Town Creek	Tidally influenced flooding
US Route 1 South; March Road and 1st St.	Tidally influenced flooding
US Route 1A (Beach Road)	Tidally influenced flooding
Jak-Len Drive	Freshwater flooding from storms
Smallpox Brook	Freshwater flooding from storms
North End Boulevard (Old Town Way to 18th St.	Storm-related flooding

61 MVPC, "Town of Salisbury Natural Hazard Risk Assessment," 243
62 MA EEA, *Shoreline Characterization and Change Analyses*
63 Salisbury Resiliency Task Force, personal communication with authors, July 15, 2015
64 MA EEA, *Shoreline Characterization and Change Analyses*
65 Ibid
66 MVPC, "Town of Salisbury Natural Hazard Risk Assessment," 232-253
67 Famely, J. et al., *Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA)*, prepared for National Wildlife Federation and U.S. Geological Survey (Falmouth, MA: Woods Hole Group, 2016)
68 Abdollahian, N. et al., *Community Exposure*
69 MVPC, "Town of Salisbury Natural Hazard Risk Assessment," 248
70 Ibid 236-240

CRITICAL INFRASTRUCTURE

Almost 30% of all buildings located within the Merrimack Valley region floodplain in Massachusetts are in Salisbury.[71] Significant *critical infrastructure* is located in the 1% flood zone and/or in hurricane flood zones (often referred to as SLOSH zones), including the current police station (which is scheduled to be moved inland), eight sewage pump stations, and three water storage/pumping stations (for specific locations see *Draft Merrimack Valley Multi-Hazard Mitigation Plan*).[72] Public input from the Great Marsh Symposium 2015 identified overall power grid vulnerability and the Seabrook (NH) Station Nuclear Power Plant in the neighboring town to the north as areas of concern.

The USGS geospatial hazard analysis of critical infrastructure in Salisbury identified the following critical facilities and infrastructure located in the current and future coastal inundation hazard zones (Table 3.2-2).[73]

Table 3.2-2. Critical facilities and infrastructure in Salisbury, MA located in the 2013 (present day) and 2070 coastal inundation hazard zones.

Asset Description	Located in 2013 Hazard Zones	Located in 2070 Hazard Zones
Critical facilities	3	3
Transportation hub	1	1
Public-utility stations	3	3
Underground storage tanks	2	2
Declared activity and use limitation site	1	1
Total roads (miles)	18	19

BARRIERS TO FLOW

The "Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed" provides additional insight into where the community may be vulnerable to flooding. As part of this screening level vulnerability assessment, this project inventoried and assessed the locations throughout Salisbury and other Great Marsh towns where man-made structures such as roads, bridges, dams, sea walls, and other structures intersect waterways and floodplains. These structures often present serious barriers to the natural movement of water and function of related physical and biological processes including sediment and nutrient transport. Undersized, improperly designed, or aging structures are vulnerable and can put related critical infrastructure, buildings, and transportation corridors at increased risk of flooding and failure, especially during extreme storms that bring heavy rains, winds, and storm surges. Many of the same barriers that present serious infrastructure risk have also been identified as causing significant ecological harm and reducing the resiliency of natural communities. Several past studies were reviewed for this project, and new surveys were conducted to assess the vulnerability of these structures in each community.

Four types of structures (non-tidal road-stream crossings, tidal road-stream crossings, dams, and public shoreline stabilization structures) that are potential barriers were assessed for their degree of vulnerability. The Town of Salisbury has 20 non-tidal road-stream crossings, 15 tidal road-stream crossings, no dams, and seven public shoreline stabilization structures. Of these, one non-tidal road-stream crossing and 10 tidal road-stream crossings are highly vulnerable to the impacts of sea level rise, coastal storms, and/or inland flooding based on our screening criteria. (See Appendix B for methodology, results, and a map).

[71] Ibid 241
[72] Ibid 242
[73] Abdollahian, N. et al., *Community Exposure*, 13

AREAS OF SPECIAL CONCERN

During the planning process, the Salisbury and Regional Resiliency Task Forces identified Areas of Special Concern due to their current and future vulnerability and the consequences if the area or asset is impacted by flooding or erosion. A discussion of the vulnerabilities of several of these assets follows (for a complete list see Appendix C).

Of the sites identified as vulnerable to climate-driven threats, the Task Force identified **Route 1A** (Beach Road)**,** from North End Boulevard west approximately .5 miles to 183 Beach Road, as one of its primary areas of concern. According to the USGS analysis and Woods Hole Group coastal inundation modeling, this portion of Route 1A is likely to be entirely flooded during at 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500 year storm). A present day 1% or 0.2% storm would likely flood the roadway with between 1 to 20 feet of water. In 2070, due to sea level rise and a likely increase in storm severity, a 1% or 0.2% storm would like flood the roadway with between 5 to 20 feet of water for both storm scenarios (Figure 3.2-3).[74]

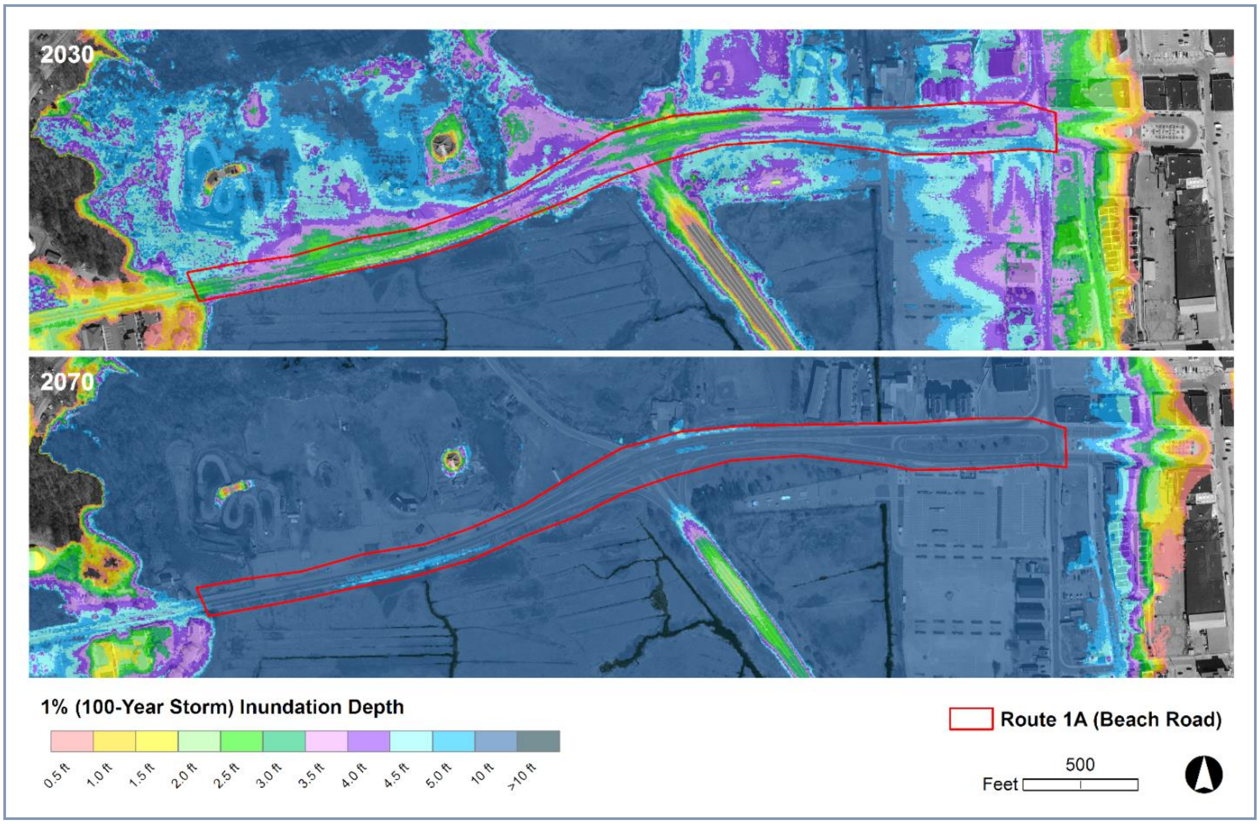


Figure 3.2-3. Route 1A/Beach Road, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

Because Route 1A is the primary access point for traffic entering and leaving Salisbury Beach, it receives high traffic volume – particularly during the summer. When the roadway floods, traffic, including emergency responders, must travel north to Route 286 in New Hampshire in order to access Salisbury

[74] Ibid

Beach. This northern egress point, however, relies on North End Boulevard remaining open to vehicular traffic. According to updated hurricane inundation mapping by the US Army Corps of Engineers, large portions of North End Boulevard would likely be inundated by a category one hurricane as would the Route 1A access point.[75] This poses a serious evacuation hazard to residents living along the beach.

Salisbury Beach, the barrier beach which stretches for nearly four miles from the Merrimack River Jetty north to the New Hampshire state border, is also an area of primary concern. Salisbury's significant tourism-based economy relies heavily on this beach. The beach and dunes also provide significant flood protection to North End Boulevard and the infrastructure built alongside it. According to the USGS analysis, by 2070 approximately 55% to 61% of the beach will likely flood during 1% and 0.2% storms, with water depths primarily ranging from 5 to 20 feet for both storm scenarios.[76] This is significant because the amount of area expected to flood combined with the depth of water means acute and severe erosion is likely to be widespread during large storms.

In particular, the section of **Salisbury Beach at** the intersection with the **Broadway Mall** has been identified as an area of special concern. This area of the beach already suffers chronic flooding from over-wash during storms that coincide with high tides,[77] requiring repetitive and costly maintenance and repair to the road, buildings, and other public and private infrastructure in that area. Further analysis by USGS, using inundation modeling by Woods Hole Group, indicates that by 2070 80% to 94% of this portion of the beach is likely to flood with between 1-20 feet of water during large 1% and 0.2% storms (Figure 3.2-4).[78] This is significant because the amount of area expected to flood combined with the depth of water means acute

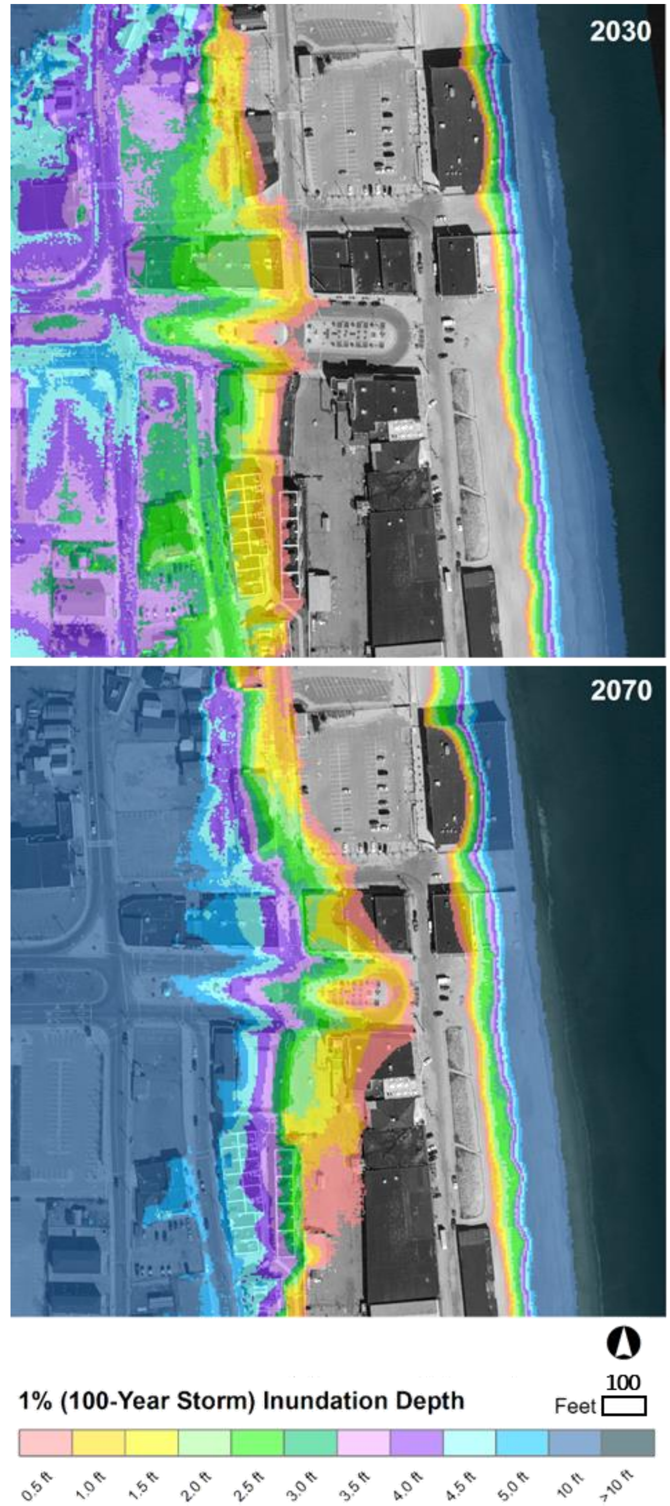


Figure 3.2-4. Salisbury Beach at Broadway, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

[75] "Hurricane Inundation Maps," USACE, accessed August 2015, http://www.mass.gov/eopss/agencies/mema/hurricane-inundation-maps.html
[76] Abdollahian, N. et al., *Community Exposure*, 13
[77] MVPC, "Town of Salisbury Natural Hazard Risk Assessment," 237
[78] Abdollahian, N. et al., *Community Exposure*, 13

Michelle Rowden/MyCoast

and severe erosion is likely to occur during large storms, similar to what will occur along the entire barrier beach.

Task Force member input as well as a review of the coastal inundation modeling highlighted several **low-lying neighborhoods along the marsh side of Salisbury Beach** that are currently vulnerable to flooding and are likely to face increased flooding as a result of sea level rise and increased storm severity and frequency. These neighborhoods include neighborhoods both south and north of Beach Road. The neighborhood south of Beach Road and east of the road to Salisbury Beach State Reservation, including homes along Cable Avenue, receives flooding from the Merrimack River when tides and storm surge bring flows north along Black Rock Creek.

Neighborhoods north of Beach Road and west of North End Boulevard are flooded when tides and storm surge bring flows south along the Blackwater River, under Route 286 and south to Salisbury through extensive salt marsh. Flooding from tributaries of the Blackwater River, including Dead Creek, has particularly impacted the homes located at 9th, 10th, 11th, 12th, Florence, and Lewis Avenues for many years. In 2017, the Blackwater River Flood Management project (a $7 million project led by the Army Corps of Engineers with support from the Department of Conservation & Recreation, the Town of Salisbury, and others) completed improvements with the goal of protecting this neighborhood near 11th and 12th Avenues from flooding. The project included a 3,000-linear-foot sheet pile 3-4 foot high above grade floodwall, improvements to the drainage in the area, repaving and new pavement, site work in the marsh, and grading and gravel fill on the landside of the wall. It will be important to continue to monitor the impact of the new construction of the sea wall, as well as the upgrades to the Route 286 bridge in Seabrook made years ago, to the overall flow of water through the Blackwater River and the health of its surrounding salt marsh.

The main north-south transportation corridor through Salisbury is **US Route 1** (Bridge Road), which runs north from Newburyport over the Merrimack River, approximately two miles into Salisbury Center, continuing beyond to Seabrook, NH. The small businesses located along Route 1 include automotive, restaurant, commercial, and other industries. Historically the road and businesses have been impacted by flooding coming across the extensive marsh system and then overflowing at Town Creek, located about half way between the Merrimack and the town center. Additionally, there is tidal flooding of homes and yards in the neighborhoods located to the east of Route 1 just north of the Merrimack River, including March Road, First Street, and Ferry Road, where improperly sized culverts are in need of repair.

The flooding in this area of Salisbury not only has a direct impact on the roads, businesses, and neighborhoods, but it also contributes to the degradation of the health of the marsh. According to the Great Marsh Coastal Wetlands Restoration Plan completed by the MA Division of Ecological Restoration (see Appendix B), this marsh area has been identified as a degraded coastal habitat and is a priority for restoration efforts.

DEMOGRAPHICS[79]

According to the USGS geospatial hazard analysis, 22% (1,827) of Salisbury's residents live in coastal-hazard zones. By 2070, this number will increase to 2,707 residents, representing 33% of the total residents of Salisbury (Figure 3.2-5). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The greatest increase in residential exposure (from 2013 to 2030 to 2070) is associated with the high inundation-probability zone. An estimated 549 residents of Salisbury are currently living in areas classified as having a high (100%) inundation probability. This number (residents living in the highest hazard zone) is estimated to nearly triple to 1,635 residents by 2070, due to changes in the extent of hazard zones.

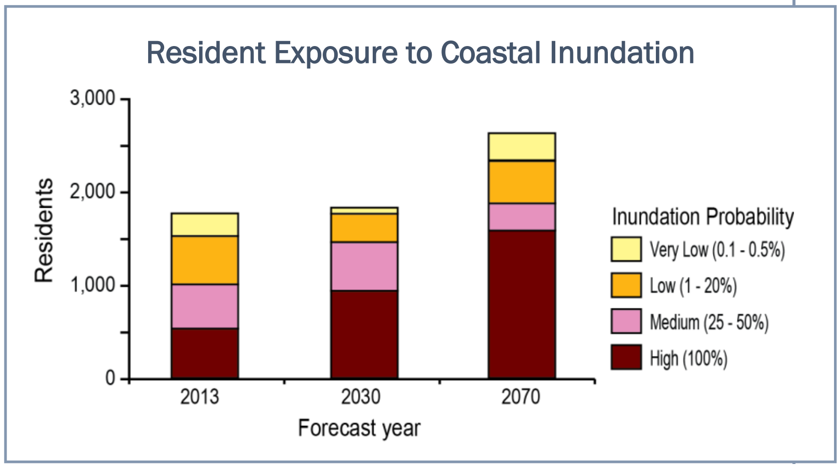


Figure 3.2-5. Resident exposure in the Town of Salisbury, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

All demographic percentages describing residents in hazard zones were relatively stable (+/- 1%) across the three time periods. Demographic results relative to 2070 hazard zones suggest that more than 5% of the residents in the hazard zones have disabilities (12%), are over 65 years in age (18%), or live in renter-occupied households (19%). Less than 5% of the residents in the hazard zones are living in mobile homes, living under the poverty line, unemployed, lack a phone, speak English as a second language, under 5 years in age, living in institutionalized group quarters, or lack a vehicle.

ECONOMIC & SOCIO-ECONOMIC[80]

The number of Salisbury employees working in coastal-hazard zones ranges from 410 currently to 617 in 2070, representing 12% to 18%, respectively, of the 3,394 employees that are presently in the community (Figure 3.2-6). As was the case with the resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zone and not projected changes in employee distributions. In present day, most employees in these hazard zones are in areas classified as having a low (1-20%) inundation probability (215 employees). By 2070, 376 employees are at businesses in

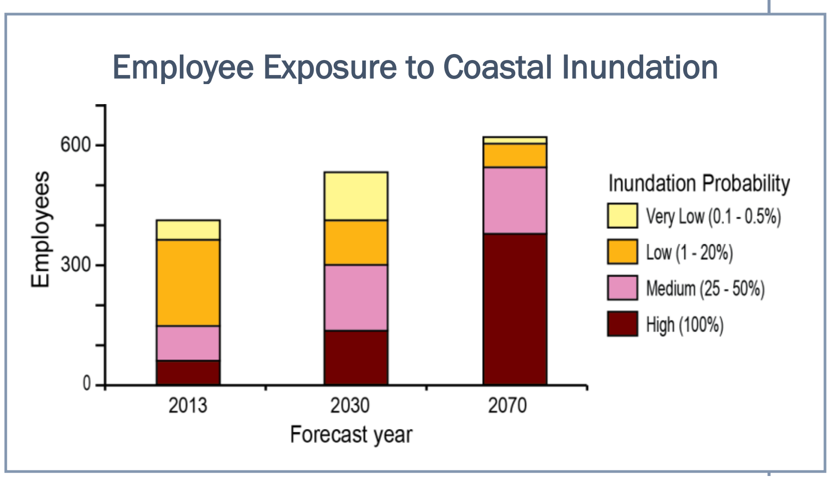


Figure 3.2-6. Employee exposure in Salisbury, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

[79] Ibid 10-11
[80] Ibid 11-12

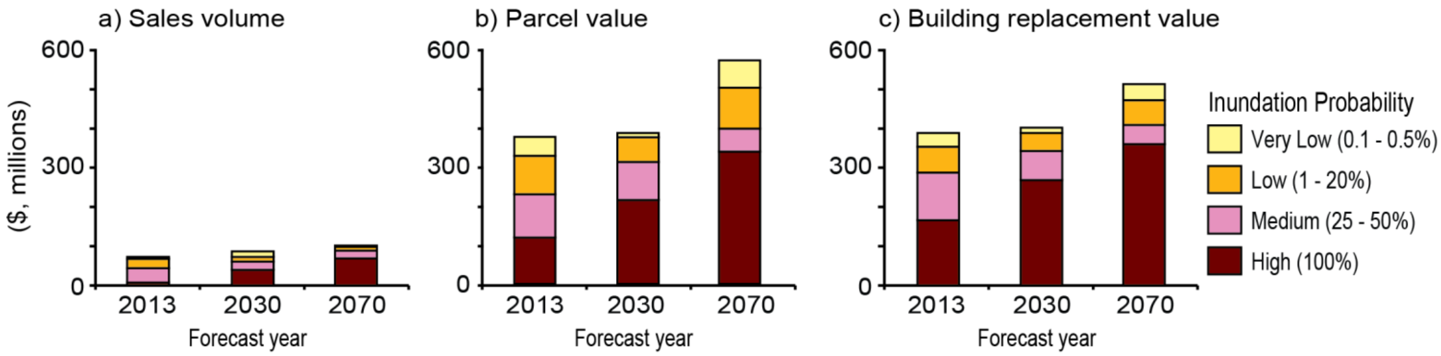


Figure 3.2-7. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Salisbury, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

the high (100%) probability zone, with additional employees in zones classified as medium (166), low (59) and very low (16) inundation probability. Sales volume exposure for private-sector businesses ranges from $73 million currently to $102 million in 2070 (Figure 3.2-7a). The number of businesses likely to have a significant customer presence (e.g. retail) in coastal-hazard zones ranges from 58 businesses in 2013 to 75 businesses in 2070. 90 businesses with fewer than 20 employees (a group typically more sensitive to disruptions), representing 21% of the Salisbury business community, are currently located in coastal hazard zones. This number will increase to 123 businesses in 2070, representing 28% of the Salisbury business community.

Similar to sales volume, parcel values and building replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $377 million present day to approximately $574 million in 2070, representing 25% to 38% of the community's tax base between the two time periods (Figure 3.2-7b). The majority of tax-parcel value in hazard zones is associated with building value for both 2013 and 2030 (50%, both years), and land value for 2070 (50%) with the remainder associated with content value. Based on building stock data in the FEMA Hazus-MH database used in the USGS analysis, estimated building replacement values range from $389 million for the current hazard zone to $514 million for 2070 hazard zone (Figure 3.2-7c). For all three time periods, the majority of potential building replacement values are in areas classified as having a high probability of inundation.

HABITATS & SPECIES

The Great Marsh is one of the most important coastal ecosystems in northeastern North America.[81] In Salisbury, this ecosystem contains high and low marsh, estuarine aquatic environments, and a barrier beach accompanied by extensive dunes. Each of these habitats provides critical foraging and breeding grounds for a many native species. The Great Marsh also provides an abundance of ecosystem services to the Town of Salisbury. The marsh absorbs wave energy and traps sediment, helping reduce erosion; the aquatic environment is a nursery for commercially important fish species; and the dunes provide protection against dangerous storm surge. In addition, the salt marsh traps and safely stores harmful sources of carbon that are the leading cause of climate change. In fact, recent analysis indicates that

[81] "The Great Marsh," Western Hemisphere Shorebird Reserve Network, accessed October 2015. http://www.whsrn.org/site-profile/great-marsh

marshes are one of the most powerful carbon sinks, with the potential of sequestering almost 50 times more carbon than tropical rainforests.[82]

A significant portion of Salisbury has received official designation recognizing the importance of its natural systems. Approximately 3,166 acres in Salisbury are designated as *core habitat* and 4,259 are listed as *critical natural landscapes* (Figure 3.2-8).[83] The term core habitat" refers to areas deemed necessary to support the long-term existence of rare or threatened species, exemplary natural communities, and intact ecosystems. "Critical natural landscapes" are intact ecosystems that are well suited to support ecological processes and/or a wide array of species and habitats over a long period of time.[84]

Marshes, barrier beaches, and dunes make up the majority of the critically important habitat in Salisbury. These habitats contain multiple vegetative zones that support a wide diversity of species, including several threatened and endangered species (Table 3.2-3).[85]

The marsh in Salisbury is vulnerable to erosion and sea level rise. Because this habitat is so low-lying and tidally influenced, the vast majority of marsh in Salisbury may become inundated under just one foot of sea level rise.[86] Furthermore, due to human development west of Route 1 along the marsh edge, these salt marsh may not be able to migrate inland, leaving this important ecosystem to disappear under water. However if deliberate steps are taken to both limit further development along the marsh edges and to facilitate marsh migration, this critical habitat may be able to gradually move landward to keep pace with sea level rise.

Salisbury Beach, and associated dunes, were highlighted by the Salisbury Resiliency Task Force as some of their highest priority concerns because of their

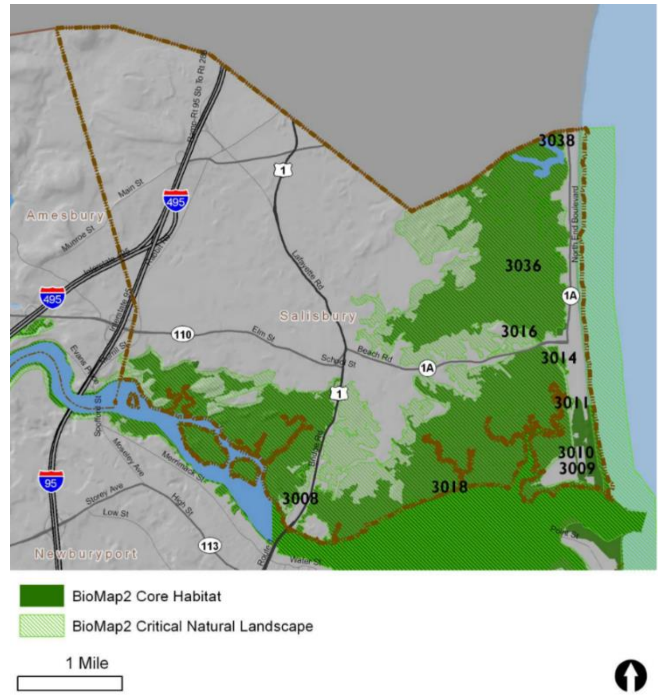


Figure 3.2-8. *BioMap2* Core Habitat in Salisbury. ID's correspond to habitat.

Table 3.2-3. List of species occurring in Salisbury that are threatened (T) or endangered (E). For complete list of species, including species of conservation concern, see the MA Dept. of Fish & Game BioMap2 report for Salisbury (2012).

Threatened and Endangered Species	Habitat Type
Birds	
Piping Plover[T]	Beach, dunes, mudflats
Bald Eagle[T]	Marsh, tidal channels, and upland habitat
Fish	
Shortnose Sturgeon[E]	Marsh, coastal rivers, tidal estuaries
Atlantic Sturgeon[E]	Marsh, coastal rivers, tidal estuaries
Plants	
Silverling[E]	Rocky outcrops, gravel barrens, sandy river banks
Seabeach Needlegrass[T]	Coastal dunes

[82] Bu, N. et al., "Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool," *Ecological Engineering*, 81 (2015): 335

[83] MA DFG & TNC, *BioMap2: Salisbury* (Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012), http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Salisbury.pdf

[84] Ibid

[85] Ibid

[86] "MORIS: CZM's Online Mapping Tool"

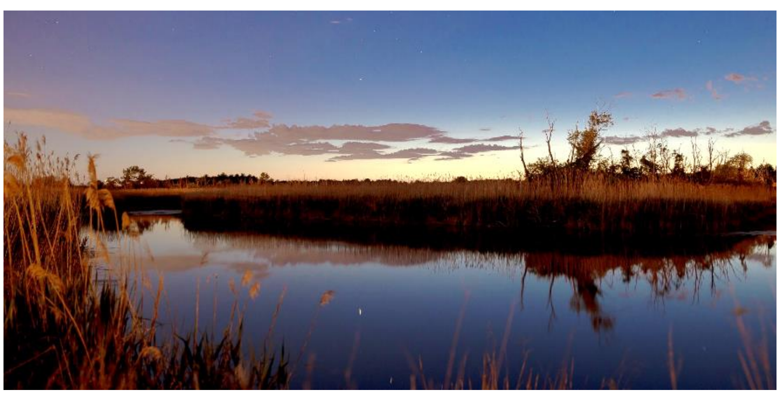
societal value (for tourism), their protective value (protecting infrastructure against storm surge), and because of the habitat they provide for wildlife (such as Piping Plovers). These habitats are eroding at an alarming rate while sea levels continue to rise and impacts from storm surge are more frequent and severe. Like all barrier beaches, natural processes cause the beach to shift over time. A beach's dynamic character and ability to move and reshape in response to constant wave energy and acute storm events is precisely what makes it resilient to sea level rise and storm surge.[87] As the Massachusetts Coastal Erosion Commission's final report notes, "The movement of sediment along the coast and the [natural] loss and gain of shoreline—erosion and accretion—are continuous and interrelated processes."[88] Because Salisbury Beach is heavily developed, natural erosion and accretion rates are disrupted, and changes in beach formation can impact houses and other infrastructure located along the coastline. If beaches and dunes are not allowed to migrate inland as the sea rises, this habitat will slowly disappear, impacting a wide variety of species including Piping Plovers.

Summary

Overall the Town of Salisbury has a relatively high level of vulnerability to climate-driven threats. Predicted increases in storm frequency and severity sea level rise, increased storm surge, and erosion have the potential to impact the town's coastal economy, the significant infrastructure located in low-lying areas along the coast, and the natural systems that the community depends upon. Because of the town's reliance on coastal tourism and coastal industries, impacts to infrastructure or natural systems may have effects that ripple across all parts of the community. The geospatial analysis conducted by USGS confirms these findings and indicates economic, infrastructure, and population vulnerabilities that will likely need to be addressed to protect human life as well as the economic well-being of Salisbury.

The natural systems in Salisbury are already being impacted by erosion that is likely to accelerate with climate change. Sea level rise will likely inundate the vast expanses of marsh that currently help reduce storm surge and reduce erosion, and provide important habitat to rare and threatened species. Storm surge, resulting from bigger and more frequent storms, may overtop existing dunes and coastal structures, potentially impacting densely populated areas along North End Boulevard. Storm surge will be further compounded by rising seas, causing a two-foot storm surge in 2050 to reach further inland than today.

For recommendations on how to address the Town of Salisbury's overall vulnerability to climate-driven hazards, including site-specific adaptation strategies for the areas of concern outlined above, see Chapter 4: Adaptation Strategies for the Great Marsh Region.



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[87] Massachusetts Barrier Beach Task Force, *Guidelines for Barrier Beach Management in Massachusetts* (Boston, MA: Massachusetts Office of Coastal Zone Management, 1994) http://www.mass.gov/eea/docs/czm/stormsmart/beaches/barrier-beach-guidelines.pdf

[88] Massachusetts Coastal Erosion Commission, "Volume 1: Findings and Recommendations" in *Report of the Massachusetts Coastal Erosion Commission* (Boston, MA: Massachusetts Executive Office of Energy and Environmental Affairs, 2015), 1

Ollie Jones/Flickr

3.3. City of Newburyport Vulnerability Assessment

Community Exposure to Climate Hazards

Newburyport is a vibrant coastal city along the North Shore of Massachusetts. It is bordered by the Merrimack River to the north, the Atlantic Ocean to the east, and Newbury and West Newbury to the south and west. According to the United State Census Bureau, in 2013 there were 17,800 residents living in Newburyport. Like many North Shore communities, the population increases during warmer months with an influx of summer residents and tourists. Although development is spread throughout the community, the historic downtown waterfront district is the civic and commercial center of the city.[89] The bustling downtown hosts a variety of shops, restaurants, city buildings, and other attractions that draw both residents and visitors. The downtown economy is intricately tied to the Merrimack River; many restaurants are located on the banks of the river and a scenic river walk runs the length of downtown.

Plum Island and the Lord Timothy Dexter Industrial Green (hereafter "Business Park") are also major epicenters of development. Plum Island is an 11 mile barrier beach, most of which falls outside the city's boundaries. However the far northern tip of the island is in Newburyport, and this portion of the island is densely populated with vacation homes, tiny summer camps, and increasingly larger year-round residences. The Business Park, located roughly between Hale Street, Low Street, Route 1 and the Newbury border, is home to approximately 60 large-scale industrial businesses.[90] According to Newburyport's 2015 draft Master Plan, zoning changes implemented in 2007 and the approval of "use variances" were intended to spur growth in the Business Park. A stated goal of the Master Plan is to "enable new and expanded commercial and industrial use at the Business Park to generate at least 15% of the city's property tax revenues."[91]

[89] City of Newburyport, *Newburyport Master Plan* (Newburyport, MA, 2001)
[90] City of Newburyport, *DRAFT Newburyport Master Plan* (Newburyport, MA, 2015), 3
[91] Ibid 3, 15

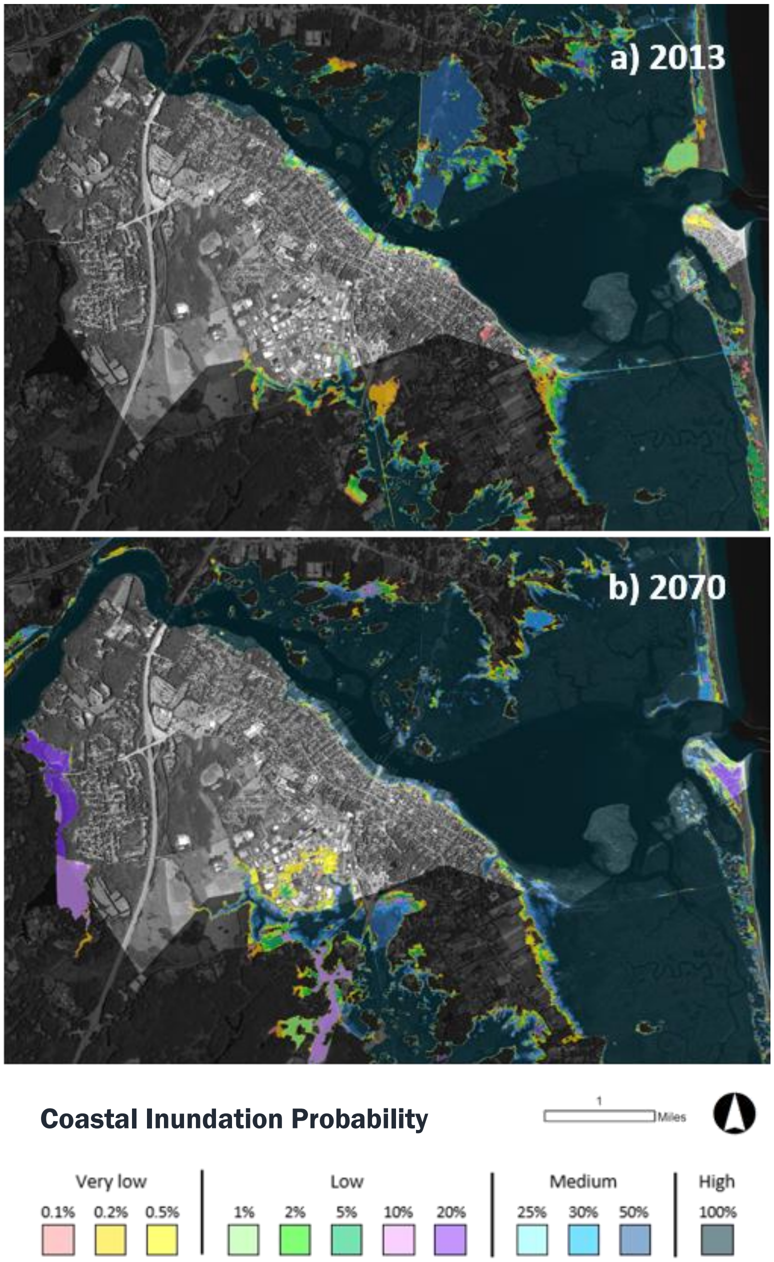


Figure 3.3-1. Newburyport, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

Newburyport is part of three watersheds: the Merrimack, the Little River, and the Artichoke.[92] At around 117 miles long, the Merrimack River is the largest river in the region and is a dominant feature of Newburyport. While the Merrimack is a scenic river and an economic driver in the City of Newburyport, it also leads to high flood exposure for a large portion of downtown. Major storms have repeatedly exposed downtown Newburyport to flooding, including (but not limited to) the Mother's Day storm of 2006, the Northeaster of 2007, and slightly smaller storms in February and March of 2013.[93] The Little River is a small tidally-influenced tributary to the Parker River in Newbury and is highly susceptible to flooding due to a combination of low gradient, restricted road crossings and tidal influences. There are several hydro-barriers along the Little River that cause the creek to spill over its banks into surrounding areas, including the Newburyport Business Park. During the October storm of 1996, 13 inches of rain fell over two days, flooding the Business Park. This area was again flooded during the major Mother's Day storm of 2006.[94] Flooding in this area has been studied extensively and is discussed in greater detail on page 45.

The portion of Newburyport located on Plum Island has extremely high exposure to coastal flooding and erosion. The barrier beach is the first line of defense against storm surge and sea level rise. In its unprotected location, the continuous onslaught of waves and wind have led to significant erosion. Two jetties extending from the mouth of the Merrimack River also may contribute to additional erosion; further study of this is under discussion.

A detailed analysis of coastal inundation, conducted by the Woods Hole Group and USGS, confirms that the City of Newburyport has high exposure to sea level rise and storm surge. Present day estimates (shown

[92] MVPC, "Newburyport Natural Hazard Risk Assessment," in the *Draft Merrimack Valley Multi-Hazard Mitigation Plan* (Haverhill, MA, 2015), 204

[93] Newburyport Resiliency Task Force, personal communication with authors, July 15, 2015

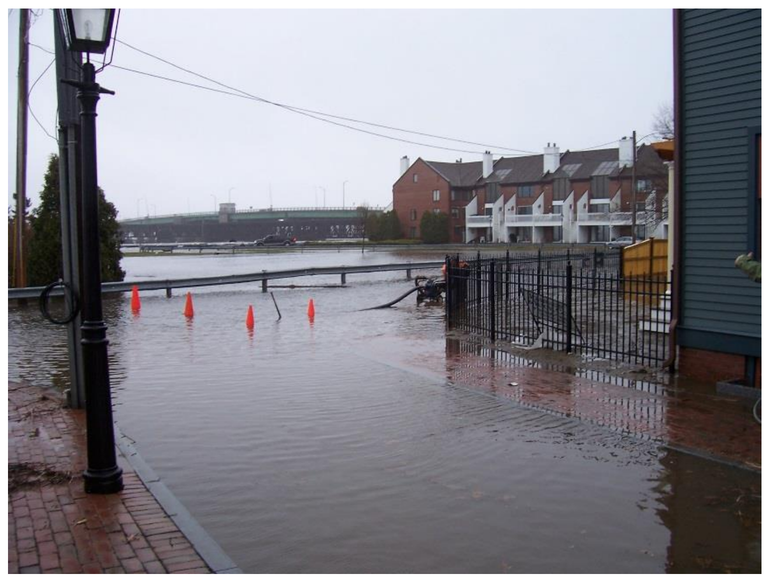
[94] Ibid

as 2013) indicate approximately 7% of the City is vulnerable to coastal inundation – depending on the severity of the storm. That number doubles to 14% in 2070 (Figure 3.3-1).[95] This means under a worst case storm scenario in 2070, about 14% of the area within the City's borders would be under water from penetrating storm surge.

In summary, Newburyport has high exposure to coastal flooding, riverine flooding, and erosion due to its topography, hydrology, and geographic location. Plum Island faces the open ocean and is highly exposed to wind, wave action, and sea level rise – with no buffering landmass to diminish these hazards. Interior portions of Newburyport rely on Plum Island to buffer the worst coastal storm effects. However the Merrimack River and Little River can also bring flood waters to much of Newburyport's most valued areas.

Community Sensitivity to Climate Hazards

The City of Newburyport has a high level of sensitivity to climate-driven threats. Much of the City's infrastructure is located in low-lying areas that are susceptible to flooding from storm surge, sea level rise, and riverine flooding. Over 20% (2.39 square miles) of Newburyport falls within the FEMA 1% flood zone (often referred to as the "100-year" flood zone).[96] Based on a geospatial analysis by MVPC, there are over 800 residential, commercial, industrial, and institutional structures, valued at over $203 million dollars, located in the 1% flood area. Residential structures, many of which are located on Plum Island, account for roughly $151 million or 74% of that valuation.[97] An additional 95 parcels outside the flood zone carry flood insurance – an indication that many property owners understand that flooding can and often does occur outside designated flood hazard areas.[98] Many areas in Newburyport that have high exposure to flooding also have the highest levels of sensitivity. Many of the roads subject to flooding and erosion have sewer and water mains buried beneath them. A road collapse would not only disrupt transportation but would also impact or even breach the City's water supply and sewage system.[99] Because hazardous materials are stored at the Business Park, the Local Emergency Plan Committee (LEPC) plans must be reviewed on a regular basis to ensure compliance and to avert potential consequences from flooding.[100] The historic downtown is also particularly sensitive to flooding because old drainage lines and catch basins have insufficient capacity to move flood water off



Joe Teixeira

[95] Abdollahian, N. et al., *Community exposure to potential climate-driven changes to coastal-inundation hazards for six communities in Essex County, Massachusetts*, U.S. Geological Survey open-file report (Reston, VA: USGS, 2016), 17
[96] MVPC, "Newburyport Natural Hazard Risk Assessment," 204
[97] Ibid 207
[98] Newburyport Resiliency Task Force, personal communication with authors, July 15, 2015
[99] Ibid
[100] MVPC, "Newburyport Natural Hazard Risk Assessment," 205

streets and away from buildings.[101] In addition, many of the residential buildings on Plum Island are ill-suited to handle severe storms and increased storm surge that threaten much of the island.

Newburyport's overall economic sensitivity is intrinsically linked to the sensitivity of the City's natural systems. Newburyport's economy has a long tradition of relying upon its rivers, marshes and ocean-front property. Historically, Newburyport was one of the country's most significant centers for maritime commerce and ship building, leading to a highly developed waterfront downtown consisting of federal-era architecture.[102] As such, the City has highly-valued historic assets along the river. Today, the Merrimack River continues to be an economic driver with commercial fishing, recreational boating, and whale watch tours relying on the downtown harbor. The beautiful beaches on Plum Island are also a major draw for tourists and the tax revenue generated from beach-front properties on this barrier island are increasingly important to the City's tax base.

The Great Marsh, which encompasses a portion of Newburyport, is designated an Important Bird Area of global significance and a Western Hemisphere Shorebird Reserve Network site. As such, it is a strong tourism draw that boosts the local economy. Each year, approximately 250,000 people visit the Parker River National Wildlife Refuge, a 4700-acre national wildlife refuge located on Plum Island. According to a Fish & Wildlife survey conducted in 2011, bird watching was the most popular activity visitors engaged in.[103, 104] MA Audubon's Joppa Flats Nature Center, two bird watching shops located in downtown, and the refuge itself directly cater to the large numbers of bird watchers.

USFWS

Marshes, barrier beaches, and rivers make up a large portion of this community, and these natural systems are inherently sensitive to the impacts of climate change; human activity can further increase their sensitivity. A healthy untouched marsh can absorb storm surge, and heavily vegetated dunes are often resilient in the face of large storms.[105,106] Depending on topographic features, marshes and dunes can sometimes migrate inland as sea levels rise. However, these natural systems are impacted by human development and management. Improperly-sized hydro barriers can disrupt marsh ecosystems by reducing flow of sediment and impacting salinity levels. Similarly, coastal development combined with an increase in severe storms will likely lead to increased runoff of pollutants, contaminating coastal rivers.

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101 Ibid 206

102 City of Newburyport, *Open Space and Recreation Plan* (Newburyport, MA, 2012), 5

103 Nancy Pau (Refuge Biologist at PRNWR), personal communication with author, 2015

104 Sexton, N. et al., National Wildlife Refuge Visitor Survey 2010/2011: Individual Refuge Results for Parker River National Wildlife Refuge, (Fort Collins, CO: USGS, 2011), 12

105 Shepard, C.C., et al., "The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis," *PLoS ONE* 6, no. 11 (November 2011): e27374, doi:10.1371/journal.pone.0027374

106 "In Defense of Dunes," ASBPA, January 13, 2015, http://www.asbpa.org/news/newsroom_14BN0113_in_defense_of_dunes.htm

Penetrating salt-water intrusion, resulting from storm surge, will threaten freshwater river habitat, along with all the species that live there.

Like rivers and marshes, dune sensitivity to climate-driven threats can be significantly impacted by human development. Unvegetated dunes, typically found in heavily populated areas, can erode quickly if they are exposed to waves. Due to human activity along Plum Island, the area has become increasingly sensitive to erosion. Based on a recent analysis completed by the Coastal Erosion Commission and presented by CZM, the public beach on Plum Island, stretching from Newbury into Newburyport, had the third highest rate of erosion among public beaches on the North Shore (behind Cranes Beach and Sandy Point). The beach lost an average of over 4 feet a year between 1978 and 2008.[107] Furthermore, preliminary observations in 2015 indicate erosion has drastically increased along areas of the beach, possibly as a result of the Merrimack River jetty system being rebuilt.[108] (See Merrimack River Jetty System discussion on page 44).

Sandy Tilton

[107] MA EEA, *Shoreline Characterization and Change Analyses. North Shore Region. Regional Coastal Erosion Commission Workshop* (Gloucester, MA, 2014) http://www.mass.gov/eea/docs/czm/erosion-commission/shoreline-profile-north-shore.pdf

[108] Newburyport Resiliency Task Force, personal communication with authors, July 15, 2015

Community Vulnerability

An extensive amount of work has already been conducted in Newburyport to assess community vulnerability to natural hazards. The most comprehensive information to date is provided in Newburyport's draft (2016) *FEMA Hazard Mitigation Plan* (which is part of the *Draft Merrimack Valley Multi-Hazard Mitigation Plan)* prepared by the Merrimack Valley Planning Commission.[109] Information from this and other documents is synthesized below along with information from the Newburyport Community Resiliency Task Force, GEI's 2015 Coastal Adaptation to Sea Level Rise analysis,[110] coastal inundation modeling conducted by the Woods Hole Group,[111] a comprehensive inventory and assessment to barriers to flow, and results from the 2016 USGS geospatial analysis of potential impacts from coastal inundation.[112] *To learn more about the methods used by Woods Hole Group to develop their modeled coastal-inundation scenarios, see Kleinfelder (2015).*[113]

Table 3.3-1. Summary of Special Flooding Problems/High Hazard Concerns listed in Newburyport's FEMA Hazard Mitigation Plan prepared by MVPC. Order of list does not indicate priority or level of concern.

High Hazard Concerns	Type of Hazard
Plum Island & Beach	Erosion and overtopping; bay/riverside flooding
Plum Island Turnpike	Road flooding, ice cakes
Plum Island Center	Overtopping, flooding
Newburyport Turnpike north of Newbury Golf Course	Flooding from astronomical high-tides and storm surge
Cashman Park	Tidal and riverine flooding
Hale Street	Flooding/inadequate infrastructure
Fox Run Road	Flooding/inadequate infrastructure
Henry Graf Road	Flooding
Lord Timothy Dexter Industrial Green (Business Park) at Malcolm Hoyt Road	Flooding
Merrimack Street	Flooding
Ocean Avenue/Water Street	Flooding/ tidal capacity
Parker Street at Scotland Road	Flooding/inadequate capacity
Quail Run Hollow	Flooding/road maintenance
Downtown State Street/Market Square	Flooding/disconnect from sanitary sewer

Overall Newburyport has a high level of vulnerability because it has both significant exposure and high sensitivity to climate hazards. Storm surge, riverine flooding, and acute and long-term erosion pose the biggest threats to this community. The City's draft *FEMA Hazard Mitigation Plan*, prepared by MVPC, reached a similar conclusion. Based on their analysis, they identified 14 areas of particular concern (Table 3.3-1) and assigned Newburyport a "high" risk rating for floods, winter storms, Northeasters, and hurricanes.[114, 115]

CRITICAL INFRASTRUCTURE

Newburyport's draft *FEMA Hazard Mitigation Plan* identified critical infrastructure located in existing flood-hazard areas or in areas at risk from future storms and sea level rise. Those sites include the Waste Water Treatment Facility, Lower Artichoke Reservoir, Bartlett Spring Pond, and the National

[109] MVPC, "Newburyport Natural Hazard Risk Assessment," 200-215

[110] Merrill, S.B. and A. Gray, "COAST Modeling for the City of Newburyport, Massachusetts," in *Final Report to the National Wildlife Federation* (Portland, ME: GEI Consultants, Inc. Portland, 2015)

[111] Famely, J. et al., Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA), Prepared by Woods Hole Group for National Wildlife Federation and U.S. Geological Survey, (Falmouth, MA, 2016)

[112] Abdollahian, N. et al., *Community Exposure*

[113] Kleinfelder, *Coastal climate change vulnerability assessment and adaptation plan: City of Gloucester, MA* (Cambridge, MA, 2015) http://gloucester-ma.gov/DocumentCenter/View/3416

[114] MVPC, "Newburyport Natural Hazard Risk Assessment," 207

[115] Ibid 211

Grid power substation at 95 Water Street.[116] Except for the substation, these assets, along with several additional assets, were identified as Vulnerable Areas of Concern by the Newburyport Resiliency Task Force. For more information on these assets, see "Areas of Special Concern." Public input from the 2015 Great Marsh Symposium identified overall power grid vulnerability and the Seabrook (NH) Station Nuclear Power Plant in the neighboring town to the north as additional areas of concern.

The USGS geospatial hazard analysis of critical infrastructure indicates there are three government offices (a legislative body, a police station, and a U.S. Coast Guard Station) that are in current-day coastal hazard zones. By 2070 that number increases to 8 government offices located within the high (2), medium (1), low (2), and very low (3) probability hazard zones.[117] *See Table 3.3-2 for a more complete list of critical infrastructure located in the inundation hazard zones*.[118]

Table 3.3-2. Critical facilities and infrastructure in Newburyport, MA located in the 2013 (present day) and 2070 coastal inundation hazard zones.

Asset Description	Located in 2013 Hazard Zones	Located in 2070 Hazard Zones
Government offices	3	8
Public utility stations	7	11
Underground storage tank	1	1
Tier-classified oil and hazardous waste release/disposal site	1	1
Sites with a declared activity and use limitation	3	6
Transportation hubs	1	2
Total roads and rails (mileage)	4.3	8.1
Transmission lines (mileage)	0	0.15

BARRIERS TO FLOW

The "Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed" provides additional insight into where the community may be vulnerable to flooding. As part of this screening level vulnerability assessment, this project inventoried and assessed locations throughout Newburyport and other Great Marsh towns where man-made structures such as roads, bridges, dams, sea walls, and other structures intersect waterways and floodplains. These structures often present serious barriers to the natural movement of water and function of related physical and biological processes including sediment and nutrient transport. Undersized, improperly designed, or aging structures are vulnerable and can put related critical infrastructure, buildings, and transportation corridors at increased risk of flooding and failure, especially during extreme storms that bring heavy rains, winds, and storm surges. Many of the same barriers that present serious infrastructure risk have also been identified as causing significant ecological harm and reducing the resiliency of natural communities. Several past studies were reviewed for this project, and new surveys were conducted to assess the vulnerability of these structures in each community.

Four types of structures (non-tidal road-stream crossings, tidal road-stream crossings, dams, and public shoreline stabilization structures) that are potential barriers were assessed for their degree of vulnerability. The City of Newburyport has 35 non-tidal road-stream crossings, 4 tidal road-stream crossings, 4 dams, and 17 public shoreline stabilization structures. Of these, 7 non-tidal road-stream crossings are highly vulnerable to the impacts of sea level rise, coastal storms, and/or inland flooding based on our screening criteria. (See Appendix B for methodology, results, and a map).

[116]Ibid 205
[117] Abdollahian, N. et al., *Community Exposure*, 23-24
[118] Ibid

AREAS OF SPECIAL CONCERN

During the planning process, the Newburyport and Regional Resiliency Task Forces identified Areas of Special Concern due to their current and future vulnerability and the consequences if the area or asset is impacted by flooding or erosion. A discussion of the vulnerabilities of several of these assets follows (for a complete list see Appendix C).

The Plum Island Turnpike runs from Newburyport, through Newbury, onto Plum Island. It is the only access point to the island and is almost entirely within FEMA's 1% flood zone.[119] According to the Newburyport Resiliency Task Force, the road is subject to frequent flooding, especially during winter months when high tides combine with Northeasters. As the only access point to Plum Island, it receives high traffic volume – particularly during the summer. When the roadway floods, general traffic and emergency responders cannot access the island and isolates residents. In addition, blinding "white-outs" during and following snowstorms and Northeasters can routinely close the road for many hours at a time. This poses a serious safety issue and is an evacuation hazard to Newburyport and Newbury residents living on the barrier island (approximately 1270 homes).

Rob Barrett, Plum Island Taxpayer's Association

During major storms, the road can also act as a hydraulic barrier preventing Merrimack River flood waters from dispersing over the marsh. In addition, the Bascule Bridge, a drawbridge carrying Plum Island Turnpike over the marsh, impacts the marsh ecosystem. Constructed in the early 1970's, the bridge foundations act as tidal restrictions to a healthy flow of tides across the marsh. This infrastructure may contribute to flooding problems in downtown Newburyport, up river, and along the Plum Island basin.[120] A hydrodynamic sediment transport model is currently focusing on the Plum Island Turnpike area, including Bascule Bridge, to better understand water and sediment flow in this area. There is the potential for salt marsh restoration here and other locations in this area.

According to the USGS analysis, using inundation modeling from Woods Hole Group, the Plum Island Turnpike (roughly from Joppa Flats Nature Center all the way onto the island) is likely to suffer significant flooding during storms – both present day and in 2070. A present day 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500-year storm) would likely flood 54-66% of the road with between 1-20 feet of water. By 2070, a 1% or 0.2% storm, would likely flood as much as 90% of the road with between 5-20 feet of water (Figure 3.3-2).[121]

[119] "MORIS: CZM's Online Mapping Tool," CZM, last updated January 9, 2012, http://maps.massgis.state.ma.us/map_ol/moris.php

[120] Newburyport Resiliency Task Force, personal communication with authors, July 15, 2015

[121] Abdollahian, N. et al., *Community Exposure.* 24

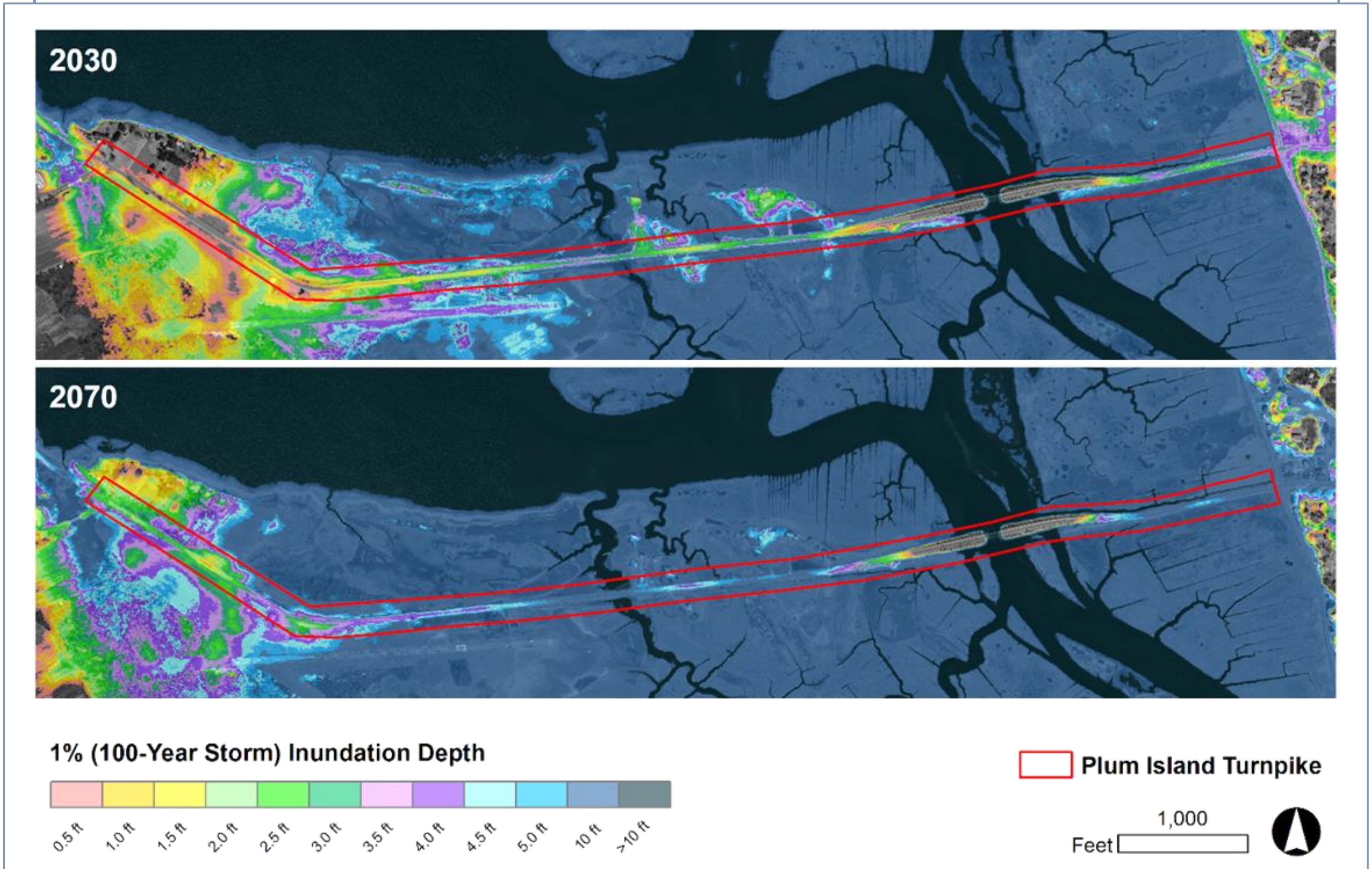

Figure 3.3-2. Plum Island Turnpike, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

The Plum Island Airport is located along Plum Island Turnpike on the boundary of Newburyport and Newbury. The fields and salt marshes along Plum Island Turnpike have been used for aviation since 1910; it is claimed to be the first flying field in New England and as such has important historical significance to the City. It has two small historic museums on site and hosts numerous educational field trips and events annually. It is owned by Historic New England and operated by Plum Island Aerodrome, Inc., another non-profit corporation for public use. It has two runways, averages 54 flights per week, and has approximately eight aircraft based at the site. The airport is located at an elevation of only 9-13 feet and is within the FEMA 1% flood zone.

During a present day 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500-year storm), the entire runway strip and portions of the airport apron (where the planes are parked) are likely to be inundated with 0.5-3.5 feet of water. By 2070 both storm scenarios would likely flood 100% of the airport grounds, including the apron, parking lots, buildings, and runways, with between 3-10 feet of water.[122]

[122] Famely, J. et al., Sea Level Rise and Storm Surge Inundation Mapping

The Newburyport Waste Water Treatment Facility, located at Joppa Flats along the Merrimack River, was built mostly above the 1% flood zone.[123] However, components of the facility are located in flood prone areas.[124] Furthermore, the draft *FEMA Hazard Mitigation Plan* notes that two to three feet of sea level rise would potentially inundate the facility and render it inoperable.[125] According to the USGS analysis, the water treatment facility will experience little if any flooding during present day 1% and 0.2% storms (roughly equivalent to FEMA's 100 or 500-year storm) (Figure 3.3-3). However by 2070, a 1% storm would likely flood 93% of the facility's grounds and a 0.2% storm would flood 98% of the area. These storms would send between 1-20 feet of water into the facility.[126]

Figure 3.3-3. Wastewater Treatment Facility, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

Lower Artichoke Reservoir and **Bartlett Spring Pond** are both surface water supplies for Newburyport and are highly vulnerable to salt-water intrusion. According to the Newburyport Resiliency Task Force and the city's draft *FEMA Hazard Mitigation Plan*, during the infamous Mother's Day Storm of 2006, flood waters came perilously close to overtopping the dam at Lower Artichoke. If overtopped, salt water would contaminate the reservoir, impacting the city's largest source of drinking water. Bartlett Spring Pond is a relatively small water supply located along the banks of the Merrimack River. A small berm separates the pond from the river; although the berm has adequately protected the water supply to date, it will likely become vulnerable to increased storm surge and increased heavy precipitation events. The USGS analysis, using inundation modeling by Woods Hole Group, indicates that Lower Artichoke Pond has minimal exposure to coastal inundation in present day and in 2030, however by 2070 a large 1% or 0.2% storm is likely to cause significant salt-water intrusion (Figure 3.3-4). Bartlett Spring Pond, which is spring-fed and

[123] MVPC, "Newburyport Natural Hazard Risk Assessment," 203-204
[124] Newburyport Resiliency Task Force, personal communication with authors, July 15, 2015
[125] Ibid
[126] Abdollahian, N. et al., *Community Exposure,* 24

supplies approximately 20% of the City's water supply, does not appear in any of the coastal-hazard zones now through 2070. However that USGS analysis does not take into consideration possible erosion of the protective berm that may occur during a storm, which could lead to salt-water infiltrating the pond.[127]

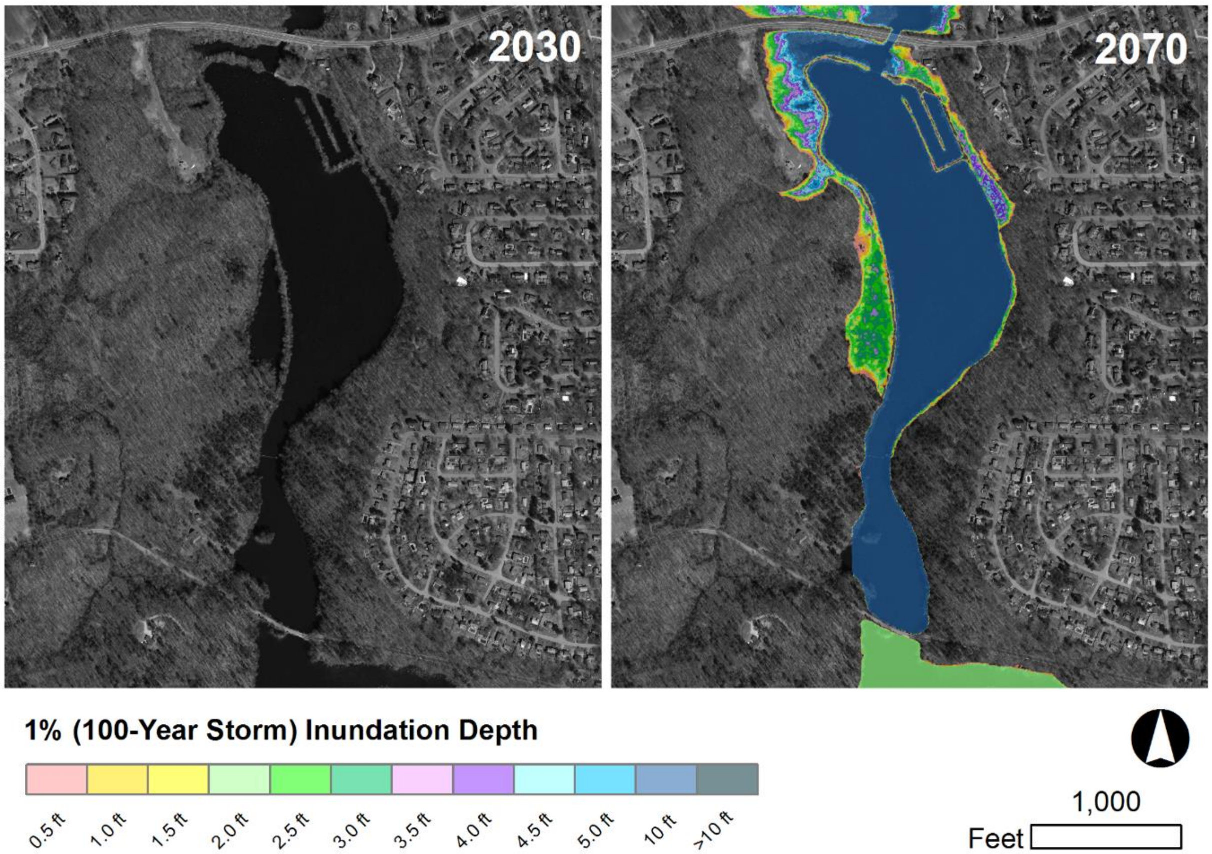

Figure 3.3-4. Lower Artichoke Reservoir, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

The Merrimack River Jetty System was highlighted as an area of concern because of its potential impact on the vulnerability of nearby land, in particular the **North End of Plum Island.** The jetty system serves to restrict the river's hydraulic flow, bi-directionally. In the early stages of a storm for example, it slows the rate at which the ocean's surge enters the river basin. But once there, the constricted river mouth serves to capture this ocean water within the river basin and marsh. When this situation is coupled with heavy storm water runoff flowing down the Merrimack, the river cannot efficiently discharge both the trapped sea water and accumulating rain water. Further hemmed in by the Plum Island Turnpike and Beach Road causeway in Salisbury, these flood waters rise along the rear of the barrier beaches and also Newburyport's water front, where they exert great (and un-quantified) amounts of hydraulic pressure. Such was the case during the Mother's day storm of 2006.[128]

[127] Ibid 24-25

[128] Newburyport Resiliency Task Force, personal communication with authors, September 1, 2017

Bill Sergeant

Initially constructed in 1899, this jetty system has been repaired at least 9 times,[129] most recently in 2015. As is typical of grey infrastructure located in sandy environments, this jetty system seems to disrupt the natural distribution of sand caused by tidal forces. Based on historical observations and correlations of CZM's shoreline change data with dates of past jetty repair and dredging, there seems to be an established association between beach erosion and the condition of the jetty.[130] According to historical observations, when the jetties are in a state of disrepair, Plum Island's coastal beach has often eroded while the beach on Plum Island Point, located within the river, has expanded.[131] This is likely because sand from the coastal beach is allowed to migrate and build up onto Plum Island Point. Conversely when the jetty is repaired, the point's sand supply is cut off, and it begins to erode while the coastal beach stabilizes and then expands. It has also been noted that past dredging programs following jetty repairs have hastened the pace of erosion at Plum Island Point.[132]

Since the most recent jetty reconstruction efforts were completed by the US Army Corps of Engineers on the south jetty in 2013 and the north jetty in 2015, residents have noticed an astounding increase in erosion along the northern tip of Plum Island, particularly the **Reservation Terrace and Old Point neighborhoods**. According to some estimates by the Newburyport Resiliency Task force, portions of the dune crest have eroded as much as 300' since 2012. Erosion of this magnitude significantly threatens residents living on Plum Island and reduces the capacity of dunes and beaches to protect properties from increased storm surge. More research is needed to identify a jetty design that better balances shoreline stabilization with navigational needs, and communication has already begun between the City of Newburyport and the Army Corps of Engineers.

The Lord Timothy Dexter Industrial Green (Business Park) and adjoining **Newburyport MBTA Train Station** suffer repetitive flooding due to their low-lying topography, high amount of impervious surfaces, and several improperly sized culverts and bridges along the Little River. Because the river is tidal, this problem is exacerbated by normal tidal cycles and storm surge. Although the Business Park and train station are located in Newburyport, the hydro barriers are located in Newbury. Flooding in this area was the subject of a study commissioned by the City in 2011 and executed by Malcom Pirnie – the water division of ARCADIS. Findings from the *Malcolm Hoyt Drainage Improvements Flood Study* found the Parker Street culvert to be the most critical flow restriction in the study area. According to the Newburyport Resiliency Task force, this culvert is structurally deficient and should be replaced to reduce the likelihood of future flooding.[133] Additional improvements were recommended for the slightly less critical Hale Street culvert as well.[134] Because the Little River runs through both Newburyport and Newbury, relieving flow restrictions along the river has the potential to increase flooding downstream and

[129] "Newburyport Harbor Jetties," Town of Newbury, accessed September 2015, http://www.townofnewbury.org/pages/history.pdf
[130] Newburyport Resiliency Task Force, personal communication with authors, July 15, 2015
[131] Ibid
[132] Ibid
[133] Ibid
[134] "MVMPO Current Transportation Projects Action Chart," MVPC, last updated September 18, 2012. http://mvpc.org/wp-content/uploads/Transportation-Project-list-9-2012.pdf

across municipal jurisdictions. Increasing the hydraulic capacity of these crossings also has the potential to increase the vulnerability of the Business Park to salt water flooding due to SLR and storm surge. It is critical that these hydro-barriers are addressed through a comprehensive watershed approach to ensure that efforts to relieve existing flood hazards do not simply shift the flood hazard to another highly developed area downstream. Action is needed, however, because the predicted increase in heavy precipitation events and SLR threaten to exacerbate existing flooding concerns.

Much of **Newburyport's historic downtown waterfront** along **Water Street** is located at a high enough elevation to be protected from all but the most severe storm surges. Natural topographic features, combined with an array of bulkheads and other grey infrastructure, protect much of downtown. However, infrastructure located immediately along the bank of the Merrimack, including the boardwalk, the Black Cow Restaurant, and other bordering businesses, are quite vulnerable to flooding and sea level rise. The future of a large open parking lot abutting the riverfront boardwalk has been a subject of discussion for many years, with plans for a hotel and commercial elements in conflict with support for an "open waterfront." Infrastructure located along Water Street and Merrimack Street is less vulnerable than the direct waterfront, however this area is also subject to occasional flooding. Infrastructure further inland doesn't flood from the river's storm surge but is vulnerable to flooding caused by heavy precipitation events. Outdated and insufficient drainage systems don't have the capacity to remove flood waters quickly enough, increasing the vulnerability of downtown areas such as Market Square.[135] The USGS analysis indicates this area is already vulnerable to inundation during a 1% or 0.2% storm, likely flooding up to 48% of the area with approximately less than four feet of water. By 2070, up to 91% of the area is susceptible to flooding during a major 1% or 0.2% storm, sending between 5-20 feet of water over much of the area (Figure 3.3-5).[136]

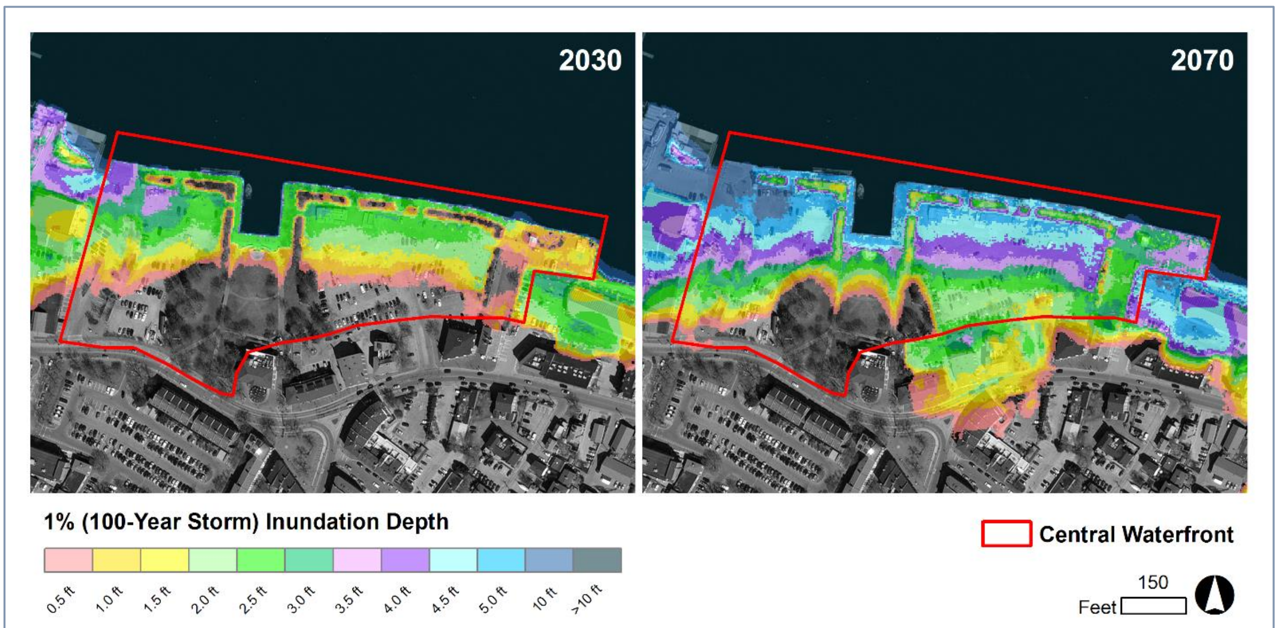

Figure 3.3-5. Central Waterfront, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

[135] MVPC, "Newburyport Natural Hazard Risk Assessment," 206
[136] Abdollahian, N. et al., *Community Exposure,* 25

Members of the public specifically identified concerns about the **Salvation Army**, located on the southern side of Water Street in the downtown, which serves as an emergency shelter for the City. By 2070, access to the emergency shelter could become compromised as the corner of Water Street and Fair Street surrounding the Salvation Army is likely to be completely inundated with 1-4.5 feet of water during a 1% or 0.2% storm. A 0.2% storm in 2070 is also likely to flood portions of the building with 0.5 feet of water.[137] Also of concern is the **U.S. Coast Guard Station**, located on the north side of Water Street. The Coast Guard Station is estimated to be entirely within the coastal hazard zone by 2030, where estimated flood-depths during a 1% and 0.2% storm could range from 0.5-2 feet. By 2070, the facility and surrounding area are likely to be inundated with 3-10 feet of water for both storm scenarios.[138]

Two additional areas of **Water Street** deserve special mention. From the junction of Union Street to Ocean Avenue, the road is very low and frequently floods during rain storms and high tides that are accompanied by north-easterly winds. Similarly, the section of Water Street along the sea wall at Joppa Park, from the public boat ramp and Hale Park up to Union Street, can flood due to high river levels and high tides that are accompanied by north-easterly winds.

Cashman Park, located along the Merrimack River shoreline just northwest of downtown, is a multi-use public park that includes ball fields, tennis courts, a playground, public boat launch area, and walking and biking paths. According to the City, this park is susceptible to flooding, particularly when high tides combine with multi-day storm events. The recreation areas as well as the nearby Rivers Edge condominiums have been flooded during these events in recent years.

COAST ANALYSIS OF DOWNTOWN WATERFRONT AREA

To further assess the vulnerability of Newburyport's **central downtown waterfront**, GEI Consultants analyzed this area for potential infrastructure losses due to flooding and sea level rise using a no-action iteration of the Coastal Adaptation to Sea level rise Tool (COAST) (version 3.0). COAST analyzed potential damages to buildings from three sea level rise scenarios, both as single snapshots in time from a 100-year flood (1% annual chance flood) in 2030 and 2070; and as cumulative damages from all possible storms from 2015 to 2030 and from 2031 to 2070. It is important to note that COAST assesses projected damage to buildings but does not incorporate potential damages to building contents. For example, the Maritime Museum houses extremely valuable, or even priceless, artifacts. Damages to the building would likely also damage the artifacts. However COAST does not calculate potential losses resulting from building contents being damaged or destroyed due to flooding.

According to the report, results of the study indicate that damages from no action through 2030 could be in the tens of millions of dollars. Due to the short length of time of the cumulative damage scenarios and topography of the study area, one-time damage estimates from the 100-yearflood were greater than the cumulative damage estimates (that adjust for the lower probability of large events). Specifically, one-time damages ranged from

Table 3.3-3. One-time damage estimates for a 100-year flood in 2030 and 2070 under low, medium, and high sea level rise scenarios. Damage estimates are to building structures only within the Newburyport, MA Study Area (does not include building contents).

Year	Sea Level Rise (ft)	Damage to Buildings
2030	Low (0.31)	$14.1 Million
2030	Med (0.50)	$14.9 Million
2030	High (0.72)	$15.8 Million
2070	Low (1.09)	$18.3 Million
2070	Med (2.19)	$24.2 Million
2070	High (3.45)	$32.4 Million

137 Famely, J. et al., Sea Level Rise and Storm Surge Inundation Mapping
138 Ibid

$14.1 Million (low sea level rise) to $15.8 Million (high sea level rise) in 2030; and $18.3 Million (low sea level rise) to $32.4 Million (high sea level rise) in 2070 (Table 3.3-3).[139]

Cumulative damages ranged from $3.2 Million (low sea level rise) to $3.6 Million (high sea level rise) between 2015 and 2030; and $9.9 Million (low sea level rise) to $25.1 Million (high sea level rise) between 2031 and 2070. Between $0.7 Million (low sea level rise) and $1.3 Million (high sea level rise) in total parcel valuation (building and land) was permanently inundated from sea level rise by 2030; and between $1.9 Million (low sea level rise) and $20.9 Million (high sea level rise) in total parcel valuation was permanently inundated from sea level rise by 2070.[140]

See Appendix C for more information on the COAST analysis and for a summary of projected costs incurred due to parcels becoming permanently inundated by SLR.

DEMOGRAPHICS[141]

According to the USGS geospatial hazard analysis, 1% (250) of Newburyport's residents currently live in coastal-hazard zones. By 2070, this number will increase to 1,206 residents, representing 7% of Newburyport's population. Very few residents currently live in areas with medium to high probability of inundation. However by 2070, that number will grow dramatically (Figure 3.3-6). All demographic percentages describing residents in hazard zones were relatively stable (+/- 1%) among the three time periods. Demographic data suggest that there are no residents in the coastal-hazard zones across the three time periods that live in mobile homes or live in institutionalized group quarters. Less than 5% of the residents in the hazard zones speak English as a second language, are under 5 years in age, are unemployed, lack a phone, or lack vehicles. Greater than 5% of the residents in the hazard zones are living under the poverty line (7%), have disabilities (11%), live in renter-occupied households (17%), are over 65 years in age (19%), or only have a high school degree (20%).

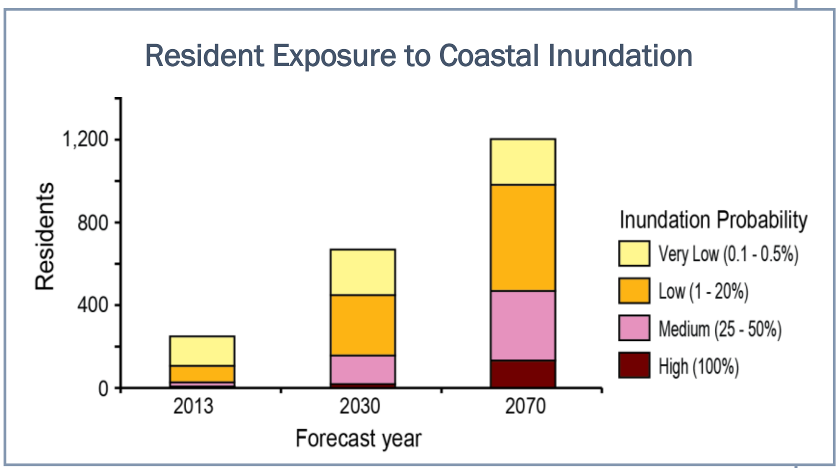

Figure 3.3-6. Resident exposure in the City of Newburyport, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

ECONOMIC & SOCIO-ECONOMIC[142]

The number of Newburyport employees working in coastal-hazard zones ranges from 484 currently to 2,580 in 2070, representing 3% to 18%, respectively, of the 14,016 employees that presently work in the community (Figure 3.3-7). As was the case with the resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zone and not projected changes in employee

[139] Merrill, S.B. and A. Gray, "COAST Modeling for the City of Newburyport, Massachusetts"
[140] Ibid
[141] Abdollahian, N. et al., *Community Exposure*, 21-22
[142] Ibid 22-23

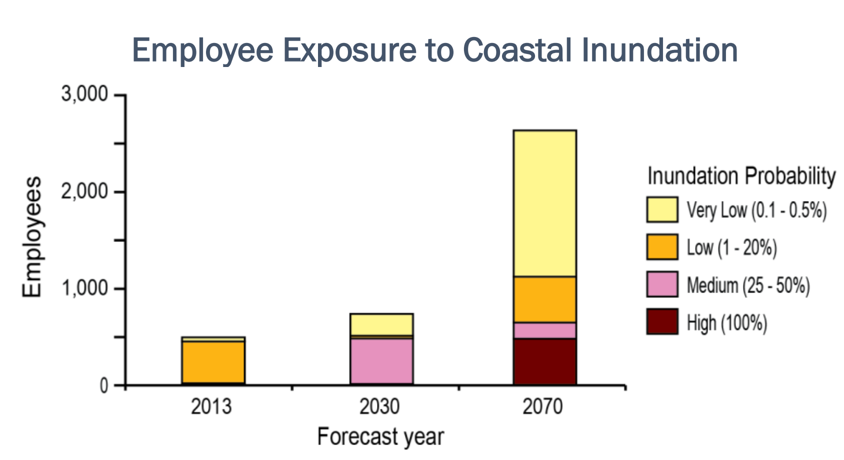

Figure 3.3-7. Employee exposure in Newburyport, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

distributions. In present day, most employees in these hazard zones are in areas classified as having a low (1-20%) inundation probability (427 employees). By 2070, 1,481 employees are at businesses in the very low (0.1-.5%) probability zone, with additional employees in zones classified as high (470), medium (165) and low (464) inundation probability.

Sales volume exposure for private-sector businesses ranges from $91.5 million currently to $489.1 million in 2070 (Figure 3.3-8a). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have a significant customer presence (e.g. retail) in coastal-hazard zones ranges from 7 businesses in 2013 to 121 businesses in 2070. Of the businesses with fewer than 20 employees (a group typically more sensitive to disruptions), there are currently 16 located in coastal hazard zones. This number will increase to 189 businesses in 2070, representing 14% of the Newburyport business community.

Similar to sales volume, parcel values and building replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $165 million present day to approximately $475 million in 2070, representing 5% to 13% of the community's tax base between the two time periods (Figure 3.3-8b). The majority of tax-parcel value in hazard zones is associated with land value for 2013 and 2030 (50% and 52% respectively), and building value for 2070 (52%). Based on building stock data in the FEMA Hazus-MH database, estimated building replacement values range from $145 million for the current hazard zone to $362 million for 2070 hazard zone (Figure 3.3-8c). The majority of potential building replacement values are in areas classified as having a very low probability in 2013 up to low probability of inundation in 2070.

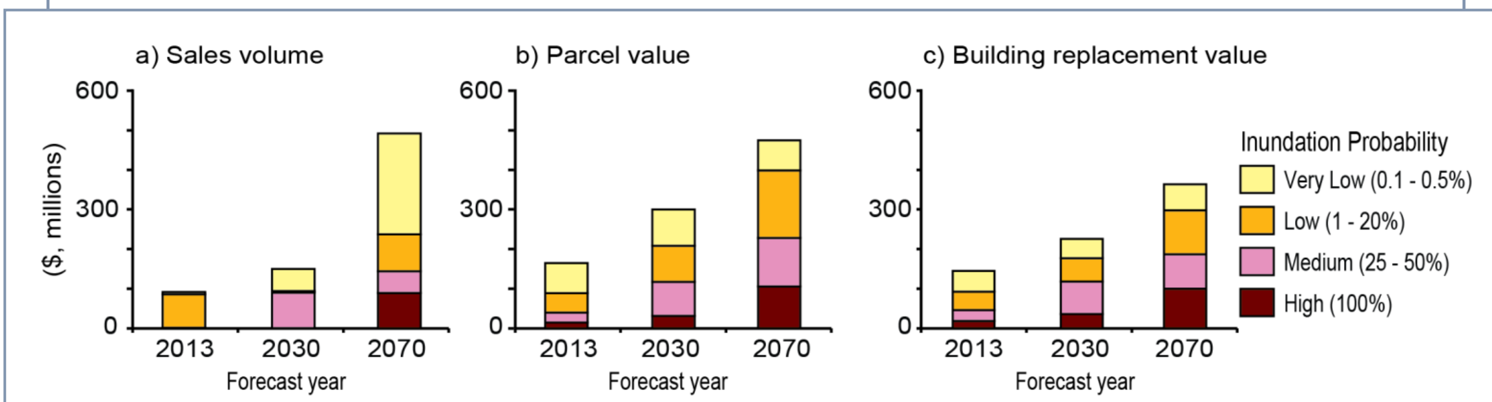

Figure 3.3-8. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Newburyport, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

Separate from the USGS analysis, FEMA and the Department of Homeland Security conducted a static analysis on Newburyport's current economic vulnerability to flooding. Their study analyzed the potential economic impact of various storm scenarios using FEMA's Flood Risk Database combined with FEMA's flood loss estimation tool, HAZUS. Potential building losses and associated business disruption costs for each storm category are shown below (Table 3.3-4).[143] Based on their analysis, the economic impact of even a relatively small 10% (10-year) storm may be quite significant.

Table 3.3-4. Newburyport's Estimated Potential Losses for Flood Event Scenarios. (*)Losses shown are rounded to nearest $10,000 for values under $100,000 and to the nearest $100,000 for values over $100,000; (**) Total Building/Contents Loss = Residential Building/Contents Loss + Commercial Building/Contents Loss + Other Building/Contents Loss; (***) Disruption = Inventory Loss + Relocation Cost + Income Loss + Rental Income Loss + Wage Loss + Direct Output Loss; (****) Total Loss = Total Building/Contents + Business Disruption.

	10% (10-yr)	2% (50-yr)	1% (100-yr)	0.2% (500-yr)	Annualized ($/yr)
	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*
Total Buildings/ Contents**	$33,500,000	$46,500,000	$58,100,000	$84,800,000	$4,200,000
Business Disruption***	$2,200,000	$3,100,000	$4,100,000	$5,500,000	$300,000
Total*****	$35,800,000	$49,800,000	$62,100,000	$90,300,000	$4,500,000

Based on this analysis, a mere 10% storm has the potential to cause as much as $35.8 million dollars in damage. A larger 1% (100-year) storm may cause as much as $49.8 million in damage and a 0.2% (500-year) storm as much as $90 million. The majority of damage comes from infrastructure losses, although business disruptions are also quite significant. It is important to note that as 1% storms become more frequent, these damage estimates are likely to increase.

HABITATS & SPECIES

The Great Marsh is one of the most important coastal ecosystems in northeastern North America.[144] In Newburyport, this ecosystem contains high and low marsh, estuarine aquatic environments, and a barrier beach accompanied by extensive dunes. Each of these habitats provides critical foraging and breeding grounds for a variety of native species. The Great Marsh also provides an abundance of ecosystem services to the City of Newburyport. The marsh absorbs wave energy and traps sediment, helping reduce erosion; the aquatic environment is a nursery for commercially important fish species; and the dunes provide protection against storm surge. In addition, the salt marsh traps and safely stores harmful sources of carbon that are the leading cause of climate change. In fact, recent analysis indicates that marshes are one of the most powerful carbon sinks, with the potential of sequestering almost 50 times more carbon than tropical rainforests.[145]

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143 FEMA, *DRAFT Flood Risk Report: Essex County, MA* (Washington, DC, 2013), 36

144 "The Great Marsh," Western Hemisphere Shorebird Reserve Network, accessed October 2015. http://www.whsrn.org/site-profile/great-marsh

145 Bu, N. et al., "Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool," *Ecological Engineering*, 81 (2015): 335

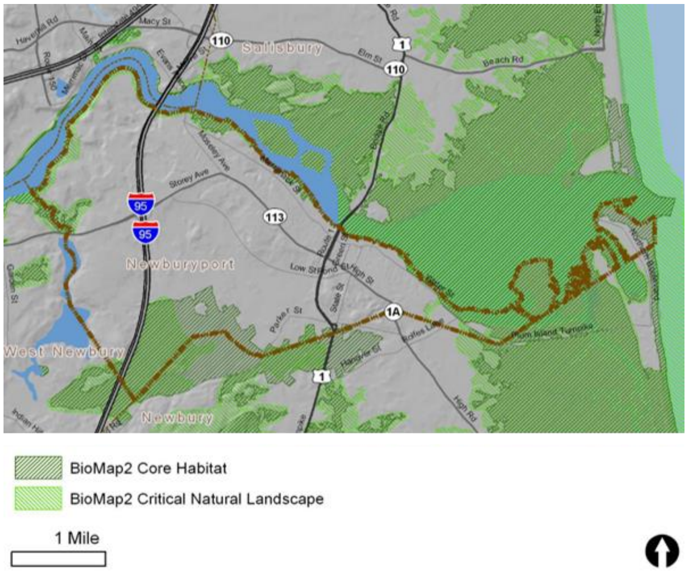

Figure 3.3-9. *BioMap2* Core Habitats & critical natural landscapes in Newburyport.

A significant portion of Newburyport has received official designation recognizing the importance of its natural systems. Approximately 1,021 acres in Newburyport are designated as *core habitat* and 926 acres are listed as *critical natural landscapes* (Figure 3.3-9).[146] The term "core habitat" refers to areas deemed necessary to support the long-term existence of rare or threatened species, exemplary natural communities, and intact ecosystems. "Critical natural landscapes" are intact ecosystems that are well suited to support ecological processes and/or a wide array of species and habitats over a long period of time.[147]

Intact river corridors, salt marshes, barrier beaches, and dunes make up the majority of the critically important habitat in Newburyport. These habitats contain multiple vegetative zones that support a wide diversity of species, including numerous threatened and endangered species (Table 3.3-5).[148]

Table 3.3-5. List of species occurring in Newburyport that are threatened (T) or endangered (E). *For complete list of species, including species of conservation concern, see the MA Dept. of Fish & Game BioMap2 report for Newburyport (2012).*

Threatened and Endangered Species	Preferred Habitat
Birds	
Upland Sandpiper[E]	Upland fields
Piping Plover[T]	Beach, dunes, mudflats
Bald Eagle[T]	Marsh, tidal channels, upland habitat
Fish	
Atlantic Sturgeon[E]	Marsh, coastal rivers, tidal estuaries
Shortnose Sturgeon[E]	Marsh, coastal rivers, tidal estuaries
Plants	
Eaton's Beggar-ticks[E]	Brackish river banks
American Waterwort[E]	Muddy shores of ponds and tidal rivers
Estuary Arrowhead[E]	Sandy shores, mudflats, brackish rivers
Seabeach Needlegrass[T]	Coastal dunes
Seabeach Dock[T]	Beaches, coastal swamps
Long's Bulrush[T]	Wet meadows, peaty wetlands
Englemann's Umbrella-sedge[T]	Wet pond shores
Reptiles & Amphibians	
Blanding's Turtle[T]	Marsh, wetlands
Eastern Spadefoot[T]	Pine barrens, coastal oak woodlands, sand

The marsh tidal flats in Newburyport are particularly vulnerable to erosion and sea level rise. Because this habitat is so low-lying, these habitats may become permanently inundated under just one foot of sea level rise.[149] Given the close proximity of development to the marsh and tidal flats, coastal ecosystems may not be able to migrate inland, leaving these important habitats to disappear under water. However if deliberate steps are taken to both limit further development along the water's edge and facilitate marsh migration, this critical habitat may be able to gradually move landward to keep pace with sea level rise. Furthermore, development combined with an increase in severe storm activity will likely lead to an increase in surface

[146] MA DFG & TNC, *BioMap2: Newburyport* (Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012), http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Newburyport.pdf

[147] Ibid

[148] Ibid

[149] "MORIS: CZM's Online Mapping Tool"

runoff quantities and rates. Storm runoff carrying bacteria, pathogens, and nutrients that can be extremely damaging to this marine environment.

Newburyport beaches and dunes on Plum Island provide critical foraging habitat to the federally threatened Piping Plover, among other species. This habitat is however disappearing as erosion rates are further accelerated by increased storm frequency and intensity, and sea level rise. Like all barrier beaches, natural processes cause the beach to shift over time. A beach's dynamic character and ability to move and reshape in response to constant wave energy as well as acute storm events, is precisely what makes it resilient to sea level rise and storm surge.[150] As the Massachusetts Coastal Erosion Commission's final report notes, "the movement of sediment along the coast and the [natural] loss and gain of shoreline—erosion and accretion—are continuous and interrelated processes."[151] Development along Newburyport's barrier beach disrupts natural erosion and accretion rates, resulting in changes in beach formation that can impact houses and other infrastructure located along the coast and adjacent to the basin. If beaches and dunes are not allowed to migrate inland as the sea rises, this habitat will slowly disappear, impacting humans and a wide variety of native species.

Summary

Overall the City of Newburyport has a high level of vulnerability to climate-driven threats. Predicted increases in storm frequency and severity, sea level rise, increased storm surge, and erosion are all major hazards facing Newburyport. These hazards may have wide-ranging impacts on the City's coastal economy, the infrastructure located in low-lying riverine and coastal areas, and the natural systems that the community depends upon. Because of the City's reliance on coastal tourism, impacts to the natural systems may have cascading effects that ripple across all parts of the community. The geospatial analysis conducted by USGS confirms these findings and indicates economic, infrastructure, and population vulnerabilities that will likely need to be addressed to protect human life as well as the economic well-being of Newburyport.

Kay Bice/MA Office of Travel & Tourism

The natural systems in Newburyport are already being impacted by erosion that is likely to accelerate with climate change. Sea level rise will likely inundate areas of marsh that currently help reduce storm surge and reduce erosion, and provide important habitat to rare and threatened species. Storm surge resulting from bigger and more frequent storms may overtop existing dunes and coastal structures, impacting densely populated areas on Plum Island. An increase in heavy precipitation events combined with penetrating storm surge will likely cause substantial damage to low-lying portions of Newburyport, including the Business Park.

For recommendations on how to address the City of Newburyport's overall vulnerability to climate-driven hazards, including site-specific adaptation strategies for the areas of concern outlined above, see Chapter 4: Adaptation Strategies for the Great Marsh Region.

150 Massachusetts Barrier Beach Task Force, *Guidelines for Barrier Beach Management in Massachusetts* (Boston, MA: Massachusetts Office of Coastal Zone Management, 1994) http://www.mass.gov/eea/docs/czm/stormsmart/beaches/barrier-beach-guidelines.pdf

151 Massachusetts Coastal Erosion Commission, "Volume 1: Findings and Recommendations" in *Report of the Massachusetts Coastal Erosion Commission* (Boston, MA: Massachusetts Executive Office of Energy and Environmental Affairs, 2015), 1

Anna Hanks/Flickr

3.4. Town of Newbury Vulnerability Assessment

Community Exposure to Climate Hazards

Newbury is a moderately sized (24.2 square miles) coastal community along the North Shore of Massachusetts, nestled between Newburyport to the north and Rowley to the south. Forests and salt marshes dominate the landscape, covering 64% of the land.[152] The Great Marsh, the largest contiguous salt marsh in New England, alone makes up 30% of the landmass in Newbury, while residential development, agriculture, and combined commercial/industrial development make up 14%, 10% and 1%, respectively.[153]

According to the 2010 Federal Census, there are approximately 6,666 year-round residents living in Newbury. However like many North Shore communities, the population swells during the summer months with an influx of summer residents and tourists. Newbury's infrastructure is located in three distinct sections: Old Town, Byfield, and Plum Island.[154] Plum Island is a barrier beach with dense residential

[152] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan* (Haverhill, MA, 2015), 174
[153] Ibid
[154] Ibid 182

development and is especially vibrant during summer months. Old Town and Byfield are inland and consist of residential homes, farm houses and land, small businesses, and municipal facilities. [155]

A network of tidally-influenced rivers and channels crisscross through Newbury. The Parker River is the largest river and is brackish as far as 9 miles inland from where it enters the Plum Island Sound.[156] The Little River, a main tributary to the Parker River, is brackish as far as 4 miles inland. During storms and abnormally high-tides, water courses through these and other tidal channels and rivers, carrying flood waters inland. Hydro-barriers can contribute to upstream flooding and often act as choke points causing fresh and tidal creeks to spill out of their banks or onto the marsh. The development in the Newburyport Industrial Park, including the establishment of the Newburyport MBTA station and associated runoff, has further impacted the natural flow of the Little River and its associated wetlands in the area. The natural low-lying topography in Newbury combined with widespread tidal and freshwater restrictions leads to chronic and widespread coastal and riverine flooding.

Newbury also has high exposure to erosion, particularly on Plum Island. This is most evident along the developed portion of beach-front property around Fordham Way and Annapolis Way.[157] The barrier beach is the first line of defense against storm surge and sea level rise. In its unprotected location, the beach experiences a continuous onslaught of waves and wind which leads to significant erosion. Large storms can also cause acute erosion events where large sections of beach are completely swept away. In February 2013, Winter Storm Nemo, along with several smaller storms, eroded significant portions of the beach and dunes. Storm surge and erosion eventually destroyed six beachfront homes. These properties were the first FEMA claims in Newbury resulting from coastal flooding rather than riverine flooding along the Parker River.[158] Coastal and inland flooding are now significant issues for Newbury and will be exacerbated by future sea level rise and storm events.

In summary, Newbury has high exposure to coastal flooding, riverine flooding, and erosion due to its topography, hydrology, and geographic location. Plum Island faces the open ocean and is highly exposed to wind, wave action, and sea level rise – with no buffering landmass to diminish these hazards. Interior portions of Newbury rely on Plum Island to buffer the worst storm effects, however the extensive number of tidal creeks and channels, combined with the overall low topography, can lead to widespread inland flooding – such as what occurred during the now infamous Mother's Day Storm of 2006.

Bill Sergeant

[155] Ibid
[156] Ibid 187
[157] Ibid 183
[158] Newbury Resiliency Task Force, personal communication with authors, July 15, 2015

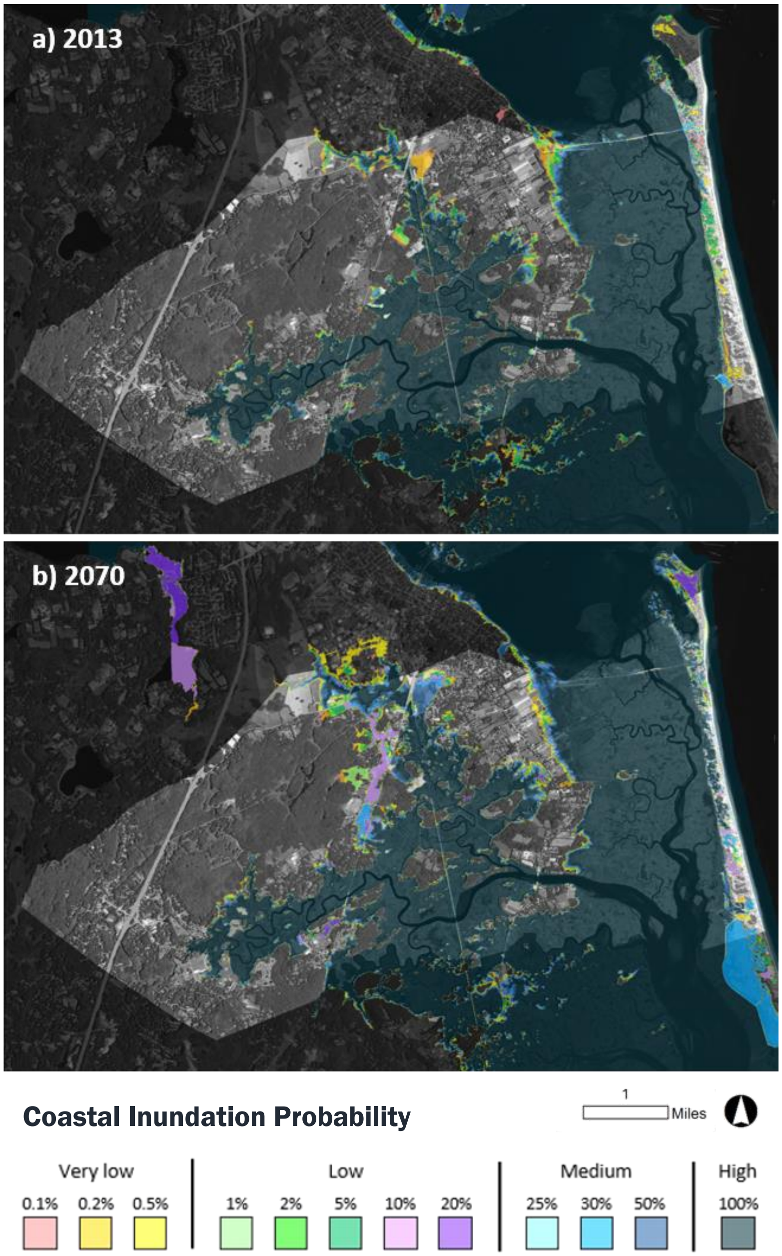

Figure 3.4-1. Newbury, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

A detailed analysis of coastal inundation, conducted by the Woods Hole Group and USGS, confirms that the Town of Newbury has high exposure to sea level rise and storm surge. Present day estimates (which are for the year 2013) indicate approximately 37% of the town is vulnerable to coastal inundation – depending on the severity of the storm. That number climbs to 45% in 2070 (Figure 3.4-1).[159] It is apparent that in a worst case storm scenario, much of the town would be under water from penetrating storm surge.

Additionally, the community's high exposure to coastal flooding is evidenced by the large amount (21%) of developed land that is currently vulnerable to coastal inundation under a worst case storm scenario. However even more telling is the fact that of the 21%, much of the developed land is in areas likely to flood on an annual or near semi-annual basis, especially by 2070 (Figure 3.4-2).[160] Undeveloped land has even higher exposure to inundation, now and in 2070.

Community Sensitivity to Climate Hazards

The Town of Newbury appears to have a relatively high level of sensitivity to climate-driven threats. Much of the town's infrastructure is located in low-lying areas that are susceptible to flooding from storm surge, sea level rise, and riverine flooding. Plum Island in particular is a main tourist attraction and is densely populated with residential development. Much of the developed areas on Plum Island fall within FEMA's High Risk Coastal Area, and overall almost 48% of Newbury is within the FEMA 1% flood zone (often referred to as the "100-year" flood zone).[161] This is the highest percentage of any of the 15 communities in the Merrimack Valley Planning Commission region.[162] Based on further analysis by MVPC, there are 799 structures located in the 1% flood zone, including residential, industrial, and commercial

[159] Abdollahian, N. et al., *Community exposure to potential climate-driven changes to coastal-inundation hazards for six communities in Essex County, Massachusetts*, U.S. Geological Survey open-file report (Reston, VA: USGS, 2016), 27

[160] Ibid

[161] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan*, 189

[162] Ibid 179

buildings. These structures are valued at almost $125 million, with 92% of the valuation coming from residential properties.[163]

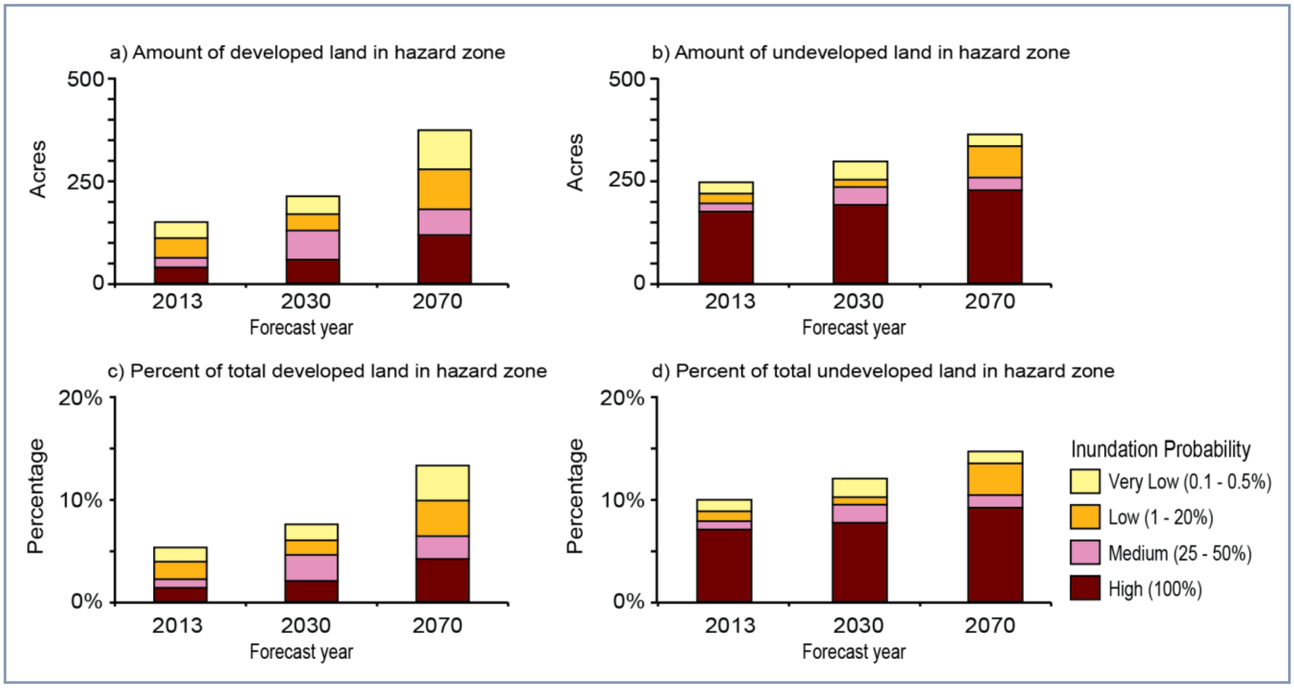

Figure 3.4-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Newbury, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

In Newbury, economic sensitivity to climate hazards is intrinsically linked to the sensitivity of the town's natural systems. Newbury's economy has a long tradition of relying upon its "relationship with the land and the sea" – a tradition that continues to this day.[164] While other North Shore communities rely heavily on tourism, Newbury has continued to embrace its heritage of shell fishing and agriculture, including salt marsh haying. Newbury currently ranks second in Massachusetts in terms of average landings for soft-shell clams in Massachusetts and still has several working farms, most of which are in low-lying areas of town.[165] It should also be noted that the tax revenue generated from the ever-expanding beach-front properties on Plum Island have benefited the community. This tax base provides a significant source of income for Newbury.

The Great Marsh, which covers 30% of the town,[166] is also a tourism draw that boosts the local economy. It is designated an Important Bird Area of global significance and a Western Hemisphere Shorebird Reserve Network site. The Parker River National Wildlife Refuge, which encompasses the Great Marsh and a significant portion of Newbury, is a major tourist attraction: the beaches, dunes, walking trails, and driving tour provide an excellent opportunity for visitors to experience the Great Marsh ecosystem.

[163] Ibid 190
[164] Town of Newbury, *Master Plan* (Newbury, MA, 2006), 99
[165] Wayne Castonguay (Executive Director of the Ipswich River Watershed Association), personal communication with authors, February 26, 2015
[166] MVPC, Draft Merrimack Valley Multi-Hazard Mitigation Plan (Haverhill, MA, 2015), 174

Approximately 250,000 people visit the refuge each year, and according to a survey conducted in 2011, bird watching was the most popular activity visitors engaged in.[167, 168]

Marshes and barrier beaches make up a large portion of Newbury, and these natural systems are inherently sensitive to the impacts of climate change; human activity can further increase their sensitivity. A healthy untouched marsh can absorb storm surge, and heavily vegetated dunes are more resilient in the face of large storms.[169, 170] Depending on topographic features, marshes and dunes can often migrate inland as sea levels rise. However, these natural systems are impacted by human development and management. Improperly-sized hydro barriers can disrupt marsh ecosystems by reducing flow of sediment and impacting salinity levels. Narrow, unvegetated dunes (typically found in heavily populated areas) can erode quickly if they are exposed to waves.

The dunes in the Parker River National Wildlife Refuge are heavily vegetated with native shrubs that increase the resiliency of the coastline. However along the non-refuge portions of Plum Island, human activity has increased beach and dune sensitivity to climate hazards, especially erosion. Based on a recent analysis completed by the Coastal Erosion Commission and presented by CZM, the public beach on Plum Island had the second highest rate of erosion among public beaches on the North Shore. The beach lost an average of over 1.2 meters (4 ft) a year between 1978 and 2008.[171] Furthermore, 86% of all locations surveyed in Newbury showed at least some level of erosion and only 13% had any level of accretion (data collected between 1970 and 2009).[172] Anecdotal information indicates erosion may have slowed in recent years, however more study is required to understand the complex processes that contribute to the ebb and flow of erosion and accretion. What is known, however, is that with rising seas and increased storm activity, erosion and its associated impacts are likely to worsen for this community already sensitive to climate-driven impacts.

Sandy Tilton

Community Vulnerability

An extensive amount of work has already been conducted in Newbury to assess community vulnerability to natural hazards. The most comprehensive information to date, particularly regarding infrastructure, is provided in Newbury's *Natural Hazard Risk Assessment* prepared by the Merrimack Valley Planning Commission.[173] Information from this and other documents is synthesized below along

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[167] Nancy Pau (Refuge Biologist at PRNWR), personal communication with author, 2015

[168] Sexton, N. et al., *National Wildlife Refuge Visitor Survey 2010/2011: Individual Refuge Results for Parker River National Wildlife Refuge*, (Fort Collins, CO: USGS, 2011), 12

[169] Shepard, C.C., et al., "The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis," *PLoS ONE* 6, no. 11 (November 2011): e27374, doi:10.1371/journal.pone.0027374.

[170] "In Defense of Dunes," ASBPA, January 13, 2015, http://www.asbpa.org/news/newsroom_14BN0113_in_defense_of_dunes.htm

[171] MA EEA, *Shoreline Characterization and Change Analyses: North Shore Region* (Gloucester, MA, 2014) http://www.mass.gov/eea/docs/czm/erosion-commission/shoreline-profile-north-shore.pdf

[172] Ibid

[173] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan*, 182-199

with information from the Newbury Resiliency Task Force, coastal inundation modeling conducted by the Woods Hole Group,[174] and results from the 2016 USGS geospatial analysis of potential impacts from coastal inundation.[175]

Overall Newbury has a high level of vulnerability because it has both significant exposure and high sensitivity to climate hazards. Storm surge, riverine flooding of tidal creeks, and acute and long-term erosion pose the biggest threats to this community. MVPC's Natural Hazard Risk Analysis reached a similar conclusion. Based on their analysis, they identified 18 areas of particular concern (Table 3.4-1) and assigned Newbury a "high" risk rating for floods, winter storms, and Northeasters.[176, 177]

Table 3.4-1. Summary of Special Flooding Problems/High Hazard Concerns listed in Newbury's Natural Hazard Risk Assessment prepared by MVPC. Order does not indicate priority or level of concern.

High Hazard Concerns	Type of Hazard
Plum Island & Beach	Erosion and overtopping
Plum Island Turnpike	Road flooding
Plum Island Center	Overtopping, flooding
Middle Road @ Tolman's Auto, Stubbs, & south of Parker River bridge	Flooding
Scotland Road @ Wolf Brook, Highfield Road intersection, & Pikul field	Flooding
River Street	Dam failure and flooding
Newman Road @ marsh	Flooding
Hanover Street @ Little River	Flooding
Pine Island Road	Flooding
Larkin Road @ bridge	Flooding
Orchard Street @ Cart Creek and north of Great Meadow	Flooding
Central Street	Dam failure, flooding
Hay Street @ Quill Pond and south of Newman Road	Overtopping, flooding
Moody Street @ 1/8 mile before Ash Street	Flooding
Cottage Road @ Parker River	Flooding
Highfield Road @ Middle Road to Merrimack Valley Beagle Club	Flooding
Newburyport Turnpike north of Newbury Golf Course	High-tide flooding
Harvard Way	Flooding

CRITICAL INFRASTRUCTURE

MVPC's Natural Hazard Risk Assessment only identified two pieces of critical infrastructure in the floodplain: Plum Island Taxpayers Association on Plum Island and the sewage pumping station on Plum Island.[178] Newbury's Town Hall and emergency operations center are outside the 1% flood zone. However the Town's Master Plan indicates that the Town Hall's basement suffers from chronic flooding.[179] The Master Plan further notes the Police Station is in violation of numerous building codes, indicating that flooding is likely the result of the building's high sensitivity to flooding rather than high exposure. Public input from the Great Marsh Symposium 2015 identified overall power grid vulnerability and the Seabrook (NH) Station Nuclear Power Plant in the neighboring town to the north as areas of concern.

The USGS geospatial analysis of critical infrastructure in Newbury indicates an airport, currently within a low-probability inundation-hazard zone, will have a 30% and 50-100% chance of being inundated by coastal flooding in 2030 and 2070 (respectively). One communication tower is in a high-probability, inundation-hazard zone for 2030 and 2070. One underground storage tank is in an area of low-inundation probability for 2070 hazard zones, but not in 2013 or 2030 zones. An overall infrastructure analysis

[174] Famely, J. et al., Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA), Prepared by Woods Hole Group for National Wildlife Federation and U.S. Geological Survey, (Falmouth, MA, 2016)
[175] Abdollahian, N. et al., *Community Exposure*
[176] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan*, 189
[177] Ibid 195
[178] Ibid 189
[179] Town of Newbury, *Master Plan,* 154

indicated that there are approximately 13 miles of roads and rail in 2013 hazard zones (primarily in the low-probability zone), increasing to 17 miles by 2070 (primarily in the medium-probability zone). Approximately 0.48 miles of transmission lines are in hazard zones, with exposure spanning primarily from low to high probability in 2013 and increasing to primarily high in 2070.[180]

BARRIERS TO FLOW

The "Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed" provides additional insight into where the community may be vulnerable to flooding. As part of this screening level vulnerability assessment, this project inventoried and assessed the locations throughout Newbury and other Great Marsh towns where man-made structures such as roads, bridges, dams, sea walls, and other structures intersect waterways and floodplains. These structures often present serious barriers to the natural movement of water and function of related physical and biological processes including sediment and nutrient transport. Undersized, improperly designed, or aging structures are vulnerable and can put related critical infrastructure, buildings, and transportation corridors at increased risk of flooding and failure, especially during extreme storms that bring heavy rains, winds, and storm surges. Many of the same barriers that present serious infrastructure risk have also been identified as causing significant ecological harm and reducing the resiliency of natural communities. Several past studies were reviewed for this project, and new surveys were conducted to assess the vulnerability of these structures in each community.

Four types of structures (non-tidal road-stream crossings, tidal road-stream crossings, dams, and public shoreline stabilization structures) that are potential barriers were assessed for their degree of vulnerability. The Town of Newbury has 80 non-tidal road-stream crossings, 27 tidal road-stream crossings, 9 dams, and 2 public shoreline stabilization structures. Of these, 15 non-tidal road-stream crossings, 8 tidal road-stream crossings, and 1 public shoreline stabilization structure are highly vulnerable to the impacts of sea level rise, coastal storms, and/or inland flooding based on our screening criteria. (See Appendix B for methodology, results, and a map).

AREAS OF SPECIAL CONCERN

During the planning process, the Newbury and Regional Resiliency Task Forces identified Areas of Special Concern due to their current and future vulnerability and the consequences if the area or asset is impacted by flooding or erosion. A discussion of the vulnerabilities of several of these assets follows (for a complete list see Appendix C).

The Plum Island Turnpike is the only access point to Plum Island, and it is almost entirely within FEMA's 1% flood zone.[181] According to the Newbury Resiliency Task Force, Plum Island Turnpike is subject to frequent flooding, especially during winter months when high tides can combine with Northeasters. Because this roadway is the only access point to Plum Island, it receives high traffic volume – particularly during the summer. When the roadway floods, general traffic and emergency responders cannot access the island and residents are unable to leave. This poses a serious safety issue and is an evacuation hazard to Newburyport and Newbury residents living on the barrier island (approximately 1270 homes). Additionally, homes in **Plumbush Downs**, the neighborhood located at the edge of the marsh along the north side of the turnpike, and the nearby popular restaurant called Bob Lobster, are presently impacted

[180] Abdollahian, N. et al., *Community Exposure,* 33-34

[181] "MORIS: CZM's Online Mapping Tool," CZM, last updated January 9, 2012, http://maps.massgis.state.ma.us/map_ol/moris.php

by tidal and storm flooding, and will be inundated regularly by 2030 and 2070. Many of these homes are being rebuilt on piles.

During major storms, the road also can act as a hydraulic barrier preventing Merrimack River flood waters from dispersing over the marsh. In addition, the Bascule Bridge, a drawbridge carrying Plum Island Turnpike over the marsh, impacts the marsh ecosystem. Constructed in the early 1970's, the bridge foundations act as tidal restrictions to a healthy flow of tides across the marsh. This infrastructure may contribute to flooding problems in downtown Newburyport, up river, and along the Plum Island basin.[182] A hydrodynamic sediment transport model is currently focusing on the Plum Island Turnpike area, including Bascule Bridge, to better understand water and sediment flow in this area. There is the potential for salt marsh restoration here and other locations in this area.

According to the USGS analysis using inundation modeling by Woods Hole Group, the Turnpike (roughly from Joppa Flats Nature Center all the way onto the island) is likely to suffer significant flooding during storms – both present day and in 2070. A present day 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500 year storm) would likely flood 54-66% of the road with between 1-20 feet of water. By 2070, a 1% or 0.2% storm, would likely flood as much as 90% of the road with between 5-20 feet of water (Figure 3.4-3).[183]

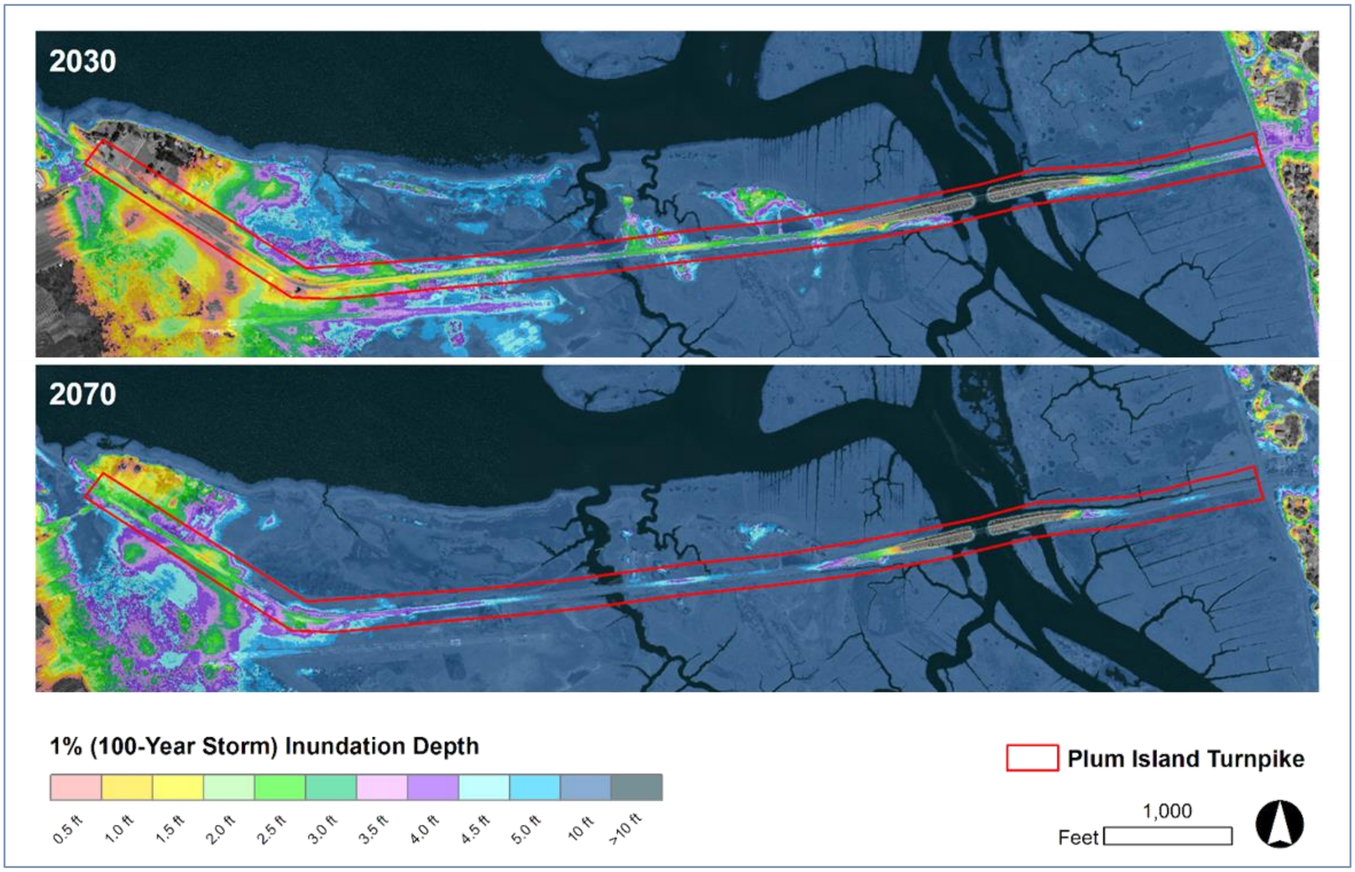

Figure 3.4-3. Plum Island Turnpike, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

[182] Newburyport Resiliency Task Force, personal communication with authors, July 15, 2015
[183] Abdollahian, N. et al., *Community Exposure*, 24

The Plum Island sewage pumping station is also subject to 1% annual chance of flooding according to FEMA flood zones;[184] however according to the Newbury Resiliency Task Force, it is relatively flood-proofed and has not been impacted by flooding to date. Nonetheless, it is located amidst a **low-lying residential neighborhood along the bayside** of the island (the Basin Harbor neighborhood beside Old Point Road), an area vulnerable to floodwaters from the Merrimack River in the west and north, and in an area that may be impacted in the future by ocean waves overtopping the beach from the east, according to the Resiliency Task Force. According to the USGS analysis using inundation modeling by Woods Hole Group, the sewage pumping station is likely to be inundated with 1-5 feet of water during a present day 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500 year storm). By 2070 both storm scenarios would likely inundate the facility with between 5-20 feet of water (Figure 3.4-4).[185]

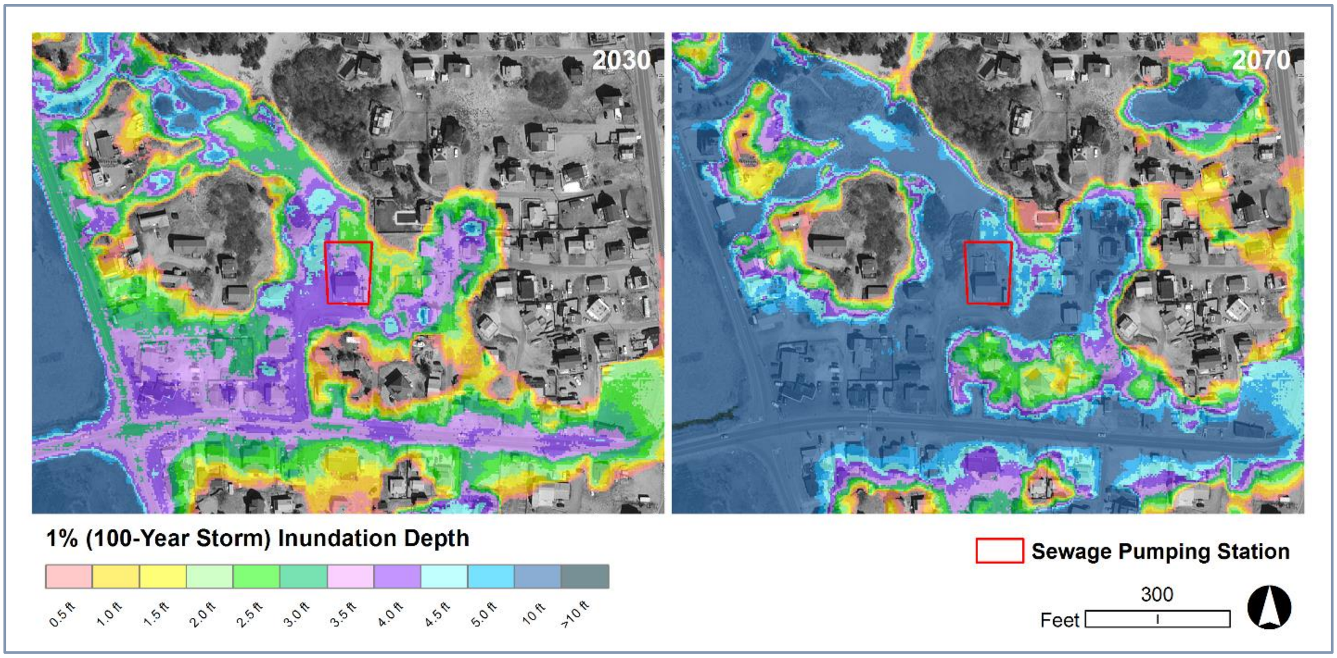

Figure 3.4-4. The Plum Island sewage pumping station, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

The Newbury Elementary School, one of the town's designated emergency shelters, is located on Hanover Street approximately ¼ mile from the Little River. While the school itself is on elevated ground and is unlikely to be impacted from flooding, Hanover Street is subject to regular storm-related flooding at the Little River. This is a logistical issue that should be addressed so that residents are not endangered when attempting to access the emergency shelter from the west during storms. Additionally, the elementary school is connected to the Newburyport waste water treatment plant, so if that plant becomes inoperable the school could not be used as an emergency shelter.

Newburyport Turnpike/Route 1 can suffer from flooding during astronomical high tides and hurricane-level storm surge. Based on Google Earth estimates, citing KSS Fuels, this road carries over 11,000 cars each day. As Route 1 is a major artery connecting the North Shore communities, flooding of this major road impacts emergency services, commerce, and tourism. According to the USGS analysis using

184 "MORIS: CZM's Online Mapping Tool"
185 Abdollahian, N. et al., *Community Exposure,* 34

inundation modeling by Woods Hole Group, the Turnpike is likely to be inundated with 1-2 feet of water during a present day 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500 year storm). By 2070 both storm scenarios would likely inundate the area with between 5-20 feet of water (Figure 3.4-5).[186]

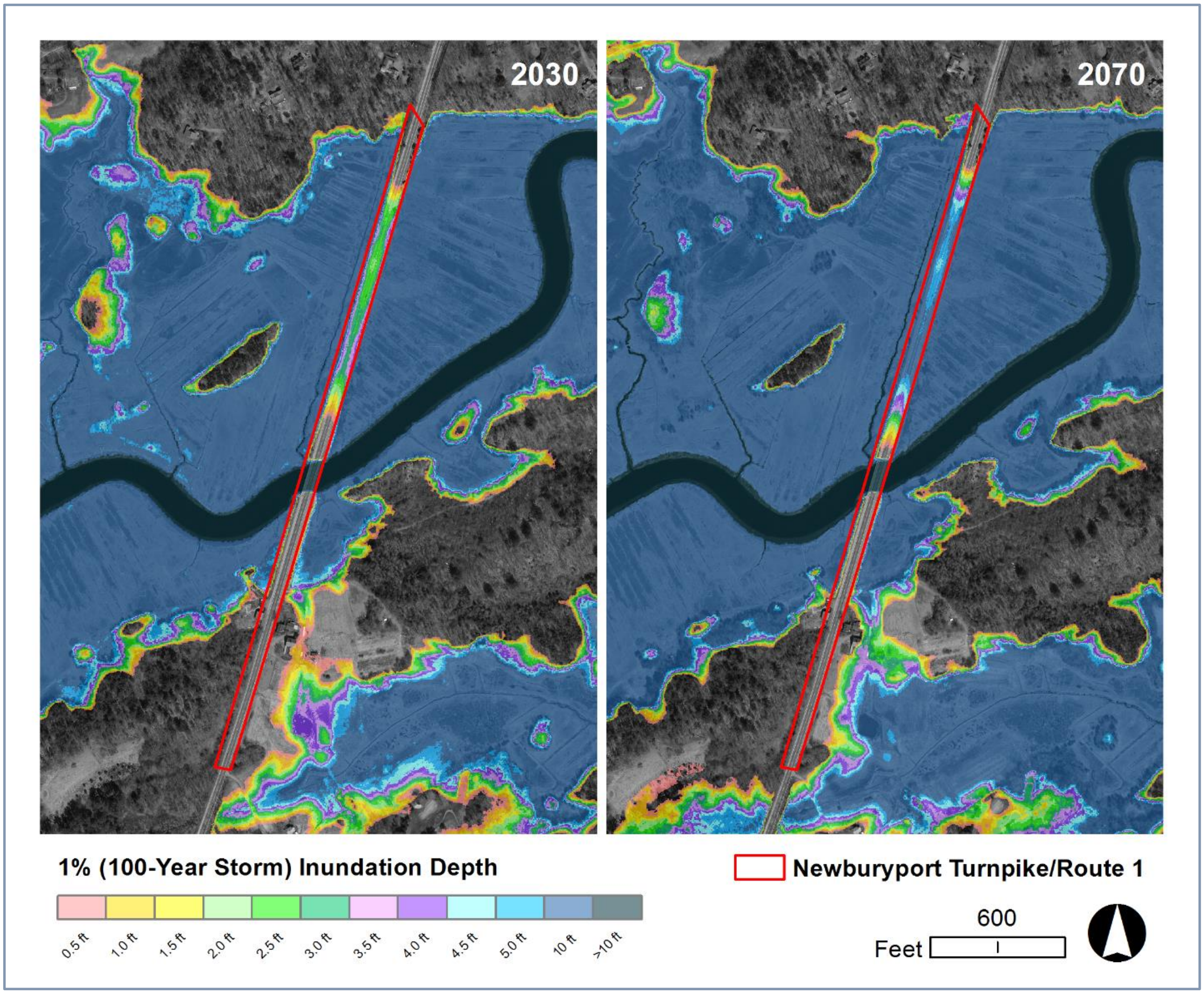

Figure 3.4-5. Newburyport Turnpike/Route 1, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

The Lord Timothy Dexter Industrial Green (hereafter "Business Park") and the adjoining **Newburyport MBTA Train Station** suffer repetitive flooding due to their low-lying topography, large amount of impervious surfaces, and improperly sized culverts and bridges along the Little River. Because the river is tidal, this problem is exacerbated by normal tidal cycles and storm surge. Although the Business Park and Train Station are located in Newburyport, the hydro barriers are located in Newbury. Because the Little River runs through both communities, relieving flow restrictions along the river has the potential to impact flooding downstream and across municipal jurisdictions. Increasing the hydraulic capacity of these crossings also has the potential to increase the vulnerability of the Business Park to salt water flooding

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[186] Ibid

due to SLR and storm surge. It is critical that Newbury and Newburyport work together to address these hydro-barriers through a comprehensive watershed approach, ensuring that efforts to relieve existing flood hazards do not simply shift the flood hazard to another highly developed area downstream. Action is needed, however, because the predicted increase in heavy precipitation events and SLR threaten to exacerbate existing flooding concerns.

Plum Island stretches for approximately 11 miles and has experienced erosion and overtopping over the years, both north and south of Plum island Boulevard. According to local residents, in recent years erosion has been particularly catastrophic along the dunes south from Plum Island Boulevard to the Parker River National Wildlife Refuge. These dunes are the only line of defense for many properties that face an otherwise open ocean. Many beach-front houses are located just behind the dunes or in some cases directly on top of them. Properties located along Fordham Way and Annapolis Way have been particularly vulnerable, and in 2013 erosion caused six houses to fall into the ocean.[187] Erosion is likely to continue in this area and may be further exacerbated by rip rap placed along dunes to protect individual houses. The rip-rap creates a flexible revetment aimed at reducing erosion, however these types of "grey infrastructure" can have unintended consequences and often reduce the resiliency of the beach and dunes.[188] Revetments and gray infrastructure used to protect individual properties often have a negative effect on adjoining properties and can actually increase erosion in the surrounding areas.[189] In addition, according to the Hydro-barrier Assessment (see Appendix B), a public shoreline structure along the beach is in poor condition.

Ron Stelline/MyCoast

Low-lying houses along the bayside of Plum Island, in both Newbury and Newburyport, are highly vulnerable to future climate impacts. Homes located off of Old Point Road and Northern Boulevard are particularly vulnerable to projected coastal inundation. These bayside neighborhoods have already experienced some flooding from storms. However sea level rise and inundation modeling indicate that flooding will likely become much more frequent and more severe in the coming years. Furthermore, flooding along Plum Island Turnpike – the only access point to Plum Island - presents an immediate and serious safety and evacuation hazard for not just these resident but all the Newburyport and Newbury residents living on the barrier island (approximately 1270 homes).

The Great Marsh itself is an asset of significant importance to the Town of Newbury. The ability of salt marshes to reduce wave energy and absorb storm surge make them one of the most effective natural

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187 MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan*, 183

188 Berry, A. et al., "Changing of the Guard: Adaptation Options That Maintain Ecologically Resilient Sandy Beach Ecosystems," *Journal of Coastal Research* 29, no.4 (2013): 899-908

189 Maryland Department of the Environment (MDE), *Shore Erosion Control Guidelines for Waterfront Property Owners: 2nd* edition (Baltimore, MD, 2008), 11

solutions to reducing community vulnerability. The marsh acts as a line of defense against flooding and provides many additional important ecosystem services to the region (see "Habitats and Species" for more information).

The Governor's Academy, an independent high school with more than 350 students (of which two-thirds live on campus) and approximately 100 resident employees and families, is located on the banks of the Parker River near Route 1 in southern Newbury. Much of the school's campus, including athletic fields and school buildings, is subject to 1% annual chance of flooding arising from the Parker River.[190] Middle Road, which runs through campus with a bridge over the river, regularly floods at high tides, closing off one of the access points to campus. The school is a critical asset for the town due to its educational and economic attributes. It is also an important historical asset: founded by Massachusetts's Lieutenant Governor William Dummer in 1763, it is the oldest boarding high school in the country and its library houses an extensive archive of local history.

The Plum Island Airport is located along Plum Island Turnpike on the boundary of Newburyport and Newbury. The fields and salt marshes along Plum Island Turnpike have been used for aviation since 1910; it is claimed to be the first flying field in New England and as such has important historical significance to the town. It has two small historic museums on site and hosts numerous educational field trips and events annually. It is owned by *Historic New England* and operated by Plum Island Aerodrome, Inc., another non-profit corporation for public use. It has two runways, averages 54 flights per week, and has approximately eight aircraft based at the site. The airport is located at an elevation of only 9-13 feet and is within the FEMA 1% flood zone.[191]

During a present day 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500-year storm), the entire runway strip and portions of the airport apron (where the planes are parked) are likely to be inundated with 0.5-3.5 feet of water. By 2070 both storm scenarios would likely flood 100% of the airport grounds, including the apron, parking lots, buildings, and runways, with between 3-10 feet of water (Figure 3.4-6).[192]

The Massachusetts Bay Transportation Authority (MBTA) Newburyport Train Line serves the commuting needs of hundreds of local residents in the area. In 2013, there was a daily average of 812 inbound passengers using the line boarding from Newburyport to Boston.[193] The reactivation of the rail line to Newburyport was completed in 1998, driving much of the region's residential and economic growth as a suburb of Boston. The rail line traverses the salt marsh, two rivers, several streams and dozens of tidal creeks in Newbury. As such, the line is vulnerable to storm surge and sea level rise. In addition, there are several bridges and culverts along the line which act as minor to major tidal barriers and the line itself functions as a major barrier to natural coastal flowage patterns. The infrastructure associated with this line is owned and maintained by the MBTA – with management decisions being made by MBTA not the municipalities. The MBTA is in the process of developing a comprehensive analysis of all of its assets, including risks based on increased climate effects, and will be an important partner for both Newbury and Newburyport in future adaptation planning and implementation efforts.

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[190] "MORIS: CZM's Online Mapping Tool"

[191] Ibid

[192] Famely, J. et al., Sea Level Rise and Storm Surge Inundation Mapping

[193] MBTA, "Chapter 4: Commuter Rail," in *Ridership and Service Statistics: Fourteenth Edition* (Boston, MA, 2014), 7-8

DEMOGRAPHICS[194]

According to the USGS geospatial hazard analysis, 9% (572) of Newbury's residents currently live in coastal-hazard zones. By 2070, this number will increase to 1,154 residents, representing 17% of Newbury's population (Figure 3.4-7). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The greatest increase in residential exposure among the three time periods is associated with the high inundation-probability zone. The majority of residents in current hazard zones are located in areas classified as having a very low (0.1-.0.5%) inundation probability (189 residents). By 2070, however, the number of residents living in the highest hazard zone is estimated to grow dramatically to 412 residents. The number of residents in the medium, low, and very low probability zones are not estimated to increase substantially.

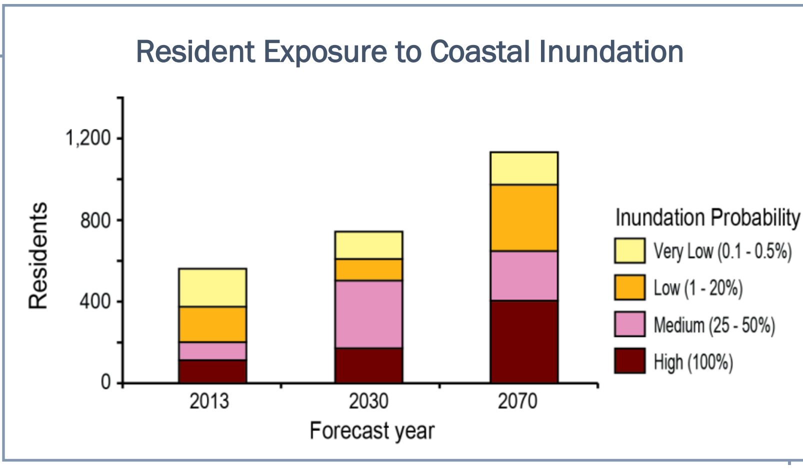


Figure 3.4-7. Resident exposure in the Town of Newbury, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

All demographic percentages describing residents in hazard zones were relatively stable (+/- 1%) across the three time periods. Demographic data suggest that there are no residents in the coastal-hazard zones across the three time periods that live in mobile homes or lack a phone. Less than 5% of the residents in the hazard zones speak English as a second language, live in group quarters, are under 5 years in age, or lack vehicles. Greater than 5% of the residents in the hazard zones are unemployed (6%), live under the poverty line (8%), are in renter-occupied households (11%), have disabilities (14%), are over 65 years in age (16%), or only have a high school degree (26%).

ECONOMIC & SOCIO-ECONOMIC[195]

The number of Newbury employees working in coastal-hazard zones ranges from 98 currently to 349 in 2070, representing 6% to 20%, respectively, of the 1,751 employees that are presently work in the community (Figure 3.4-8). As was the case with the resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zone and not projected changes in employee distributions. In present day, most employees in these hazard zones are in areas classified as having a very low (0.1-0.5%) inundation probability (55 employees). By 2070, 165 employees are working in the medium (25-50%) probability zone, with additional employees in zones classified as high (89), low (83) and very low (12) inundation probability.

Sales volume exposure for private-sector businesses ranges from $8 million currently to $36 million in 2070 (Figure 3.4-9a). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have a significant customer presence (e.g. retail) in coastal-hazard zones ranges from 10 businesses in 2013 to 18 businesses in 2070. Of the businesses with fewer than 20 employees (a group typically more sensitive to disruptions, fifteen are located in present day hazard zones and 33 are located in 2070 hazard zones.

[194] Abdollahian, N. et al., *Community Exposure,* 31-32
[195] Ibid 32-33

Similar to sales volume, parcel values and building replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value of parcels in the coastal-hazard zones ranges from approximately $191 million present day to approximately $345 million in 2070, representing 14% to 25% of the community's tax base (Figure 3.4-9b). The majority of tax-parcel value in hazard zones is associated with land value for all three time periods (66%, 61% and 61%, respectively), with the remainder associated with building/content value. Based on building stock data in the FEMA Hazus-MH database, estimated building replacement values range from $119 million for the current hazard zone to $206 million for 2070 hazard zone (Figure 3.4-9c). For all three time periods, the majority of potential building replacement values are in areas classified as having a high probability of inundation.

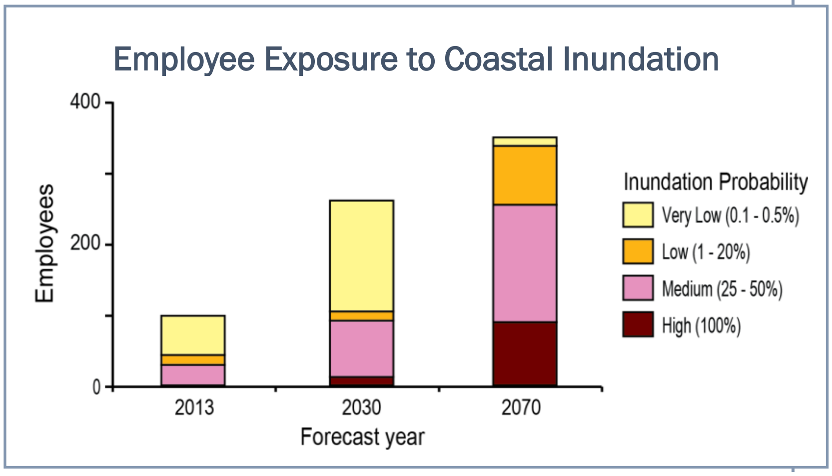


Figure 3.4-8. Employee exposure in Newbury, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

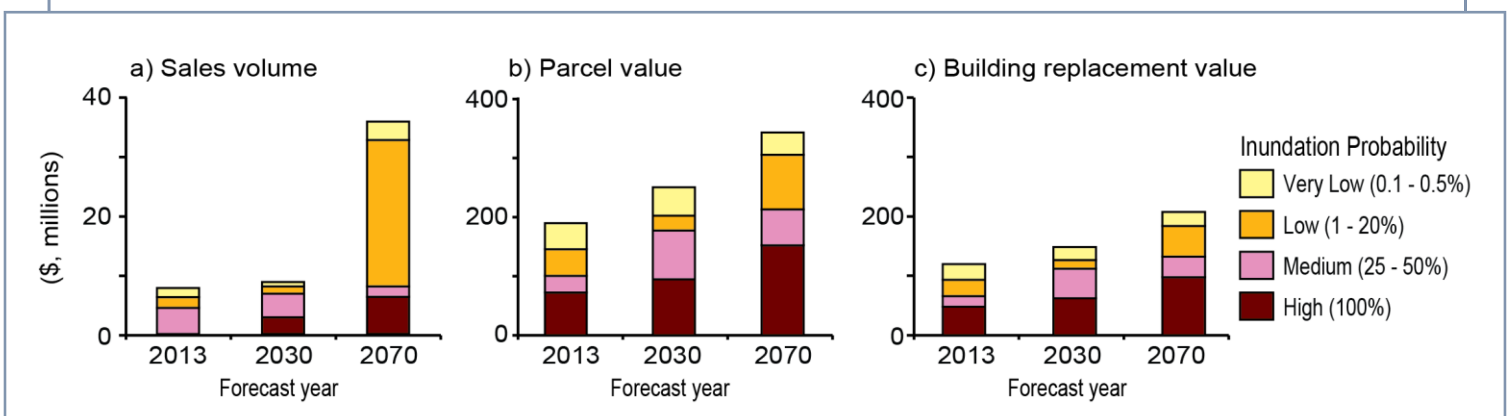


Figure 3.4-9. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Newbury, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

Separate from the USGS analysis, FEMA and the Department of Homeland Security conducted a static analysis on Newbury's current economic vulnerability to flooding. Their study analyzed the potential economic impact of various storm scenarios using FEMA's Flood Risk Database combined with FEMA's flood loss estimation tool, HAZUS. Potential building losses and associated business disruption costs for each storm category are shown below (Table 3.4-2).[196] Based on their analysis, the economic impact of even a relatively small 10% (10-year) storm may be quite significant.

[196] FEMA, *DRAFT Flood Risk Report: Essex County, MA* (Washington, DC, 2013), 69

Table 3.4-2. Newbury's Estimated Potential Losses for Flood Event Scenarios. (*)Losses shown are rounded to nearest $10,000 for values under $100,000 and to the nearest $100,000 for values over $100,000; (**) Total Building/Contents Loss = Residential Building/Contents Loss + Commercial Building/Contents Loss + Other Building/Contents Loss; (***) Disruption = Inventory Loss + Relocation Cost + Income Loss + Rental Income Loss + Wage Loss + Direct Output Loss; (****) Total Loss = Total Building/Contents + Business Disruption.

	10% (10-yr)	2% (50-yr)	1% (100-yr)	0.2% (500-yr)	Annualized ($/yr)
	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*
Total Buildings/ Contents**	$28,200,000	$54,100,000	$71,100,000	$89,800,000	$3,500,000
Business Disruption***	$600,000	$900,000	$1,200,000	$1,400,000	$30,000
Total****	$28,900,000	$55,100,000	$72,300,000	$91,300,000	$3,500,000

Based on this analysis, a mere 10% (10-year) storm has the potential to cause as much as $28.9 million dollars in damage. A larger 1% (100-year) storm may cause as much as $72.3 million in damage and a 0.2% (500-year) storm as much as $91.3 million. The majority of damage comes from infrastructure losses, although business disruptions are also quite significant. It is important to note that as "100-year" storms become more frequent, these damage estimates are likely to increase.

HABITATS & SPECIES

The Great Marsh is one of the most important coastal ecosystems in northeastern North America.[197] In Newbury, this ecosystem contains high and low marsh, estuarine aquatic environments, and a barrier beach accompanied by extensive dunes. Each of these habitats provide critical foraging and breeding grounds for a plethora of native species. The Great Marsh also provides an abundance of ecosystem services to the Town of Newbury. The marsh absorbs wave energy and traps sediment, helping reduce erosion; the aquatic environment is a nursery for commercially important fish species; and the dunes provide protection against dangerous storm surge. In addition, the salt marsh traps and safely stores harmful sources of carbon that are the leading cause of climate change. In fact, recent analysis indicates that marshes are one of the most powerful carbon sinks, with the potential of sequestering almost 50 times more carbon than tropical rainforests.[198]

Sandy Tilton

A significant portion of Newbury has received official designation recognizing the importance of its natural systems. Approximately 8,133 acres in Newbury are designated as *core habitat* and 5,340 acres are listed

197 "The Great Marsh," Western Hemisphere Shorebird Reserve Network, accessed October 2015. http://www.whsrn.org/site-profile/great-marsh

198 Bu, N. et al., "Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool," *Ecological Engineering*, 81 (2015): 335

as *critical natural landscapes* (Figure 3.4-10).[199] The term "core habitat" refers to areas deemed necessary to support the long-term existence of rare or threatened species, exemplary natural communities, and intact ecosystems. "Critical natural landscapes" are intact ecosystems that are well suited to support ecological processes and/or a wide array of species and habitats over long period of time.[200]

Marshes, barrier beaches, and dunes make up the majority of the critically important habitat in Newbury. These habitats contain multiple vegetative zones that support a wide diversity of species, including numerous threatened and endangered species (Table 3.4-3).[201]

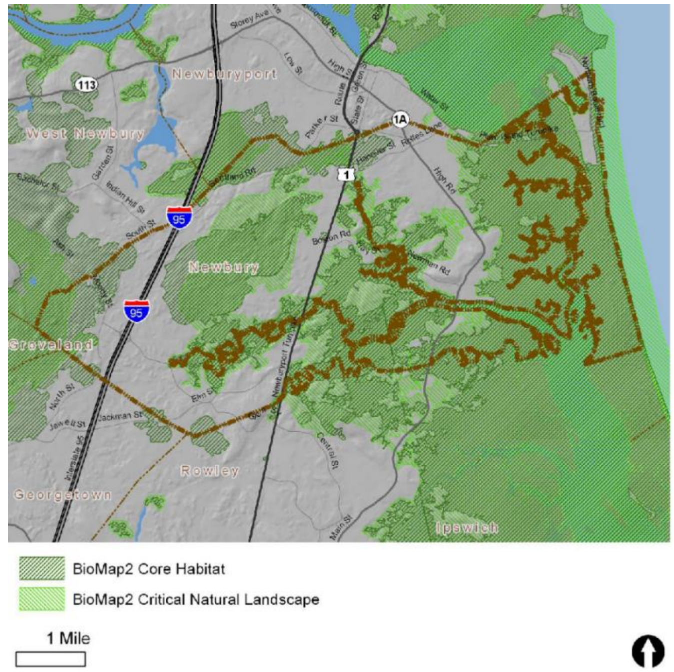


Figure 3.4-10. *BioMap2* Core Habitats & critical natural landscapes in Newbury.

The marsh in Newbury is particularly vulnerable to erosion and sea level rise. Because this habitat is so low-lying and tidally influenced, the vast majority of marsh in Newbury may become inundated under just one foot of sea level rise.[202] Given the topography and close proximity of development along the landward edge of the marsh, coastal ecosystems may not be able to migrate inland, leading to a net loss in marsh as sea level rises. However if deliberate steps are taken to both limit further development along the marshes' edge and facilitate marsh migration, this critical habitat may be able to gradually move landward to keep pace with sea level rise.

Changes in precipitation and sea level may also alter the balance between freshwater and saltwater in the Newbury Estuary. As salinity levels change and the water temperature increases, this habitat may become less hospitable for native

Table 3.4-3. List of species occurring in Newbury that are threatened (T) or endangered (E). For complete list of species, including species of conservation concern, see the MA Dept. of Fish & Game BioMap2 for Newbury (2012).

Threatened and Endangered Species	Preferred Habitat
Birds	
Upland Sandpiper[E]	Upland fields
American Bittern[E]	Marsh
Sedge Wren[E]	Wet sedges
Least Bittern[E]	Marsh
Northern Harrier[T]	Marsh
King Rail[T]	Marsh
Piping Plover[T]	Beach, dunes, mudflats
Bald Eagle[T]	Marsh, tidal channels, upland habitat
Fish	
Atlantic Sturgeon[E]	Marsh, coastal rivers, tidal estuaries
Plants	
Estuary Arrowhead[E]	Sandy shores, mudflats, brackish rivers
Long's Bulrush[T]	Wet meadows, peaty wetlands
Seabeach Needlegrass[T]	Coastal dunes
Reptiles & Amphibians	
Blanding's Turtle[T]	Marsh, wetlands
Eastern Spadefoot[T]	Pine barrens, coastal oak woodlands, sand

199 MA DFG & TNC, *BioMap2: Newbury* (Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012), http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Newbury.pdf
200 Ibid
201 Ibid
202 "MORIS: CZM's Online Mapping Tool"

plant and animal species and more suitable for exotic invasive species. For example, native razor clams and blue mussels were extirpated from Newbury following the Mother's Day storm. Changes in salinity levels could also drive a dramatic expansion of invasive phragmites. The important anadromous fish populations in the Parker River are likely to be at risk as are many species of animals that inhabit the high marsh such as the globally threatened saltmarsh sparrow. The region's salt marsh hay industry, which is already in steep decline, could disappear as well.

Furthermore, additional coastal development combined with an increase in severe storm activity will likely lead to an increase in surface runoff quantities and rates. Stormwater runoff carrying bacteria, pathogens, and nutrients is currently one of the major anthropogenic-related stressors on the marsh and is likely to be exacerbated by climate change. Currently shellfish harvesters lose millions of dollars annually due to stormwater contamination.[203] Nitrogen has also recently been identified as a leading cause of marsh bank disintegration.[204]

Shellfish are a particularly important natural resource asset in Newbury where widespread commercial harvesting occurs. Maintaining healthy, stable shellfish populations is a high priority in Newbury. However the habitat used by shellfish is quite vulnerable to sea level rise and increased erosion. Intertidal mud flats, sandy estuarine environments, and sea grass beds are all likely to suffer under the added strain of climate-driven threats. Sea level rise may permanently inundate clam flats, converting once productive harvesting areas into unsuitable habitat devoid of shellfish. Erosion also threatens to further shrink these estuarine environments so important to shellfish.

Newbury beaches and dunes on Plum Island provide critical foraging habitat to the federally threatened Piping Plover, however the habitat is eroding at an alarming rate while sea levels continue to rise. Like all barrier beaches, natural processes cause the beach to shift over time. A beach's' dynamic character and ability to move and reshape in response to constant wave energy as well as acute storm events, is precisely what makes it resilient to sea level rise and storm surge.[205] As the Massachusetts Coastal Erosion Commission's final report notes, "The movement of sediment along the coast and the [natural] loss and gain of shoreline—erosion and accretion—are continuous and interrelated processes."[206] Because Newbury's barrier beach is heavily developed, natural erosion

Alex Lamoreaux

[203] Ipswich Coastal Pollution Control Committee, *Coastal Stormwater Remediation Plan for the Town of Ipswich* (Ipswich, MA: Town of Ipswich Massachusetts Planning Department, 2000), 1

[204] Deegan, L.A. et al., "Coastal eutrophication as a driver of salt marsh loss*," Nature,* 490 (18 October 2012), 388

[205] Massachusetts Barrier Beach Task Force, *Guidelines for Barrier Beach Management in Massachusetts* (Boston, MA: Massachusetts Office of Coastal Zone Management, 2014) http://www.mass.gov/eea/docs/czm/stormsmart/beaches/barrier-beach-guidelines.pdf

[206] Massachusetts Coastal Erosion Commission, "Volume 1: Findings and Recommendations" in *Report of the Massachusetts Coastal Erosion Commission* (Boston, MA: Massachusetts Executive Office of Energy and Environmental Affairs, 2015), 1

and accretion rates are disrupted, and changes in beach formation can impact houses and other infrastructure located along the coastline. If beaches and dunes are not allowed to migrate inland as the sea rises, this habitat will slowly disappear, impacting a wide variety of species including Piping Plovers.

Summary

Overall the Town of Newbury has a high level of vulnerability to climate-driven threats. Predicted increases in storm frequency and severity, sea level rise, increased storm surge, and erosion have the potential to impact the town's coastal economy, the infrastructure located in low-lying riverine and coastal areas, and the natural systems that the community depends upon. Because of the town's reliance on coastal industries and taxes from coastal properties, impacts to infrastructure or natural systems may have cascading effects that ripple across all parts of the community. The geospatial analysis conducted by USGS confirms these findings and indicates economic, infrastructure, and population vulnerabilities that will likely need to be addressed to protect human life as well as the economic well-being of Newbury.

The natural systems in Newbury are already being impacted by erosion that is likely to accelerate with climate change. Sea level rise will likely inundate the vast expanses of marsh that currently help reduce storm surge and reduce erosion as well as provide important habitat to rare and threatened species. Storm surge resulting from bigger and more frequent storms may overtop existing dunes and coastal structures, impacting densely populated areas on Plum Island. An increase in heavy precipitation events combined with penetrating storm surge will likely cause substantial damage to low-lying interior portions of Newbury.

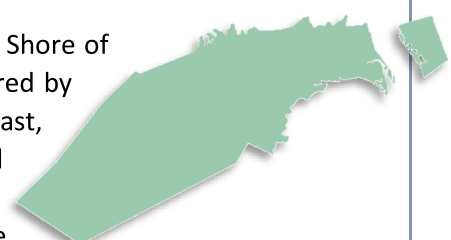
For recommendations on how to address the Town of Newbury's overall vulnerability to climate-driven hazards, including site-specific adaptation strategies for the areas of concern outlined above, see Chapter 4: Adaptation Strategies for the Great Marsh Region.

Chris Luczkow/Flickr

Matthew Kirwan/USGS

3.5. Town of Rowley Vulnerability Assessment

Community Exposure to Climate Hazards



The Town of Rowley is a relatively rural coastal community along the North Shore of Massachusetts. Its total size is approximately 19 square miles.[207] It is bordered by Newbury to the north, Plum Island Sound and the Atlantic Ocean to the east, Ipswich to the south and Georgetown to the west. According to the United States Census Bureau, in 2010 there were 5,856 residents living in Rowley. Unlike many of the more developed tourist-driven coastal communities in the region, Rowley has maintained much of its rural community character and appearance.[208] Approximately 42% of land is forested, 20% is marsh or wetlands, 10% is residential development, and 5% is agriculture. Commercial and industrial activities combined account for less than 2% of land use.[209] The vast majority of the "marsh or wetlands" are part of the Great Marsh, the largest contiguous salt marsh in New England.

With almost 90% of the town zoned for residential use, it's not surprising that the majority of development consists of low-density single family residential homes.[210] The residential development is spread fairly evenly throughout town, except in the northeastern portion of Rowley where salt marshes dominate the landscape. There is some limited commercial and/or city-owned development along Route 1, Route 133, and Interstate 95 as well as in the Central District that encompasses the historical village area of the town center.[211]

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[207] Town of Rowley, *Rowley Master Plan* (Rowley, MA, 2003), 15

[208] Ibid

[209] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan* (Haverhill, MA, 2015), 225

[210] Town of Rowley, *Rowley Master Plan*, 20

[211] Ibid

Rowley is part of the Parker River and Ipswich River watersheds and is endowed with many of rivers, tidal creeks, and estuarine wetlands.[212] The Mill River, Rowley River, Mud Creek, and Great Swamp Brook are a few of the rivers and tidal channels that wind through this small community. These ecologically diverse streams provide critical habitat to a variety of species and offer recreational opportunities to residents and visitors. While normally scenic and idyllic in nature, during storms water can inundate much of the landscape. There are several hydro-barriers and dams, particularly along the Mill River, that can cause water to overtop its banks and flood into surrounding areas.

The portion of Rowley located on Plum Island falls entirely within the Parker River National Wildlife Refuge. The refuge consists of fresh-water impoundments, salt marsh, dunes and beach. This portion of Rowley has extremely high exposure to coastal flooding and erosion. Plum Island is the first line of defense against storm surge and sea level rise. It protects the Plum Island sound, vast salt marshes, and coastal infrastructure on the mainland from the worst impacts of flooding and erosion caused by the Atlantic Ocean.

A detailed analysis of coastal inundation, conducted by the Woods Hole Group and USGS, confirms that the Town of Rowley has medium to high exposure to sea level rise and storm surge. Present day estimates (which are for the year 2013) indicate approximately 20% of the town is vulnerable to coastal inundation – depending on the severity of the storm (Figure 3.5-1). That number climbs to 25% in 2070.[213]

Only 3% of the developed land in Rowley is currently vulnerable to coastal inundation under a worst case storm scenario (Figure 3.5-2). Undeveloped land has a much higher exposure to inundation, now and in 2070. Of the

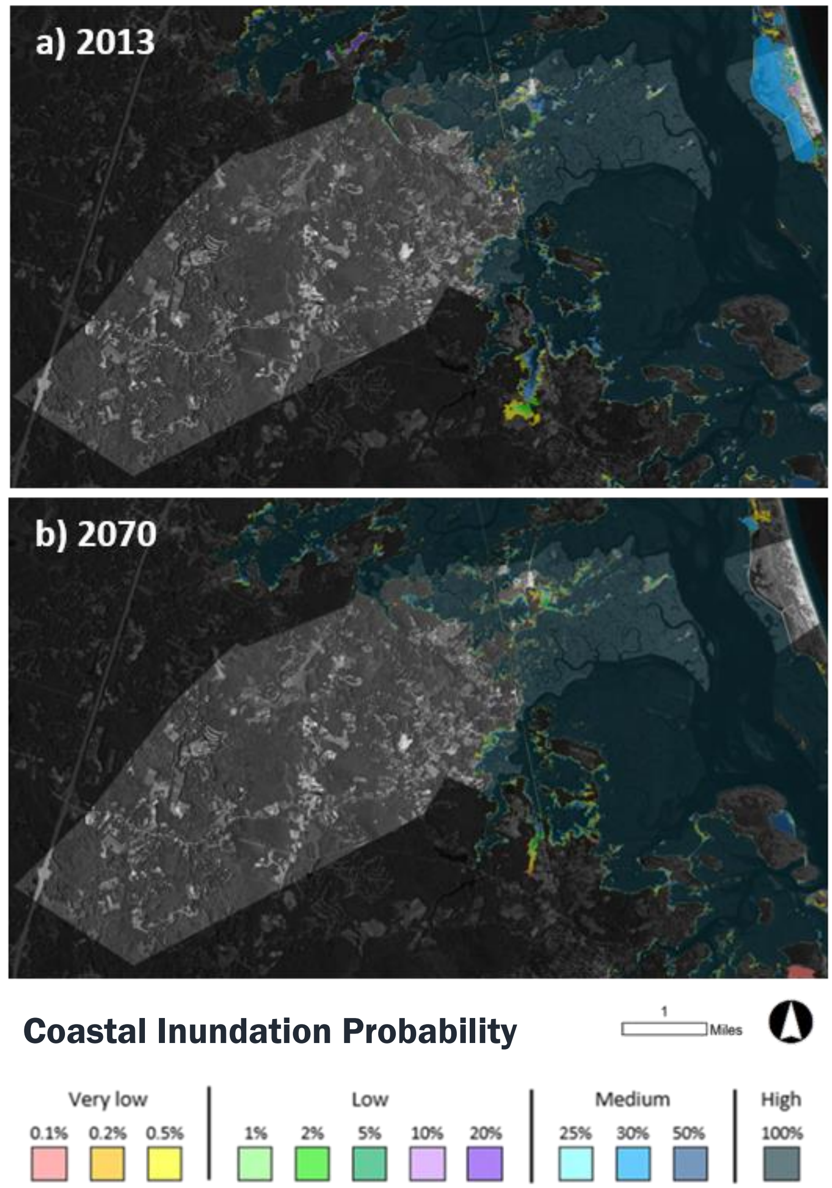

Figure 3.5-1. Rowley, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

[212] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan*, 227

[213] Abdollahian, N. et al., *Community exposure to potential climate-driven changes to coastal-inundation hazards for six communities in Essex County, Massachusetts*, U.S. Geological Survey open-file report (Reston, VA: USGS, 2016), 37

developed and undeveloped land that is subject to coastal inundation, the majority is likely to flood on an annual or near semi-annual basis, especially by 2070.

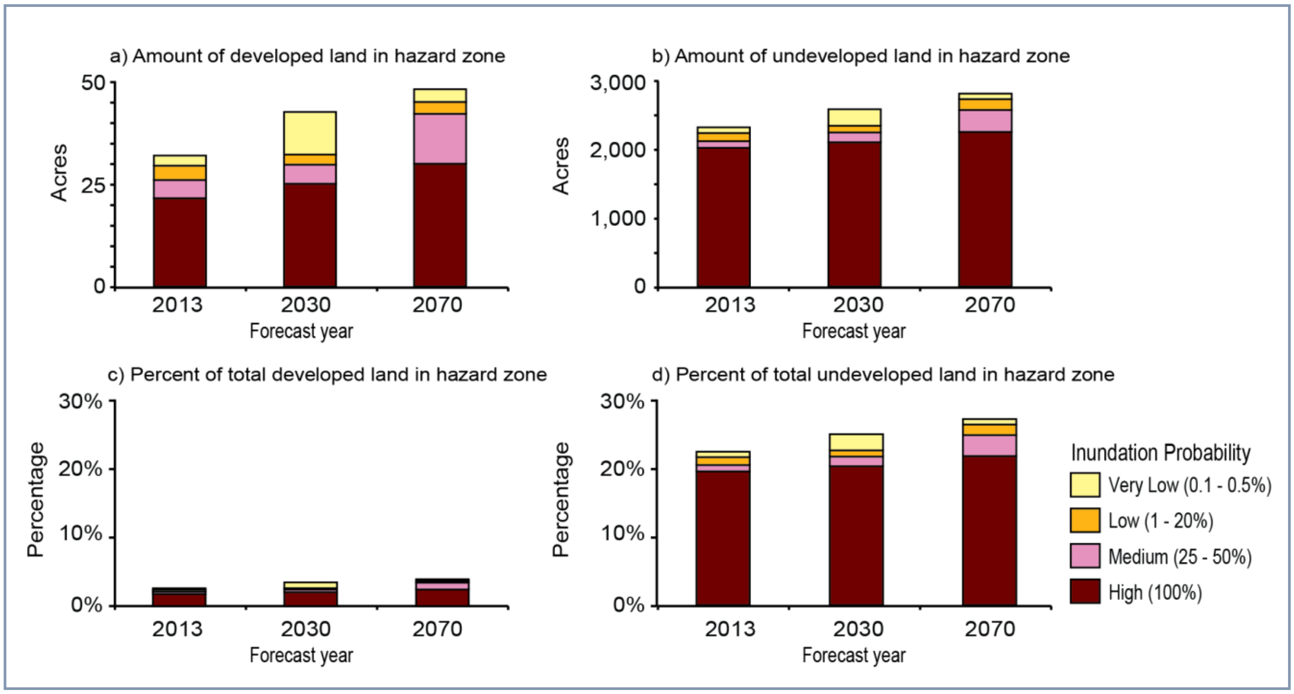

Figure 3.5-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Rowley, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

In summary, Rowley has moderate to high exposure to coastal flooding, riverine flooding, and erosion due to its topography, hydrology, and geographic location. Plum Island faces the open ocean and is highly exposed to wind, wave action, and sea level rise – with no buffering landmass to diminish these hazards. Interior portions of Rowley rely on Plum Island to buffer the worst storm effects. However the abundance of fresh and tidal rivers that crisscross the landscape can bring flood waters to many parts of the town.

Community Sensitivity to Climate Hazards

The Town of Rowley has moderate sensitivity to climate-driven threats. Because the community's infrastructure is scattered throughout the town and not concentrated along a single stretch of river or coastal area, damage caused by sea level rise and increased precipitation is likely to be less severe than what neighboring coastal communities are likely to experience. Overall, approximately 7.5 square miles of land and marsh are within the FEMA 1% flood zone (often referred to as the "100-year" flood zone) and an additional 0.63 square miles are within the 0.2% (500-year) flood zone.[214] This accounts for roughly 40% of the land area in Rowley. However the overall lack of development in the floodplain reduces the town's sensitivity. 98 non-critical residential and commercial buildings are located in the floodplain, valued at approximately $11.5 million.[215] Three additional "critical facilities" are also located in the floodplain (see page 78 for more details).

[214] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan*, 228
[215] Ibid 229

Economic growth in Rowley does have the potential to increase the community's sensitivity. As open land is converted to impervious surfaces, flooding has the potential to become more widespread with greater consequences to the town. Increased precipitation, storm surge, and erosion are all likely to be additional stressors. Development of new residential or commercial buildings in flood-prone areas would also increase the town's overall sensitivity. Similarly, development along marsh edge would increase the community's sensitivity to sea level rise.

Rowley's economic sensitivity to climate hazards is tied to the sensitivity of the town's natural systems. Rowley has become largely a "bedroom" community for folks commuting to the Boston metropolitan area because of its location, rural character and scenic qualities.[216] The abundant marshes, forests, and rivers appeal to residents. If these natural systems are impacted by climate change, it could alter the makeup of the community.

The Great Marsh in particular, which covers roughly 20% of the town, is a scenic resource for Rowley. It is designated an Important Bird Area of global significance and is also a Western Hemisphere Shorebird Reserve Network site. As such, it is a strong tourism draw that boosts the local economy. While exact estimates are unknown, large numbers of bird watchers from throughout the northeast, and throughout the country, travel to the area to witness the spectacular influx of birds during spring and fall migrations.

Marshes, barrier beaches, and rivers make up a large portion of this community, and these natural systems are inherently sensitive to the impacts of climate change; human activity can further increase their sensitivity. A healthy untouched marsh can absorb storm surge, and heavily vegetated dunes are often resilient in the face of large storms.[217, 218] Depending on topographic features, marshes and dunes can sometimes migrate inland as sea levels rise. However, these natural systems are impacted by human development and management. Improperly-sized hydro barriers can disrupt marsh ecosystems by reducing flow of sediment and impacting salinity levels. Similarly, coastal and inland development combined with an increase in severe storms will likely lead to increased runoff of pollutants, contaminating coastal rivers. Penetrating salt-water intrusion, resulting from storm surge, threatens freshwater river habitat, along with all the marine species that live there.

Like rivers and marshes, dune sensitivity to climate-driven threats can be significantly impacted by human development. Unvegetated dunes, typically found in heavily populated areas, can erode quickly if they are exposed to waves. Similar processes occur in poorly vegetated salt marshes. Unlike many other North Shore Communities, in Rowley there is little human activity along the dunes and marshes because the land is largely within the boundaries of the Parker River National Wildlife Refuge. Nonetheless, based on a recent analysis completed by the Coastal Erosion Commission and presented by CZM, around 92% of shoreline change transects in Rowley showed some

Kegger/Wikipedia Commons

[216] Town of Rowley, *Rowley Master Plan*, 66

[217] Shepard, C.C., et al., "The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis," *PLoS ONE* 6, no. 11 (November 2011): e27374, doi:10.1371/journal.pone.0027374.

[218] "In Defense of Dunes," ASBPA, January 13, 2015, http://www.asbpa.org/news/newsroom_14BN0113_in_defense_of_dunes.htm

level of erosion between 1970 and 2009.[219] Interestingly Rowley's high exposure and overall geographic location in the Plum Island Sound seem to negate any reduction in sensitivity achieved through vegetated dunes and undeveloped salt marsh. This is an area of particular interest. The hydro-dynamic sediment transport model being created by the Woods Hole Group, in support of the Great Marsh Hurricane Sandy Resiliency project, may answer the question of how and why erosion is such a major issue in Rowley.

Community Vulnerability

A fair amount of work has already been conducted in Rowley to assess community vulnerability to natural hazards. The most comprehensive information to date is provided in Rowley's *Draft Natural Hazard Risk Assessment* prepared by the Merrimack Valley Planning Commission.[220] Information from this and other documents is synthesized below along with information from the 2015/16 Rowley Resiliency Task Force, coastal inundation modeling conducted by the Woods Hole Group,[221] a comprehensive inventory and assessment to barriers to flow, and results from the 2016 USGS geospatial analysis[222] of potential impacts from coastal inundation.

Table 3.5-1. Summary of High Hazard Concerns listed in Rowley's Natural Hazard Risk Assessment prepared by MVPC. Order does not indicate priority or level of concern.

High Hazard Concerns	Type of Hazard
Wethersfield Street at Bachelder Brook	Flooding
Hillside Street at Great Swamp Brook	Flooding
Route 133 at Cedarwood Lane	Flooding
Boxford Road	Flooding
Leslie Road	Flooding
Newbury Road	Flooding
Rowley Town Well #3 at 129 Boxford Road	Flooding
Communications Cell Tower at 594 Main Street	Flooding
Majestic Harbor Community School at 303 Haverhill Street	Flooding
Jewel Mill Dam at Mill River	Flooding resulting from dam failure
Lower Mill Pond Dam at Lower Millpond	Flooding resulting from dam failure

Overall Rowley is moderately to highly vulnerable to climate-driven hazards. Storm surge, riverine flooding, and acute and long-term erosion pose the biggest threats to this community. MVPC's *Multi-Hazard Mitigation Plan* reached a similar conclusion. Based on their analysis, as well as information provided by the Rowley Highway Department, they identified 6 areas prone to flooding, 3 critical facilities within the 100-year floodplain, and 2 high-hazard dams (Table 3.5-1).[223] Overall Rowley was assigned a "high" risk rating for floods, winter storms, and Northeasters.[224]

CRITICAL INFRASTRUCTURE

The USGS geospatial hazard analysis of critical infrastructure indicates there are no government offices, public-utility stations, first-responder facilities, communication towers, transportation hubs, public work offices or storage yards, public water supply sources, MBTA parking lot locations, transmission lines, park and ride lots, solid waste composting operations or small transfer stations, underground storage tanks, tier-classified oil and hazardous material release/disposal sites, or oil and hazardous material release/disposal sites located in areas that are likely to be flooded by coastal inundation – now through 2070. An overall infrastructure analysis

[219] MA EEA, *Shoreline Characterization and Change Analyses: North Shore Region* (Gloucester, MA, 2014) http://www.mass.gov/eea/docs/czm/erosion-commission/shoreline-profile-north-shore.pdf
[220] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan*, 225-231
[221] Famely, J. et al., *Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA)*, Prepared by Woods Hole Group for National Wildlife Federation and U.S. Geological Survey, (Falmouth, MA, 2016)
[222] Abdollahian, N. et al., *Community Exposure*
[223] MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan,* 227-228
[224] Ibid 231

indicated that there are approximately 3.7 miles of roads and rail in the 2013 hazard zones, and that number increases to 6.2 miles by 2070.

BARRIERS TO FLOW

The "Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed" provides additional insight into where the community may be vulnerable to flooding. As part of this screening level vulnerability assessment, this project inventoried and assessed the locations throughout Rowley and other Great Marsh towns where man-made structures such as roads, bridges, dams, sea walls, and other structures intersect waterways and floodplains. These structures often present serious barriers to the natural movement of water and function of related physical and biological processes including sediment and nutrient transport. Undersized, improperly designed, or aging structures are vulnerable and can put related critical infrastructure, buildings, and transportation corridors at increased risk of flooding and failure, especially during extreme storms that bring heavy rains, winds, and storm surges. Many of the same barriers that present serious infrastructure risk have also been identified as causing significant ecological harm and reducing the resiliency of natural communities. Several past studies were reviewed for this project, and new surveys were conducted to assess the vulnerability of these structures in each community.

A.D. Chandler

Four types of structures (non-tidal road-stream crossings, tidal road-stream crossings, dams, and public shoreline stabilization structures) that are potential barriers were assessed for their degree of vulnerability. The Town of Rowley has 76 non-tidal road-stream crossings, 9 tidal road-stream crossings, 6 dams, and no public shoreline stabilization structures. Of these, 22 non-tidal road-stream crossings, 2 tidal road-stream crossings, and 1 dam are highly vulnerable to the impacts of sea level rise, coastal storms, and/or inland flooding based on our screening criteria. (See Appendix B for methodology, results, and a map).

AREAS OF SPECIAL CONCERN

During the planning process, the Rowley and Regional Resiliency Task Forces identified Areas of Special Concern due to their current and future vulnerability and the consequences if the area or asset is impacted by flooding or erosion. A discussion of the vulnerabilities of several of these assets follows (for a complete list see Appendix C).

Jewel Mill Dam at Mill River is located just west of the intersection of Route 1 and Central Street. There are seven dams in Rowley, two of which are considered "significant hazard" due to their chance of failure: the Jewel Mill Dam and the Lower Mill Pond Dam.[225] The Rowley Resiliency Task Force identified the Jewel Mill Dam as its highest-priority dam. According to the Barriers survey and the report published on Massachusetts's Energy and Environmental Affairs web site, this dam is made out of concrete and stone and creates a 4-acre impoundment of the Mill River. The impoundment is noted to lack any significant habitat and reduces the stream's potential for greater biodiversity.[226] The old bridge at Glen Street is extremely vulnerable in the event of a breach at the Jewel Mill dam. A new bridge has been designed as part of the Central Street extension, and this may alleviate some of the flooding concern if it is built. Coastal inundation modeling indicates that by 2070, a large storm may have the potential to push ocean water up to this dam, although what impact that would have is uncertain at this time (Figure 3.5-3).[227]

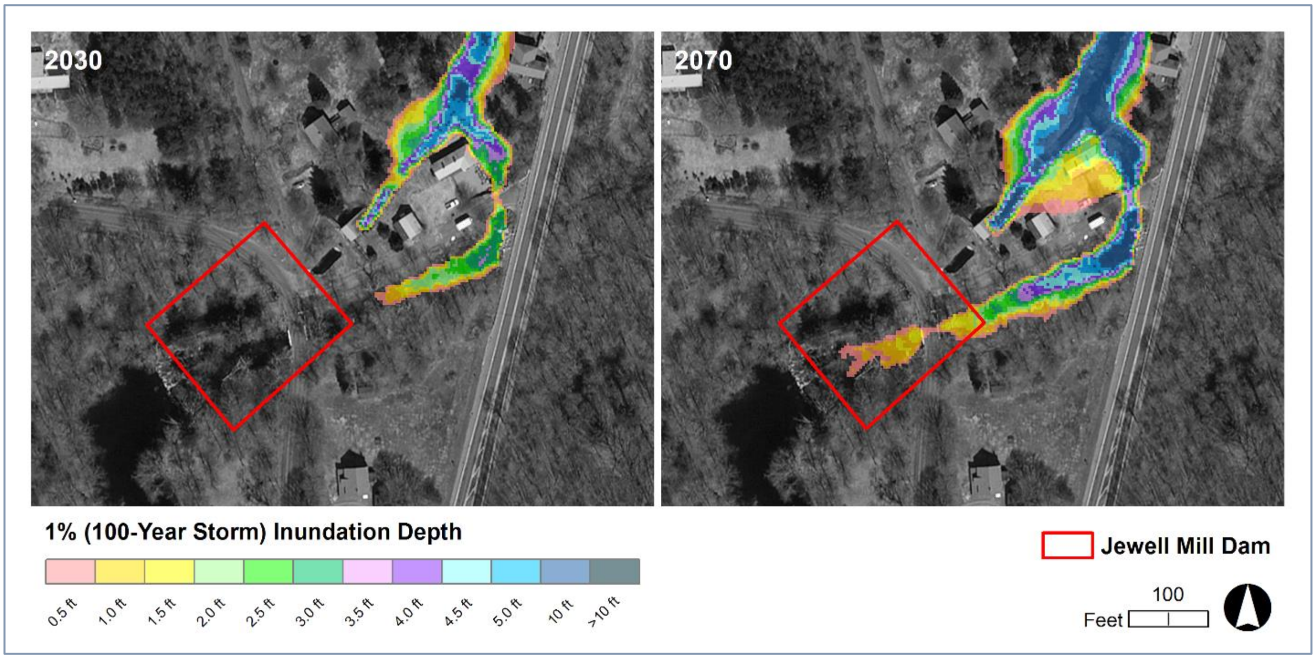

Figure 3.5-3. Jewel Mill Dam, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

Route 133 at Bachelder Brook experiences chronic flooding and is entirely within the 1% flood zone.[228] According to the barriers assessment, this culvert is undersized and vulnerable to failure. Route 133 is one of Rowley's major roads and connects Interstate 95 and Route 1 with the downtown area as well as Route 1A. Based on Google Earth estimates, citing KSS Fuels, this road carries over 13,000 cars each day. Although flooding, and subsequent closure of the road, does not pose an evacuation hazard it, it is a major traffic disruption. The nearest alternative routes to the south and north are much smaller roads that are not designed to carry heavy traffic loads. The Rowley Resiliency Task Force also noted that beaver activity

225 MVPC, *Draft Merrimack Valley Multi-Hazard Mitigation Plan*, 230

226 Brady, P.D. et al., "Part 4. Boston Harbor, North Shore and Merrimack River," in *A Survey of Anadromous Fish Passage in Coastal Massachusetts* (Boston, MA: Massachusetts Division of Marine Fisheries, 2005) , 93

227 Famely, J. et al., *Sea Level Rise and Storm Surge Inundation Mapping*

228 "MORIS: CZM's Online Mapping Tool," CZM, last updated January 9, 2012, http://maps.massgis.state.ma.us/map_ol/moris.php

in this vicinity exacerbates existing flood hazards and could be addressed rather easily. Coastal inundation modeling indicates this asset is unlikely to be affected by sea level rise or storm surge, at least through 2070.[229]

Rowley Town Well #3 is located northwest of Boxford Road and east of the Mill River. This well provides drinking water for the community and is also subject to 1% annual chance of flooding.[230] Water from the well is pumped through a 10 inch transmission water main to the town's filtration plant where it is treated and then released into the town's water distribution lines.[231] Flooding has the potential to impact the hydraulics of the well's pumping equipment, interrupting the town's supply of drinking water. More information on the vulnerability of this site is needed. In particular, what components of the well are particularly vulnerable to flooding? Are vulnerable pump mechanisms located close to the ground or higher up away from potential flood waters? Are there wide-ranging consequences to the community if the well fails? Coastal inundation modeling indicates this asset is unlikely to be affected by sea level rise or storm surge, at least through 2070.[232]

The **13 acres of beach on Plum Island** have high value for the community. This beach is in the Parker River National Wildlife Refuge and provides habitat to a variety of shorebirds, including the federally-threatened Piping Plover. These beaches are typically closed to the public during spring and summer to ensure nesting plovers aren't disturbed. During late summer and fall, the beach provides significant recreational opportunity to tourists and residents and is often crowded with sunbathers and bird watchers. However, as noted in the "Community Sensitivity" section above, beach erosion is a major problem for Rowley and the Wildlife Refuge that manages this stretch of beach. Erosion is likely to increase because of sea level rise and the occurrence of larger, more powerful storms. According to the USGS analysis, by 2070 approximately 75-100% of the beach will likely flood during 1% and 0.2% storms, with water depths primarily ranging from 5 to 20 feet for both storm scenarios. [233] This is significant because the amount of area expected to flood combined with the depth of water means acute and severe erosion is likely to be widespread during large storms. As the beach erodes, upland habitats, such as dunes and low-land coastal shrub areas, will become more exposed to coastal flooding.

Hillside Street Culvert at Great Swamp Brook is located along Hillside Street, northwest of Wethersfield Street. Great Swamp Brook is a tributary to the Mill River, and this particular hazard area is within the 0.2% (500-year) flood zone.[234] Although not a major transportation route, there is significant residential development along both Hillside and Wethersfield Streets. Flooding, due to the undersized culvert and its vulnerability to failure, is an inconvenience to residents and repeated or severe flooding has the potential to significantly damage the road, leading to costly repairs. Flooding here does not pose a major threat to transportation or the ability of emergency services to reach housing developments. Coastal inundation modeling indicates this asset is unlikely to be affected by sea level rise or storm surge, at least through 2070.

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[229] Famely, J. et al., *Sea Level Rise and Storm Surge Inundation Mapping*
[230] "MORIS: CZM's Online Mapping Tool"
[231] Town of Rowley, *Annual Drinking Water Quality Report* (Rowley, MA: Rowley Water Department, 2014), 2
[232] Famely, J. et al., Sea Level Rise and Storm Surge Inundation Mapping
[233] Abdollahian, N. et al., *Community Exposure*, 44
[234] "MORIS: CZM's Online Mapping Tool"

The extensive salt marsh surrounding **Route 1A** in the northern section of Rowley, running from Stackyard Road north to the town line with Newbury, experiences coastal flooding that occasionally impacts this well-travelled coastal scenic route. The estimated flood-water depths for Stackyard Road for current hazard zones is primarily 5 feet or less, but increase to primarily 5 to 20 feet in 2070 hazard zones (Figure 5).[235] East of Route 1A and further south towards the historic center of Rowley is a low-lying neighborhood that includes the **Rowley Marina and Boat Launch** and the Rowley train station, also subject to coastal flooding. All of these areas are currently largely protected from significant impacts in two ways: both Plum Island and the north-south running railroad bed, also to the east, serve as a protective barrier from storms. However, as shown by the maps below, projected coastal flooding will significantly impact the roads and neighborhoods (Figure 3.5-4 and 3.5-5).

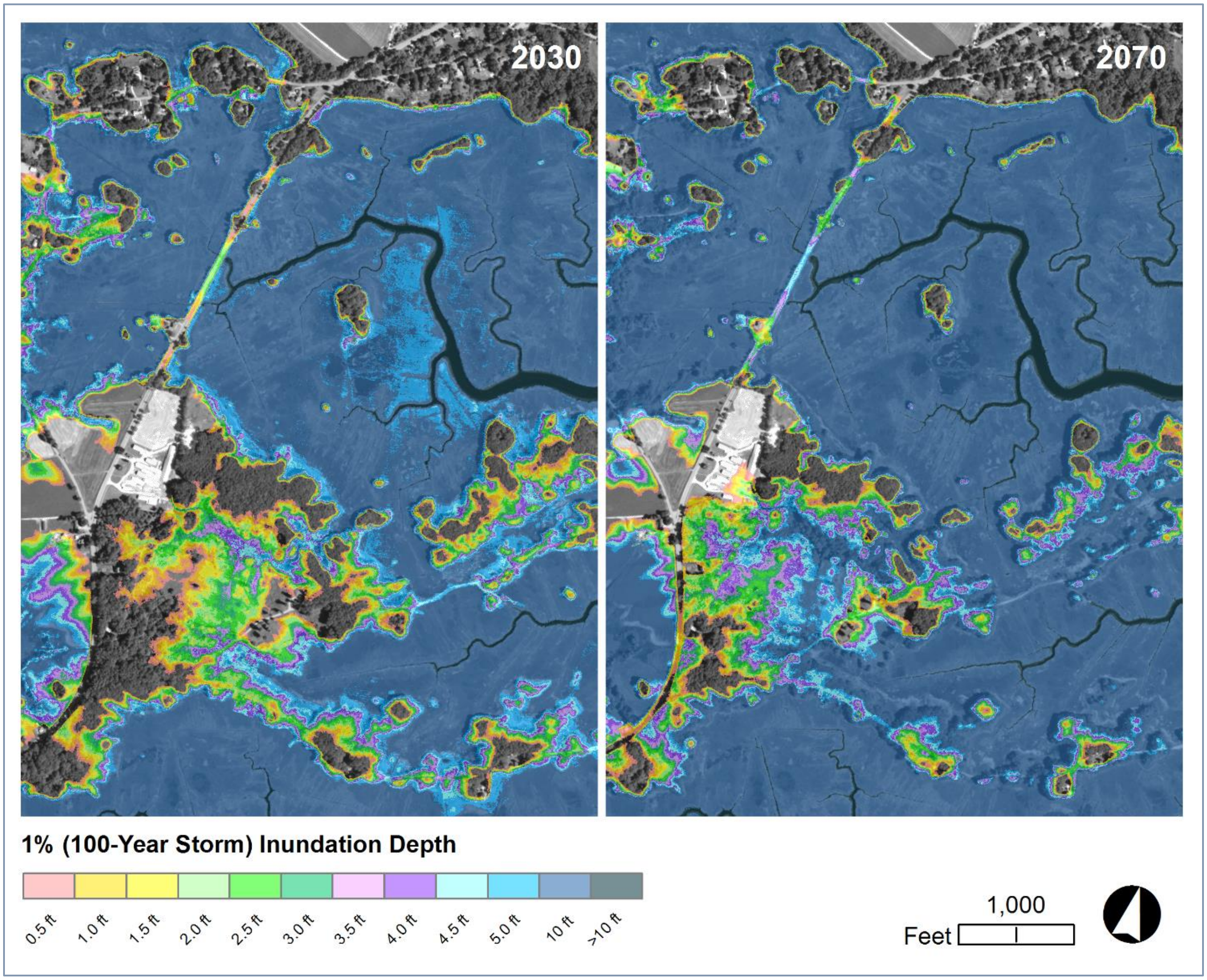

Figure 3.5-4. Stackyard Road at Route 1A, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

[235] Abdollahian, N. et al., *Community Exposure*, 44

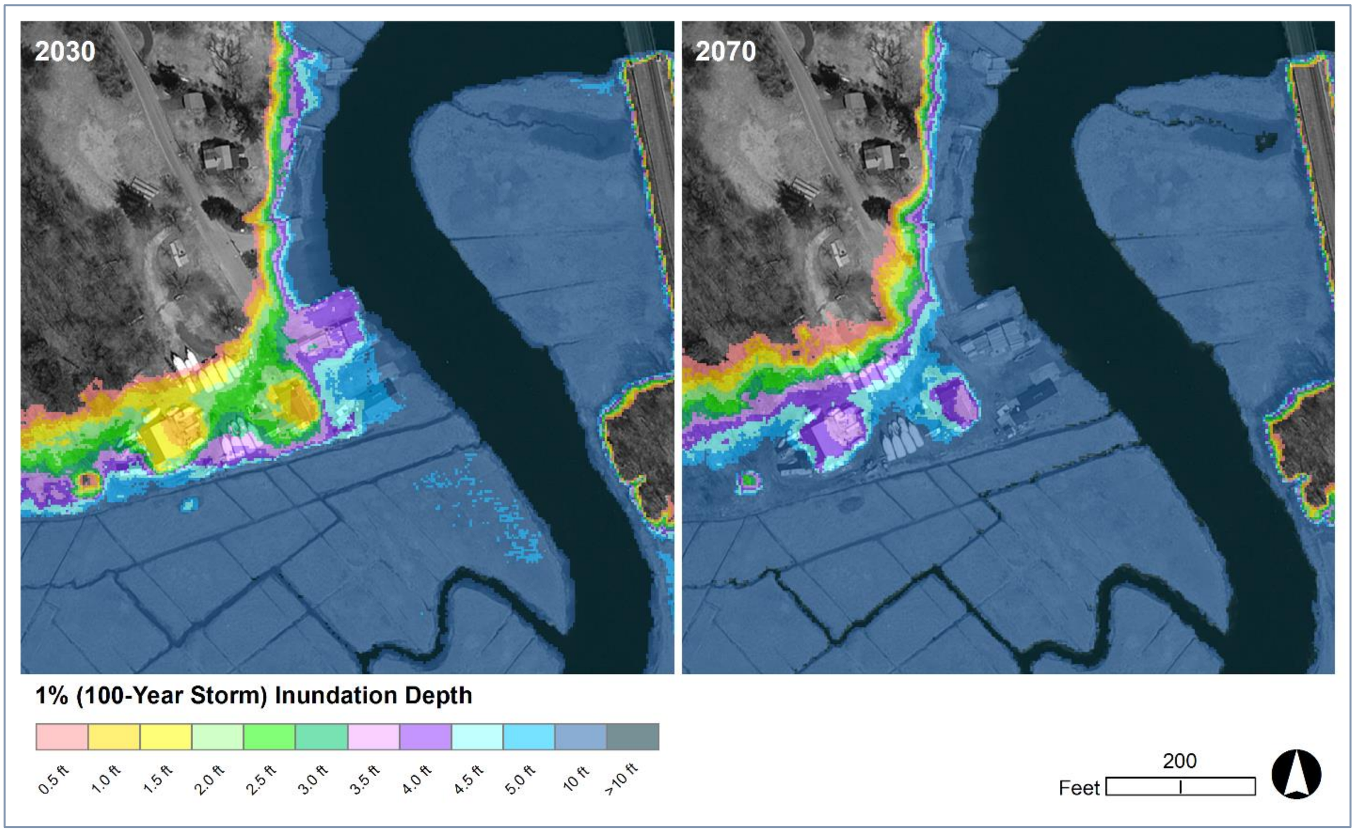

Figure 3.5-5. Rowley Marina and Boat Launch, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

The Massachusetts Bay Transportation Authority (MBTA) Newburyport Train Line serves the commuting needs of hundreds of local residents in the area. In 2013, there was a daily average of 812 inbound passengers using the line boarding from Newburyport to Boston.[236] The reactivation of the rail line to Newburyport was completed in 1998, driving much of the region's residential and economic growth as a suburb of Boston. The rail line traverses the salt marsh, two rivers, several streams and dozens of tidal creeks in the area. As such, the line is vulnerable to storm surge and sea level rise. In addition, there are several bridges and culverts along the line which act as minor to major tidal barriers and the line itself functions as a major barrier to natural coastal flowage patterns. The infrastructure associated with this line is owned and maintained by the MBTA – with management decisions being made by MBTA not the municipalities. The MBTA is in the process of developing a comprehensive analysis of all of its assets, including risks based on increased climate effects, and will be an important partner for Rowley in future adaptation planning and implementation efforts. As such, the vulnerability of this asset was not studied in depth as part of this study.

DEMOGRAPHICS[237]

According to the USGS geospatial hazard analysis, only 2% (108) of Rowley's residents currently live in coastal-hazard zones. By 2070, this number will increase to 151 residents, representing 3% of Rowley residents (Figure 3.5-6). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The greatest increase in residential exposure

[236] MBTA, "Chapter 4: Commuter Rail," in *Ridership and Service Statistics: Fourteenth Edition* (Boston, MA, 2014), 7-8
[237] Abdollahian, N. et al., *Community Exposure*, 41-42

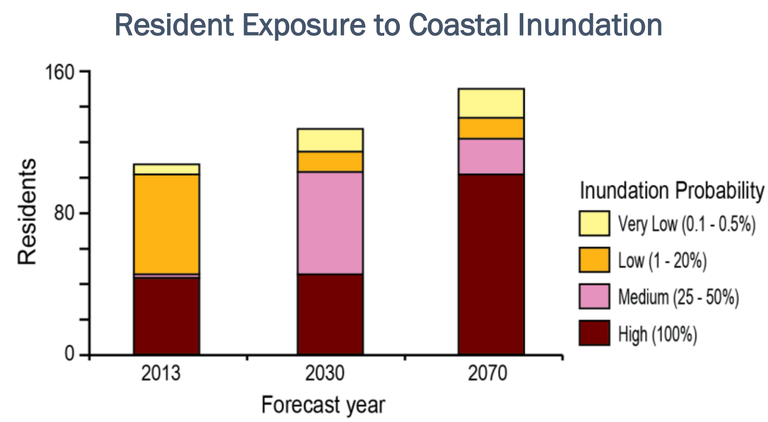

Figure 3.5-6. Resident exposure in the Town of Rowley, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

among the three time periods is associated with the high inundation-probability zone. The majority of residents in current hazard zones are located in areas classified as having a low (1-20%) inundation probability (57 residents). By 2070, the majority of residents (102) in the hazard zone will live in areas with a high probability of inundation.

All demographic percentages describing residents in hazard zones were relatively stable (+/- 1%) across the three time periods. Demographic data suggest that there are no residents in the coastal-hazard zones across the three time periods that live in mobile homes or lack a phone. Less than 5% of the residents in the hazard zones speak English as a second language, are unemployed, are under 5 years in age, or lack vehicles. Greater than 5% of the residents in the hazard zones are in renter-occupied households (9%), are living in institutionalized group quarters (11%), are living under the poverty line (15%), have disabilities (20%), are over 65 years in age (23%), or only have a high school degree (45%).

ECONOMIC & SOCIO-ECONOMIC[238]

Only four employees currently work in the coastal hazard zones in Rowley, and that number increases only marginally to 10 in 2070 (Figure 3.5-7). As was the case with the resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zone and not projected changes in employee distributions. Sales volume exposure for private-sector businesses ranges from $0.7 million currently to $1.6 million in 2070 (Figure 3.5-8a). None of the businesses in the various hazard zones were classified as related to natural resources, and only 1-2 businesses are likely to have a significant customer presence (e.g. retail).

Similar to sales volume, parcel values and building replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $12.8 million present day to approximately $21.4 million in 2070, representing 1% to 2% of the community's tax base between the two time periods (Figure 3.5-8b). The majority of tax-parcel value in hazard zones is associated with land value rather than building/content value. Based

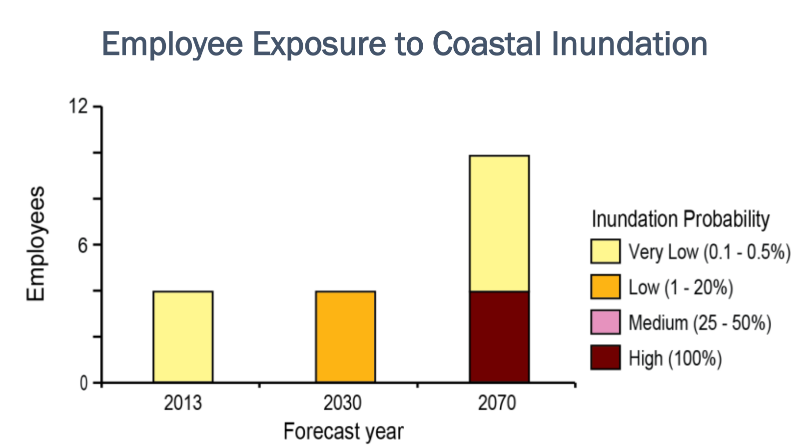

Figure 3.5-7. Employee exposure in Rowley, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

[238] Ibid 42-43

on building stock data in the FEMA Hazus-MH database, estimated building replacement values range from $22.3 million for the current hazard zone to $31 million for 2070 hazard zone (Figure 3.5-8c). For all three time periods, the majority of potential building replacement values are in areas classified as having a high probability of inundation.

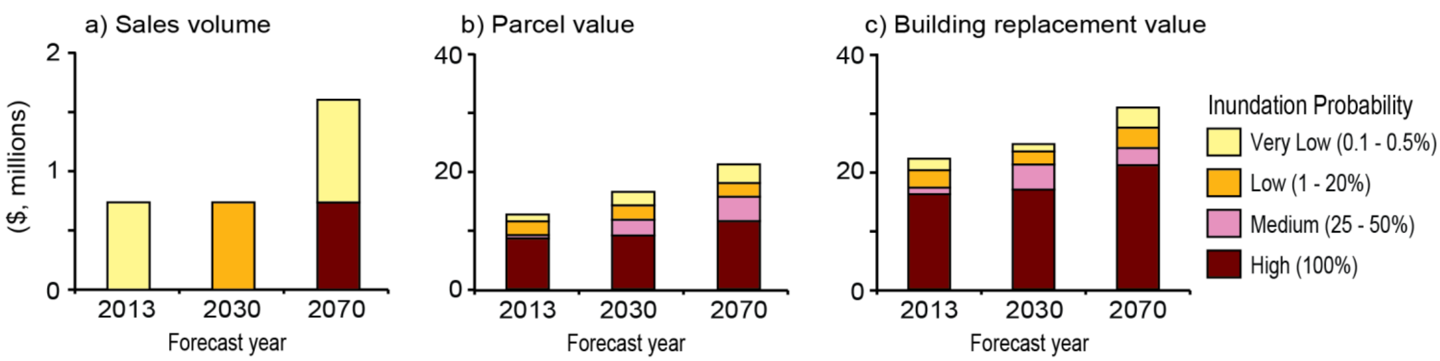

Figure 3.5-8. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Rowley, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

Separate from the USGS analysis, FEMA and the Department of Homeland Security conducted a static analysis on Rowley's current economic vulnerability to flooding. Their study analyzed the potential economic impact of various storm scenarios using FEMA's Flood Risk Database combined with FEMA's flood loss estimation tool, HAZUS. Potential building losses and associated business disruption costs for each storm category are shown below (Table 3.5-2).[239] Based on their analysis, the economic impact of even a relatively small 10 % (10-year) storm may be quite significant.

Table 3.5-2. Rowley's Estimated Potential Losses for Flood Event Scenarios. (*)Losses shown are rounded to nearest $10,000 for values under $100,000 and to the nearest $100,000 for values over $100,000; (**) Total Building/Contents Loss = Residential Building/Contents Loss + Commercial Building/Contents Loss + Other Building/Contents Loss; (***) Disruption = Inventory Loss + Relocation Cost + Income Loss + Rental Income Loss + Wage Loss + Direct Output Loss; (****) Total Loss = Total Building/Contents + Business Disruption.

	10% (10-yr)	2% (50-yr)	1% (100-yr)	0.2% (500-yr)	Annualized ($/yr)
	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*
Total Buildings/ Contents**	$33,500,000	$46,500,000	$58,100,000	$84,800,000	$4,200,000
Business Disruption***	$2,200,000	$3,100,000	$4,100,000	$5,500,000	$300,000
Total******	$35,800,000	$49,800,000	$62,100,000	$90,300,000	$4,500,000

[239] FEMA, *DRAFT Flood Risk Report: Essex County, MA* (Washington, DC, 2013), 75

Based on this analysis, a mere 10% storm has the potential to cause as much as $3.7 million dollars in damage. A larger 1% (100-year) storm may cause as much as $17.2 million in damage and a 0.2% (500-year) storm as much as $22 million. The majority of damage comes from infrastructure losses, although business disruptions are also quite significant. It is important to note that as 1% storms become more frequent, these damage estimates are likely to increase.

HABITATS & SPECIES

The Great Marsh is one of the most important coastal ecosystems in northeastern North America.[240] In Rowley, this ecosystem contains high and low marsh, estuarine aquatic environments, and a barrier beach accompanied by extensive dunes. Each of these habitats provide critical foraging and breeding grounds for a plethora of native species. The Great Marsh also provides an abundance of ecosystem services to the Town of Rowley. The marsh absorbs wave energy and traps sediment, helping reduce erosion; the aquatic environment is a nursery for commercially important fish species; and the dunes provide protection against storm surge. In addition, the salt marsh traps and safely stores harmful sources of carbon that are the leading cause of climate change. In fact, recent analysis indicates that marshes are one of the most powerful carbon sinks, with the potential of sequestering almost 50 times more carbon than tropical rainforests.[241]

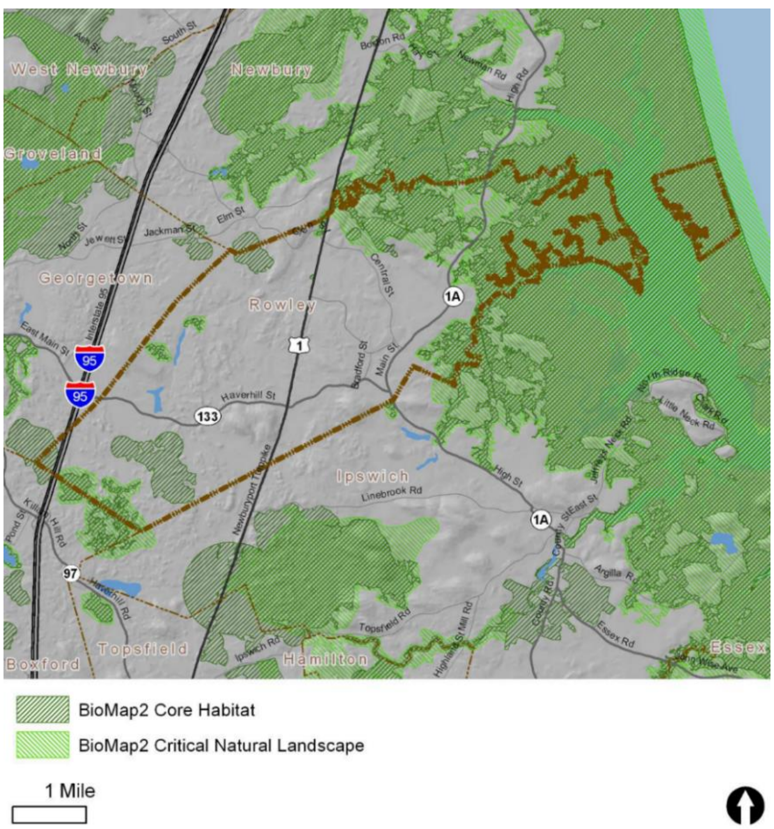

Figure 3.5-8. *BioMap2* Core Habitats & critical natural landscapes in Rowley

A significant portion of Rowley has received official designation recognizing the importance of its natural systems. Approximately 3,365 acres in Rowley are designated as *core habitat* and 3,913 acres are listed as *critical natural landscape* (Figure 3.5-9).[242] The term "core habitat" refers to areas deemed necessary to support the long-term existence of rare or threatened species, exemplary natural communities, and intact ecosystems. "Critical natural landscapes" are intact ecosystems that are well suited to support ecological processes and/or a wide array of species and habitats over long period of time.[243]

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240 "The Great Marsh," Western Hemisphere Shorebird Reserve Network, accessed October 2015. http://www.whsrn.org/site-profile/great-marsh

241 Bu, N. et al., "Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool," *Ecological Engineering*, 81 (2015): 335

242 MA DFG & TNC, *BioMap2: Rowley* (Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012), http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Rowley.pdf

243 Ibid

Intact river corridors, marshes, barrier beaches, and dunes make up the majority of the critically important habitat in Rowley. These habitats contain multiple vegetative zones that support a wide diversity of species, including numerous threatened and endangered species (Table 3.5-3).[244]

The marsh in Rowley is quite vulnerable to erosion and sea level rise. Because this habitat is so low-lying and tidally influenced, the vast majority of marsh may become inundated under just one foot of sea level rise.[245] Additionally, hydro-barriers disrupt natural flows, impacting sediment transport and impeding the migration of aquatic organism. However because of the limited development along the marsh edge, Rowley is particularly well positioned to allow and even promote marsh migration inland. If deliberate steps are taken to limit further development along the marshes' edge this critical habitat may be able to gradually move landward to keep pace with sea level rise.

Table 3.5-3. List of species occurring in Rowley that are threatened (T) or endangered (E). For complete list of species, including Species of Conservation Concern, see the MA Dept. of Fish & Game BioMap2 report for Rowley (2012).

Threatened and Endangered Species	Preferred Habitat
Birds	
American Bittern[E]	Freshwater and brackish marshes
Least Bittern[E]	Freshwater and brackish marshes
Pied-billed Grebe[E]	Freshwater and brackish marshes, ponds
Piping Plover[T]	Beach, dunes, mudflats
Grasshopper Sparrow[T]	Grasslands, pastures, hayfields
Northern Harrier[T]	Wed meadows, grasslands, coastal and inland marshes
King Rail[T]	Freshwater marshes, wet meadows
Plants	
Estuary Arrowhead[E]	Sandy shores, mudflats, brackish rivers
Seabeach Needlegrass[T]	Coastal dunes
Amphibians	
Eastern Spadefoot[T]	Pine barrens, coastal oak woodlands, sand

Changes in precipitation and sea level rise may also alter the balance between freshwater and saltwater in the Rowley River and its tributaries. As a result of climate-driven threats, this habitat may become less suitable for anadromous populations in the future. Saltwater intrusion and loss of freshwater input may impact the successful development of species like Alewife herring. Furthermore, development combined with an increase in severe storm activity will likely lead to an increase in surface runoff quantities and rates. Storm runoff carrying bacteria, pathogens, and nutrients can be extremely damaging to the diversity of habitats and species, such as shellfish, that occupy the Essex River estuary.

Shellfish are an important natural resource in Rowley where widespread commercial harvesting occurs. Maintaining healthy, stable shellfish populations is a high priority in Rowley. However the habitat used by shellfish is quite vulnerable to sea level rise and increased erosion. Intertidal mud flats, sandy estuarine environments, and sea grass beds are all likely to suffer under the added strain of climate-driven threats. Sea level rise will likely permanently inundate existing clam flats, converting once productive harvesting areas into unsuitable habitat devoid of shellfish. Erosion also threatens to further shrink these estuarine environments so important to shellfish. Concerted effort is required to preserve this natural resource.

The undeveloped barrier beach and associated dunes on Plum Island provide critical foraging habitat to the federally threatened Piping Plover. Like all barrier beaches, natural processes cause the beach to shift over time. A beach's dynamic character, and ability to move and reshape in response to constant wave energy as well as acute storm events, is precisely what makes it resilient to sea level rise and storm

[244] Ibid
[245] "MORIS: CZM's Online Mapping Tool"

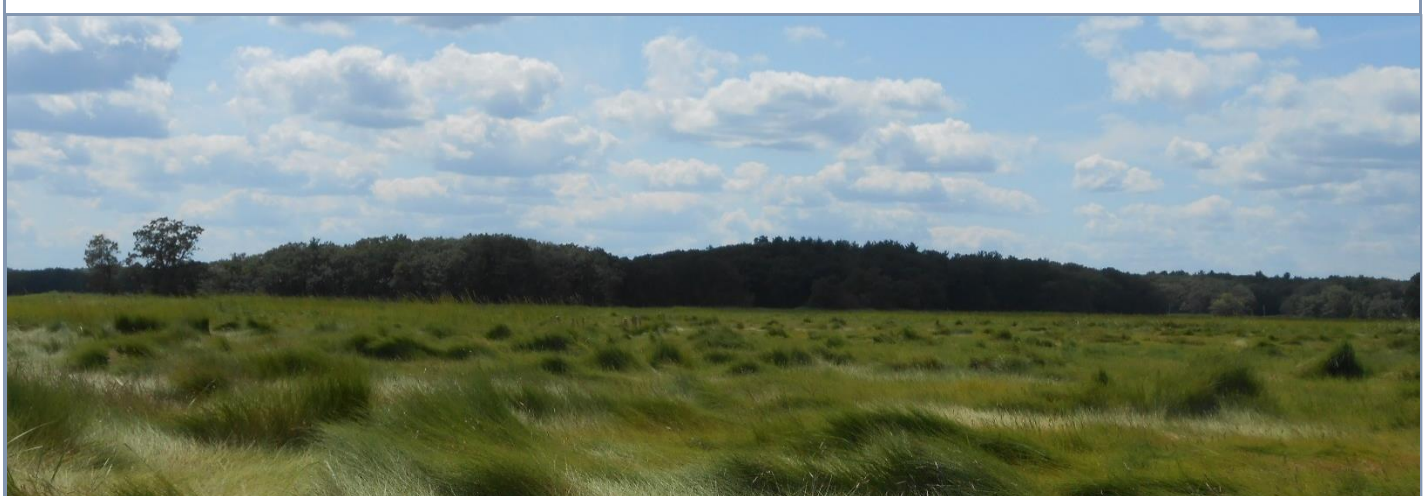
surge.[246] As the Massachusetts Coastal Erosion Commission's final report notes, "The movement of sediment along the coast and the [natural] loss and gain of shoreline—erosion and accretion—are continuous and interrelated processes."[247] Because Rowley's barrier beach remains in a natural state, this stretch of beach is more likely to be resilient to future storms and sea level rise.

Summary

Overall the Town of Rowley is moderately to highly vulnerable to climate-driven threats. Predicted increases in storm frequency and severity, sea level rise, increased storm surge, and erosion are all major hazards facing Rowley. These hazards may have wide-ranging impacts on the town's economy, the infrastructure located in low-lying riverine and coastal areas, and the natural systems that the community depends upon. Because of much of the town's charm is derived from its rural character and scenic natural areas, impacts to the marsh and beaches may have cascading effects that ripple across all parts of the community. The geospatial analysis conducted by USGS confirms these findings and indicates some economic, infrastructure, and population vulnerabilities that will likely need to be addressed to protect human life as well as the economic well-being of Rowley.

The natural systems in Rowley are already being impacted by erosion that is likely to accelerate with climate change. Sea level rise will likely inundate areas of marsh that currently help reduce storm surge and reduce erosion, and provide important habitat to rare and threatened species. Storm surge resulting from bigger and more frequent storms may overtop existing dunes, impacting upland habitats. An increase in heavy precipitation events combined with penetrating storm surge will likely cause flooding to low-lying portions of Rowley.

For recommendations on how to address the Town of Rowley's overall vulnerability to climate-driven hazards, including site-specific adaptation strategies for the areas of concern outlined above, see Chapter 4: Adaptation Strategies for the Great Marsh Region.



David S. Johnson

[246] Massachusetts Barrier Beach Task Force, *Guidelines for Barrier Beach Management in Massachusetts* (Boston, MA: Massachusetts Office of Coastal Zone Management, 1994) http://www.mass.gov/eea/docs/czm/stormsmart/beaches/barrier-beach-guidelines.pdf

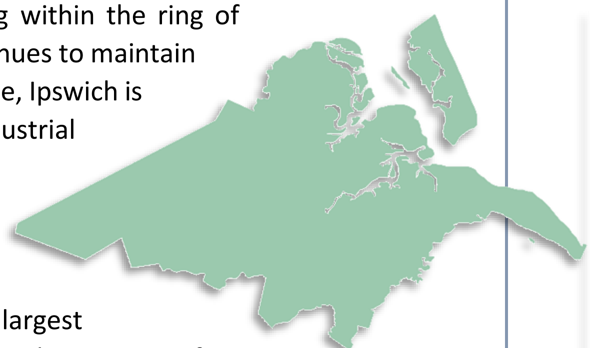
[247] Massachusetts Coastal Erosion Commission, "Volume 1: Findings and Recommendations" in *Report of the Massachusetts Coastal Erosion Commission* (Boston, MA: Massachusetts Executive Office of Energy and Environmental Affairs, 2015), 1

David Stone

3.6. Town of Ipswich Vulnerability Assessment

Community Exposure to Climate Hazards

Located south of Rowley and north of Essex, the Town of Ipswich is a unique coastal community along the North Shore of Massachusetts. Despite being within the ring of suburbs and prosperous districts that surround Boston, Ipswich continues to maintain its identity as a rural community. Approximately 33 square miles in size, Ipswich is predominately forested (41%), while residential, commercial, and industrial development combined make up about 15%.[248] Agriculture in Ipswich also contributes to the town's semi-rural character, and its open fields and farms represent about 10% of the town's land area.[249] However the town is best known for its seaboard, lowland landscape, and plentiful coastal habitats. The Great Marsh, the largest contiguous salt marsh in New England, dominates the landscape and makes up 21% of the landmass in Ipswich.[250]



According to the 2010 Federal Census, there are approximately 13,175 residents living Ipswich. However during the summer months, this number tends to increase as some of the town's 5,601 housing units are seasonal or second homes.[251] Similar to most New England towns, Ipswich is characterized by a densely populated town center and more sparsely populated rural areas. Downtown Ipswich harbors the majority of the town's infrastructure. Located along the western bank of the Ipswich River at the overlap of Route

[248] MAPC, *Town of Ipswich Hazard Mitigation Plan* (Boston, MA, 2012), 4
[249] Town of Ipswich, *Open Space and Recreation Plan* (Ipswich, MA, 2013), 24
[250] Ibid 35
[251] Town of Ipswich, *Ipswich Community Development Plan* (Ipswich, MA, 2003), 66

Dennis Kelley/Ipswich River Watershed Association

1A and Route 133, the Ipswich town center is vibrant and diverse. Downtown businesses include restaurants, specialty stores, convenience stores, banks, attorneys' offices, and beauty salons.[252]

The majority of Ipswich's land area (61%) lies within the Ipswich River Watershed, while the northern 39% of the town falls within the Parker River Watershed.[253] The Rowley River separates the northernmost portion of Ipswich from Rowley. A tidally influenced river system, the Rowley River is fed in part by three freshwater tributaries, Bull Brook, Muddy Run, and Dow Brook. Bull Brook Reservoir and Dow Brook Reservoir both serve as the town's surface water supply.[254] The Ipswich River emanates 35 miles to the west and flows to the downtown area, where it meets the Ipswich Mills Dam at the head of the tidal estuary. Like many North Shore communities, much of Ipswich is low-lying, leading to high exposure to sea level rise and flooding hazards. During storms and abnormally high tides, water courses through these rivers and tidal channels, carrying flood waters inland. Hydro-barriers often act as choke points causing tidal creeks to spill out of the marsh into surrounding areas. The natural topography combined with erosion and tidal restrictions lead to chronic and widespread coastal and riverine flooding.

The beaches in Ipswich have high exposure to erosion, particularly Plum Island and Crane Beach. These barrier beaches are the first line of defense against storm surge and sea level rise. In their unprotected locations, the continuous onslaught of waves and wind have led to significant erosion. Large storms can also cause acute erosion events where large sections of beach are completely swept away. Given high exposure to the Atlantic Ocean, Ipswich experiences some of the highest erosion of any North Shore community.[255]

Additionally, both Clark Beach and Pavilion Beach, located on Great Neck, have high exposure to sea level rise and storm surge. The headlands of Great Neck and Little Neck are exposed to storms and have significant vulnerability to erosion. Major bank armoring occurred to Great Neck following the "No Name Storm" of 1991, and armoring occurred on Little Neck following erosion in 2013. Armoring of the coastline seems to have impacted Clark Beach and Pavilion Beach by disrupting the natural flow of sediment and by deflecting wave energy towards the beach, exacerbating existing erosion.

A detailed analysis of coastal inundation, conducted by the Woods Hole Group and USGS, confirms that the Town of Ipswich has fairly high exposure to sea level rise and storm surge. Present day estimates (which are for the year 2013) indicate approximately 25% of the town is vulnerable to coastal inundation – depending on the severity of the storm. That number climbs to 30% in 2070 (Figure 3.6-1).[256] Of the

[252] Ibid 108

[253] Massachusetts Watershed Initiative, *Parker River Watershed: Year 3 Watershed Assessment Report* (Wilmington, MA: Massachusetts Department of Environmental Protection, 2002), 1

[254] Town of Ipswich, *Open Space and Recreation Plan*, 32

[255] MA EEA, *Shoreline Characterization and Change Analyses: North Shore Region* (Gloucester, MA, 2014) http://www.mass.gov/eea/docs/czm/erosion-commission/shoreline-profile-north-shore.pdf

[256] Abdollahian, N. et al., *Community exposure to potential climate-driven changes to coastal-inundation hazards for six communities in Essex County, Massachusetts*, U.S. Geological Survey open-file report (Reston, VA: USGS, 2016), 47

areas subject to coastal inundation, the vast majority are subject to nearly annual or semi-annual flooding – now and in 2070 (Figure 3.6-2).[257]

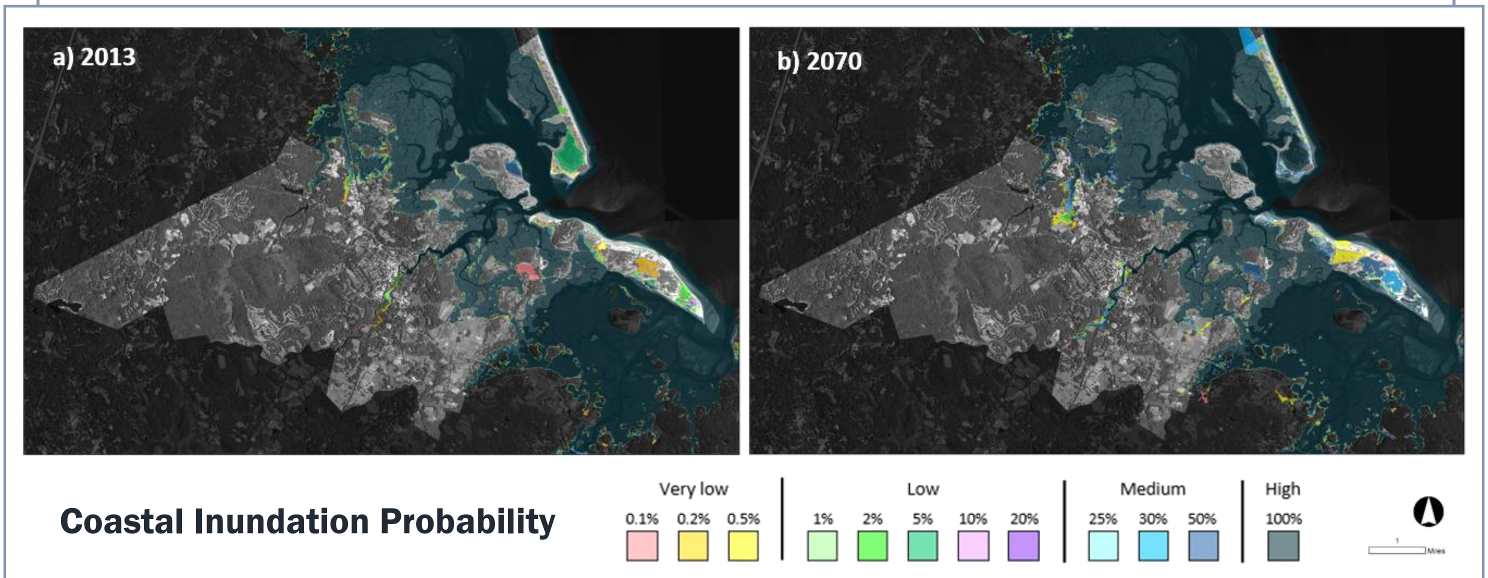


Figure 3.6-1. Ipswich, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

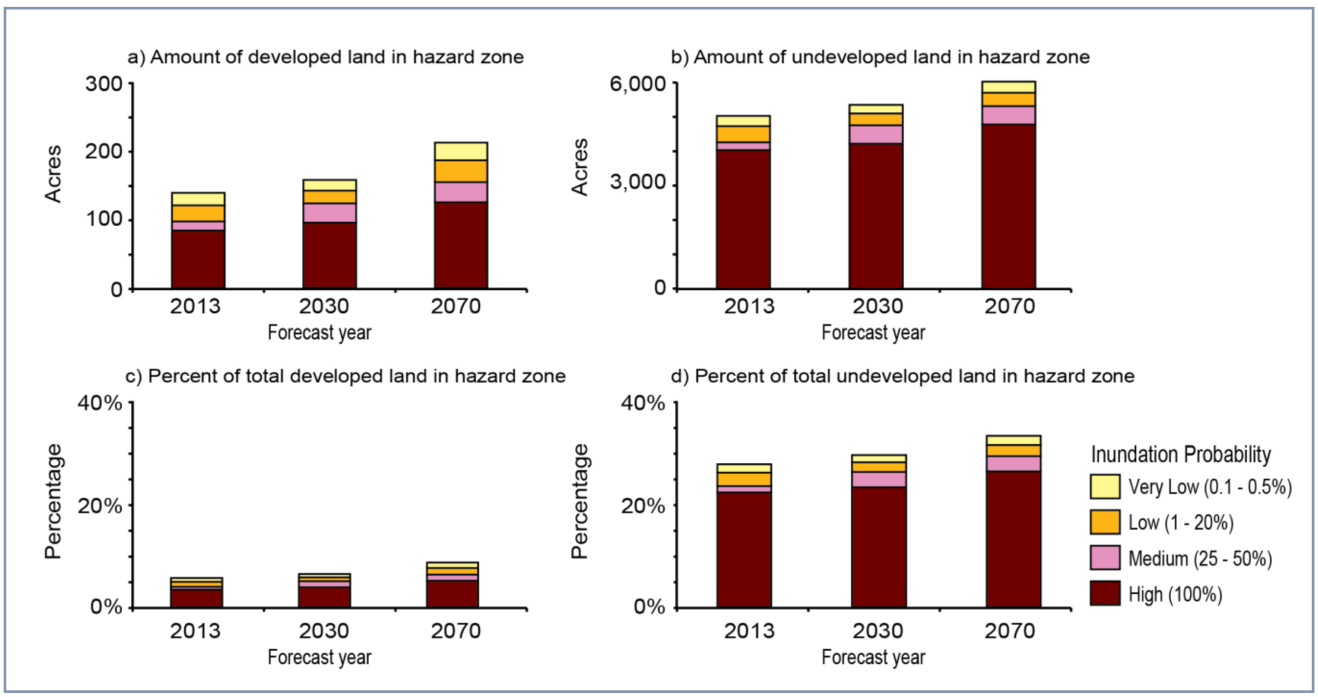


Figure 3.6-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Ipswich, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

[257] Ibid

In summary, Ipswich has high exposure to coastal flooding, riverine flooding, and erosion due to its topography, hydrology, and geographic location. Plum Island and Crane Beach face the open ocean and are highly exposed to wind, wave action, and sea level rise – with no buffering landmass to diminish these hazards. Interior portions of Ipswich rely on these barrier beaches to buffer the worst storm effects, however the extensive number of tidal creeks and channels, combined with the overall low topography, can lead to widespread inland flooding – such as what occurred during the now infamous Mother's Day Flood of 2006 and the March 2010 Flood. Both floods set record high peak water flows and caused widespread damage to homes, business, and bridges in Ipswich.[258]

Community Sensitivity to Climate Hazards

The Town of Ipswich has a relatively high level of sensitivity to climate-driven threats, including flooding from storm surge, sea level rise, and riverine flooding. Overall 48% of the town's landmass lies within the FEMA 1% flood zone (often referred to as the "100-year" flood zone).[259] Based on an automated analysis by ClimateCentral.org (using lidar elevation data supplied by NOAA), approximately 100 people (48 homes) live in areas less than 6 feet above sea level, of which none are protected or isolated from flooding by levees or natural topographic ridges.[260] Further analysis indicated that 4% of roads are located less than 6 feet above sea level (as defined by total road mileage).[261]

In Ipswich, economic sensitivity to climate hazards is intrinsically linked to the sensitivity of the town's natural systems. The Trustees of Reservations' Crane Beach is one of the town's most important recreational areas and draws over 250,000 users annually—both locals and visitors.[262] The open fields and farms in Ipswich also support a strong agri-tourism industry; a number of family-owned and operated farms attract tourists looking for a hands-on agriculture experience.[263] Ipswich is also the largest shellfish producer in Massachusetts. In 2010, a total of 1.5 million pounds of shellfish were commercially produced in Ipswich. This harvest equated to about $2 million in total value and had an estimated economic impact in the area of $8 million.[264] The shellfish industry in Ipswich is directly tied to the health of its coastal areas. For example, since the 1970s red tide has shut down the town's shellfish beds for parts of most years.[265] Shellfishing areas in Ipswich are also known to close after most significant storm events as runoff, carrying fecal coliform and other pollutants, washes into the creeks and marshes.[266]

David Stone

[258] MAPC, *Town of Ipswich Hazard Mitigation Plan*, 11
[259] FEMA, *DRAFT Flood Risk Report: Essex County, MA* (Washington, DC, 2013), 55
[260] "Surging Seas: Risk Finder," Climate Central, last modified April 2014, http://sealevel.climatecentral.org/ssrf/massachusetts
[261] Ibid
[262] Barringer, P., *Downtown Assessment: Ipswich, Massachusetts* (Brookline, MA: FinePoint Associates, 2014), 6
[263] Town of Ipswich, *Open Space and Recreation Plan*, 24-26
[264] Ibid 26
[265] Wayne Castonguay (Executive Director of the Ipswich River Watershed Association), personal communication with authors, September 15, 2015
[266] Town of Ipswich, *Open Space and Recreation Plan*, 26

Kirk R. Williamson/Flickr

The diversity of natural resources in Ipswich contributes to the town's character, enhances the quality of life for residents and visitors, and provides economic opportunity. The Ipswich River and its watershed support rich and diverse habitat for a myriad of species, including mink, otter, wood ducks, spotted turtle, wood frogs, and brook trout. Ipswich's seaboard lowland landscape features coastal barrier beaches with extensive sand dunes, pitch pine forests, thickets, and red maple swamps. This mosaic landscape of important habitat is fairly well protected: over 9,000 acres, approximately 45% of the land in Ipswich, is currently protected in perpetuity. These protected lands provide habitat for an abundant mix of wildlife, including some threatened and endangered species.[267] For example, Crane Beach and Plum Island provide critical nesting ground for the federally threatened piping plovers – Crane Beach being one of the most productive breeding sites for this species in the world.[268, 269] Over 1,500 acres of intertidal land are contained behind Ipswich's barrier beaches. Together, these habitats make up 39% of the Parker River/Essex Bay's Area of Critical Environmental Concern (ACEC), as designated by the Massachusetts Executive Office of Environmental Affairs.[270] This area also includes the Great Marsh, which covers 21% of Ipswich.[271] In addition to being an important habitat for shellfish, the marsh provides critical feeding and staging habitat for resident and migratory birds. This area has therefore been designated an Important Bird Area of global significance. While exact estimates are unknown, large numbers of bird watchers from throughout the northeast, and throughout the country, travel to the area to witness the spectacular influx of birds during spring and fall migrations.

Marshes and barrier beaches are inherently sensitive to the impacts of climate change, and human activity can further increase their sensitivity. A healthy untouched marsh can attenuate storm surge by reducing wave height, and heavily vegetated dunes are often resilient in the face of large storms.[272,273] Depending on topographic features, marshes and dunes can migrate inland as sea levels rise. However, these natural systems are impacted by human development and management. Improperly-sized hydro barriers can disrupt marsh ecosystems by reducing flow of sediment and impacting salinity levels. Narrow, unvegetated dunes (typically found in heavily populated areas) can erode easily if they are exposed to waves.

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[267] MA DFG & TNC, *BioMap2: Ipswich* (Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012), http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Ipswich.pdf

[268] Town of Ipswich, *Open Space and Recreation Plan*, 38

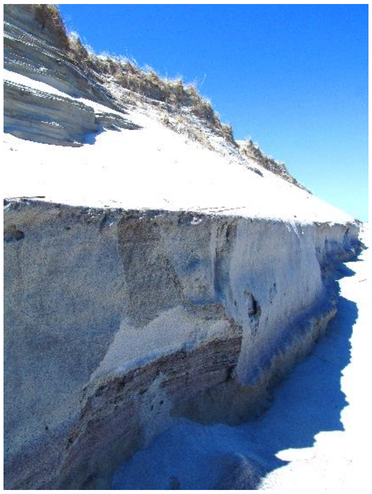
[269] Wayne Castonguay (Executive Director of the Ipswich River Watershed Association), personal communication with authors, September 15, 2015

[270] Rickards, B. et al., *An Assessment of Resource Management Strategies in the Parker River/Essex Bay Area of Critical Environmental Concern* (Boston, MA: Massachusetts Office of Coastal Zone Management, 2002), 9

[271] Town of Ipswich, *Open Space and Recreation Plan*, 35

[272] Shepard, C.C., et al., "The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis," *PLoS ONE* 6, no. 11 (November 2011): e27374, doi:10.1371/journal.pone.0027374.

[273] "In Defense of Dunes," ASBPA, January 13, 2015, http://www.asbpa.org/news/newsroom_14BN0113_in_defense_of_dunes.htm



Sandy Tilton

Barrier beaches in Ipswich are becoming increasingly sensitive to climate hazards, especially erosion. Based on a recent analysis completed by the Coastal Erosion Commission and presented by CZM, Sandy Point Reservation, located on the southern tip of Plum Island in Ipswich, had the highest erosion rates along the North Shore, with an average beach loss of 5.0 feet a year (data collected between 1970 and 2009). During this same time period, Crane Beach experienced the second highest rate of erosion with a loss of 1.4 meters (4.6 ft) a year.[274] With rising seas and increased storm activity, erosion and its associated impacts are likely to worsen for this community already sensitive to climate-driven impacts.

Community Vulnerability

The most comprehensive community assessment of Ipswich's vulnerability to natural hazards is provided in the *Town of Ipswich Hazard Mitigation Plan* prepared by the Metropolitan Area Planning Council.[275] Information from this and other documents is synthesized below along with information from the Ipswich Community Resiliency Task Force, coastal inundation modeling conducted by the Woods Hole Group,[276] and results from the 2016 USGS geospatial analysis of potential impacts from coastal inundation. [277]

According to the Town's Hazard Mitigation Plan, flooding, caused by hurricanes, northeasters, intense rainstorms and thunderstorms, is the most prevalent and serious natural hazard in the community.[278] Most flooding in Ipswich has historically occurred upstream of the Ipswich Mill Dam located in the Downtown area.[279] However, over the last several decades, development throughout the upper Ipswich River Watershed has resulted in an increase in impervious surfaces. As a result, during large storm events the stormwater storage capacity throughout the Ipswich River Watershed becomes easily overwhelmed and results in more widespread flooding.

CRITICAL INFRASTRUCTURE

The Ipswich Hazard Mitigation Plan identifies 46 structures subject to 1% annual chance of flooding according to FEMA flood zones, of which 11 are regarded as *critical infrastructure*: one well, two dams, and eight bridges (for specific locations of these assets, see the *Town of Ipswich Hazard Mitigation Plan*).[280]

The USGS geospatial hazard analysis of critical infrastructure indicated there's no critical infrastructure located in areas likely to be inundated, now through 2070. An overall infrastructure analysis indicated there are approximately 8.1 miles of roads and rail in 2013 hazard zones (distributed evenly between low to very low probability zones) that increases to 9.9 miles by 2070 (primarily in medium-probability zones).[281]

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274 MA EEA, *Shoreline Characterization and Change Analyses*
275 MAPC, *Town of Ipswich Hazard Mitigation Plan*, 1-76
276 Famely, J. et al., *Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA)*, Prepared by Woods Hole Group for National Wildlife Federation and U.S. Geological Survey, (Falmouth, MA, 2016)
277 Abdollahian, N. et al., *Community Exposure*
278 MAPC, *Town of Ipswich Hazard Mitigation Plan*, 13
279 Ibid 10
280 Ibid 16
281 Abdollahian, N. et al., *Community Exposure,* 53-54

BARRIERS TO FLOW

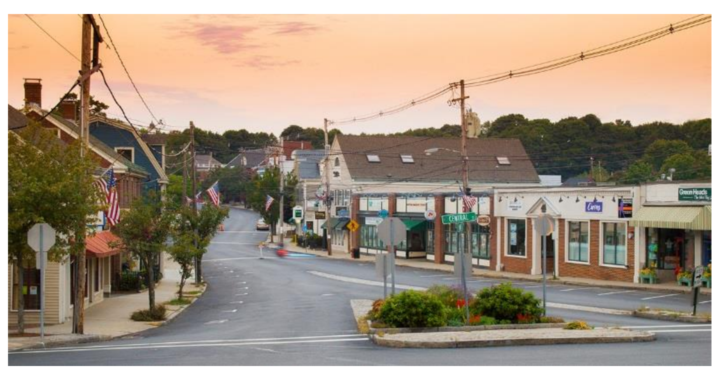
The "Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed" provides additional insight into where the community may be vulnerable to flooding. As part of this screening level vulnerability assessment, this project inventoried and assessed the locations throughout Ipswich and other Great Marsh towns where human-made structures such as roads, bridges, dams, sea walls, and other structures intersect waterways and floodplains. These structures often present serious barriers to the natural movement of water and function of related physical and biological processes including sediment and nutrient transport. Undersized, improperly designed, or aging structures are vulnerable and can put related critical infrastructure, buildings, and transportation corridors at increased risk of flooding and failure, especially during extreme storms that bring heavy rains, winds, and storm surges. Many of the same barriers that present serious infrastructure risk have also been identified as causing significant ecological harm and reducing the resiliency of natural communities. Several past studies were reviewed for this project, and new surveys were conducted to assess the vulnerability of these structures in each community.

Four types of structures (non-tidal road-stream crossings, tidal road-stream crossings, dams, and public shoreline stabilization structures) that are potential barriers were assessed for their degree of vulnerability. The Town of Ipswich has 87 non-tidal road-stream crossings, 17 tidal road-stream crossings, 6 dams, and 1 public shoreline stabilization structure. Of these, 22 non-tidal road-stream crossings, 7 tidal road-stream crossings, and 1 dam are highly vulnerable to the impacts of sea level rise, coastal storms, and/or inland flooding based on our screening criteria (see Appendix B for methodology, results, and a map).

AREAS OF SPECIAL CONCERN

During the planning process, the Ipswich and Regional Resiliency Task Forces identified Areas of Special Concern due to their current and future vulnerability and the consequences if the area or asset is impacted by flooding or erosion. A discussion of the vulnerabilities of several of these assets follows (for a complete list see Appendix C).

Downtown Ipswich has been identified as an area of critical concern. Flooding of the downtown area often occurs along the Ipswich River, particularly in parking lots behind Market Street and on the east side of South Main Street. This section of the downtown is located along a narrow section of the Ipswich River, which acts as a choke point during heightened river flows caused by large storms. Flooding here is a major threat to public infrastructure as well as several private homes and businesses, including EBSCO–the largest private-sector employer in Town.[282] As illustrated by the Mother's Day Flood of 2006, flooding along this stretch of the Ipswich River can cause extensive damage to homes and businesses located in the downtown.[283] Flooding in this area also poses a significant threat to many historic resources that serve the local community, especially the Choate Bridge which is vulnerable to both flooding and erosion (see page 95).



David Stone

282 Town of Ipswich, *Ipswich Community Development Plan*, 98
283 MAPC, *Town of Ipswich Hazard Mitigation Plan*, 11

According to the USGS analysis using inundation modeling by Woods Hole Group, a significant portion of downtown Ipswich may flood with between 1-20 feet of water during a present-day 1% or 0.2% storm (roughly equivalent to a FEMA 100 year and 500 year storm). By 2070, much of downtown would likely flood during a 1% or 0.2% storm; flood depths would range from 5-20 feet of water (Figure 3.6-3).[284]

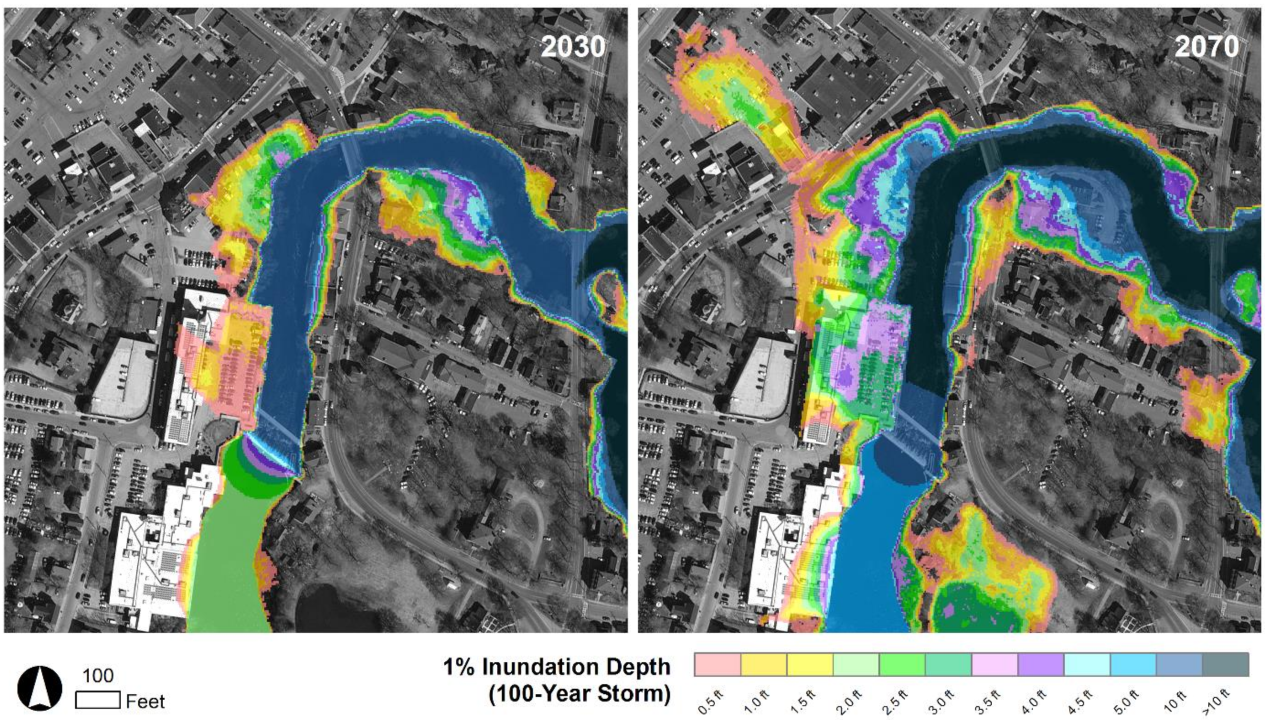
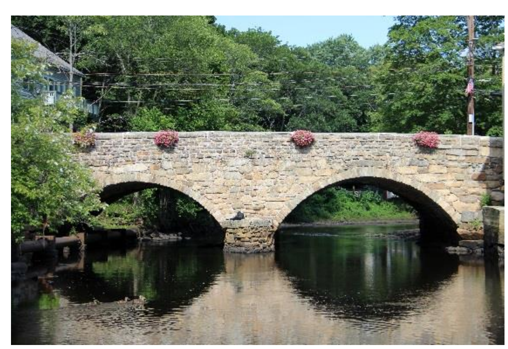


Figure 3.6-3. Downtown Ipswich, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

Near the downtown is the **Choate Bridge** which carries Route 1A/South Main Street over the Ipswich River. It is the oldest stone arch bridge in the United States, and is one of several sites in Ipswich with important historic and architectural value. The Choate Bridge carries traffic traveling to and from downtown along Route 1A, and receives an average of 17,000 cars daily. The bridge is subject to 1% annual chance of flooding according to FEMA flood zones and is highly vulnerable to increased storm activity and riverine flooding.[285] The narrowing of the river's channel at this site exacerbates flooding around the bridge. The volume and velocity of the river during large storm events can cause significant erosion of the surrounding river bank that supports the bridge foundation. Closure of Route 1A at the Choate Bridge is a major transportation nuisance, however it does not pose an evacuation or emergency response hazard: two additional river crossings are located to the north on County Street and Green Street. According to the



cmh2315fl/Flickr

[284] Abdollahian, N. et al., *Community Exposure*, 54
[285] MAPC, *Town of Ipswich Hazard Mitigation Plan*, 23

USGS analysis and Woods Hole Group coastal inundation modeling, only a small portion of the bridge and surrounding area would likely flood during a present-day 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500 year storm). However the area that does flood would likely be inundated with between 5-20 feet of water.[286]

The Sewage Pumping Station and the exposed sewer main were identified by the Ipswich Community Resiliency Task Force as areas of major concern. The pumping station is located in the parking lot of the Town Wharf, and the sewer main runs from downtown along the Riverwalk trail and the bank of the Ipswich River, behind Town Hall, and down Water Street to the pumping station. The pump station handles 100% of the wastewater in the community and is subject to 1% annual chance of flooding according to FEMA flood zones. It is also likely to be completely inundated by a modest sea level rise of 1 foot.[287] According to the USGS analysis using inundation modeling by Woods Hole Group, the sewage pumping station is likely to suffer significant flooding during storms – both present day and in 2070. A present day, 1% or 0.2% storm (roughly equivalent to FEMA's 100 or 500-year storm) would likely flood 63-74% of the road with between 1-20 feet of water. By 2070, a 1% or 0.2% storm, would likely flood as much as 91% of the road with between 5-20 feet of water (Figure 3.6-4).[288]

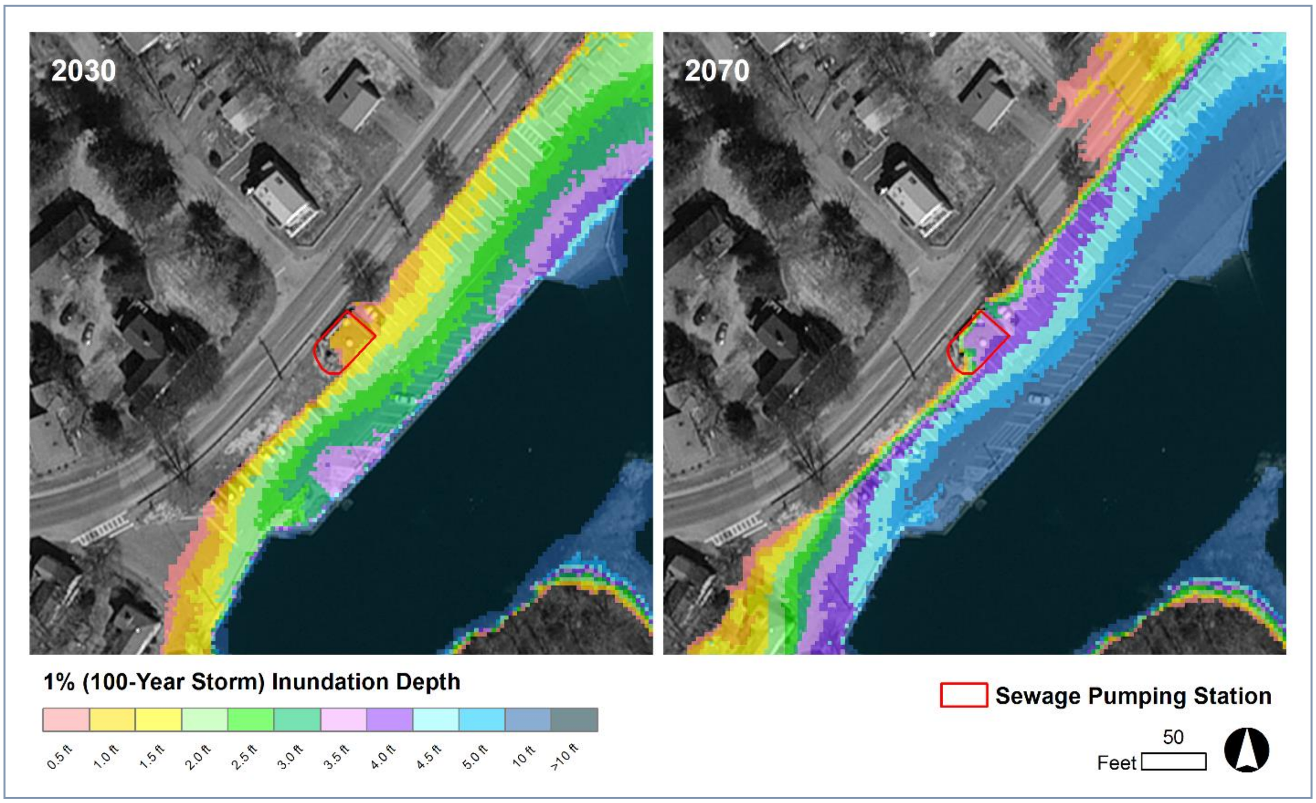


Figure 3.6-4. Sewage Pumping Station, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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[286] Abdollahian, N. et al., *Community Exposure*, 54

[287] "MORIS: CZM's Online Mapping Tool," Massachusetts Office of Coastal Zone Management, accessed August 2015, http://maps.massgis.state.ma.us/map_ol/moris.php

[288] Abdollahian, N. et al., *Community Exposure*, 54

Flooding of this site could cause extensive damage to the electrical equipment inside the pumping station. It would be a major health risk if the sewer main and station were to be inundated. Overflow of untreated sewage into the Ipswich River and its associated salt marsh would present an environmental risk to humans and a diversity of natural resources. In addition, Task Force members raised concern about the location of the wastewater treatment plant outfall. Treated effluent is discharged to Greenwood Creek which is part of the Great Marsh ACEC. Increased precipitation and storms could overwhelm the system, potentially leading to contamination of the salt marsh as well as health and safety impacts to the Newmarch Street neighborhood.

Jeffrey's Neck Road is extremely susceptible to flooding from coastal storm surge events and white-out closures during blizzards. Closure of this road presents a major public safety concern because it isolates over 1,200 (winter) residents living on Great Neck and Little Neck. A modest increase in sea level rise of 2 feet will make these residents and nearby developments even more vulnerable to both surface water inundation and saltwater intrusion, which can contaminate private wells and underground freshwater supplies.[289] The Town of Ipswich is already addressing some of these concerns. Based on information provided by the Ipswich Department of Public Works (DPW), Jeffrey's Neck Road from Newmarch Street to Island Park Road was dug up and repaved during the fall of 2015. The town also received limited FEMA funding to support the design phase of raising the portion of Jeffrey's Neck Road from Island Park to Eagle Hill. The DPW staff predicts this work will reduce road flooding to one or two times a year, and even during flood events the road would likely remain passable to emergency vehicles with higher clearance. Additional guard rails or other edge markers will be included in design for safety improvements. A roadside flood gauge may also be installed as well.

Abby Manzi/DeRosa Environmental Consulting, Inc.

According to the USGS analysis, large portions of the road would likely flood with between 1-20 feet of water during a present-day 1% or 0.2% storm (roughly equivalent to a FEMA 100-year and 500-year storm). By 2070, a 1% or 0.2% storm would likely flood the entire road with between 5-20 feet of water.[290]

Crane Beach is a 5-mile barrier beach that stretches from the Ipswich River southeast to Essex Bay. Ipswich's significant tourism-based economy relies heavily on this beach. However several times a year, flood waters, coming around the back side of the beach through the marshes, can close Argilla Road and even flood the beach parking lot. A recent culvert upgrade was designed to alleviate some of this flooding. The beach itself provides significant flood protection to 1,500 acres of salt marsh and nearly 2,000 acres of dunes and beaches.[291] Crane Beach is also an important storm buffer to several year-round and seasonal homes located on Argilla Road. Crane Beach, along with these homes and much of the habitat it protects, are all located within FEMA's 1% flood zone.[292]

[289] Town of Ipswich, *Open Space and Recreation Plan*, 13
[290] Abdollahian, N. et al., *Community Exposure*, 54
[291] Ibid
[292] "MORIS: CZM's Online Mapping Tool"

According to the USGS analysis, a present day 1% storm is likely to flood 74% of the beach's area with between 1-20 feet of water. These percentages rise to 86% and 88% for the two storm probabilities by 2070. Flood-water depths over the majority of the asset are estimated to be on the order of 5 to 20 feet for all time periods and storm probabilities (Figure 3.6-5).[293]

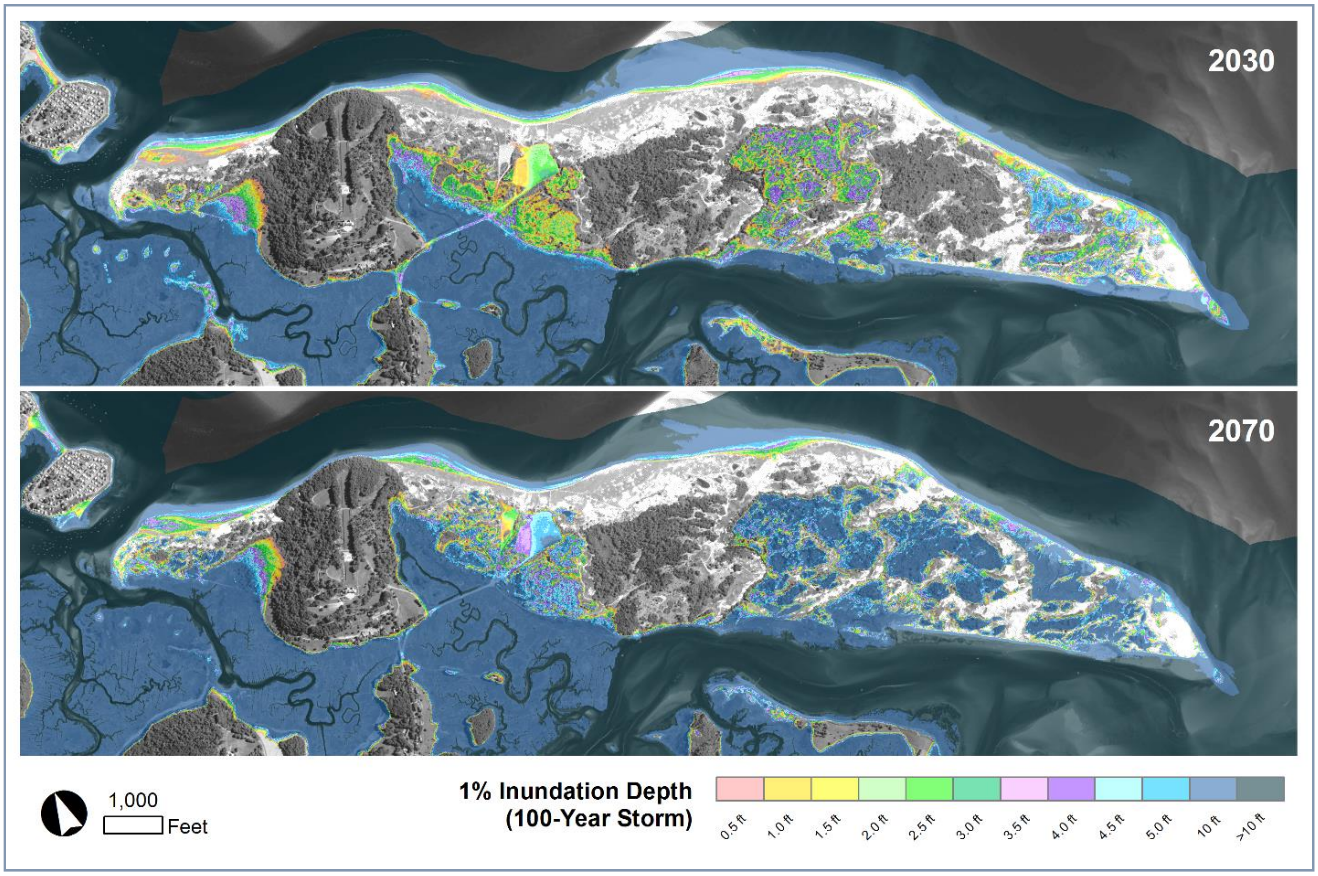

Figure 3.6-5. Crane Beach, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

Sea level rise, storm surge, and erosion are the biggest threats to Crane Beach.[294] As mentioned previously, Crane Beach is already experiencing significant rates of erosion.[295] Climate-driven threats will likely accelerate the transport of sand and sediment throughout the barrier beach ecosystem, leading Crane Beach to gradually shift in shape and size. Any change in size or shape could impact the areas it currently protects from storm surge, leaving them more exposed. Without the current landmass to buffer the worst climate-driven threats, significant damage may occur to nearby roads and seaside neighborhoods, particularly along Argilla Road. Furthermore, flooding of onsite sewage disposal systems and agriculture land along Argilla Road will also pose a significant threat to aquatic resources of the Ipswich and Essex River estuaries.[296]

[293] Abdollahian, N. et al., *Community Exposure*, 54
[294] Town of Ipswich, *Open Space and Recreation Plan*, 13
[295] MA EEA, *Shoreline Characterization and Change Analyses*
[296] Town of Ipswich, *Open Space and Recreation Plan*, 43

Pavilion Beach, located between Great and Little Neck, is the only public beach in Ipswich and as such is highly valued by the community. The mixed cobble and sand beach experiences frequent erosion as well as coastal flooding from storms. When tidal surges overtop the beach, the flooding can isolate Little Neck from the mainland. The community on Little Neck has historically consisted primarily of summer homes, but recently many of the houses have converted to year-round residences. At a three-meter storm surge, Pavilion Playground and Park, located on the north and west side of the access road to the beach (Little Neck Road) becomes beachfront: the public beach will be underwater, homes on Little Neck will have their access to the mainland cut off, and large portions of Little Neck Road will be flooded. Due to the location of Pavilion Beach, just off the southern tip of Plum Island (Sandy Point), it is likely that sand movement from Sandy Point affects sediment on Pavilion Beach – a topic that needs more study. As mentioned earlier, armoring of the coastline of both Great Neck and Little Neck seems to have impacted Clark Beach and Pavilion Beach by disrupting the natural flow of sediment and by deflecting wave energy towards the beach, exacerbating existing erosion.

David Stone

The Massachusetts Bay Transportation Authority (MBTA) Newburyport Train Line was not initially identified by the Ipswich Resiliency Task Force as an asset of concern, however it is deserving of mention due to its regional significance and likelihood of inundation. The MBTA train line serves the commuting needs of hundreds of local residents in the area. In 2013, there was a daily average of 812 inbound passengers using the line boarding from Newburyport to Boston.[297] The reactivation of the rail line to Newburyport was completed in 1998, driving much of the region's residential and economic growth as a suburb of Boston. The rail line traverses the salt marsh, two rivers, several streams and dozens of tidal creeks in the area. As such, the line is vulnerable to storm surge and sea level rise. In addition, there are several bridges and culverts along the line that act as minor to major tidal barriers, and the line itself functions as a major barrier to natural coastal flowage patterns. The infrastructure associated with this line is owned and maintained by the MBTA – with management decisions being made by MBTA not the municipalities. The MBTA is in the process of developing a comprehensive analysis of all of its assets, including risks based on increased climate effects, and will be an important partner for Ipswich in future adaptation planning and implementation efforts. As such, the vulnerability of this asset was not studied in depth as part of this study.

Brown's well, one of Ipswich's primary supplies for public drinking water, is located just north of Route 1A in the Muddy Run watershed. Due to its proximity to the extensive salt marsh around Town Farm Road to the east, this well is subject to salt water infiltration. Currently, the rail line mentioned above gives some protection to the area, as a protective buffer from storms. However, the vulnerability of this water

[297] MBTA, "Chapter 4: Commuter Rail," in *Ridership and Service Statistics: Fourteenth Edition* (Boston, MA, 2014), 7-8

source will increase significantly as sea level rises and brings additional flooding to the well, as well as to nearby businesses, roads, and residences (Figure 3.6-6).

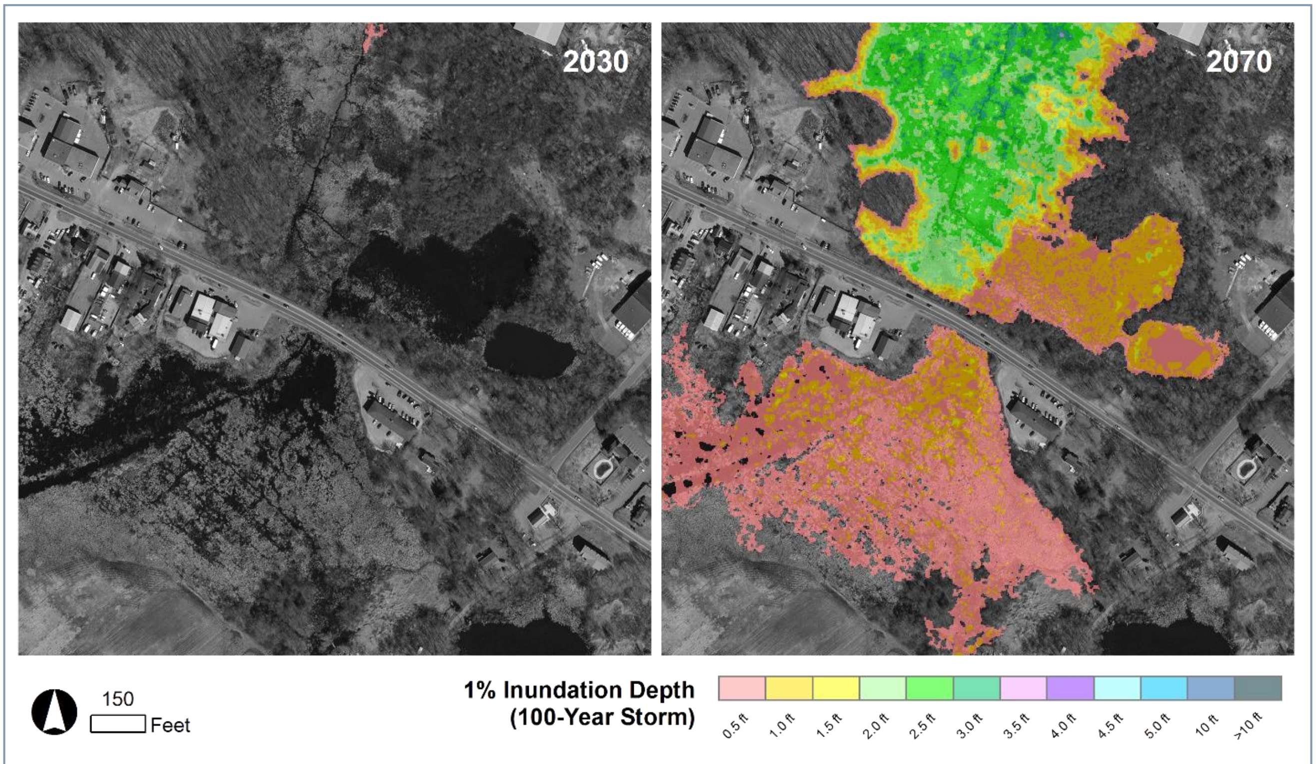

Figure 3.6-6. Brown's Well, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

DEMOGRAPHICS[298]

According to the USGS geospatial hazard analysis, only 2% (237) of residents in Ipswich live in coastal-hazard zones. By 2070, this number will increase to 492 residents, representing 4% of the total population (Figure 3.6-7). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on static 2010 population counts. All demographic percentages describing residents in hazard zones were relatively stable (+/- 1%) across the three time periods. Demographic results relative to 2070 hazard zones suggest that none of the residents in the coastal-hazard zones reside in mobile homes. Less than 5% of the

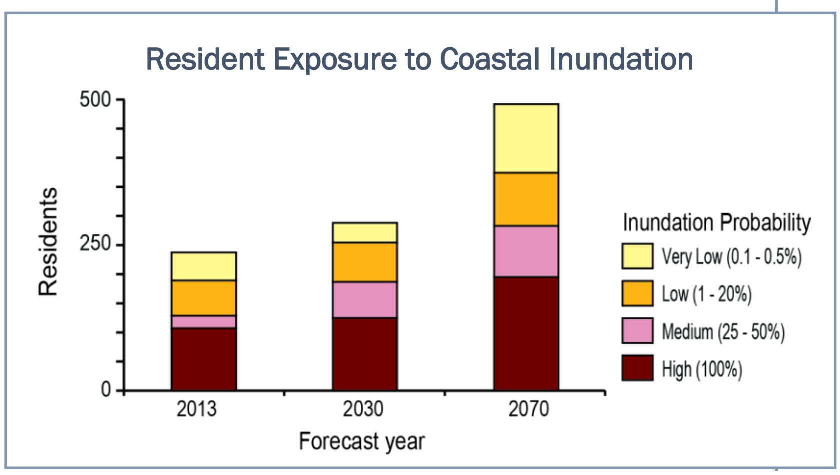

Figure 3.6-7. Resident exposure in the Town of Ipswich, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

[298] Abdollahian, N. et al., *Community Exposure*, 51-52

residents in the hazard zones are living in institutionalized group quarters, speak English as a second language, are unemployed, lack a phone, are under 5 years in age, or lack vehicles. Greater than 5% for residents in the hazard zones include individuals that are living under the poverty line (7%), have disabilities (10%), are in renter-occupied households (12%), are over 65 years in age (17%), and only have a high school degree (22%).

ECONOMIC & SOCIO-ECONOMIC[299]

The number of Ipswich employees working in coastal-hazard zones ranges from 100 currently to 457 in 2070, representing 2% to 9%, respectively, of the 5,086 employees that presently work in the community (Figure 3.6-8). As was the case with the resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zone and not projected changes in employee distributions. In present day, most employees in these hazard zones are in areas classified as having a high (100%) inundation probability (45 employees). By 2070, 224 employees are at businesses in the low probability zone, with additional employees in zones classified as high (100), medium (16), and very low (117) inundation probability.

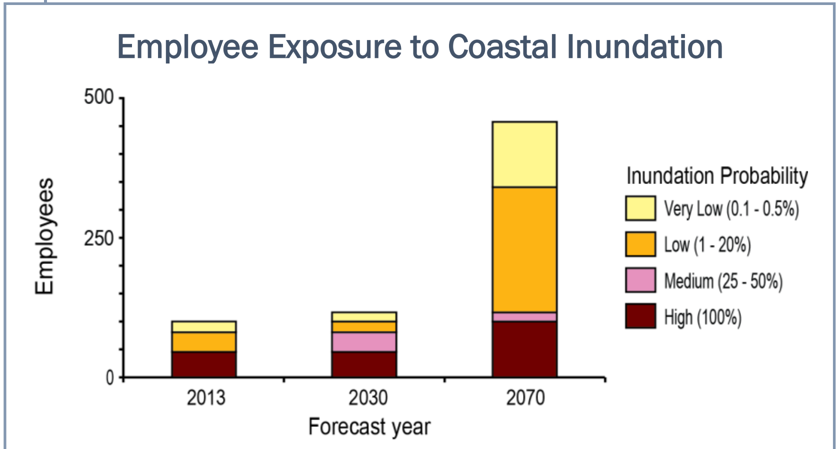

Figure 3.6-8. Employee exposure in Ipswich, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

Sales volume exposure for private-sector businesses ranges from $19.5 million currently to $48.1 million in 2070 (Figure 3.6-9a). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have a significant customer presence (e.g. retail) in coastal-hazard zones ranges from 20 businesses in 2013 to 56 businesses in 2070. Of the small business (20 employees or less), 26 are located in present day hazard zones and that number will more than triple to 85 in 2070. This is important because small businesses are typically more sensitive to disruptions and may be unable to cope with flooding as easily as larger businesses.

Similar to sales volume, parcel values and building replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $83.9 million present day to approximately $155.3 million in 2070, representing 3% to 6% of the community's tax base (Figure 3.6-9b). The majority of tax-parcel value in hazard zones is associated with land value with the remainder associated with building/content value. Based on building stock data in the FEMA Hazus-MH database, estimated building replacement values range from $79 million for the current hazard zone to $154.4 million for 2070 hazard zone (Figure 3.6-9c). For all three time periods, the majority of potential building replacement values are in areas classified as having a high probability of inundation.

[299] Ibid 52-53

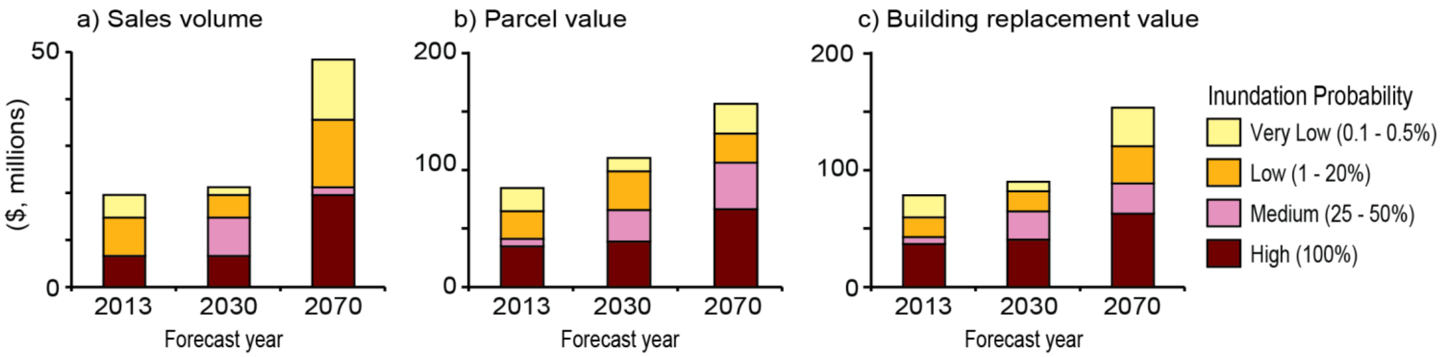

Figure 3.6-9. Cumulative value of (A) business sales volume, (B) total parcels, and (C) building replacement costs in coastal-hazard zones for Ipswich, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

Separate from the USGS analysis, FEMA and the Department of Homeland Security conducted a static analysis on Ipswich's current economic vulnerability to flooding. Their study analyzed the potential economic impact of various storm scenarios using FEMA's Flood Risk Database combined with FEMA's flood loss estimation tool, HAZUS. Potential building losses and associated business disruption costs for each storm category are shown below (Table 3.6-1).[300] Based on their analysis, the economic impact of even a relatively small 10% (10-year storm) may be quite significant: a mere 10% (10-year) storm has the potential to cause as much as $21.1 million dollars in damage. A larger 1% (100-year) storm may cause as much as $67.9 million in damage and a 0.2% (500-year) storm as much as $93.6 million. The majority of damage comes from infrastructure losses, although business disruptions are also quite significant. It is important to note that as 100-year storms become more frequent, these damage estimates are likely to increase.

Table 3.6-1. Ipswich's Estimated Potential Losses for Flood Event Scenarios. (*) Losses shown are rounded to nearest $10,000 for values under $100,000 and to the nearest $100,000 for values over $100,000; (**) Total Building/Contents Loss = Residential Building/Contents Loss + Commercial Building/Contents Loss + Other Building/Contents Loss; (***) Business Disruption = Inventory Loss + Relocation Cost + Income Loss + Rental Income Loss + Wage Loss + Direct Output Loss; (****) Total Loss = Total Building/Contents + Business Disruption.

	10% (10-yr)	2% (50-yr)	1% (100-yr)	0.2% (500-yr)	Annualized ($/yr)
	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*
Total Buildings/ Contents**	$20,400,000	$43,900,000	$65,900,000	$90,800,000	$3,500,000
Business Disruption***	$800,000	$1,500,000	$1,800,000	$2,800,000	$80,000
Total****	$21,100,000	$45,400,000	$67,900,000	$93,600,000	$3,500,000

300 FEMA, *DRAFT Flood Risk Report*, 57

HABITATS & SPECIES

John Phelan/Flickr

The Great Marsh is one of the most important coastal ecosystems in northeastern North America.[301] In Ipswich, this ecosystem contains high and low marsh, estuarine aquatic environments, and a barrier beach accompanied by extensive dunes. Each of these habitats provide critical foraging and breeding grounds for a plethora of native species. The Great Marsh also provides an abundance of ecosystem services to the Town of Ipswich. The marsh absorbs wave energy and traps sediment, helping reduce erosion; the aquatic environment is a nursery for commercially important fish species; and the dunes provide protection against storm surge. In addition, the salt marsh traps and safely stores harmful carbon gases that are the leading cause of climate change. In fact, recent analysis indicates that marshes are one of the most powerful carbon sinks, with the potential of sequestering almost 50 times more carbon than tropical rainforests.[302]

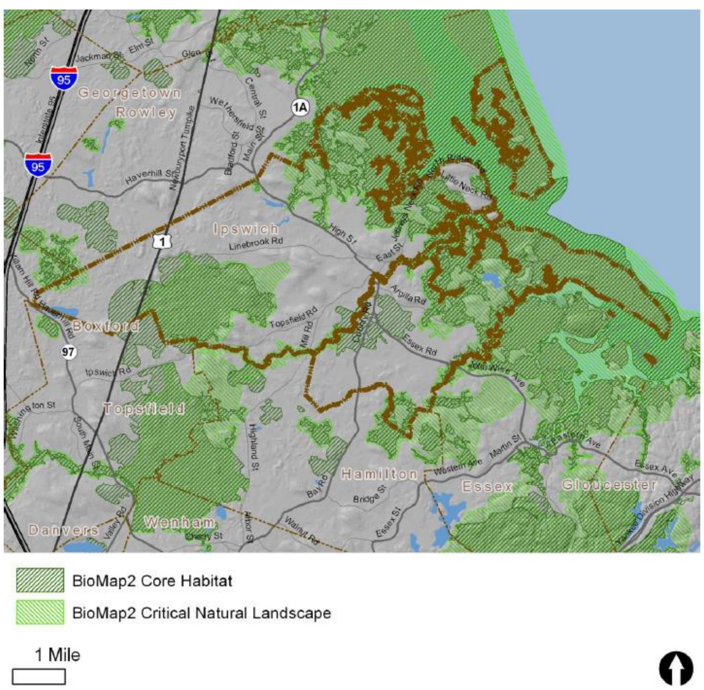

Figure 3.6-10. *BioMap2* Core Habitats & critical natural landscapes in Ipswich.

A significant portion of Ipswich has received official designation recognizing the importance of its natural systems. As identified by the state of Massachusetts Department of Fish & Game's BioMap2 report, approximately 9,035 acres in Ipswich are designated as *core habitat* and 10,615 are listed as *critical natural landscapes* (Figure 3.6-10).[303] The term "core habitat" refers to areas deemed necessary to support the long-term existence of rare or threatened species, exemplary natural communities, and intact ecosystems. "Critical natural landscapes" are intact ecosystems that are well suited to support ecological processes and/or a wide array of species and habitats over long period of time.[304]

Marshes, barrier beaches, and dunes make up the majority of the critically important habitat in Ipswich. These habitats contain multiple vegetative zones that support a wide diversity of species, including several threatened and endangered species (Table 3.6-2).[305]

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[301] "The Great Marsh," Western Hemisphere Shorebird Reserve Network, accessed October 2015. http://www.whsrn.org/site-profile/great-marsh

[302] Bu, N. et al., "Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool," *Ecological Engineering*, 81 (2015): 335

[303] MA DFG & TNC, *BioMap2: Ipswich*

[304] Ibid

[305] Ibid

Crane Beach and the southern end of Plum Island are relatively undeveloped barrier beaches that absorb much of the ocean's brunt force before waves and storm surge penetrate into the Plum Island Sound and up the Ipswich River. Like all barrier beaches, natural processes cause these beaches to shift over time. A barrier beach's dynamic character and ability to move and reshape in response to constant wave energy as well as acute storm events, is precisely what makes it resilient to sea level rise and storm surge.[306] Crane Beach and Plum Island, as defined today in terms of shape, size, and location, are vulnerable and are unlikely to remain in their current form. However the barrier beaches as a whole are quite resilient and will likely adapt to sea level rise and storm surge by migrating inland and/or shifting shape.

Table 3.6-2. List of species occurring in Ipswich that are of special conservation concern (SC), including threatened (T) and endangered (E) species.

Species of Conservation Concern	Habitat Type
Birds	
American Bittern[E]	Marsh and freshwater wetlands
Least Bittern[E]	Forest, marsh, coastal woodland, freshwater wetland
Pie-billed Grebe[E]	Marsh and freshwater wetlands, lakes, ponds
Piping Plover[T]	Beach, dunes, mudflats
King Rail[T]	Marsh and freshwater wetlands
Common Tern[SC]	Marsh, beach, dunes
Common Moorhen[SC]	Marsh and freshwater wetlands
Least Tern[SC]	Beach, dunes
Amphibians	
Eastern Spadefoot[T]	Forest, marsh, coastal woodland, freshwater wetland
Blue-spotted Salamander[SC]	Marshes, floodplain swamps, floodplain forest
Plants	
Seabeach Needlegrass	Coastal dunes

Ipswich is also home to federally threatened Piping Plovers that nest on its barrier beaches. The plover nests are particularly vulnerable to minor overwash events which are occurring with increased frequency in this region, likely due to climate change. As erosion increases and sea levels rise, beaches will need to be allowed to migrate inland if Piping Plovers are to continue breeding in Ipswich.

Marsh habitat is also vulnerable to erosion and sea level rise. These marshes provide water filtration services, storm surge reduction, erosion control, and are home to numerous rare and threatened species. However, because this habitat is so low-lying and tidally influenced, the vast majority of critical marsh in Ipswich may become inundated under just one foot of sea level rise,[307] and researchers have already taken notice to areas within the Great Marsh that are being degraded by standing water as a result of excessive flooding and poor drainage. Furthermore, due to coastal development at the marsh's edge, coastal ecosystems may not be able to migrate inland as sea levels rise, leading these important habitats to disappear under water.

Important commercial and recreation fish populations are also present in the ocean, estuaries, ponds, and streams of Ipswich. Striped bass, cod, mackerel, bluefish, and flounder are a popular catch for marine anglers fishing off the coast of Ipswich. At Hood Pond and other small ponds through Ipswich you can find bass, perch, pickerel, and sunfish. Trout fisheries are state-maintained in the Ipswich River and the Ipswich

[306] Massachusetts Barrier Beach Task Force, *Guidelines for Barrier Beach Management in Massachusetts* (Boston, MA: Massachusetts Office of Coastal Zone Management, 1994) http://www.mass.gov/eea/docs/czm/stormsmart/beaches/barrier-beach-guidelines.pdf
[307] "MORIS: CZM's Online Mapping Tool"

River estuary which serve as a spawning area for anadromous rainbow smelt.[308] Although not currently listed as threatened or endangered, fish populations in Ipswich may become threatened due to climate driven impacts. Changes in precipitation and sea level rise will likely alter the balance between freshwater and saltwater in the Ipswich River and its tributaries. As a result, this habitat would become less suitable for anadromous populations in the future. Furthermore, development combined with an increase in severe storm activity will likely lead to an increase in surface runoff quantities and rates. Storm runoff carrying bacteria, pathogens, and nutrients can be extremely damaging to the diversity of habitats and species found within the Ipswich River Watershed. Currently shellfish harvesters lose millions of dollars annually due to stormwater contamination.[309] Nitrogen has also recently been identified as a leading cause of marsh bank disintegration.[310]


Judy Schneider/Ipswich River Watershed Association

Shellfish are a particularly important natural resource in Ipswich where widespread commercial harvesting occurs. Maintaining healthy, stable shellfish populations is a high priority. However the habitat used by shellfish is quite vulnerable to sea level rise and increased erosion. Intertidal mud flats, sandy estuarine environments, and sea grass beds are all likely to suffer under the added strain of climate-driven threats. Sea level rise may permanently inundate clam flats, converting once productive harvesting areas into unsuitable habitat devoid of shellfish. Erosion also threatens to further shrink these estuarine environments so important to shellfish.

The town's two freshwater coastal ponds, Clark and Rantoul, are also at risk of inundation from sea level rise and storm surge. These man-made, former salt impoundments provide some of the most important freshwater waterfowl and shorebird habitats along coastal Massachusetts.[311] Both are already impacted by storm surge and saltwater intrusion and are at risk of future climate-driven impacts. Although these are "unnatural" impoundments, they provide significant resource values and any potential habitat changes should be assessed and managed to maintain their resource and property protection value.

Summary

Overall the Town of Ipswich has a high level of vulnerability to climate-driven threats. Predicted sea level rise, increased storm surge, and erosion have the potential to drastically impact the town's coastal economy, the significant infrastructure located in low-lying areas along the coast, and the natural systems that the community depends upon. Because of the town's reliance on coastal tourism and coastal industries, impacts to infrastructure or natural systems may have cascading effects that ripple across all

[308] Town of Ipswich, *Open Space and Recreation Plan*, 43
[309] Ipswich Coastal Pollution Control Committee, *Coastal Stormwater Remediation Plan for the Town of Ipswich*, (Ipswich, MA: Town of Ipswich Massachusetts Planning Department, 2000), 1
[310] Deegan, L.A. et al., "Coastal eutrophication as a driver of salt marsh loss," *Nature,* 490 (18 October 2012), 388
[311] Wayne Castonguay (Executive Director of the Ipswich River Watershed Association), personal communication with authors, September 15, 2015

parts of the community. The geospatial analysis conducted by USGS confirms these findings and indicates economic, infrastructure, and population vulnerabilities that will likely need to be addressed to protect human life as well as the economic well-being of Ipswich.

The natural coastal systems in Ipswich are already being impacted by erosion that is likely to accelerate with climate change. Sea level rise will likely inundate the vast expanses of marsh that currently help reduce storm surge and reduce erosion as well as provide important habitat to rare and threatened species. Storm surge resulting from bigger and more frequent storms will likely overtop existing dunes and coastal structures, impacting larger portions of intertidal land and populated areas along Argilla Road and east of Jeffrey's Neck Road. An increase in heavy precipitation events combined with penetrating storm surge will likely cause substantial damage to low-lying interior portions of Ipswich. Storm surge will be further compounded by rising seas, causing a two-foot storm surge in 2050 to reach further inland than today.

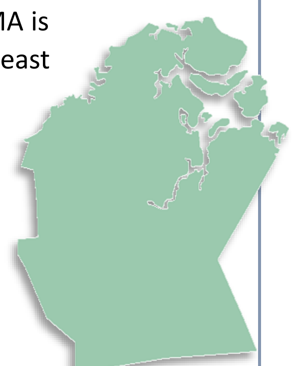
For recommendations on how to address the Town of Ipswich's overall vulnerability to climate-driven hazards, including site-specific adaptation strategies for the areas of concern outlined above, see Chapter 4: Adaptation Strategies for the Great Marsh Region.

Philip Jessup

Abby Manzi/DeRosa Environmental Consulting, Inc.

3.7. Town of Essex Vulnerability Assessment

Community Exposure to Climate Hazards



Long noted as one of the original maritime centers of New England, the Town of Essex, MA is located just 30 miles northeast of Boston. Situated north of Manchester-by-the-Sea and east of Hamilton and Ipswich, Essex is the northwestern most town of Cape Ann. The town encompasses approximately 16 square miles, of which approximately 48% is forested.[312] The Great Marsh, the largest contiguous salt marsh in New England, makes up 22% of the landmass in Essex, while residential and commercial, and industrial development combined make up about 13%.[313]

Essex is located within the Essex Bay and Ipswich Bay systems of the North Coastal Watershed. The majority of the town's surface water drains into the Essex Bay through the Essex River. Also feeding into the Essex River is Chebacco Lake, a 209-acre Great Pond located within the borders of Essex and Hamilton. The southwestern portion of Essex drains into Cat Brook which flows southwest into the Manchester Harbor. Like many North Shore communities, much of Essex

312 MAPC, *Town of Essex Hazard Mitigation Plan* (Boston, MA, 2012), 3
313 Ibid 4

is low-lying, exposing it to sea level rise and flooding hazards. Penetrating storm surge and increased precipitation could exacerbate existing choke points along rivers, leading to coastal and riverine flooding.

According to the 2010 Federal Census, there were approximately 3,504 residents living in Essex. Compared to neighboring towns, like Ipswich and Gloucester, Essex has experienced a relatively low rate of development. The majority of the town's infrastructure is located along the Route 133/Main Street Causeway. The causeway stretches for 0.8 miles and spans both salt marsh and the Essex River. The causeway is a critical connective corridor between Cape Ann and other North Shore communities; it is the main bus route for students traveling between Essex and Manchester and also provides access to a number of restaurants, stores, churches, and marinas in the town center.[314]

The Route 133/Main Street Causeway has historically been subject to frequent flooding caused by extreme high tides and medium to severe storm events.[315] In 2012, construction was completed on the Route 133/Main Street Causeway that raised the road 8 inches – the maximum height allowed without creating an undue burden on businesses with adjoining driveways and parking lots. Tide flaps were also installed to further reduce flooding. These efforts have reduced the frequency of flooding, however the causeway is still subject to flooding multiple times a year.

Robert Barossi/MyCoast

Crane Beach, the sixth largest barrier beach in Massachusetts, protects much of Essex Bay from the harsh and direct energy of the Atlantic Ocean. This barrier beach, located in the neighboring Town of Ipswich, offers important storm protection to both the Bay and community of Essex.[316] In fact, only 3 miles of Essex shoreline is exposed to the open ocean.[317] Nevertheless, marsh erosion is reportedly increasing in Essex Bay due in part to sea level rise as well as heightened wave energy caused by erosion at the southern tip of Crane Beach.[318, 319]

A detailed analysis of coastal inundation, conducted by the Woods Hole Group and USGS, confirms that the Town of Essex has high exposure to sea level rise and storm surge. Present day estimates (which are for the year 2013) indicate approximately 27%

314 MAPC, *Essex Community Development Plan* (Boston, MA, 2004), 2
315 Essex Community Resiliency Task Force, personal communication with authors, July 15, 2015
316 Rickards, B. et al., *An Assessment of Resource Management Strategies in the Parker River/Essex Bay Area of Critical Environmental Concern* (Boston, MA: MA CZM, 2002), 9
317 MA DCR, *Massachusetts Coastal Infrastructure Inventory and Assessment Project* (Cambridge, MA, 2009)
318 *"Marsh Edge Erosion*," Boston University, accessed August 2015, http://sites.bu.edu/novak/research/marsh-edge-erosion/
319 Essex Community Resiliency Task Force, personal communication with authors, July 15, 2015

of the town is vulnerable to coastal inundation – depending on the severity of the storm. That number climbs marginally to 30% in 2070 (Figure 3.7-1).[320] Of the area subject to coastal inundation, a significant portion is developed land that is subject to nearly annual or semi-annual flooding – now and in 2070 (Figure 3.7-2).[321]

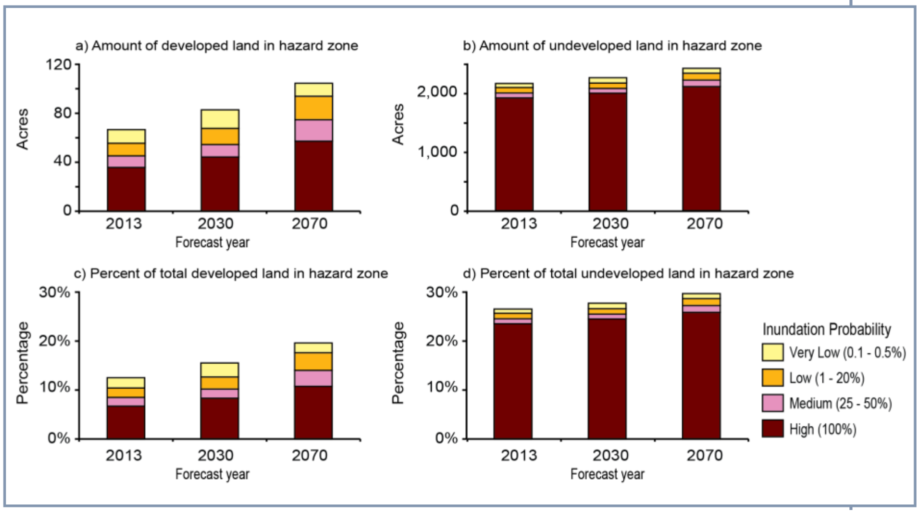


Figure 3.7-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Salisbury, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

In summary, Essex has high exposure to flooding due to its topography, hydrology, and geographic location. The community's high exposure is best evidenced by the significant flooding and erosion that have occurred from recent storms such as Super Storm Sandy in 2011, the Patriots Day storm of 2007, the Mother's Day Storm of 2006, and numerous other Northeasters – particularly those that have occurred during high tides. Its substantial acreage of salt marsh currently acts as a sponge during storms and provides a vital buffer from coastal flooding.[322] However as the health of the salt marsh continues to decline due to sea level rise and erosion, the community will become even more exposed to coastal flooding.

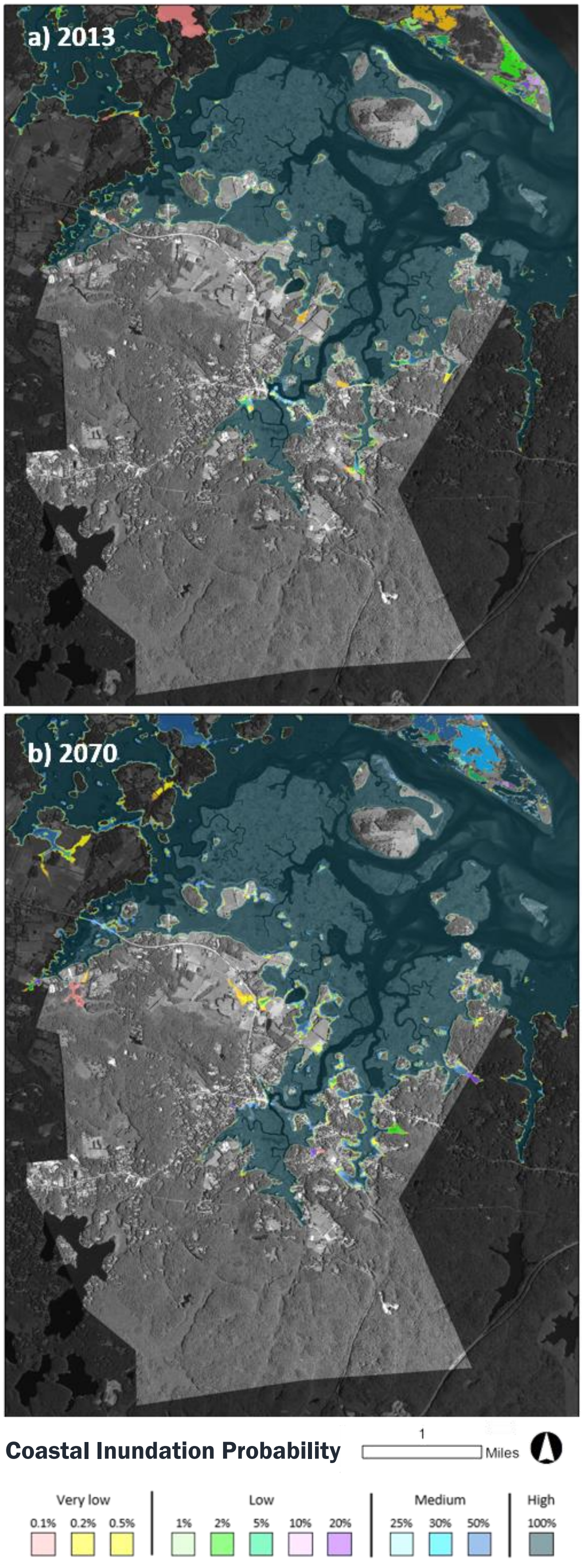


Figure 3.7-1. Essex, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

[320] Abdollahian, N. et al., *Community exposure to potential climate-driven changes to coastal-inundation hazards for six communities in Essex County, Massachusetts*, U.S. Geological Survey open-file report (Reston, VA: USGS, 2016), 57

[321] Ibid

[322] Town of Essex, *Open Space and Recreation Plan* (Essex, MA, 2016), 25

Community Sensitivity to Climate Hazards

The Town of Essex has a high level of sensitivity to climate-driven threats. Much of the infrastructure in Essex is located in low-lying areas that are susceptible to flooding from storm surge, sea level rise, and riverine flooding. Overall 43.5% of Essex falls within the FEMA 1% flood zone (often referred to as the "100-year" flood zone) including Essex Village - the economic hub of the community.[323] Although much of Essex is within flood hazard zones, based on a separate automated analysis by ClimateCentral.org (using lidar elevation data supplied by NOAA), only 146 people live in areas less than 6 feet above sea level, of which only 9 are isolated from flooding by levees or natural topographic ridges.[324] Further analysis indicates that only 7% of roads are located less than 6 feet above sea level (as defined by total road mileage).[325]

Abby Manzi/DeRosa Environmental Consulting, Inc.

In Essex, economic sensitivity to climate hazards is intrinsically linked to the sensitivity of the town's natural systems. Diverse recreational activities, rich dining experiences, and beautiful river vistas draw large numbers of tourists to the Essex Village, especially during the summer months. The Causeway, a 0.8 mile section of Route 133/Main Street, provides direct access to Essex Village and, as previously mentioned, is a major artery connecting Cape Ann with North Shore communities. Being a major transportation corridor, approximately 16,000 vehicles cross the causeway daily.[326] There are also approximately 15 antique dealers and 6 restaurants located in this area, drawing many visitors.[327] These restaurants and antique shops, in particular, are a major economic driver for the town; the food-service industry alone accounts for 40% of all jobs in Essex.[328] Because the majority of the town's infrastructure, major tourist attractions, and businesses are directly accessed via the causeway and Route 133/Main Street, the Essex economy is highly sensitive to climate-driven threats that impact this area. Closing of the Causeway due to tidal inundation and riverine flooding directly impedes the economic prosperity of businesses located in the Village, and consequently the community as a whole.

The diversity of natural resources in Essex contributes to the town's character and enhances the quality of life for residents and visitors alike. The confluence of river systems, watersheds, wetlands, and undisturbed forest provide critical habitat for wildlife, including some rare and endangered species. The Manchester-Essex Woods Wilderness Conservation Area is located on the border between Essex and Manchester. It is recognized as having some of the most outstanding habitat remaining in the region.[329]

[323] FEMA*, DRAFT Flood Risk Report: Essex County, MA* (Washington, DC, 2013), 46
[324] "Surging Seas: Risk Finder*,"* Climate Central, last modified April 2014, http://sealevel.climatecentral.org/ssrf/massachusetts
[325] Ibid
[326] Town of Essex Long Term Planning Committee, *Essex Village Initiative* (Essex, MA, 2009)
[327] MAPC, *Essex Community Development Plan*, 2
[328] Ibid 35
[329] Town of Essex, *Open Space and Recreation Plan*, 5

Having never been farmed or developed, the soils found in the Woods are undisturbed. As such, they provide pristine habitat for many rare and threatened species.[330] A warming climate may threaten this habitat as precipitation patterns change, extreme temperatures become more common, and invasive species expand their range. Because these lands are intact and protected, they may be less sensitive to these threats. However more in-depth study would be required to fully assess how this habitat is likely to be impacted. Due to its inland location the property is not particularly exposed to many of the coastal hazards discussed in this paper, although some portions of the area are subject to 1% annual chance of flooding according to FEMA flood zones.[331]

Elizabeth Thomsen/Flickr

The Essex River and its estuary make up 13% of the Parker River/Essex Bay's Area of Critical Environmental Concern (ACEC), as designated by the Massachusetts Executive Office of Environmental Affairs.[332,333] Within the ACEC, the 3,435 acres located in Essex are, acre for acre, the most biologically productive habitat in Massachusetts.[334] The Essex River system provides excellent habitat for anadromous fish and its headwater pond system including Chebacco Lake is the largest breeding population for Alewife on the North Shore.[335] Continued climate change may threaten this valuable fishery by restricting access and egress to/from the breeding grounds and increases in temperature, eutrophication, and invasive species.

In addition to the Essex River, the estuary encompasses a variety of creeks and coves, salt marsh, tidal mud flats, beaches, islands, and landings. Throughout the coastal waters of Essex, the estuary is peppered with clam flats. These clam flats are critically important to the vitality of both the ecological and economic systems in Essex. Clamming remains one of the town's principle industries.[336] Increasing inundation already impacts the clamming industry: during storms and extreme high tides, the tidal flaps at the Causeway are closed, preventing clammers from accessing these productive harvesting grounds.[337] As sea levels rise more rapidly, the duration and frequency of tidal inundation and tidal current velocities could change – producing habitat unsuitable for the recruitment and survival of clams in this area.

The Essex River and its estuary are also connected to the Great Marsh. The Great Marsh, which covers 22% of the town, is designated an Important Bird Area of global significance and a Western Hemisphere Shorebird Reserve Network site.[338] As such, it is a strong tourism draw that boosts the local economy. While exact estimates are unknown, large numbers of bird watchers from throughout the northeast, and

[330] Ibid 41
[331] "MORIS: CZM's Online Mapping Tool," CZM, last updated January 9, 2012, http://maps.massgis.state.ma.us/map_ol/moris.php
[332] Town of Essex, *Open Space and Recreation Plan*, 5
[333] Rickards, B. et al., *An Assessment of Resource Management Strategies in the Parker River/Essex Bay Area of Critical Environmental Concern,* 9
[334] Town of Essex, *Open Space and Recreation Plan*, 39
[335] MAPC, *Town of Essex Hazard Mitigation Plan*, 5
[336] MAPC, *Town of Essex Hazard Mitigation Plan*, 5
[337] Essex Community Resiliency Task Force, personal communication with authors, July 15, 2015
[338] MAPC, *Town of Essex Hazard Mitigation Plan*, 5

throughout the country, travel to the area to witness the spectacular influx of birds during spring and fall migrations.

NWF

Marshes are inherently sensitive to the impacts of climate change, and human activity can further increase their sensitivity. A healthy untouched marsh can attenuate storm surge by reducing wave height, and heavily vegetated dunes are often resilient in the face of large storms.[339,340] Human development can not only prohibit a marsh's landward movement but can also disrupt levels of sediment and salinity suitable for a self-sustaining marsh habitat. For example, improperly-sized hydro barriers can reduce the flow of sediment and negatively impact salinity levels. While human activity in Essex hasn't significantly increased the sensitivity of the marsh, Essex Bay does appear to have high sensitivity to storm surge and erosion. Based on the ongoing research at Boston University investigating marsh bank erosion, Essex Bay is showing increased rates of erosion.[341] At one of the sites being monitored, the marsh eroded a total of 4.57 meters (15 ft) between the summer of 2014 and May 2015 alone.[342]

Crane Beach currently provides some buffering protection to the Bay, but continued erosion of this barrier beach will likely increase the exposure and sensitivity of Essex's salt marsh to storm surge and erosion. Based on a recent analysis completed by the Coastal Erosion Commission and presented by CZM, Crane Beach had the second highest erosion rates along the North Shore, with an average beach loss of 1.4 meters (4.6 ft) a year (data collected between 1970 and 2009).[343] As this barrier beach naturally shifts over time and the river mouth widens, it is possible that Essex Bay will experience increased wave energy. Regardless of Crane Beach, rising seas and increased storm activity are likely to exacerbate erosion and its associated impacts for this community already sensitive to climate-driven threats.

Community Vulnerability

The most comprehensive community assessment of Essex's vulnerability to natural hazards is provided in the *Town of Essex Hazard Mitigation Plan* prepared by the Metropolitan Area Planning Council.[344] Information from this and other documents is synthesized below along with information from the Essex Resiliency Task Force, coastal inundation modeling conducted by the Woods Hole Group,[345] and results from the 2016 USGS geospatial analysis of potential impacts from coastal inundation.[346]

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339 Shepard, C.C., et al., "The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis," *PLoS ONE* 6, no. 11 (November 2011): e27374, doi:10.1371/journal.pone.0027374.

340 "In Defense of Dunes," ASBPA, January 13, 2015, http://www.asbpa.org/news/newsroom_14BN0113_in_defense_of_dunes.htm

341 "*Marsh Edge Erosion*"

342 Alyssa Novak, PhD (Boston University), personal communication with authors, May 21, 2015

343 MA EEA, *Shoreline Characterization and Change Analyses: North Shore Region* (Gloucester, MA, 2014) http://www.mass.gov/eea/docs/czm/erosion-commission/shoreline-profile-north-shore.pdf

344 MAPC, *Town of Essex Hazard Mitigation Plan*, 14

345 Famely, J. et al., *Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA)*, Prepared by Woods Hole Group for National Wildlife Federation and U.S. Geological Survey, (Falmouth, MA, 2016)

346 Abdollahian, N. et al., *Community Exposure*

Overall, the Town of Essex has a high level of vulnerability because it has both significant exposure and high sensitivity to climate hazards. According to the town's Hazard Mitigation Plan, flooding, caused by hurricanes, northeasters, intense rainstorms and thunderstorms, is the most prevalent serious natural hazard in the community. [347] Based on a review of the town's hazard mitigation plan,[348] National Flood Insurance Maps, and information provided by town staff, a total of twelve discreet locations were identified as being subject to chronic flooding (Table 3.7-1).

Table 3.7-1. Summary of discreet assets in Essex identified within the Flood Hazard Area. Order in which listed does not indicate priority or level of concern.

Locally Identified Areas of Flooding	Cause of Flooding
Main Street Causeway (Route 133)/Woodman's Landing	Tidal inundation, Storm-related flooding, storm surge
Island Road	Tidal inundation, Storm-related flooding, storm surge
Conomo Point Road/Robbins Island Road	Tidal inundation, Storm-related flooding, storm surge
J.T. Farnham's Restaurant Culvert/Eastern Avenue @ Ebben Creek	Tidal inundation, projected storm-related flooding, scouring/erosion
Apple Street Bridge	Storm-related flooding
Lake Chebacco	Storm-related flooding
Gregory Island Road	Storm-related flooding
Walnut Park	Storm-related flooding
Quinn Brothers	Storm-related flooding
Landing Road Culvert	Storm-related flooding
Apple Street Culvert near Andrews Street	Storm-related flooding
Route 22 Culvert near County Road	Storm-related flooding

CRITICAL INFRASTRUCTURE

The Essex Hazard Mitigation Plan identifies a total of 31 structures that have a 1% annual chance of flooding according to FEMA flood zones, of which seven are regarded as *critical infrastructure*: the Department of Public Works Barn, Essex Town Hall, 2 water pump stations, a water tank, the Tennessee gas line pump station, and a fire tower.[349] In addition to these assets, the Essex Resiliency Task Force also identified Richdale's Gas Station, located 0.4 miles southeast of the Causeway, as a major concern. Although the gas station does not meet the criteria of *critical infrastructure*, the site is deemed critical because it has increasingly high exposure and extremely high sensitivity to flooding; if the gas station is inundated there is the potential for an oil spill that could significantly impact the wider community.

The USGS geospatial hazard analysis of critical infrastructure indicates there is one executive office, a public finance office, and three legislative bodies in areas classified as low-probability inundation zones in 2013 that become medium-probability zones in 2030, and ultimately high-probability zones by 2070. Two public-utility stations (commercial property) are in the coastal-hazard zones, distributed evenly between low and very low probability zones in 2013. By 2070, there will be five utility stations primarily in low-probability zones. One underground storage tank is in the hazard zones, with the probability of inundation

[347] MAPC, *Town of Essex Hazard Mitigation Plan*, 13
[348] Ibid 15
[349] Ibid 22

increasing from very low in 2013 to medium in 2070. One tier-classified site is found in low probability hazard zone in 2013 and increases to high probability in 2070. There are no "declared activity and use limitation sites" exposed in 2013 with an increase to three sites in the 2070 low probability zone. An overall infrastructure analysis indicated that there are approximately 2.4 miles of roads in 2013 hazard zones (distributed evenly between medium to very low probability zones) that increases to 3.3 miles by 2070 (distributed evenly across all four probability zones).[350]

BARRIERS TO FLOW

The "Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed" provides additional insight into where the community may be vulnerable to flooding. As part of this screening level vulnerability assessment, this project inventoried and assessed the locations throughout Essex and other Great Marsh communities where human-made structures such as roads, bridges, dams, sea walls, and other structures intersect waterways and floodplains. These structures often present serious barriers to the natural movement of water and function of related physical and biological processes including sediment and nutrient transport. Undersized, improperly designed, or aging structures are vulnerable and can put related critical infrastructure, buildings, and transportation corridors at increased risk of flooding and failure, especially during extreme storms that bring heavy rains, winds, and storm surges. Many of the same barriers that present serious infrastructure risk have also been identified as causing significant ecological harm and reducing the resiliency of natural communities. Several past studies were reviewed for this project, and new surveys were conducted to assess the vulnerability of these structures in each community.

Four types of structures (non-tidal road-stream crossings, tidal road-stream crossings, dams, and public shoreline stabilization structures) that are potential barriers were assessed for their degree of vulnerability. The Town of Essex has 38 non-tidal road-stream crossings, 12 tidal road-stream crossings, no dams, and no public shoreline stabilization structures. Of these, 8 non-tidal road-stream crossings and 5 tidal road-stream crossings are highly vulnerable to the impacts of sea level rise, coastal storms, and/or inland flooding based on our screening criteria (see Appendix B for methodology, results, and a map).

AREAS OF SPECIAL CONCERN

During the planning process, the Essex and Regional Resiliency Task Forces identified Areas of Special Concern due to their current and future vulnerability and the consequences if the area or asset is impacted by flooding or erosion. A discussion of the vulnerabilities of several of these assets follows (See Appendix C for a complete list).

Of particular concern and interest are four discreet assets: 1) the Causeway and Woodman's Landing, 2) Conomo Point Road, 3) Route 133 at Ebben Creek, and 4) Crane Beach. These assets are currently vulnerable and will become even more vulnerable as sea levels rise and storm surge and riverine flooding increases. The combined hazards facing these assets pose a significant threat to the town's residents, its infrastructure, and its economy.

The Causeway and Woodman's Landing are both located in the 100-year flood zone and are subject to frequent flooding during heavy rain storms and tidal surges. According to members of the Essex Resiliency Task Force, flooding typically occurs first at the Fortune Palace Restaurant and then at Woodman's Landing – a tiny gravelly beach along the eastern portion of the Causeway. Woodman's Landing floods

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[350] Abdollahian, N. et al., *Community Exposure,* 64-65

approximately four to six times a year due to tidal inundation and has been identified by the Task Force as a likely breach point for floodwaters overtopping the causeway. Flooding often results in extensive property damage and roadway closures, causing major interruptions to businesses and transportation. Critical water and sewer lines also run along the causeway and are vulnerable if flooding causes structural damage to the causeway.

Flooding at the Causeway is also a serious public safety concern. It is the primary access route between eastern and western portions of Essex. Because the town's police and fire departments are both located in the western portion of Essex, flooding of the causeway and at Woodman's Landing can significantly impact emergency response times for incidents occurring in Eastern Essex.[351]

According to the USGS analysis using inundation projections by the Woods Hole Group, a present day 1% or 0.2% storm would likely flood 43% of Woodman's Landing and 54% of the Causeway with between 1-20 feet of water. By 2070, a 1% or 0.2% storm would likely flood 76% of Woodman's Landing and 79% of the Causeway with between 5-20 feet of water (Figure 3.7-3).[352] The significant depth and velocity of this water would significantly impact the road and surrounding businesses beyond just nuisance flooding.

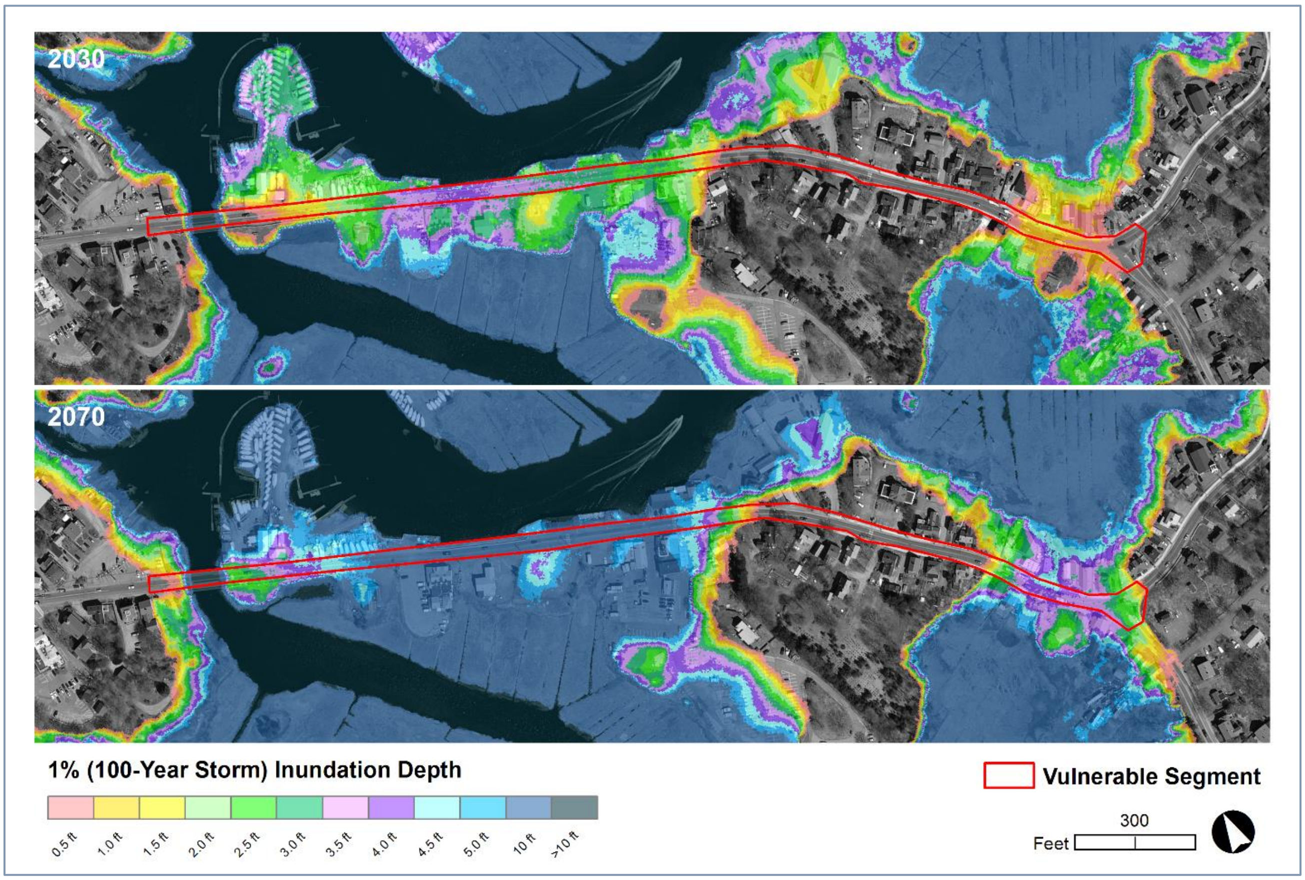


Figure 3.7-3. Essex Causeway and Woodman's Landing, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

[351] MAPC, *Town of Essex Hazard Mitigation Plan*, 16
[352] Abdollahian, N. et al., *Community Exposure,* 65

Abby Manzi/DeRosa Environmental Consulting, Inc.

Conomo Point Road and Robbins Island Road are susceptible to flooding from storm surge during astronomical high tides and large storm events. This road provides access to a neighborhood located on a small peninsula known as Conomo Point. The openness of Conomo Point and its scenic views of the Essex River estuary and nearby island make this neighborhood an important heritage landscape. Flooding of this road cuts off access to numerous residential homes, hampering the ability of emergency response personnel to assist residents living beyond Harlow Street.[353] According to the updated hurricane inundation mapping by the US Army Corps of Engineers, portions of Conomo Point Road would likely be inundated by a category one hurricane, posing a significant evacuation hazard for those living on the point.[354]

According to the USGS analysis using inundation projections by the Woods Hole Group, large portions of the road are likely to flood during major 1% and 0.2% storms. By 2070, these storms would flood the road with between 5-20 feet of water (Figure 3.7-4).[355] The significant depth and velocity of this water would significantly impact the road beyond nuisance flooding.

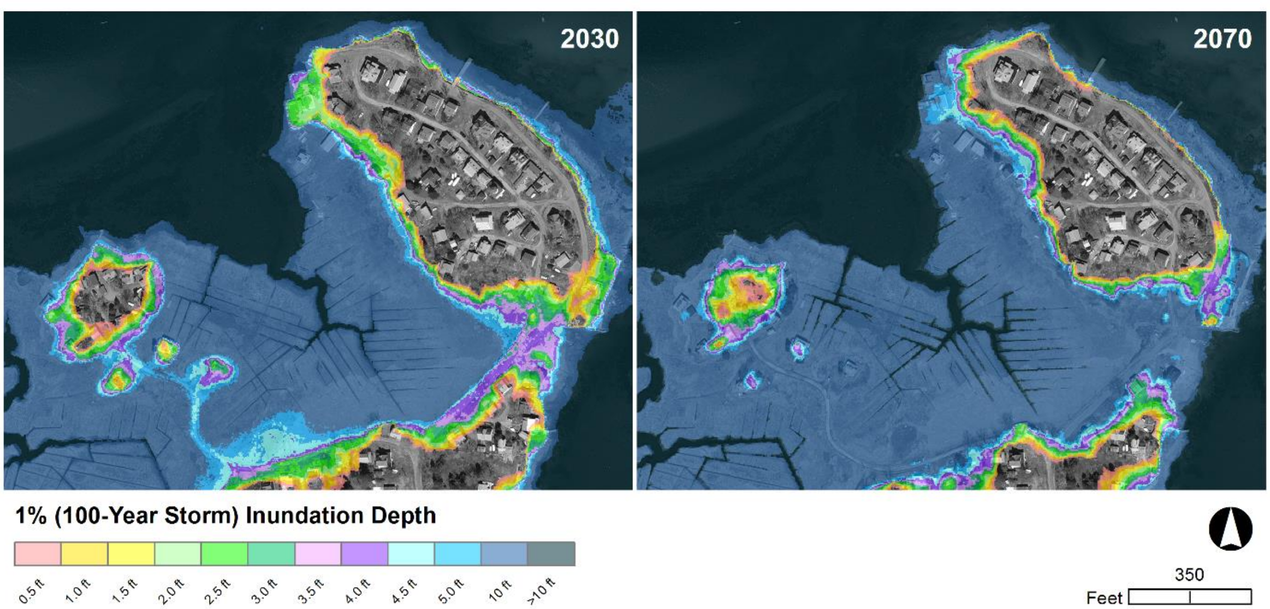


Figure 3.7-4. Conomo Point Road and Robbins Island Road, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

[353] MAPC, *Town of Essex Hazard Mitigation Plan*, 16

[354] "Hurricane Inundation Maps," USACE, accessed August 2015, http://www.mass.gov/eopss/agencies/mema/hurricane-inundation-maps.html

[355] Abdollahian, N. et al., *Community Exposure,* 65

Eastern Avenue at Ebben Creek, a 0.14 mile section of Route 133 located south of the Causeway, was identified by the Task Force as a high-priority concern. Eastern Avenue is major artery in and out of Essex, however an improperly sized culvert near J.T. Farnham's Restaurant acts as a choke point for tidal waters flowing to and from Ebben Creek.[356] During storms and astronomical high tides, the culvert is visibly overwhelmed with water pouring out of it at high velocity. The Division of Ecological Restoration study identified this area as a significant tidal restriction. This section of Route 133 has a 1% annual chance of flooding according to FEMA flood zones and may be inundated by a modest 1 foot of sea level rise.[357] Scouring, likely caused in part by the improperly sized culvert, is also a concern. Significant erosion could impact the stability of the embankment and the road itself.

According to the USGS analysis using inundation projections by the Woods Hole Group, the road is likely to flood during major 1% and 0.2% storms. By 2070, these storms would flood the road with between 1-20 feet of water (Figure 3.7-5).[358] The significant depth and velocity of this water would significantly impact the road beyond nuisance flooding.

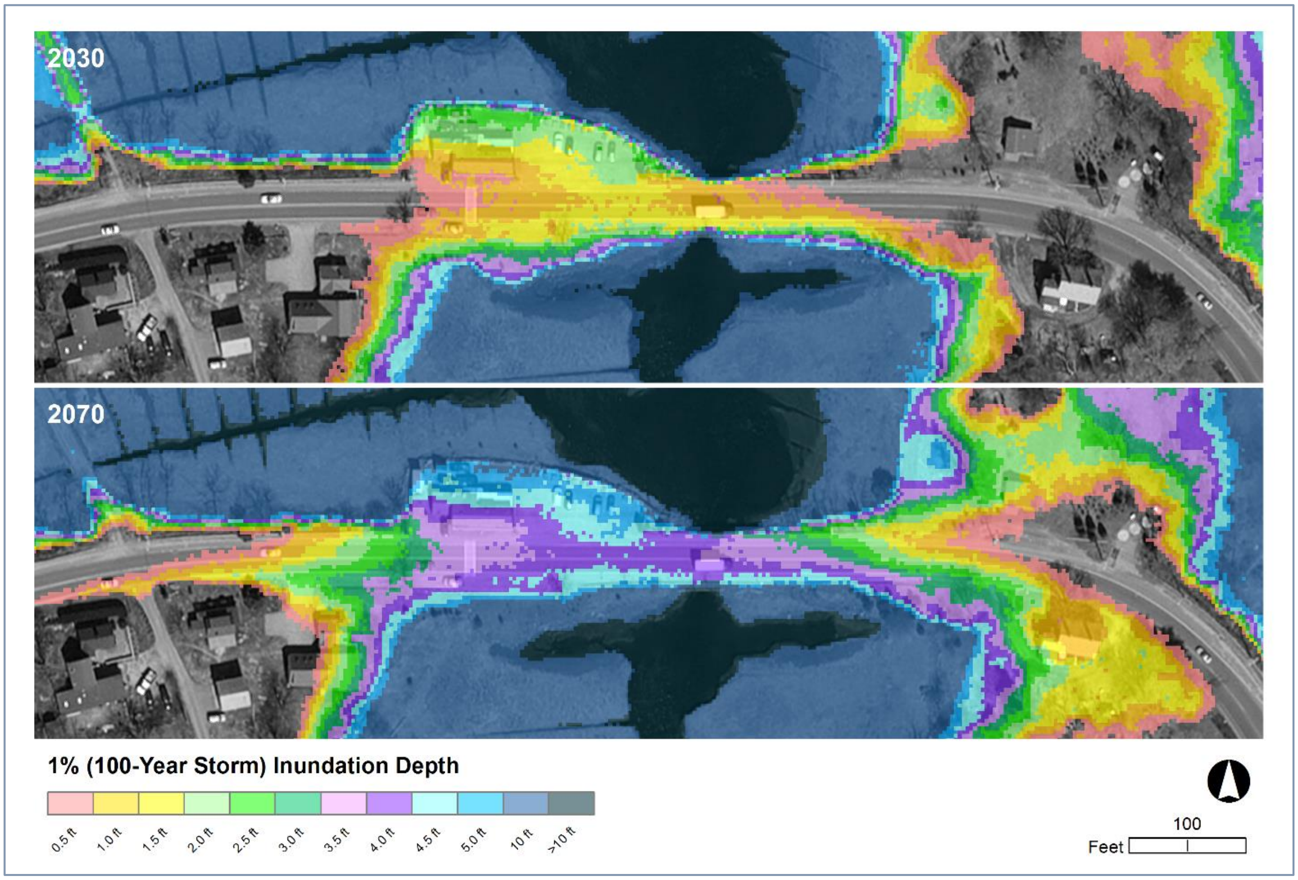


Figure 3.7-5. Eastern Avenue at Ebben Creek, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

[356] MAPC, *Town of Essex Hazard Mitigation Plan*, 16
[357] "MORIS: CZM's Online Mapping Tool"
[358] Abdollahian, N. et al., *Community Exposure,* 65

Crane Beach, although located in the neighboring Town of Ipswich, is regarded as a high priority asset by the Essex Resiliency Task Force. Crane Beach acts as a buffer between Essex Bay and the open ocean, however the beach is eroding at an increasing rate. Shoreline change at the south end of the beach is particularly pronounced. The southern tip of the beach is receding northward, leaving an ever widening river mouth. In 1995 the distance from Gloucester to the tip of Crane Beach was approximately 534 meters (or .33 miles). The distance has now grown to approximately 1002 meters (.62 miles).[359] As Crane Beach erodes, Essex Bay will be further exposed to the open ocean with less of a barrier to absorb storm hazards. Constant erosion and loss of buffering landmass at Crane Beach may also intensify marsh erosion throughout Essex Bay and will likely increase the town's overall vulnerability to climate-driven impacts. *For more on this asset, see the "Habitat and Species" section*.

DEMOGRAPHICS[360]

According to the USGS geospatial hazard analysis, 5% (181) of Essex residents currently live in coastal-hazard zones. By 2070, this number will increase to 331 residents, representing 9% of the town's total residents (Figure 3.7-6). This estimate is based solely on changes in the extent of the hazard zones, as resident distributions are based on 2010 population counts. The greatest increase in residential exposure among the three time periods is associated with the high inundation-probability zone. By 2070, 159 residents will be living in the highest hazard zone. All demographic percentages describing residents in hazard zones were relatively stable (+/-1%) across the three time periods. Demographic results relative to 2070 hazard zones suggest that none of the residents in the coastal-hazard zones across the three time periods are in mobile homes, living under the poverty line, have disabilities, speak English as a second language, or are living in institutionalized group quarters. Less than 5% of the residents in the hazard zones are unemployed, lack a phone, are in renter-occupied households, are under 5 years in age, or lack vehicles. Greater than 5% of residents in the hazard zones include individuals that are over 65 years in age (18%) and residents with only a high school degree (31%).

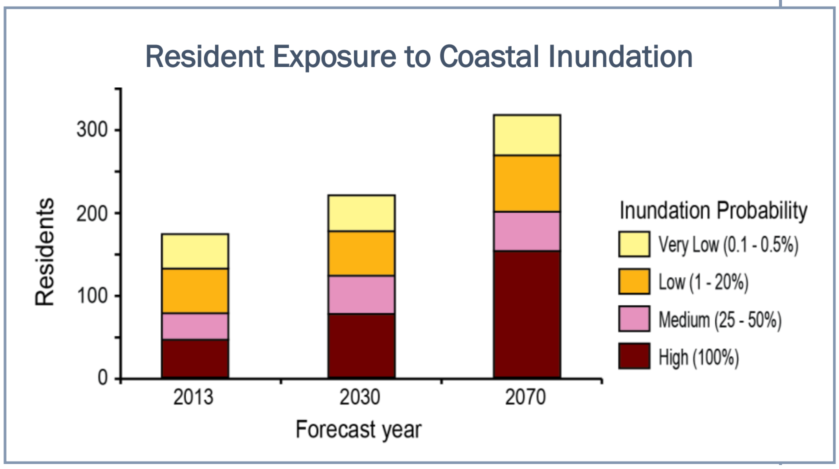


Figure 3.7-6. Resident exposure in the Town of Essex, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

ECONOMIC & SOCIO-ECONOMIC[361]

The number of Essex employees working in coastal-hazard zones ranges from 142 currently to 191 in 2070, representing 10% to 14%, respectively, of the 1,410employees that are presently in the community (Figure 3.7-7). As was the case with the resident-exposure estimates, employee exposure is based solely on changes in the extent of the hazard zone and not projected changes in employee distributions. In present day, most employees in these hazard zones are in areas classified as having a low (1-20%) inundation

[359] Essex Community Resiliency Task Force, personal communication with authors, July 15, 2015
[360] Abdollahian, N. et al., *Community Exposure,* 62-63
[361] Ibid 63-34

probability (105 employees). By 2070, however, the vast majority of employees (142) will be working at businesses in the high (100%) probability zone. Sales volume exposure for private-sector businesses ranges from $11.3 million currently to $16.4 million in 2070 (Figure 3.7-8a). None of the businesses in the various hazard zones were classified as related to natural resources. The number of businesses likely to have a significant customer presence (e.g. retail) in coastal-hazard zones ranges from 11 businesses in 2013 to 15 businesses in 2070. Of the small business (20 employees or less), 24 are located in present day hazard zones and that number will grow to 33 in 2070. This is important because small businesses are typically more sensitive to disruptions and may be unable to cope with flooding as easily as larger businesses.

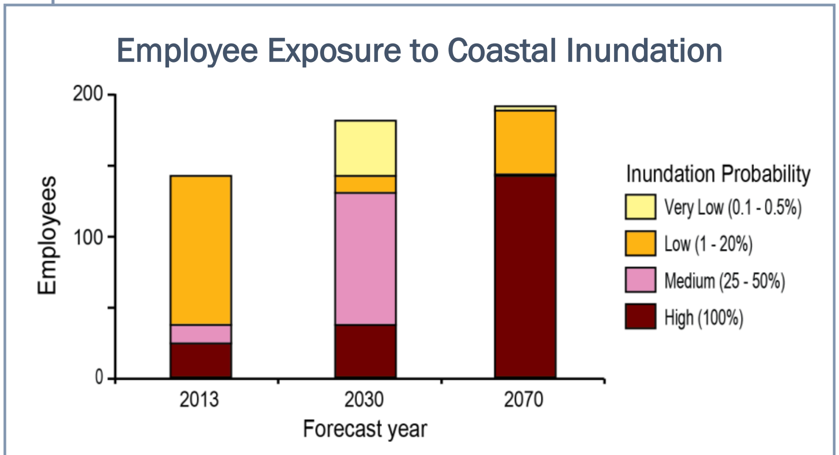


Figure 3.7-7. Employee exposure in Essex, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

Similar to sales volume, parcel values and building replacement costs in hazard zones increase due to changes in the extent of hazard zones over time. The total value for parcels in coastal-hazard zones ranges from approximately $76.5 million present day to approximately $125.1 million in 2070, representing 10% to 16% of the community's tax base between the two time periods (Figure 3.7-8b). The majority of tax-parcel value in hazard zones is associated with land value with the remainder associated with building/content value. Based on building stock data in the FEMA Hazus-MH database, estimated building replacement values range from $55.6 million for the current hazard zone to $87.7 million for 2070 hazard zone (Figure 3.7-8c). For all three time periods, the majority of potential building replacement values are in areas classified as having a high probability of inundation.

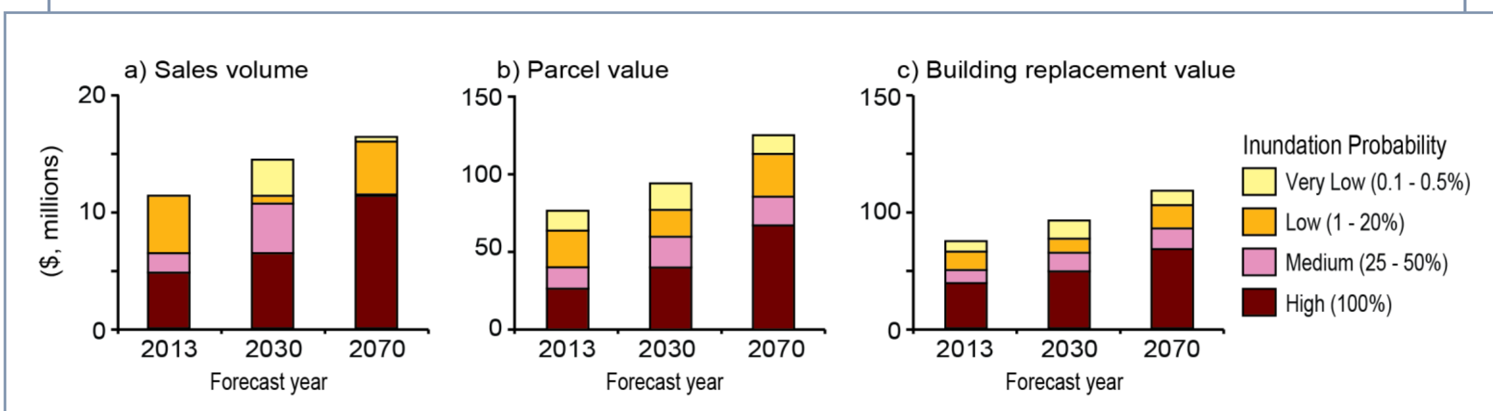


Figure 3.7-8. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Essex, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

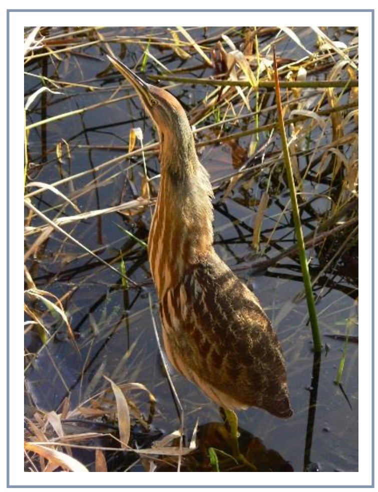
Separate from the USGS analysis, FEMA and the Department of Homeland Security conducted a static analysis on Essex's current economic vulnerability to flooding. Their study analyzed the potential economic impact of various storm scenarios using FEMA's Flood Risk Database combined with FEMA's flood loss estimation tool, HAZUS. Potential building losses and associated business disruption costs for each storm category are shown below (Table 3.7-2).[362] Based on this analysis, a mere 10-year storm has the potential to cause as much as $6.7 million dollars in damage. A larger 100-year storm may cause as much as $28.2 million in damage and a 500-year storm as much as $38 million. The majority of damage comes from infrastructure losses, although business disruptions are also quite significant. It is important to note that as "100-year" storms become more frequent, these damage estimates are likely to increase.

Table 3.7-2. Essex's Estimated Potential Losses for Flood Event Scenarios. (*) Losses shown are rounded to nearest $10,000 for values under $100,000 and to the nearest $100,000 for values over $100,000; (**) Total Building/Contents Loss = Residential Building/Contents Loss + Commercial Building/Contents Loss + Other Building/Contents Loss; (***) Business Disruption = Inventory Loss + Relocation Cost + Income Loss + Rental Income Loss + Wage Loss + Direct Output Loss; (****) Total Loss = Total Building/Contents + Business Disruption.

	10% (10-yr)	2% (50-yr)	1% (100-yr)	0.2% (500-yr)	Annualized ($/yr)
	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*	Dollar Losses*
Total Buildings/ Contents**	$6,300,000	$18,000,000	$27,300,000	$37,000,000	$1,300,000
Business Disruption***	$400,000	$700,000	$800,000	$1,000,000	$40,000
Total****	$6,700,000	$18,900,000	$28,200,000	$38,000,000	$1,400,000

HABITATS & SPECIES

The Great Marsh is one of the most important coastal ecosystems in northeastern North America.[363] In Essex, this ecosystem contains high and low marsh, estuarine aquatic environments. Each of these habitats provide critical foraging and breeding grounds for a plethora of native species. The Great Marsh also provides an abundance of ecosystem services to the Town of Essex. The marsh absorbs wave energy and traps sediment, helping reduce erosion; the aquatic environment is a nursery for commercially important fish species. In addition, the salt marsh traps and safely stores harmful carbon gases that are the leading cause of climate change. In fact, recent analysis indicates that marshes are one of the most powerful carbon sinks, with the potential of sequestering almost 50 times more carbon than tropical rainforests.[364]



Walter Seigmund/Flickr

A significant portion of Essex has received official designation recognizing the importance of its natural systems. 71.4% (6,519 acres) of

[362] FEMA, *DRAFT Flood Risk Report*, 48

[363] "The Great Marsh," Western Hemisphere Shorebird Reserve Network, accessed October 2015. http://www.whsrn.org/site-profile/great-marsh

[364] Bu, N. et al., "Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool," *Ecological Engineering*, 81 (2015): 335

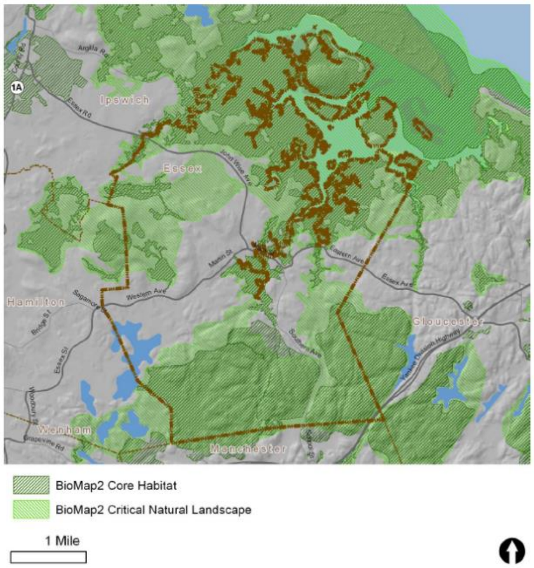


Figure 3.7-9. *BioMap2* Core Habitat in Essex. ID's correspond to habitat summaries.

the land in Essex is listed as *critical natural landscapes,* of which 4,416 acres are designated as *core habitat* (Figure 3.7-9).[365] The term "core habitat" refers to areas deemed necessary to support the long-term existence of rare or threatened species, exemplary natural communities, and intact ecosystems. "Critical natural landscapes" are intact ecosystems that are well suited to support ecological processes and/or a wide array of species and habitats over a long period of time.[366]

Salt marshes, forests, and freshwater wetlands make up the majority of the critically important habitat in Essex. These habitats contain multiple vegetative zones that support a wide diversity of species, including several threatened and endangered species (Table 3.7-3).[367] The Essex-Manchester Woods in particular, provide roughly 3,400 acres of contiguous woodlands.[368] Having never been developed, these Woods offer pristine habitat for an abundant mix of species and are noted to have some of the most outstanding habitat currently remaining along the entire Atlantic Seaboard.[369]

Table 3.7-3. List of species occurring in Essex that are threatened (T) or endangered (E). *For complete list of species, including species of conservation concern, see the MA Dept. of Fish & Game BioMap2 report for Essex (2012).*

Threatened and Endangered Species	Habitat Type
Birds	
American Bittern[E]	Marsh and freshwater wetlands
Bald Eagle[E]	Marsh, tidal channels, and upland habitat
King Rail[T]	Marsh and freshwater wetlands
Least Bittern[E]	Forest, marsh, coastal woodland, freshwater wetland
Northern Harrier[T]	Marsh and freshwater wetlands
Sedge Wren[E]	Marsh and freshwater wetlands
Fish	
Shortnose Sturgeon[E]	Marsh, coastal rivers, tidal estuaries
Atlantic Sturgeon[E]	Marsh, coastal rivers, tidal estuaries
Insects	
Hentz's Redbelly Tiger Beetle[T]	Forest
Amphibians	
Eastern Spadefoot[T]	Forest, marsh, coastal woodland, freshwater wetland
Plants	
Sweetbay Magnolia[E]	Forest
Estuary Arrowhead[E]	Marsh, coastal rivers, tidal estuaries
Long's Bulrush[T]	Marsh, coastal rivers, tidal estuaries

[365] MA DFG & TNC, *BioMap2: Essex* (Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012), http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Essex.pdf
[366] Ibid
[367] Ibid
[368] Town of Essex, *Open Space and Recreation Plan*, 26
[369] Ibid 5

The marsh in Essex is particularly vulnerable to erosion and sea level rise. Because this habitat is so low-lying and tidally influenced, the vast majority of marsh in Essex may become inundated under just one foot of sea level rise.[370] Given the close proximity of Route 133 to the landward edge of the marsh and potential future development of the Essex coastline, coastal ecosystems may not be able to migrate inland, leaving these important habitats to disappear under water. However if deliberate steps are taken to limit further development along the marshes' edge, this critical habitat may be able to gradually move landward to keep pace with sea level rise.

Robin Lubbock/WBUR

Changes in precipitation and sea level may also alter the balance between freshwater and saltwater in the Essex River and its tributaries. As salinity levels change and the water temperature increases, this habitat may become less hospitable for native plant and animal species and more suitable for exotic invasive species. For example, as invasive phragmites expand dramatically, many species of animals that inhabit the high marsh are likely to be at risk – particularly the globally threatened saltmarsh sparrow. The region's salt marsh hay industry, which is already in steep decline, could also disappear entirely.

Furthermore, additional coastal development combined with an increase in severe storm activity will likely lead to an increase in surface runoff quantities and rates. Stormwater runoff carrying bacteria, pathogens, and nutrients is currently one of the major anthropogenic-related stressors on the marsh and is likely to be exacerbated by climate change. Currently shellfish harvesters lose millions of dollars annually due to stormwater contamination.[371] Nitrogen has also recently been identified as a leading cause of marsh bank disintegration.[372]

Shellfish are a particularly important natural resource in Essex. As previously noted, clamming is one of the town's principle industries. Maintaining healthy, stable shellfish populations is a high priority in Essex. However the habitat used by shellfish is quite vulnerable to sea level rise, increased erosion, and changes in water temperature. Intertidal mud flats, sandy estuarine environments, and sea grass beds are all likely to suffer under the added strain of climate-driven threats. Sea level rise may permanently inundate clam flats, converting once productive harvesting areas into unsuitable habitat devoid of shellfish. Erosion also threatens to further shrink these estuarine environments so important to shellfish. Furthermore, changes to these invaluable ecosystems as a result of warming temperatures may lead to a decline in shellfish productivity, health, and survival.

Crane Beach is a largely undeveloped barrier beach that absorbs much of the ocean's brunt force before waves and storm surge penetrate into Essex Bay through the inlet at the southern tip of the beach. Like all barrier beaches, natural processes cause the beach to shift over time. Its dynamic character and ability to move and reshape in response to constant wave energy as well as acute storm events, is precisely what

370 "MORIS: CZM's Online Mapping Tool"

371 Ipswich Coastal Pollution Control Committee, *Coastal Stormwater Remediation Plan for the Town of Ipswich* (Ipswich, MA: Town of Ipswich Massachusetts Planning Department, 2000), 1

372 Deegan, L.A. et al., "Coastal eutrophication as a driver of salt marsh loss," *Nature,* 490 (18 October 2012), 388

makes it resilient to sea level rise and storm surge.[373] Crane Beach, as defined today in terms of shape, size, and location is vulnerable and is unlikely to remain in its current form. However the barrier beach as whole is quite resilient and will likely adapt to sea level rise and storm surge by migrating inland and/or shifting shape. Observations currently indicate that the southern tip of the beach is shifting most rapidly, widening the mouth of the inlet.[374] This is an area of concern for communities such as Essex that rely on Crane Beach to provide natural protection benefits. More study is required to assess the rate of change at the southern tip of the beach and the impact it will have on wave energy and erosion within Essex Bay.

Overall, the *critical natural landscapes* and *core habitats* in Essex are likely to become more vulnerable given future climate change projections. Terrestrial habitats are likely to become stressed as temperatures warm and precipitation fluctuates. The change in availability of necessary resources, including food, shelter, and water, may result in a loss of biodiversity. In addition, these stressors associated with climate change will be magnified by future development and fragmentation of the landscape. In a more fragmented landscape, habitat connectivity is lost, inhibiting the ability of species to access vital resources and shift their range as the climate warms.[375]

Summary

Overall the Town of Essex has a high level of vulnerability to climate-driven threats. The Essex Causeway is highly vulnerable and when it's impacted the economic consequences and transportation disruptions ripple throughout the entire community. Predicted sea level rise, increased storm surge, and erosion have the potential to drastically impact the town's coastal economy and the natural systems that the community depends upon. Because of the town's reliance on coastal tourism and coastal industries, impacts to infrastructure or natural systems may have cascading effects that ripple across all parts of the community. The geospatial analysis conducted by USGS confirms these findings and indicates economic, infrastructure, and population vulnerabilities that will likely need to be addressed to protect human life as well as the economic well-being of Essex.

The natural systems in Essex are already being impacted by erosion that is likely to accelerate with climate change. Sea level rise will likely inundate the vast expanses of marsh that currently help reduce storm surge and reduce erosion, and provide important habitat to rare and threatened species. Storm surge resulting from bigger and more frequent storms will likely course its way landward through Essex Bay, impacting larger portions of Route 133 and the town's center. An increase in heavy precipitation events combined with penetrating storm surge will likely cause substantial damage to low-lying interior portions of Essex.

NWF

For recommendations on how to address the Town of Essex's overall vulnerability to climate-driven hazards, including site-specific adaptation strategies for the areas of concern outlined above, see Chapter 4: Adaptation Strategies for the Great Marsh Region.

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[373] Massachusetts Barrier Beach Task Force, *Guidelines for Barrier Beach Management in Massachusetts* (Boston, MA: Massachusetts Office of Coastal Zone Management, 1994) http://www.mass.gov/eea/docs/czm/stormsmart/beaches/barrier-beach-guidelines.pdf

[374] Essex Community Resiliency Task Force, personal communication with authors, July 15, 2015

[375] Grund, S., and E. Walberg, *Climate Change Adaptation for Conservation Lands in New England* (Plymouth, MA: Manomet Center for Conservation Sciences, 2013), 3

Ranger Poole/USFWS

CHAPTER 4

Adaptation Strategies for the Great Marsh Region

Assessing vulnerability is the first step in generating adaptation options to increase resilience and reduce vulnerability. Understanding why an asset is vulnerable is especially critical to thinking about adaptation and in particular, identifying adaptation options that can address one or more of the three components of vulnerability (i.e. exposure, sensitivity, and adaptive capacity). Furthermore, while vulnerability assessments provide the context necessary for identifying important issues to consider when designing adaptation strategies, the identification of "key vulnerabilities" can help steer the generation of adaptation options in a direction that focuses on the most critical issues. [376]

This chapter outlines a range of adaptation strategies identified through the Community Adaptation Planning Process (see Chapter 2). The following strategies and recommendations are broken into two categories: regional strategies and town-specific strategies. Successful short and long-term implementation of all of these recommendations will require an extensive amount of intra- and inter-municipal cooperation, regional collaboration, and ongoing environmental research and monitoring. The Great Marsh Region is fortunate to have a wide diversity of organizations, agencies, and municipalities working to protect and restore the Great Marsh. However, these efforts will need to be continually strengthened to achieve the degree of change and level of project implementation recommended in this report.

[376] Stein, B.A., P. Glick, N. Edelson, and A. Staudt (eds.), *Climate-Smart Conservation: Putting Adaptation Principles into Practice* (Reston, VA: National Wildlife Federation, 2014), 120

4.1 Regional Strategies and Recommendations

This section highlights adaptation strategies that should be adopted to reduce vulnerability on a regional scale. These recommendations focus on broad targets, including specific habitats (such as dunes, salt marsh, and freshwater riparian systems), types of infrastructure (buildings, roads, and shoreline stabilization structures), and conservation goals (enhanced stormwater management, land conservation, and species diversity). These strategies serve to reduce shared vulnerabilities that span jurisdictions and because of their broad regional benefits, they are as critically important as the strategies identified for individual assets (see Section 4.2).

Regional strategies and recommendations outlined in the section were identified across two stages. To begin, the Project Team reviewed and synthesized a range of local, state, and regional documents, plans, and reports to identify and collate strategies to increase the resiliency of natural systems throughout the Great Marsh Region. Regional plans reviewed included the Massachusetts Climate Change Adaptation Report,[377] the Great Marsh ACEC – Resource Management planning document,[378] the PIE-Rivers Restoration Partnership: Action Plan,[379] Massachusetts Bays Comprehensive Conservation & Management Plan,[380] Massachusetts State Wildlife Action Plan,[381] the Ecosystems & Wildlife Climate Change Adaptation Plan,[382] and various local open space and climate action plans, among others.

A day-long workshop was then held to identify and develop specific recommendations to improve overall ecosystem health and resilience. This workshop convened approximately 20 natural resource professionals working in the Great Marsh, representing conservation staff from the municipalities as well as technical experts from the following agencies and non-profits:

- Boston University
- Greenbelt
- Ipswich River Watershed Association
- Mass Audubon
- Massachusetts Bays National Estuary Program
- MA Department of Fish & Game
- MA Division of Ecological Restoration
- MA Division of Marine Fisheries
- MA Natural Heritage Commission
- MA Office of Coastal Zone Management
- Waquoit Bay National Estuarine Research Reserve
- Merrimack Valley Planning Commission
- National Wildlife Federation
- Northeast MA Mosquito Control & Wetlands Management District
- Parker River Clean Water Association
- Plum Island Ecosystems Long Term Ecological Research Program
- Trustees
- USFWS Parker River National Wildlife Refuge
- University of New Hampshire

[377] Massachusetts Executive Office of Energy and Environmental Affairs (MA EEA), Massachusetts Climate Change Adaptation Report (Boston, MA, 2011) http://www.mass.gov/eea/waste-mgnt-recycling/air-quality/climate-change-adaptation/climate-change-adaptation-report.html

[378] Horsley Witten Group, *Managing the Great Marsh ACEC – Next Steps? Options for Developing a Resource Management Plan,* (Newburyport, MA, 2011) http://www.pie-rivers.org/wp-content/uploads/2015/03/Great-Marsh-Options-Plan.pdf

[379] Ipswich River Watershed Association, Restoration Priorities for the Parker, Ipswich and Essex River Watersheds (Ipswich, MA, 2013), http://www.pie-rivers.org/wp-content/uploads/2015/01/PIE-Rivers_ActionPlan_Final_02262013.pdf

[380] Massachusetts Bays National Estuary Program, *Comprehensive Conservation and Management Plan*, public review draft (Boston, MA, 2015) http://www.mass.gov/eea/docs/mbp/publications/massbays-public-review-draft-ccmp-4-15-15.pdf

[381] "State Wildlife Action Plan (SWAP)," Commonwealth of Massachusetts, http://www.mass.gov/eea/agencies/dfg/dfw/wildlife-habitat-conservation/state-wildlife-conservation-strategy.html

[382] New Hampshire Fish & Game Department, *Ecosystems and Wildlife Climate Change Adaptation Plan*, (Concord, NH, 2013) http://www.town.hillsborough.nh.us/sites/hillsboroughnh/files/file/file/eco_wildlife_cc_adapt_plan.pdf


NWF

The agenda for this workshop was to 1) review the breadth of policy, land-use planning, regulatory, restoration, and management tools and approaches to increase ecosystem resiliency, as outlined in existing guidance documents, plans, and reports; and 2) identify new strategies and on the ground recommendations that would improve ecosystem resilience in the Great Marsh.

The following general adaptation recommendations are the result of this workshop, and are grouped into five categories: (1) Best Practices; (2) Natural and Nature-based Strategies; (3) Gray Infrastructure and Retrofits; (4) Land-use Planning and Policy; and (5) Outreach and Engagement (see also Box 4.1-1).

Best Practices

The following best practices, also referred to as "no regret" strategies, should be at the forefront of each community's action to support resiliency across the greater region. While adaptation strategies also require site-specific considerations, these recommendations are relevant across towns and driven by simple principles of communication, collaboration, and planning.

Establish and maintain a permanent Municipal Resiliency Task Force or committee

The Municipal Task Forces formed for this Great Marsh Resiliency Planning Project worked together over two years, fostering a comprehensive approach to coastal planning in the Great Marsh. These kinds of committees can serve as the connective tissue between municipal departments and officials, helping ensure climate projections and adaptation considerations are incorporated at all levels of municipal governance. The Great Marsh Resiliency Partnership, comprised of regional, governmental, municipal, and NGO partners working in the Great Marsh, can serve as an umbrella resource, connecting the municipal task forces and moving strategies forward.

Set clear goals for addressing existing and projected vulnerability

As outlined in *Climate-smart Conservation*,[383] before selecting an adaptation strategy, it is important to set clear goals that are broad, yet attainable. This principle should be carried forward as communities look to implement strategies outlined in this plan. For example, Argilla Road connects Crane Beach to the mainland of Ipswich, however the road is often subject to flooding. It is easy to assume the goal is to reduce flooding of Argilla Road. However, with this narrow goal, the range of adaptation strategies may be somewhat limited. A more appropriate goal may be "to ensure safe access to and from the Crane Beach and the mainland under all but extreme conditions." Under this broader goal, the range of adaptation strategies becomes much wider: alternate routes can be assessed, early flood warning systems can be installed, and community outreach can help educate residents on the existing and future potential of flood hazards so that they have the knowledge and resources to prepare accordingly.

As important as it is to set clear, attainable goals, it is equally important to revisit these goals as new information becomes available. For instance, as climate-driven threats accelerate, initial goals that seemed reasonable may no longer be realistic. Goals can and should evolve over time to ensure they stay relevant to the community's overall priorities.

[383] Stein, B.A., P. Glick, N. Edelson, and A. Staudt (eds.), *Climate-Smart Conservation*

Box 4.1-1. Regional Adaptation Strategies & Recommendations for the Great Marsh Region

Best Practices *(see also page 126-130)*

- Establish and maintain a permanent Municipal Resiliency Task Force or committee
- Set clear goals for addressing existing and projected vulnerability
- Collaborate across municipal departments
- Collaborate across municipal boundaries
- Protect and enhance biodiversity
- Reduce non-climate stressors
- Evaluate effectiveness of adaptation strategies at regular intervals
- Monitor coastal hazards and maintain strong research initiatives
- Promote economic diversity
- Incorporate climate change adaptation planning and climate projections into all relevant local and regional plans as well as capital investment projects

Natural and Nature-Based Strategies *(see also page 130-137)*

- Ensure and restore connectivity of river and coastal systems
- Use living shorelines to stabilize shoreline edges, where appropriate
- Explore construction of offshore shellfish reefs and beds to attenuate wave energy, reduce erosion, and improve water quality
- Protect and restore barrier beaches and dunes through renourishment and revegetation
- Explore opportunities to beneficially reuse dredged material
- Restore sub-aquatic vegetation
- Restore degraded salt marshes
- Facilitate marsh migration
- Enhance land conservation efforts

Gray Infrastructure and Retrofits *(see also page 138-139)*

- Remove unnecessary dams
- Upgrade road-stream crossings
- Retrofit buildings to be more flood resilient
- Elevate roadways to prevent nuisance flooding and to withstand projected sea level rise
- Pursue retrofits and planning for Massachusetts Bay Transportation Authority (MBTA) railroad

Land-use Planning and Policy *(see also page 140-144)*

- Update municipal policies
- Prioritize low-impact development (LID) practices
- Revise local wetlands protection bylaws and regulations
- Move development away from the coast and from wetlands
- Create "freeboard incentive" for residential and commercial buildings
- Use transferable development credits (TDCs) to reduce risky coastal development
- Institute comprehensive water resources management, including strategies for stormwater, waste water, and public drinking water

Outreach and Engagement *(see also page 144-146)*

- Develop municipal strategies for enhanced outreach and education
- Strengthen existing regional outreach and education programs
- Support and develop opportunities for citizen science

Collaborate across municipal departments

An open line of communication between municipal departments is absolutely critical to ensuring a shared understanding of the coastal hazards likely to impact each community. Where applicable, municipal staff from the public works, conservation, planning and development, public health, and emergency response departments, as well as others, should all collaborate to address vulnerabilities. Collaboration across municipal departments will enhance the likelihood of holistic strategies being implemented and will guard against the risk of any one department unknowingly exacerbating stressors that increase vulnerability.

Collaborate across municipal boundaries

Coastal hazards are not bound by municipal borders, and the strategies to address those hazards shouldn't be either. Communities along the Great Marsh share responsibility for the incredible natural resources of the region and also share its vulnerabilities as identified earlier in this Plan (see Chapter 3). Successful strategies to reduce those vulnerabilities will require joint efforts between towns. Creating formal or informal collaborations between municipalities - and enhancing existing collaborations, such as the 8 Towns and the Great Marsh Committee[384] - will also help ensure that risk-reduction strategies implemented by one community will not exacerbate the vulnerability of a neighboring community. For example, replacing an improperly sized culvert to reduce upstream flooding may exacerbate down-stream flooding in another community. Working across communities and using a holistic, ecosystem approach will lead to the greatest benefit for the most number of people and infrastructure assets. To begin this conversation, we encourage municipalities to partner with regional organizations and coalitions to achieve their goals in collaboration with their Great Marsh neighbors.

Sandy Tilton

Protect and enhance biodiversity

Even in relatively intact ecosystems such as the Great Marsh, anthropogenic stressors are omnipresent and consequently contributing to the degradation and loss of important habitat and species. At the same time, these issues are further exacerbated by climate change and the combined effects ultimately threaten to disrupt critical ecological functions and processes that both human and natural communities depend on. To address these challenges, it is essential that natural resource conservation and management initiatives focus on protecting and enhancing biodiversity within and across ecosystems, as maintaining biodiversity is ultimately key to maximizing the resiliency and adaptive capacity of ecosystems. Communities, natural resource managers and practitioners within the Great Marsh region should fully implement the Massachusetts BioMap2[385] as a tool to help improve and maximize biodiversity protection and enhancement efforts. This document offers a strategic guide to conserving biodiversity in Massachusetts over the next decade by focusing land protection and stewardship on the areas that are most critical for

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[384] "Eight Towns and the Great Marsh," http://www.8tgm.org/

[385] "BioMap2: Conserving the Biodiversity of Massachusetts in a Changing World," Natural Heritage & Endangered Species Program (MA Department of Fish & Game: Westborough, MA, 2012) http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/land-protection-and-management/biomap2/

ensuring the long-term persistence of rare and other native species and their habitats, exemplary natural communities, and a diversity of ecosystems.

Reduce non-climate stressors

Reducing existing threats that are not specifically related to climate change (i.e. non-climate stressors) can be a highly effective adaptation approach given that climate change is not happening in isolation from other challenges we face. In fact, it is the combined effects of climate change with other stressors that often lead to the biggest challenges. In some instances, removing the added stressors is easier and more cost-effective than addressing the climate-driven threat itself. Examples of non-climate stressors affecting the Great Marsh include invasive species that disrupt ecosystem structure and function, nutrient and bacterial pollution in stormwater runoff that degrades the freshwater and saltwater ecosystems, tidal and freshwater restrictions that contribute to habitat fragmentation, and increased water withdrawals that alter streams and aquifers.

Peter Phippen

Evaluate effectiveness of adaptation strategies at regular intervals

It is important to regularly evaluate adaptation strategies to ensure they are achieving the desired outcomes. A strategy may seem like a good idea in principle however it may not work in practice. Other strategies might work initially, however after time they become less effective. Evaluating strategies on a regular basis will allow for adaptive management.

Monitor coastal hazards and maintain strong research initiatives

It is important to research and monitor coastal hazards over time to gather new information and track long-term trends as well as acute changes. Information collected from monitoring, including (but not limited to) flood depth, frequency of flooding, and erosion rates, should be used to help guide infrastructure improvements and to help determine when managed retreat may be necessary. Fortunately there are many research partners working in the Great Marsh to assist with these efforts, including the Plum Island Ecosystems Long-Term Ecological Research (PIE-LTR) program,[386] several academic institutions (i.e. University of New Hampshire, Boston University), and other agency and non-profit partners, such as MA Office of Coastal Zone Management, Mass Audubon, and the Parker River National Wildlife Refuge. Strengthening the existing Great Marsh Resiliency Partnership will also improve coordination and increase institutional capacity to provide technical assistance and to implement measures at the local-level.

Promote economic diversity

A diverse coastal economy is inherently a more resilient economy. For example, if a community relies entirely on beach tourism and the tax base from expensive shore-front properties, then a single major

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[386] "Plum Island Ecosystems LTER," http://pie-lter.ecosystems.mbl.edu/

coastal storm can devastate the community. However if the community also supports farming and agriculture further inland, a healthy manufacturing sector, and ecotourism, then the economic impact from a single storm is likely to be less severe.

Incorporate climate change adaptation planning and climate projections into all relevant local and regional plans as well as capital investment projects

Adaptation planning and climate projections should not be siloed and kept separate from other community efforts. To be truly successful in reducing vulnerability, climate projections should be incorporated into all community and regional planning efforts. Adaptation strategies should be considered in master plans, open space plans, capital investment plans, and more: Climate change considerations should permeate through every facet of governmental planning.

Natural and Nature-Based Strategies

Natural and nature-based strategies can provide a multitude of short and long-term societal, economic, and environmental benefits. *Natural strategies* (often referred to as natural solutions) are those strategies that support pre-existing natural features like dunes, beaches, and salt marshes that provide risk reduction. Natural strategies maximize the effectiveness of coastal habitats to serve as "natural defenses" against sea level rise, increased erosion, and other climate-driven threats. *Nature-based strategies*, while similar, are created by human design, engineered, and constructed to provide specific services such as coastal risk reduction and other ecosystem services; examples of nature-based strategies include living shorelines, bio-swales, engineered dunes, and oyster reefs.[387] Nature-based strategies are often designed using a hybrid of natural and nature-based features, where natural materials and non-natural material or synthetic materials are combined to reduce risk and maximize resilience. Both natural and nature-based strategies have the capacity to evolve naturally overtime, and are therefore inherently dynamic, suggesting that some management or maintenance may be required to sustain the function and desired services of such features. However, with the ability to evolve through a variety of natural processes, both natural and nature-based strategies have the potential to repair themselves from damage and even adapt to changing conditions over time. Such approaches can therefore offer equal if not more resilient protection to coastal hazards compared to hard or gray infrastructure.[388]

The following natural and nature-based strategies are recommended for the Great Marsh Region:

Ensure and restore connectivity of river and coastal systems

River and coastal aquatic systems are inherently dynamic and resilient in the face of storms, floods, and tidal action. In fact, they were largely formed by these driving forces. Much of the resilience of these natural systems is derived from their internal and external connections. Well-connected river systems efficiently transfer water, sediment, and organic material from the upland to the estuary. Rivers that are connected to their natural undeveloped floodplains are less likely to cause damage when they inevitably overtop their banks. Well-connected salt marshes are more resilient to storm surges and other hazards. Overall, connectivity across coastal habitats provides tangible ecosystem services to coastal communities. Additionally, well-connected aquatic systems provide critical habitat for a wide variety of aquatic and terrestrial species that are both commercially and ecologically valuable. When connectivity is lost, it can

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[387] Ibid

[388] Gittman, R.K. et al., "Engineering away our natural defenses: an analysis of shoreline hardening in the US," *Frontiers in Ecology and the Environment* 13, no.6 (2015): 301-307, doi: 10.1890/150065

have a detrimental effect on the ecological resources of the region as well as on the region's resilience to storms and other climate events. In the Great Marsh, collective effort must be made to restore natural flow regimes and connectivity of aquatic and coastal habitats by planning, designing, and implementing improvements to undersized or improperly designed culverts and bridges identified by the *Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed* (see Appendix B).

Use living shorelines to stabilize shoreline edges, where appropriate

Living shorelines encompass a range of techniques to naturally stabilize a shoreline and, "unlike rigid armoring, are designed to absorb wave energy while still maintaining some of the natural processes and ecological integrity of the shore zone."[389] Despite the perception that living shorelines are less durable than hard infrastructure, certain living shorelines have in fact been shown to survive a Category 1 hurricane better than bulkheads.[390] Living shorelines can include a wide variety of components, such as a combination of coconut-fiber logs, rock sills and breakwaters, sandy fill, plants, and shellfish.[391] However a number of site-specific considerations need to be taken into account when designing a living shoreline, as well as determining its feasibility. Site-specific considerations include (but are not limited to) fetch, boat wakes, nearshore gradient, substrate consistency, tide range, and sun exposure, among others. As both engineering and ecological expertise are required to properly site, design, and construct a living shoreline, municipalities should contact MA CZM's Northshore Regional MA coordinator for further information and guidance. In addition, there are a number of online resources available that provide useful guidance on how to identify, assess, and incorporate site-specific considerations into a successful living shoreline design, including the Stevens Institute of Technology's report on *Living Shorelines Engineering Guidelines*[392] and NOAA's *Guidance for Considering the Use of Living Shorelines*.[393]

Partnership for the Delaware Estuary/Flickr

Opportunities for living shorelines in specific communities have been identified through the task force planning process (see Section 4.2). Such opportunities include replacing, retrofitting, or enhancing coastal stabilization structures with living shorelines at Cashman Park (Newburyport), Joppa Flats (Newburyport), and in low to medium energy shorelines throughout region, including Ipswich River, Merrimack River, Plum Island Sound, and Essex Bay. It is also important to restore natural vegetated buffers along riparian areas of all order streams, as has begun in Ipswich along the

[389] Small-Lorenz, S.L., W.P. Shadel, and P. Glick., *Building Ecological Solutions to Coastal Community Hazards* (Washington, DC: National Wildlife Federation, 2017), 74
[390] Ibid
[391] Ibid
[392] Miller, J.K., A. Rella, A. Williams, and E. Sproule, *Living Shorelines Engineering Guidelines*, prepared for New Jersey Department of Environmental Protection (Hoboken, NJ: Stevens Institute of Technology, 2016), http://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf
[393] NOAA Living Shorelines Workgroup, *Guidance for Considering the Use of Living Shorelines* (2012), (http://www.habitat.noaa.gov/pdf/noaa_guidance_for_considering_the_use_of_living_shorelines_2015.pdf

portions of the Ipswich River near downtown. Additionally, it should be noted that impacts from human uses along riverbanks and other shorelines can be considerable, causing erosion and limiting the ability of the natural feature to act as a buffer against storms and other climate impacts. It is critical that communities enforce regulations that prohibit the seasonal storage of floating docks, dinghies, and associated structures on the intertidal shoreline, coastal bank, or in tidal wetlands.

Explore construction of offshore shellfish reefs and beds to attenuate wave energy, reduce erosion, and improve water quality

Lynnhaven River NOW

Shellfish reefs and beds (also considered a type of living shoreline) are among nature's most effective stabilizing features and can significantly reduce erosion, attenuate waves, and trap sediments. These offshore, submerged structures function similarly to constructed breakwaters or sills, however they also provide critical aquatic habitat and a number of ecosystem services. Shellfish reefs and beds are typically constructed using shellfish bags, or concrete structures (i.e. reef balls and castles) depending on wave conditions (low-moderate energy vs. high- energy, respectively). Opportunities may exist throughout the Great Marsh to create these stabilizing structures using native shellfish species including Ribbed Mussel, Blue Mussel, and American Oyster. By working with the MA Division of Marine Fisheries, Mass Bays, MA CZM, and other partners, local communities should identify locations to implement shellfish reef creation/enhancement projects to reduce wave energy and protect the shoreline.

Protect and restore barrier beaches and dunes through renourishment and revegetation

Coastal beaches and dunes are inherently dynamic systems, constantly moving and shifting in response to wind, waves, tides, and other factors such as changes in sea level rise and human interactions.[394] The movement of sediment and the erosion and accretion of coastal shorelines is a continuous, interrelated process that provides a primary source of sand to the beaches and dunes of Massachusetts.[395] It is because of this dynamic nature that beaches and dunes also provide invaluable storm protection to coastal and inland areas. During a storm, sediments within the beach-dune system shift, allowing wave energy to be absorbed and consequently buffering the direct impact of the storm to inland areas. Sediment displaced from the beach is then moved offshore or added to the surrounding beach and nearshore areas where it can continue to absorb wave energy. The ability of a dune to prevent flooding is determined in part by how sturdy and resilient it is. Native dune grasses and vegetation have deep roots that develop over time and are particularly well equipped at binding otherwise loose piles of sand into a sturdy, natural seawall. In addition to providing a second layer of protection, dunes also provide beaches with a critical supply of

"Coastal beaches and dunes change constantly in response to wind, waves, tides, and other factors such as sea level rise and human changes to the shoreline system."[394]

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[394] "Restore natural coastal buffers: Beach and dune nourishment and restoration," Massachusetts Wildlife Action Tool (Amherst, MA: University of Massachusetts Amherst, 2017), http://climateactiontool.org/content/restore-natural-coastal-buffers-beach-and-dune-nourishment-and-restoration

[395] Massachusetts Coastal Erosion Commission, "Volume 1: Findings and Recommendations" in *Report of the Massachusetts Coastal Erosion Commission* (Boston, MA: Massachusetts Executive Office of Energy and Environmental Affairs, 2015), 2-1, http://www.mass.gov/eea/docs/czm/erosion-commission/cec-final-report-dec2015-complete.pdf

sediment during a storm. Coastal development, including shoreline stabilization structures, disrupts this natural process of erosion and accretion – resulting in changes in sediment supply and rates of erosion. At the same time, increased storm frequency and intensity and sea level rise threaten to exacerbate erosion rates and the potential loss of coastline.

Where appropriate, increasing the volume of beaches and dunes through nourishment can effectively support the beach system as a whole (i.e. the dune, beach, and nearshore area), including its ability to provide storm damage protection and critical habitat for wildlife.[396] Compared to hard stabilization structures like seawalls and bulkheads, regulatory agencies are generally supportive of nourishment projects given how closely they complement natural processes. All nourishment projects must take in a number of site-specific considerations to ensure the project will have no adverse impacts on coastal resources, including sensitive habitats and species. The most important consideration for implementing a successful nourishment project is the use of compatible sediment; the sediment added must match the sediment characteristics native to the project site in terms of grain size distribution and shape.[397] In Massachusetts, the most common type of nourishment projects beneficially reuse dredged sediment to build up the beach or dune. However, to reuse dredged material for a nourishment project, state policy requires that the sediment is clean, in addition to compatible, and be placed on beaches adjacent to the dredging site in order to keep the material in the littoral system.[398]

As a general best practice, beach and dune nourishment projects should incorporate other restoration techniques to help maximize their overall effectiveness. For example, planting native, salt-tolerant vegetation along the backside of the beach or dune can help anchor sediment in place. In the Great Marsh Region, restoration experts have had success planting American beach grass, beach pea, sea rocket, and seaside goldenrod to naturally stabilize dunes. In conjunction with plantings, sand fencing can be erected to trap windblown sand, enhance accretion rates, and prevent people from walking on the restored dunes. For all beach and dune restoration initiatives, an outreach component should also be included so that residents and visitors understand why the work is occurring. In the case of dune restoration in particular, outreach can help relay the importance of staying off the dunes and deflating public perception that dune restoration and fencing is preventing public access to the beach.

Gregg Moore/UNH

[396] "Restore natural coastal buffers: Beach and dune nourishment and restoration," Massachusetts Wildlife Action Tool
[397] Rebecca Haney et al., *Beach Nourishment: MassDEP's Guide to Best Management Practices for Projects in Massachusetts* (Boston, MA: MA Department of Environmental Protection & Office of Coastal Zone Management, 2007), 6, http://www.mass.gov/eea/docs/dep/water/resources/a-thru-m/bchbod.pdf
[398] Ibid

The following steps should be taken to increase the success of beach and dune restoration efforts:

- Update and implement ecosystem-based Barrier Beach Management Plans for Salisbury Beach, Plum Island, and Crane Beach;
- Work with the Merrimack River Beach Alliance to identify and implement beach nourishment using best available science, including results of the Plum Island Sedimentation Study and other wave and sediment studies;
- Restore vegetated shoreline and dunes by planning, designing, and implementing site-specific dune restoration projects;
- Educate, encourage, and incentivize landowners to remove damaging debris from dune habitat;
- Identify dune areas heavily impacted by foot traffic and off-leash dogs and work with neighborhood and recreation groups to establish improved management of trails.

Explore opportunities to beneficially reuse dredged material

For many coastal communities throughout Massachusetts, dredging is recognized as being essential to maintaining accessibility of waterways for recreational and commercial uses. The phrase "beneficial reuse of dredged material" refers to opportunities where disposing of (or recycling) dredged material can provide environmental and socio-economic benefits. By returning sediment to the system where it is needed, beneficial reuse projects can also offer a more efficient way of using dredged material, as opposed to treating it as waste. While reusing dredged material can offer a number of benefits, it can also have significant impacts on the environment. For example, placing dredged material where it is not compatible with existing substrate can significantly impact the health of aquatic resources and habitats (i.e. salt marshes, eelgrass beds, and shellfish habitat) by physically altering the sediment composition within a system. Adding contaminated material to a system can also impact water quality, which can lead to a number of wide-spread consequences, both acute and chronic. In order to minimize potential impacts to coastal resources, state policy requires dredged material proposed for beneficial reuse projects to be thoroughly evaluated in terms of its suitability with respect to the biological and physical characteristics of the receiving-site and its intended use.[399]

Recognizing the importance of keeping sediment where it can benefit the environment and economy, the "Commonwealth is committed to ensuring the beneficial use of dredged material where feasible."[400] In Massachusetts, beneficial reuse opportunities are currently considered greatest for restoring beaches subject to erosion, however there are other ways in which dredged material can be beneficially used. To help balance the need to keep waterways navigable with the need to keep sediment in the system, communities are encouraged to work with state and federal natural resource agencies, watershed groups, and other interested parties to discuss all practical beneficial reuse opportunities. It's important that options be considered within a regional context by incorporating knowledge of regional sediment trends, system relationships, and the interrelationships between dredging projects and natural resource management activities.[401] Doing so will ultimately help promote coordinated beneficial reuse projects that maximize economic efficiencies and foster more balanced, resilient ecosystems.

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[399] Massachusetts Office of Coastal Zone Management, Massachusetts Office of Coastal Zone Management: Policy Guide (Boston, MA, 2011), 57-61, http://www.mass.gov/eea/docs/czm/fcr-regs/czm-policy-guide-october2011.pdf

[400] Ibid 59

[401] Martin, L.M., *Regional Sediment Management: Background and Overview of Initial Implementation*, IWR Report 02-PS-2 (USACE Institute for Water Resources, 2002), http://www.aldenst.com/wordpress/wp-content/uploads/2017/01/RSM-Background-and-Overview-IWR_2002.pdf, 1

Restore submerged-aquatic vegetation

Underwater grasses, also known as submerged-aquatic vegetation (SAV), provide tremendous benefits for marine wildlife while also benefiting people. SAV, such as eelgrass, filters polluted runoff by absorbing nitrogen and phosphorus, supports sediment accretion, and reduces shoreline erosion by absorbing wave energy.[402] In addition, SAV can sequester and store large amounts of carbon, making it an effective carbon sink.[403] Through a pilot project in the Great Marsh, researchers with Boston University have successfully restored 2 acres of eelgrass in the Essex Bay and Plum Island Sound using a unique restoration method that builds a genetically diverse population with the adaptive capacity to resist current and future stressors. Further work should be done to restore eelgrass, including continuing and expanding efforts to control green crab and other invasive aquatic species that negatively impact SAV.

Restore degraded salt marshes

Margie Brenner/USFWS

There are many ways to improve the health and resilience of salt marshes. Anthropogenic stressors of salt marshes include tidal restrictions, filling, artificial ponding, excessive or impaired drainage, stormwater, hydrologic/salinity changes, water pollution (nutrients), structures, physical alteration, boat wakes, and invasive species; all of which can be mitigated through active restoration efforts. Identifying the best method of salt marsh restoration depends on the site and the specific impairment, and can include: removing tidal restrictions, removing fill, invasive species removal, runneling, reducing nutrients, reducing impacts of boats with wake limits and "deceleration" zones located prior to the vulnerable shoreline,[404] thin layer deposition, and restoring natural hydrology and salinity levels. All of these methods are underway to some degree in the Great Marsh and provide a solid foundation to build on.

Specifically, municipalities should work with the Great Marsh Resiliency Partnership to:

- Maintain and expand initiatives to control and eradicate phragmites control, such as those spearheaded by the Great Marsh Revitalization Task Force;[405]
- Maintain and expand the Perennial Pepperweed Control Project,[406] led by Mass Audubon, and US Fish and Wildlife Service;
- Support and participate in efforts led by the US Fish & Wildlife Refuge to monitor and address impaired hydrology for salt marsh resiliency;

402 "Eelgrass-Habitat of the Month," NOAA Habitat Conservation, http://www.habitat.noaa.gov/abouthabitat/eelgrass.html
403 "Coastal Blue Carbon," NOAA Habitat Conservation, Fhttp://www.habitat.noaa.gov/coastalbluecarbon.html
404 Small-Lorenz, S.L., W.P. Shadel, and P. Glick., *Building Ecological Solutions to Coastal Community Hazards* (Washington, DC: National Wildlife Federation, 2017), 75
405 "Great Marsh Revitalization Task Force," PIE-Rivers, http://www.greatmarsh.org/resources/scientific-studies/80-resources/95-great-marsh-revitalization-task-force
406 "Perennial Pepperweed Control Project," PIE-Rivers, http://www.massaudubon.org/learn/nature-wildlife/invasive-plants/pepperweed/project

- Plan, design, and implement the salt-marsh restoration projects including those identified within the *Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed* (see Appendix B);
- Limit further development along the marsh edges to reduce impacts and facilitate marsh migration;
- Educate, encourage, and incentivize landowners to remove debris from marsh habitat including wrack deposits trapped by municipal/private infrastructure (e.g. along causeways);
- Review, revise, and enforce boat wake limits to reduce erosion of the marsh edge;
- Strengthen volunteer and professional invasive species monitoring programs with a focus on early detection;
- Reduce nitrogen inputs to the Great Marsh Watershed.

Facilitate marsh migration

Every year coastal wetlands provide 23 billion dollars in storm surge protection services.[407] Recognizing that with no action, these wetlands will slowly drown under sea level rise, many entities in the Great Marsh (and elsewhere) are looking at how to facilitate the landward migration of salt marshes. Without a viable path to migrate, marshes can become pinched between the ocean and impermeable surfaces like roads, parking lots and buildings – and can eventually disappear, along with the systems that rely on them. As a result, any groups interested in restoring wetlands and saltwater marshes may need to become more strategic in planning for the future of these resources. Specifically, areas for future marsh migration may need to be acquired and habitats may need to be restored in advance of the migration and before development restricts their path or ability to thrive. Candidate parcels also need to be compared so that funds are allocated to the land that could provide the greatest public benefits over time. Prioritization efforts of this type can help land managers be more proactive and make significant contributions to strategic land conservation in an era of marsh migration.

To facilitate marsh migration, communities and land managers will need to employ strategic land use planning to maintain or create new paths for marshes to migrate inland. Specific strategies are to:

- Utilize the new Sea Level Affecting Marshes Model (SLAMM) analysis from MA Coastal Zone Management to inform conservation investments that will enhance marsh migration;
- Incorporate SLAMM data into town master plans, open space plans, and resource management plans where applicable;
- Incorporate marsh migration considerations into open space and conservation planning, including relevant results from the Great Marsh Adaptation Strategy Tool (MAST)[408] (see Appendix E).

Enhance land conservation efforts

Protecting land through acquisition or easements (conservation restrictions) over private property has long been understood as one of the most effective approaches to protecting natural habitats, and, by extension, reducing community vulnerability. Undeveloped lands allow for natural processes to occur without direct impact from humans. The Great Marsh region is unique in the Northeast coastal area for

[407] National Fish & Wildlife Foundation, *National Fish, Wildlife & Plants Climate Adaptation Strategy*, https://www.st.nmfs.noaa.gov/Assets/ecosystems/documents/FactSheet_econ_stats_3.pdf

[408] Merrill, S.B. and A. Gray, "MAST Modeling for the Great Marsh in Coastal Massachusetts," in *Final Report to the National Wildlife Federation* (Portland, ME: GEI Consultants, Inc. Portland, 2015), http://www.pie-rivers.org/wp-content/uploads/2015/09/Great-Marsh-MAST-Report-Final-09282015.pdf

the amount of protected open space and is the primary reason that it remains a relatively intact ecosystem. As such, a high priority should be placed on this strategy and efforts should continue to increase the amount of protected land in the region.

Specific land conservation strategies include:

- Conserve priority landscapes for habitat expansion and/or connectivity;
- Conserve coastal land areas to allow for inland migration of salt marsh due to sea level rise;
- Conserve inland landscapes more likely to flood due to climate change as well as important groundwater recharge areas;
- Conserve specific landscapes identified by the MAST planning process[409] (see Appendix E);
- Conserve specific high priority landscapes identified in local municipal Open Space Plans;
- Work with partners to incorporate best available natural resource data into municipal open space plans;
- Support regional land conservation efforts and organizations, such as the Essex County Greenbelt Association,[410] Mass Audubon,[411] Trustees,[412] and Massachusetts Fish and Game.[413]

Matt Poole/USFWS

[409] Ibid

[410] "Greenbelt: Essex County's Land Trust," http://www.ecga.org/

[411] "Land Conservation," Mass Audubon, http://www.massaudubon.org/our-conservation-work/land-conservation

[412] "Land," Trustees, http://www.thetrustees.org/what-we-care-about/land/

[413] "Land Protection Program," MA Executive Office of Energy and Environmental Affairs, http://www.mass.gov/eea/agencies/dfg/dfw/wildlife-habitat-conservation/land-acquisition-and-protection.html

Gray Infrastructure and Retrofits

Historically, concrete structures - such as seawalls, revetments, bulkheads, groins, jetties, and breakwaters – were built along the coast of Massachusetts to protect buildings and infrastructure. These hard, engineered structures – also known as "gray infrastructure" – were installed for economic, recreational, and property-protection reasons. Expensive to implement and maintain, much of this gray infrastructure is now failing and deteriorating.[414] In some cases, gray infrastructure techniques have had negative impacts on abutting areas. Bulkheads, for example, which are vertical sea walls built in high-energy settings to help stabilize the shoreline and reduce flooding, can increase erosion of adjacent areas. It has been well documented that many gray infrastructure techniques ultimately cause more damage than they prevent.[415] In contrast, natural and nature-based solutions can be more resilient, more cost-effective, and provide a range of co-benefits in addition to providing comparable levels of protection. While this will require a broad-based cultural shift in how society views physical adaptation efforts, we should strive to have traditional gray infrastructure viewed as a last resort. The following gray infrastructure strategies should however be implemented with respect to existing infrastructure to support natural resource and emergency management objectives:

Remove unnecessary dams

Ipswich River Watershed Association

Dam removal is one of the most effective ways to restore natural river processes and connectivity. Removing outdated and unneeded dams restores natural flow of water, sediments and organic materials downstream. With the structure gone, community risk of dam failure and dam owner liability is permanently removed. At the same time, upstream connectivity for aquatic migratory species (e.g. river herring, trout) is restored, upstream flood risk is reduced, and upstream flood storage capacity is restored. The cost-benefit of dam removal is site-specific and depends on many factors including owner interest, current use, dam condition and community support. Most of the dams in the Great Marsh region are relatively small structures with small impounded reservoirs (as measured by surface area and volume). None of the dams in the region were designed to function as flood control structures. Based on their design and operation they can generally be assumed to provide no flood control benefits. Identified high-priority dam removal projects include the Ipswich Mills Dam in Ipswich, the Jewell Mill Dam in Rowley, and the Larkin Mill Dam in Newbury (see Section 4.2).

Upgrade road-stream crossings

Improvements to undersized or improperly designed culverts and bridges can significantly reduce the risk of flooding and road failure during extreme storms, and can also improve river function and ecological connectivity. Crossings designed to meet the MA Stream Crossing Standards[416] are sized and placed so that they can effectively pass water and material transported by most floods and provide both upstream

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[414] MA DCR, *Massachusetts Coastal Infrastructure Inventory and Assessment Project* (Cambridge, MA, 2009), 4

[415] Gittman, R.K. et al., "Engineering away our natural defenses: an analysis of shoreline hardening in the US," *Frontiers in Ecology and the Environment* 13, no.6 (2015): 301-307, doi: 10.1890/150065

[416] MA Division of Ecological Restoration, *Massachusetts Stream Crossing Handbook* (Boston, MA, 2012), http://www.mass.gov/eea/docs/dfg/der/pdf/stream-crossings-handbook.pdf

and downstream ecological connectivity. Site-specific considerations, including presence of utilities, cost and potential effects on undersized downstream structures, need to be taken into account during the design and permitting process. In particular, communities should implement the high priority culvert and bridge improvements identified by the *Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed* (see Appendix B).

Retrofit buildings to be more flood resilient

Buildings located in areas that are likely to flood should either be moved to a safer location (reducing their exposure) or retrofitted to make them more resilient to flooding (reducing their sensitivity). Communities should encourage, pursue, and incentivize retrofits, including the following specific recommendations:

- Elevate buildings above National Flood Insurance Program (NFIP) minimums (1-3 feet of freeboard can reduce the likelihood of flooding and reduce flood insurance premiums);
- Elevate utilities to prevent flood damage if water penetrates the building;
- Seal interior conduits for water entry (e.g., electrical conduits and through-floor pipes);
- Increase the capacity of existing sump pump systems;
- Ensure critical equipment and safety systems are connected to emergency generators located in areas unlikely to flood.

Elevate roadways to prevent nuisance flooding and to withstand projected sea level rise

For this project, local knowledge, inundation modeling, and hazard monitoring were used to determine which roadways will likely need to be raised. How high each road should be raised will depend on site-specific considerations, including current and projected flooding hazards, impacts to connecting driveways, roads, and natural habitats. Municipalities should consult with regional planning commissions, the MA Department of Transportation (DOT), and MA Coastal Zone Management as they plan to raise roadways. In addition, adequate drainage should be established beneath the road and stormwater runoff should be considered. In areas where a slightly wider road would not impact surrounding habitat, a "complete street" model should be considered (where possible) to enable safe access for all users, such as pedestrians, bicyclists, and motorists, of all ages and abilities.

Specific strategies are to:

- Consult and work with transportation agencies and regional planning commissions so that all road projects take into account climate projections and best practices;
- Elevate roads as identified by town-specific recommendations (see Section 4.2)

Pursue retrofits and planning for Massachusetts Bay Transportation Authority railroad

The Newburyport to Boston commuter rail line is a major public infrastructure bisecting four of the six coastal towns in this study (Newburyport, Newbury, Rowley, and Ipswich). The vast majority of the line is a constructed causeway built on filled land across the saltmarsh with dozens of culverts and bridges. The railroad causeway restricts natural hydrology, which can negatively impact surrounding salt marsh. Simultaneously, the railroad also protects coastal communities from flooding by acting as a storm surge barrier. Specific strategies to restore the natural hydrology surrounding the railroad without compromising its protective services include working with the Massachusetts Bay Transportation Authority (MBTA) to prioritize retrofits and upgrade projects for the Newburyport Commuter Rail Line that would help restore surrounding, degraded salt marsh in areas identified within the Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed (see Appendix B).

University of Florida

Land-Use Planning and Policy

Municipal land use planning is typically guided by an array of policies and regulations that ensure any development that occurs is in the best interest of the community and doesn't cause undo harm to important natural resources. From zoning and wetland bylaws to incentives and tax breaks, communities have a wide variety of existing tools at their disposal to guide development and land use. With sea level rise and other climate-driven threats accelerating, communities are beginning to adopt new land use policies that specifically target climate-driven threats. These strategies can incentivize climate-smart development practices, prohibit development in flood prone areas, or create market-based systems that over time move development away from coastal hazards. The adoption of climate-smart policies can dramatically reduce community vulnerability, however they require fairly substantial political will and buy-in from decision makers and residents. Successful adoption of new policies and bylaws will often require extensive outreach and education ahead of time.

It is important to note that municipal regulations and policies must fall within the bounds of state law, and as such some desirable municipal policies that have been adopted in other states may not be legal in Massachusetts. Recognizing this fact, the Project Team compiled a list of adaptation policies and regulations from around the country; however, this report is intentionally highlighting policies and strategies that have already been implemented in Massachusetts, or have been recommended by Massachusetts state agencies. If and when state laws are amended, a broader range of policies may become available to communities in the Great Marsh Region.

Update municipal policies

Communities should require that all major capital projects take into account sea level rise, more extreme precipitation patterns, and coastal erosion (where applicable). Using the best available science, the placement and design of public infrastructure should incorporate an assessment of likely impacts from these coastal hazards based on the life-span of the infrastructure. For example, a culvert with a lifespan of 25 years should be designed to withstand projected increases in precipitation over the next 25 years. A building along the coastline might be expected to have a 100 year lifespan, and in that case the placement and design should take into account 100 years of sea level rise. This will help ensure that municipal investments in infrastructure and land use planning are long lasting and in the best interest of the overall community.

Prioritize low-impact development (LID) practices

Particularly in locations where storm drains may be overwhelmed by high water due to sea level rise or flood waters[417], communities should be implementing LID principles and practices. By doing so, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed. There are many practices that have been used to adhere to low impact development principles, including bio-retention facilities, rain gardens, vegetated rooftops, rain barrels, and permeable pavement.

[417] California Emergency Management Agency, *California Adaptation Planning Guide: Identifying Adaptation Strategies* (Mather, CA, 2012), 54, http://resources.ca.gov/docs/climate/APG_Identifying_Adaptation_Strategies.pdf

Revise local wetlands protection bylaws and regulations

Strong, innovative, and comprehensive wetland regulations are one of the most effective broad-based tools that communities have to reduce community risk. Massachusetts is unique nationally to the degree it regulates wetland resources, allowing municipal wetlands protection bylaws that include management measures that improve community resiliency. The wetland resource areas as defined by state and local law can encompass the full extent of areas impacted by coastal storms and flooding. Great Marsh communities should:

Abby Manzi/DeRosa Environmental Consulting, Inc.

- Update or create local wetland protection bylaws to account for sea level rise and increased inland flooding with a focus on increased buffer zone protection, including maximizing no-disturb and no-build zones (e.g. Ipswich wetlands regulations[418]);
- Implement floodplain use regulations (e.g. Rowley floodplain regulations[419]).

Move development away from the coast and from wetlands

Along with revising wetlands bylaws, coastal communities need to actively work to move development away from the coast and wetlands. Several communities in Massachusetts serve as good models for this work. As presented in a recent NOAA-funded report entitled *Cost-Efficient Climate Change Adaptation in the North Atlantic*,[420] the Town of Brewster recently implemented a 35-foot setback from wetlands and a 50-foot setback from coastal areas, specifically referencing sea level rise, erosion, and storm damage as justification. The Town of Chatham created a bylaw establishing a conservancy district that encompasses all land within FEMA's 100 year floodplain and that delineates three associated activities in those land areas: permitted uses, special permit uses, and prohibited uses.[421]

Learning from these examples, communities in the Great Marsh should:

- Review existing zoning bylaws and conservancy districts, enhancing them where necessary, and ensure consistent enforcement is occurring;
- Establish setbacks and buffers as outlined in the *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use*[422] report (Table 4.12) and using models from the Town of Brewster's regulations.

418 "Regulations and Policies," Town of Ipswich, MA, http://www.ipswichma.gov/259/Regulations-Policies
419 Town of Rowley, MA, *Rowley Protective Zoning Bylaw* (2013), http://www.townofrowley.net/pdf/130611%20Zoning%20ALL.pdf
420 Schechtman, J. and M. Brady, *Cost-Efficient Climate Change Adaptation in the North Atlantic* (New Brunswick, NJ: Rutgers University, 2013), 62, http://www.regions.noaa.gov/north-atlantic/wp-content/uploads/2013/07/CEANA-Final-V11.pdf
421 Shaw, W., *Case Study – A Cape Cod Community Prevents New Residences in Floodplains* (Boston, MA: MA CZM, 2008), http://www.mass.gov/eea/docs/czm/stormsmart/ssc/ssc3-chatham.pdf
422 Grannis, J., *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use* (Washington, DC: Georgetown Climate Science Center, 2001), 26, http://www.georgetownclimate.org/files/report/Adaptation_Tool_Kit_SLR.pdf

Table 4.1-2. Example mechanisms for establishing setbacks and buffers.[422]

Mechanism	Description
Fixed mandatory	Require that all structures, including sea walls, be set back a specific distance from a predetermined point (e.g., 100 feet from the mean high tide line or the vegetation line)
Erosion-based	Determined by a projected shoreline position that assumes a specific increase in sea level and erosion rates over a specific time frame such as the life of the structure (e.g., 60 times the annual rate of erosion)
Tiered	Require a lesser setback or buffer for smaller structures and a greater setback for larger structures that are more difficult to move if they become damaged and put more people at risk.

Create "freeboard incentive" for residential and commercial buildings

Freeboard refers to elevating the bottom of a building above minimum height requirements laid out by the National Flood Insurance Program.[423] Building higher than what is mandated can help protect buildings from anticipated increases in coastal and freshwater flooding. Including freeboard also dramatically lowers flood insurance premiums. The Town of Hull, MA, adopted a freeboard incentive that reduces building department application fees by $500 if an elevation certificate is provided to verify that the building is elevated a minimum of two feet above the highest federal or state requirement for the flood zone.[424] While this incentive might not seem very large, it has proved fairly successful in increasing the number of new buildings that incorporate freeboard. Great Marsh communities could benefit greatly from implementing a freeboard incentive similar to that adopted by the Town of Hull.

Use transferable development credits to reduce risky coastal development

Transferable development credits (TDCs), also referred to as transferable development rights (TDRs), is a market-based approach to discourage development in one area (for example an area vulnerable to coastal hazards) and encourage development in another more suitable location. As outlined in the *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use*,[425] municipalities can utilizing zoning ordinances to encourage development in designated "receiving areas" and discourage development in "sending areas". Credits "monetized by the level of development the base zoning ordinance would allow" are then bought and sold, allowing development in the receiving area to exceed typical zoning regulations (i.e. the developer can build taller or more densely than would otherwise be allowed). Property owners in the sending areas then receive "financial compensation for forgoing development and preserving his or her property." In order to ensure "property in the sending area is conserved, a permanent conservation easement is recorded against the sending property in conjunction with the sale of the development credit."[426]

In Massachusetts, The Executive Office of Energy and Environmental Affairs published two model TDC/TDR bylaws as part of their Smart Growth/Smart Energy Toolkit.[427] One model bylaw "relies heavily on restrictions in sending areas as a disincentive to developing those lands, while the other relies more on bonuses in receiving areas as an incentive to looking elsewhere for higher economic gain."[428]

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423 "Freeboard," Federal Emergency Management Agency (FEMA), https://www.fema.gov/freeboard
424 Schechtman, J. and M. Brady, *Cost-Efficient Climate Change Adaptation in the North Atlantic*, 68
425 Grannis, J., *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use*, 57-59
426 Ibid
427 "Smart Growth/Smart Energy Toolkit," MA EEA, http://www.mass.gov/envir/smart_growth_toolkit/bylaws/TDR-Bylaw.pdf
428 MA EEA, *Smart Growth/Smart Energy Toolkit Bylaw: Transfer of Development Rights* (Boston, MA), 2, http://www.mass.gov/envir/smart_growth_toolkit/bylaws/TDR-Bylaw.pdf

While this strategy is described relatively succinctly and may seem straightforward, it is in fact one of the more complicated policy strategies to prevent or disincentive risky coastal development. It combines municipal policy changes along with the creation of market-based credits that can be purchased and sold. While it is an effective strategy, communities should be aware of the complexities associated with implementing a TDC/TDR program.

Institute comprehensive water resources management

The way in which human society has disrupted the natural water cycle is among the largest anthropogenic stressors on the natural world. The built environment often increases flooding, exacerbates drought, and disrupts the water cycle. Stormwater and wastewater are the one of the greatest threats to clean water in the United States and our region.[429] Water withdrawals for domestic, landscaping, and agricultural use dramatically affect both surface and groundwater hydrology. Historically, society has dealt with these interconnected and related issues separately, thereby exacerbating the problem and multiplying their negative impacts. Comprehensive water resources management is an effective tool to minimize these impacts on the environment while increasing the resiliency of human society.

To achieve comprehensive water resources management, Great Marsh communities and their partners should pursue the following activities:

Stormwater

- ☐ Implement EPA stormwater regulations[430] and monitor implementation progress;
- ☐ Expand local stormwater regulations to all areas of coastal communities outside of the mandatory EPA-regulated areas;[431]
- ☐ Incorporate and adopt CZM's *Assessment of Climate Change Impacts on Stormwater BMPs and Recommended BMP Design Considerations in Coastal Communities*;[432]
- ☐ Prioritize the identification and elimination of illicit discharges to municipal storm drain systems.

Wastewater

- ☐ Implement septic system management programs in each community;
- ☐ Pursue tertiary treatment for municipal and private wastewater plant discharges with a focus on reducing nitrogen and phosphorous discharges, including but not limited to the Town of Salisbury's discharge to the Merrimack River, the City of Newburyport's discharge to the Merrimack River, Governor's Academy's discharge to the Mill River in Newbury, and the Town of Ipswich's discharge to Greenwood Creek);
- ☐ Review all permitted point sources of pollution under the National Pollution Discharge Elimination System[433] (NPDES) and seek conditions to minimize their impact to the environment;

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[429] "Soak Up the Rain: What's the Problem?," EPA, https://www.epa.gov/soakuptherain/soak-rain-whats-problem
[430] "NPSED Stormwater Permit Program in New England," EPA, https://www.epa.gov/npdes-permits/npdes-stormwater-permit-program-new-england
[431] "Regulated MS4 in Massachusetts Communities,: EPA, https://www.epa.gov/npdes-permits/regulated-ms4-massachusetts-communities
[432] "Report on Climate Change Impacts to Coastal Stormwater Best Management Practices (BMPs)," MA CZM, http://www.mass.gov/eea/agencies/czm/program-areas/coastal-water-quality/cpr/climate-change-stormwater-bmps.html
[433] "Regulated MS4 in Massachusetts Communities,: EPA, https://www.epa.gov/npdes-permits/regulated-ms4-massachusetts-communities

- Increase frequency of the Massachusetts Division of Marine Fisheries estuarine Shoreline Surveys (to identify pollution sources) and expand surveys to first order freshwater streams;
- Implement boatyard and marina waste management[434] and expand/maintain boat pump-out programs.[435]

Public Drinking Water

- Pursue sustainable development without increasing overall water demands;
- Use the Net Blue Ordinance Toolkit[436] to develop water-neutral growth ordinances to either require or incentivize residential and commercial developments to offset their projected additional water demand through water-efficient retrofits of existing development;
- Implement comprehensive enhanced water conservation measures in each community;
- Broaden regional and town-specific water conservation outreach programs utilizing existing programs such as the Greenscapes North Shore Coalition[437] and others;
- Change local rate structures to de-incentivize the sale of non-essential water;
- Implement local bylaws to regulate private wells consistent with regulated municipal withdrawals, using Massachusetts Rivers Alliance resources[438] and bylaws in neighboring towns (Ipswich, Topsfield, and Wenham) as a model;
- Work with stakeholders to implement sustainable water management regulations at the state level to cover all water withdrawals.

Outreach and Engagement

As outlined elsewhere in this report, maximizing the resiliency of the communities and ecosystems of the Great Marsh will require collaboration, coordination, and funding over a sustained period. Communities should work in collaboration with neighboring communities, citizens groups, and regional partners to increase public awareness of climate-driven threats and solutions through implementation of a comprehensive, coordinated program. In addition, it will be incredibly important to get support from the general public and municipal officials in order to success in implementing resiliency and adaptation strategies. Therefore, municipalities and their regional partners should:

Develop municipal strategies for enhanced outreach and education

Individual communities should develop and enhance municipal education and outreach initiatives by these strategies among others:

- Identifying trusted neighborhood and citizens groups (such as Storm Surge or the Salisbury Beach Citizens for Change) to champion awareness of climate-driven threats and solutions to their unique audiences;
- Educating and reaching out to all sectors of the community, including cross-sector outreach initiatives with realtors, emergency management officials, public health workers, and business associations, among others;

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[434] "Marina Management – Massachusetts Office of Coastal Zone Management," MA CZM, http://www.mass.gov/eea/agencies /czm/program-areas/coastal-water-quality/marina-management/

[435] "Clean Boating – Massachusetts Office of Coastal Zone Management," MA CZM, http://www.mass.gov/eea/agencies/czm/ program-areas/coastal-water-quality/clean-boating/

[436] "Net Blue: Supporting Water-Neutral Community Growth," Alliance for Water Efficiency, http://rivernetwork.us9.list-manage.com/track/click?u=37451e588b04a942f75ed66d3&id=d516bfeabe&e=806966bd0a

[437] "Landscapes for Clean and Plentiful Water," Greenscapes Massachusetts North Shore Coalition, http://greenscapes.org/

[438] "Resources," Massachusetts River Alliance, http://massriversalliance.org/resources/

- Using traditional and innovative media with informative content for public consumption;
- Developing high-visibility interpretative signage and installations in prominent public locations such as the Essex Causeway, the Newburyport Waterfront, and the Ipswich River Walk;
- Working with student groups, teachers, schools, and parents to educate and engage them in climate awareness programs, including adaptation strategies they can participate in on both private and public properties.

Strengthen existing regional outreach and education programs

Regional partners working in the Great Marsh should enhance collaborative outreach efforts across the region, including:

- Supporting and expanding the work of the Great Marsh Coalition,[439] including the Great Marsh Symposium, and developing messaging to reach broader audiences;
- Supporting the efforts of the Gulf of Maine Institute's Climate Café programs;[440]
- Expanding the efforts of Storm Surge,[441] the Merrimack Valley Coastal Adaptation Workgroup;
- Promoting the valuation of ecosystem services and functions and publicize the environmental, economic, and social benefits of doing so (triple bottom line);
- Expanding individual organizational outreach efforts, such as those run by Mass Audubon,[442] PIE-Rivers Partnership,[443] and others, to include a more specific focus on the recommendations of the *Great Marsh Coastal Regional Adaptation Plan*, including emphases on nature-based solutions.
- Promoting the valuation of ecosystem services and functions and publicize the environmental, economic, and social benefits of doing so (triple bottom line).

Support and develop opportunities for citizen science

There are few better ways for the general public to develop a sense of ownership of resiliency efforts than by directly engaging them in citizen science projects. There are many opportunities that currently exist in the Great Marsh and that could be further developed, including:

- Expanding use of the "MyCoast Massachusetts" web site[444] to document flooding and erosion;
- Establishing citizen groups on Plum Island to help track and document erosion rates;
- Engaging more local residents in the University of New Hampshire habitat restoration work[445] on the barrier beaches;
- Support and expand environmental education programs for K-12 students, such as those offered by Mass Audubon's Joppa Flats Education Center[446] and Ipswich River Wildlife Sanctuary;[447]

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439 The Great Marsh Coalition, http://www.greatmarsh.org/
440 "Climate Cafe," Gulf of Maine Institute, www.gulfofmaineinstitute.org/climatecafe
441 Storm Surge, https://storm-surge.org/
442 "Addressing the Challenges of Climate Change," Mass Audubon, www.massaudubon.org/our-conservation-work/climate-change
443 Parker-Ipswich-Essex Rivers Restoration Partnership, www.pie-rivers.org
444 "MyCoast: Massachusetts," MA CZM, https://mycoast.org/ma
445 "Coastal Habitat Restoration," University of New Hampshire, New Hampshire Sea Grant, https://seagrant.unh.edu/Coastal-HabitatRestoration
446 "Joppa Flats Education Center," Mass Audubon, http://www.massaudubon.org/get-outdoors/wildlife-sanctuaries/joppa-flats/programs-classes-activities/schools-groups/schools
447 "Ipswich River Wildlife Sanctuary," Mass Audubon, http://www.massaudubon.org/get-outdoors/wildlife-sanctuaries/ipswich-river/programs-classes-activities/schools-groups/schools

- Maintaining and expanding the Great Marsh Revitalization Task Force[448] invasive *Phragmites* control program;
- Maintaining and expanding the Perennial Pepperweed Control Project,[449] led by Mass Audubon, and US Fish and Wildlife Service;
- Expanding the RiverWatch Volunteer Monitoring Program;[450]
- Assessing and creating additional Citizen Science programs

Implementation of the strategies identified within these five categories (Best Practices, Natural and Nature-based Strategies, Gray Infrastructure and Retrofits, Land-use Planning and Policy, and Outreach and Engagement) will require ongoing regional collaboration among local municipalities and regional or state partners. However, it should be noted that in Massachusetts, local municipalities have almost complete control over land use planning. As such, action must happen at the local level and through cross-town collaboration. Local communities have primary control over the fate of the Great Marsh and its ability to provide risk-reduction services for the region.

Matt Poole/USFWS

[448] "Great Marsh Revitalization Task Force," The Great Marsh Coalition, http://www.greatmarsh.org/resources/scientific-studies/80-resources/95-great-marsh-revitalization-task-force
[449] "Perennial Pepperweed Control Project," Mass Audubon, http://www.massaudubon.org/learn/nature-wildlife/invasive-plants/pepperweed/project
[450] "RiverWatch Volunteer Monitoring Program," Ipswich River Watershed Association, http://www.ipswichriver.org/riverwatch/

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4.2. Town-specific Strategies and Recommendations

This section highlights specific adaptation strategies and recommendations for the town-specific assets and areas of concern identified in Chapter 3: *Assessing Climate Impacts and Vulnerabilities*. The following town-specific strategies and recommendations were generated across three stages. To begin, the Project Team worked with the Municipal Task Forces to create a catalog (hereinafter “adaptation catalog”) of over 90 potential adaptation options that communities could use to address vulnerabilities of specific assets, as well as more general coastal vulnerabilities and climate-related threats. A wide-range of physical and non-physical tools, strategies, and approaches applicable to the Great Marsh Region were explored and organized into categories. With the adaptation catalog in hand, the Project Team worked with the Municipal Task Forces, regional agencies, and NGO partners to evaluate the range of strategies based on those likely to (a) be most effective, (b) provide the most co-benefits, and (c) be operationally feasible from a social, technical, financial, and regulatory perspective. These strategies were further vetted through direct consultation with individuals and entities with professional and technical expertise in the planning, design, and implementation of adaptation strategies in the Great Marsh geography.

The following town-specific strategies and recommendations outlined below describe each Vulnerable Area of Concern (as identified by the Task Forces; ◊ = Within the Great Marsh Area of Critical Environmental Concern (ACEC)), Short-term Adaptation Strategies (now-2030), and Long-term Adaptation Strategies (2030-2070; inclusive of Short-term Adaptation Strategies).

4.2-1. TOWN OF SALISBURY: Adaptation Strategies and Recommendations for Selected Areas of Concern

Route 1A (Beach Road)

Location: Intersection with North End Blvd and west 0.5 miles.
Description of hazard: Tidal flooding and storm surge, especially around 191 Beach Road. Coastal inundation of marsh/back bay. Beach Road traps flood waters from dispersing across marsh.
Consequences of hazard: Flooding blocks the only evacuation route from the beach to the center of town. There is an alternate route via Route 286 thru Seabrook but Salisbury has no control of that route. The population of the beach is approx. 4000 year-round residents which swells to 20,000 in summer months, plus 1000s of daily visitors.
Existing efforts underway: The town has discussed the flooding and consequences with the Army Corps of Engineers and Mass DOT for studies to possibly raise Beach Road, but no funding for such studies or projects has materialized.

Short-term Strategies (now-2030)

- Remove debris from marsh and dunes along the causeway to increase resiliency of marsh (focus on natural debris which is trapped by structure and currently smothers marsh).
- Create early warning system to alert residents when the road is likely to be flooded or is flooded.
- Monitor flood frequency and depth to help with future road planning efforts.
- Coordinate with state DOT that manages this road to complete studies to possibly raise road.
- Require any road redesign to take climate change into consideration; explore green redesign, such as sustainable "Complete Streets."[450]
- Investigate option of improving culverts & removing tidal restriction on adjacent Old County Road to improve drainage.
- Explore green infrastructure opportunities throughout abutting properties and neighborhoods, such as bioswales and rain gardens.

Long-term Strategies (2030-2070)

- Working with the State, raise road, build bridge, and/or add culvert(s) to reduce flooding and establish flow under roadway to restore hydrology and increase natural resiliency of marsh.

Salisbury Beach at Broadway *continued on next page*

Location: East of Broadway Mall, stretching 200ft north and south
Description of hazard: Chronic and storm-related erosion; storm surge flooding.
Consequences of hazard: Intersection is not drivable during peak of flood; requires access via Route 286 in northern part of town. Debris cleanup and maintenance from storms is regular and costly to town.
Existing efforts underway: MA DCR recently acquired land (a former building site, just south of Beach Center) to enlarge beach area to compensate for erosion from storms. Dune nourishment and sand fencing underway. Boardwalk above dunes is being built.

Short-term Strategies (now-2030)

- Continue public acquisition of land for open space, if/when available, and installation and restoration of dunes.
- Continue dune grass planting & fencing.
- Local enforcement of existing state barrier beach regulations.
- Create freeboard incentive.

[450] National Complete Streets Coalition, *Implementing Complete Streets: Sustainable Complete Streets* (Washington, DC) https://smartgrowthamerica.org/app/uploads/2016/08/cs-greenstreets.pdf

- Educate property owners on projected sea level rise estimates and adaptation strategies, including the benefits of freeboard as well as specific building retrofits Engage with town staff, committees, residents, and business owners including Salisbury Beach Partnership, Merrimack River Beach Alliance, and the "Project for Public Spaces" to assure that long-term climate projections are being incorporated into the effort to redesign Broadway Mall.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the beach and associated infrastructure located along and directly behind the beach.
- Explore incorporating natural features and a seawall to enhance flood protection.

Low-lying Houses along the Salt Marsh west of Salisbury Beach

Location: Multiple neighborhoods abutting salt marsh north and south of Beach Road, including Cable Avenue neighborhood east of the road to Salisbury Reservation, and homes along 9th, 10th, 11th, 12th, Florence, and Lewis Avenues west of North End Boulevard.
Description of Hazard: Current & projected coastal inundation. Regular flooding from Blackwater River north of Beach Road and from Black Rock Creek south of Beach Road.
Consequences of hazard: Flooded houses and impacts to health of salt marsh.
Existing efforts underway: 3-4 foot high sheet pile sea wall has been recently built along neighborhood near 11^{th} and 12^{th} Avenues.

Short-term Strategies (now-2030)

- Property owner education, including the benefits of freeboard as well as specific building retrofits such as installing backflow valves on sewer drains, elevating utilities to prevent flood damage, and breakaway walls to prevent structure collapse during storm surge.
- Create municipal freeboard incentive (see Hull case study) & state freeboard policy/regulations.
- Establish conservancy district - zoning overlay to prevent future development in flood-prone areas and to create a permanent buffer between development and flooding (see Chatham case study.)
- Investigate whether restoring more natural tidal exchange through culvert improvements along State Reservation Road would decrease or increase flood risk in the Cable Ave neighborhood.
- Improve resilience of surrounding salt marsh by mapping and maintaining blocked ditches.

Long-term Strategies (2030-2070)

- Consider rolling easements to facilitate planned retreat: Town or state pays some amount to landowners in vulnerable locations today; when house eventually floods, town takes ownership.

US Route 1 & Associated Infrastructure *continued on next page*

Location: At Town Creek & surrounding area.
Description of hazard: Tidal flooding, culvert is small and in need of repair.
Consequences of hazard: Floods road cutting off primary transportation corridor. Floods businesses causing economic harm. Tidal restriction at Route 1impacts marsh; could be contributing to its degradation.
Existing efforts underway: Tide gate installed a few years ago at nearby bike path crossing (downstream of Route) has dramatically reduced flooding of Route 1 while improving tidal conditions.

Short-term Strategies (now-2030)

- Restore hydrology where possible after considering potential upstream impacts. Conceptual design for improved crossing at Route 1 was developed as part of this project.
- Engage/educate business community about current/future risk and adaptation options.
- Encourage landscaping techniques for stormwater mitigation, e.g. rain gardens, pervious walkways & patios, infiltration trenches, and other green infrastructure techniques.

US Route 1 & Associated Infrastructure continued

- Provide part-time flood storage through open space planning.
- Renovate or retrofit buildings for resiliency.

Long-term Strategies (2030-2070)

- Raise road and establish flow under roadway to restore hydrology and increase natural resiliency of marsh.
- Use Ferry Road and Railroad bed for temporary tidal protection - evaluate if feasible.
- Incorporate climate projections into long-term planning.
- Move businesses to other business centers in town (Salisbury Square, Route 110) and demolish Route 1 buildings.

March Road, First Street, and Ferry Road

Description of hazard: Tidal flooding at two separate culverts (March Road and First Street), culverts are small & in need of repair. A separate tidal connection at Ferry Road is also restricting tidal exchange and is in disrepair.
Consequences of hazard: Floods yards, has flooded Ferry Road & homes. Tidal restrictions are degrading the marsh. Scouring is visible at Ferry Road culvert.
Existing Efforts Underway: Tidal restriction may provide some protection to low lying houses and businesses upstream. High restoration potential identified in the Great Marsh Plan Rapid assessment and tidal survey conducted in 2005.

Short-term Strategies (now-2030)

- Conduct comprehensive assessment of Ferry Road culverts and elevation as a potential means to mitigate this hazard.
- Upgrade March Road and First Street culverts.
- Implement marsh restoration plan.

Long-term Strategies (2030-2070)

- Monitor and continue marsh restoration efforts as needed.

4.2-2. CITY OF NEWBURYPORT: Adaptation Strategies and Recommendations for Selected Areas of Concern

Plum Island Turnpike◊ *continued on next page*

Location: Joppa Flats Nature Center east to Sunset Drive.
Description of hazard: Tidal and storm-driven roadway flooding, ice cakes, high winds, zero visibility during nor'easters.
Consequences of hazard: Road closure and access to and from the island is cut off.
Existing efforts underway: Hydrodynamic sediment transport model is focusing on the PI Turnpike area, including Bascule Bridge, to better understand water and sediment flow in this area. The Great Marsh Plan identifies degraded salt marsh south of PI Turnpike near the Plum Island Airport; potential for salt marsh restoration here and other locations in this area.
Additional Notes: Newburyport & Newbury are both affected. Turnpike traps flood waters from dispersing across marsh. Need joint solution as issues and solutions are common.

Short-term Strategies (now-2030)

- Recognizing shared vulnerability, create joint Newbury and Newburyport working group to address these issues.
- Create early warning system to alert residents when the road is likely to be flooded or is flooded.
- Monitor flood frequency and depth to help with future road planning efforts.
- To increase public safety, install plastic road reflectors to show the road during storms when it's flooded and/or during blizzards.

Long-term Strategies (2030-2070)

- Raise road elevation based on detailed analysis of current and future conditions.
- Develop long-term master plan for Plum Island and redesign road accordingly, taking climate change into consideration.

Waste Water Treatment Facility

Location: 157 Water Street
Description of hazard: Flooding from storm surge and sea level rise. Critical equipment located just above 100-year flood elevation. Could be inundated by sea level rise alone.
Consequences of hazard: Flooding of the facility could have catastrophic impacts across the community.
Existing efforts underway: Is a priority focus for the Newburyport Resiliency Committee

Short-term Strategies (now-2030)

- Elevate critical utilities.
- Flood-proof areas of the facility likely to flood.
- Pursue a feasibility study to assess the effectiveness of a seawall and/or berm with natural components to protect the facility.
- Consider living shoreline to attenuate wave energy.
- Assess the impacts if the outflow is to become entirely submerged/flooded.
- Have temporary inflatable berm available for deployment during storms.

Long-term Strategies (2030-2070)

- Plan for relocation.

North End of Plum Island *continued on next page*

Location: Reservation Terrace & Old Point neighborhood
Description of hazard: (1) Projected coastal inundation and (2) beach/dune erosion. Flooding when river basin is full of trapped flood waters & particularly during storms with W/NW winds. Erosion along Reservation Terrace.
Consequences of hazard: Flooding of heavily populated bayside neighborhoods, erosion threatens populated ocean-front neighborhoods.
Existing efforts underway: City received 2016 CZM Resiliency grant to address erosion from foot traffic over the dunes. Has conducted dune nourishment and installed sand fencing.

Short-term Strategies (now-2030)

- Continue installation & maintenance of sacrificial dunes.
- Continue dune grass planting & fencing.
- Reduce foot traffic on dunes.
- Ensure local enforcement of existing state barrier beach regulations.
- Create municipal freeboard incentive (see Hull case study).
- Review, evaluate, and revise Plum Island zoning and regulations using new climate projections.
- Explore instituting a voluntary buyback and financing program.
- Continue to work with Department of Conservation and Recreation and the Merrimack River Beach Alliance to closely monitor storm damage and erosion rates within the Reservation Terrace dune system to support decisions regarding dune protection and potential emergency response actions.
- Develop an emergency response plan for potential inundation of Reservation Terrace during extreme storm damage and erosion events.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the beach and associated infrastructure located along and directly behind the beach.
- Consider planned retreat.

Business Park

Location: 104 Parker Street/Scotland Road.
Description of hazard: Flooding from the Little River exacerbated by stormwater runoff. The hydraulic capacity screening model shows poor performance of crossings at Scotland Road and Hale Street as well as a few other crossings on tributaries to the Little River within the Business Park.
Consequences of hazard: Flooding could disperse on-site hazardous materials and can cut off access to and from businesses.
Existing efforts underway: City is coordinating with Newbury on barrier assessments (entire Little River watershed) & flood resiliency planning. Newburyport is planning replacement of the culvert at Scotland Road. This project is developing conceptual designs for the replacement of two at-risk crossings at Hale Street.
Additional Notes: Newburyport & Newbury are affected.

Short-term Strategies (now-2030)

- Business owner engagement and education
- Review possible building retrofits including drop-in flood barriers & longer term flood proofing.
- Install improved culverts where needed to restore hydrology and reduce flooding. Create flood-storage opportunities through open space planning.
- Consider creating a city-wide stormwater utility & implement BMPs across the Business Park.
- Ensure updated emergency response plans for dealing with chemicals on site if flooding occurs
- Encourage/require Low Impact Development standards for any new buildings or upgrades.
- Plant trees that are particularly well suited to absorbing water (such as willows).

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the Business Park and associated access routes.
- Renovate for resiliency.

Lower Artichoke Reservoir *continued on next page*

Location: Between Storey Ave & Middle Rd.
Description of hazard: Salt-water intrusion. The Mother's Day Storm of 2006 caused the Merrimack River to reach the top of the dam at the Lower Artichoke Reservoir and almost contaminated the public water supply with pollutants and saltwater. An equal or more intense storm, combined with sea level rise, could result in a breach of the water supply.
Consequences of hazard: Would contaminate the city's drinking water supply.
Existing efforts underway: Proposed FY18 budget has a Capital Improvement Project to fund a feasibility study to determine if this dam should be raised or if improvements should be made to another dam downstream of this one.

Short-term Strategies (now-2030)

- Raise the elevation of the dam to prevent overtopping.
- Assess additional possible breach points.
- Increase flood-storage options using surrounding natural area.
- Install overflow pumping.
- Control new development projects to be water neutral so as not to increase water demand.
- Set up monitoring and response plan to deal with a possible breach and the influx of contaminants from the Merrimack River.

Long-term Strategies (2030-2070)

- Pursue new and additional drinking water supplies, particularly new groundwater supplies (i.e. wells) that are not hydrologically connected to the Artichoke or Bartlett Spring Pond.

Bartlett Spring Pond

Location: 742 Spring Ln
Description of hazard: Salt-water intrusion. Safe from near-term sea level rise, however ancillary structures and the piping network may be vulnerable to sea level rise and will need to be evaluated further.
Consequences of hazard: Would contaminate the city's drinking water supply.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Set up monitoring and response plan to deal with a possible breach and the influx of contaminants from the Merrimack River.
- Raise the road which rests on a natural floodwall (berm).
- Enhance existing berm, raising and terracing it while also including a drainage outlet.

Long-term Strategies (2030-2070)

- Pursue alternative drinking water supply and new back-up or emergency water supplies, particularly new groundwater supplies (i.e. wells), that are not hydrologically connected to the Artichoke or Bartlett Spring Pond.

Central Waterfront *see also Water Street & Cashman Park categories*

Location: East of Merrimac/Water Street, between Green Street and the Harbor Master Shack.
Description of hazard: Flooding during astronomical tides that coincide with multi-day storm events. . Storm surge on ocean raises sea level above river, not allowing river to discharge. Plum Island Turnpike & Beach Rd in Salisbury trap/concentrate flood waters.
Consequences of hazard: Waterfront and park become inaccessible. Flooding at the Rivers Edge condos well as waterfront businesses**.** Over time, usefulness of parks will be impacted & businesses may be significantly impacted.
Existing efforts underway: City is currently in the planning phase of redevelopment, including exploring raising the elevation of the park and associated parking lots.

Short-term Strategies (now-2030)

- Engage and educate central waterfront committees, associations, property owners, waterfront trust and redevelopment authority so that future development/planning incorporates climate projections.
- Raise the ground elevations of the park and parking lots.
- Create flood-storage opportunities/dual purpose parking lots.
- Review possible building retrofits including drop-in flood barriers & longer term flood proofing.
- For large businesses, consider additional retrofits such as sealing interior conduits for water entry, elevating utilities, installing backup generator.
- Incentivize climate-smart development away from flood-prone areas; consider Transfer of Development Credits to create a "sending" and "giving" area.

Long-term Strategies (2030-2070)

- Renovate for resiliency or demolish.
- Consider raising seawall coupled with new flood walls at open end of streets - should include natural components.

Water Street (part 1)

Location: Junction of Water and Union St. to Ocean Ave
Description of hazard: Coastal & freshwater flooding. Road is too low & floods during storms with rain and E/NE winds.
Consequences of hazard: Road becomes impassable.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Resident/business owner engagement and education.
- Investigate benefits of establishing a natural living shoreline/offshore reef to attenuate wave energy.
- Consider a hybrid living shoreline to reduce flooding and reduce erosion.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning.
- Raise buildings and the road.
- Raise seawall coupled with new flood walls at open end of streets.

Water Street (part 2)

Location: Seawall, Joppa Park Boat Ramp, Hale Park area to Union St.
Description of hazard: Coastal inundation during storms. During storms, water splashes over the seawall, becoming trapped and flooding residences. Sedimentation along Joppa park has attenuated wave energy a bit, as has marsh grass that has begun to establish itself in front of the seawall.
Consequences of hazard: Flooded residences, roads, and potential property loss.
Existing efforts underway: Seawall is in disrepair and needs to be updated/replaced. Town has set aside limited funds for this.

Short-term Strategies (now-2030)

- Resident/business owner engagement and education.
- Install openings (or scuppers) in the seawall to allow water to drain back into river after it splashes over.
- Investigate benefits of establishing a natural living shoreline/reef offshore.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning.
- Raise seawall coupled with new flood walls at open end of streets.

Cashman Park

Location: Cashman Park, west-northwest of waterfront
Description of hazard: Flooding during astronomical tides that coincide with multi-day storm events. Storm surge on ocean raises sea level above river, not allowing river to discharge. Plum Island Turnpike & Beach Rd in Salisbury may also trap flood waters.
Consequences of hazard: Waterfront and park become inaccessible due to flooding. Rivers Edge condos flood as well as waterfront businesses.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Consider living shoreline to replace existing armored shoreline. Presents a good opportunity due to its high visibility and open area.
- Explore incorporating drainage improvements to speed up removing flood waters after storms.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning.
- Raise the fields, but keep it an open space.

Plum Island & Beach

Location: Barrier beach and dunes along Plum Island.
Description of hazard: Erosion on beach shore and on northern river shore near jetties. Retreating shoreline is encroaching on residences. The ocean shore seems to erode when the Merrimack River Jetty degrades, and the inside river shore erodes when the jetty is repaired.
Consequences of hazard: Erosion threatens residential houses, impacts beach access, and results in loss of critical wildlife habitat.
Existing efforts underway: City is in communication with Army Corps of Engineers to address erosion issues.

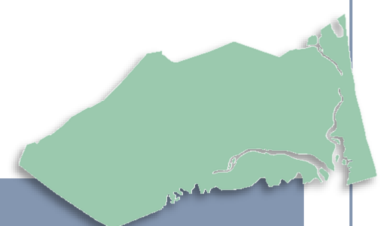
Short-term Strategies (now-2030)

- Continue installation & maintenance of sacrificial dunes.
- Continue dune grass planting & fencing.
- Reduce foot traffic.
- Ensure local enforcement of existing state barrier beach regulations.
- Create municipal freeboard incentive (see Hull case study).

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the beach and associated infrastructure located along and directly behind the beach.
- Consider planned retreat.

4.2-3. TOWN OF NEWBURY: Adaptation Strategies and Recommendations for Selected Areas of Concern



Plum Island Turnpike◊

Location: Joppa Flats Nature Center east to Sunset Drive.
Description of hazard: Tidal and storm-driven roadway flooding, ice cakes, high winds, zero visibility during nor'easters.
Consequences of hazard: Road closure and access to and from the island is cut off.
Existing efforts underway: Hydrodynamic sediment transport model is focusing on the PI Turnpike area, including Bascule Bridge, to better understand water and sediment flow in this area. The Great Marsh Plan identifies degraded salt marsh south of PI Turnpike near the Plum Island Airport; potential for salt marsh restoration here and other locations in this area.
Additional Notes: Newburyport & Newbury are both affected. Turnpike traps flood waters from dispersing across marsh.

Short-term Strategies (now-2030)

- Recognizing shared vulnerability, create joint Newbury and Newburyport working group to address these issues.
- Create early warning system to alert residents when the road is likely to be flooded or is flooded.
- Monitor flood frequency and depth to help with future road planning efforts.
- To increase public safety, install plastic road reflectors to show the road during storms when it's flooded and/or during blizzards.

Long-term Strategies (2030-2070)

- Raise road elevation based on detailed analysis of current and future conditions.
- Consider planned retreat from Plumbush Downs.
- Assess long-term master plan for Plum Island and redesign road accordingly, taking climate change into consideration.

Low-lying houses along bayside of Plum Island

Location: Basin Harbor neighborhood located between Old Point Road and Northern Boulevard, north of Plum Island turnpike.
Description of hazard: Tidal and storm-driven coastal flooding.
Consequences of hazard: Residential houses are flooded as are side streets.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Property owner education, including the benefits of freeboard as well as specific building retrofits such as installing backflow valves on sew drains, elevating utilities to prevent flood damage, and breakaway walls to prevent structure collapse during storm surge.
- Create municipal freeboard incentive (see Hull case study).

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term infrastructure planning.
- Consider rolling easements to facilitate planned retreat: town or state pays some amount to landowners in vulnerable locations today; when house eventually floods, town or state takes ownership.
- Consider planned retreat

Plumbush Downs◊

Location: Plum Bush Downs Road.
Description of hazard: Tidal and storm-driven flooding.
Consequences of hazard: Residential houses are flooded.
Existing Efforts Underway: The Great Marsh Plan identifies degraded salt marsh within Plumbush Downs development; potential for salt marsh restoration. Houses being rebuilt at Plumbush are being built on stilts.

Short-term Strategies (now-2030)

- Property owner education, including the benefits of freeboard as well as specific building retrofits such as installing backflow valves on sewer drains, elevating utilities to prevent flood damage, and breakaway walls to prevent structure collapse during storm surge.
- Create municipal freeboard incentive (see Hull case study) & state freeboard policy/regulations.

Long-term Strategies (2030-2070)

- Consider planned retreat

Sewage Pumping Station on Plum Island *continued on next page*

Location: Webbers Ct. & Olga Way
Description of hazard: Near area subject to overtopping**.** Building is relatively flood proof but surrounding area could flood cutting off access.
Consequences of hazard: Plum Island sewage system is vulnerable due to the way the system is segmented. If sewage system goes down, residents have to relocate until issue is fixed.
Existing efforts underway: Tried to remedy problem with a one-way valve but system got backed up with sediment; it didn't work. Study underway to reduce sewer system vulnerability in winter, but still vulnerable to storm surge.

Short-term Strategies (now-2030)

- Explore retrofits such as sealing interior conduits for water entry, elevating utilities, installing backup generator, etc. to allow the facility to continue operating during a storm.
- Consider a vegetated berm surrounding the plant.
- Explore alternate sites for sewage pumping station.

Long-term Strategies (2030-2070)

- Plan for possible future relocation depending on the level of risk the Newburyport and Newbury are willing to accept at the current location.
- Consider planned system shutdown in times of emergency & evacuating island until flooding recedes and you can turn system back on.

Plum Island & Beach

Location: Barrier beach and dunes along Plum Island.
Description of hazard: Erosion on beach shore and on northern river shore near jetties. Retreating shoreline is encroaching on residences. The ocean beach shore seems to erode when the Merrimack River Jetty degrades, and the inside river shore erodes when the jetty is repaired.
Consequences of hazard: Erosion threatens residential houses, impacts beach access, and results in loss of critical wildlife habitat.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Install & maintain sacrificial dunes.
- Conduct dune restoration, planting dune grass and installing sand fencing.
- Coordinate with Newburyport to develop strategies to reduce foot traffic over the dunes.
- Create municipal freeboard incentive (see Hull case study).
- Review, evaluate, and revise Plum Island zoning and regulations using new climate projections.
- Public and resident outreach and education

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the beach and associated infrastructure located along and directly behind the beach.
- Consider rolling easements to facilitate planned retreat: town or state pays some amount to landowners in vulnerable locations today; when house eventually floods, town or state takes ownership.

Newburyport Turnpike/Rt. 1◊

Location: Rt.1 at Parker River
Description of hazard: Tidal and storm flooding. Flooding north of Old Newbury Golf Course near the Plum Island Ecosystems Long Term Ecological Research Center.
Consequences of hazard: Major roadway can close during flooding.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Increase communication between state agency (that manages the road) and local officials.
- Create early warning system to alert residents when the road is likely to be flooded or is flooded, and to notify residents of alternate routes.
- Coordinate with evacuation planning for major storms.
- Monitor flood frequency and depth to help with future road planning efforts.

Long-term Strategies (2030-2070)

- Make plan to raise road in low lying areas coupled with causeway "best practices" of increasing drainage under road & removing debris along roadway to increase resiliency of marsh.
- Require any redesign or upgrade to road to take climate projections into consideration.

Newman Road

Location: Low-lying portions of Newman Rd. at Little River between The Trustees' Old Town Hill Reservation & Hay St.
Description of hazard: Approximately half mile of the western end of the road is often overtopped at high tide. Tidal flooding is a regular event, not just a storm occurrence, and will worsen with sea level rise and storm surge.
Consequences of hazard: Flooding impacts travel between Route 1 and 1A and is an inconvenience, but doesn't leave anyone stranded. Road is the access the Trustees have to the Adams Pasture parcel of Old Town Hill Reservation.
Existing efforts underway: Tidal restrictions have been identified in Barriers report (see Appendix B).

Short-term Strategies (now-2030)

- Create early warning system to alert residents when the road is likely to be flooded or is flooded, and to notify residents of alternate routes.
- Monitor flood frequency and depth to help with future road planning efforts.

Long-term Strategies (2030-2070)

- Make plan to raise road in low lying areas coupled with causeway "best practices" of increasing drainage under road & removing debris along roadway to increase resiliency of marsh.
- Require any redesign or upgrade to road to take climate projections into consideration.

Hanover Street at Little River◊

Location: 99-85 Hanover St.
Description of hazard: Flooding at Little River.
Consequences of hazard: Flooding impacts businesses, school bus parking lot, train tracks, several homes; not an impact on Elementary School which is higher elevation and has Newburyport water/sewer. Access road to school when it is needed as an emergency shelter could be cut off from the west side.
Existing efforts underway: Task force members are exploring relocating emergency shelter site to Triton Middle/High School on Elm St, Newbury. The Great Marsh Plan identified a tidally restricted marsh between Boston Road and Hanover Street on the Little River that may be affecting this site.

Short-term Strategies (now-2030)

- Work with emergency management personnel to relocate emergency shelter (find location that is free from flooding and accessible from all directions).
- Assess cost/benefit of raising road and new bridge crossing over Little River.

Crossings on Middle Road and Highfield Street

Location: Unnamed tributary to Little River that crosses under Route 1 ~1000 feet south of Hanover Street
Description of hazard: A number of crossings upstream (west) of and including the crossing under Route 1 were identified as high hazard by the hydraulic capacity screen. Four of these are not expected to pass the flow associated with a 2-year (50% likelihood) storm.
Consequences of hazard: Possible culvert failure and threat to roadways, including Route 1.
Existing efforts underway: Conceptual designs for the replacement of two crossings (Highfield Road and Middle Road) were developed as part of this project.

Short-term Strategies (now-2030)

- Replace existing undersized culverts with structures designed to meet pass higher flows and meet the MA Stream Crossing standards
- After consideration of possible downstream impacts of upgrading structures it may be necessary to design and replace structures beginning at the Route 1 crossing.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

Crossing on Orchard Street north of Central Street

Location: Tributary to Parker River that crosses under Orchard Street ~250 feet north of Central Street intersection.
Description of hazard: The barriers study identified this crossing as a high priority, ranking in the top 35 across the entire study region for combined infrastructure risk and ecological impact. The hydraulic capacity screening tool predicts that it is unable to pass the flow associated with a 25-year (4% likelihood) storm in addition to being an extreme barrier for fish and wildlife.
Consequences of hazard: Risk to property and road during floods. High ecological impact.
Existing efforts underway: The associated barriers study produced a conceptual design for the replacement of this structure.

Short-term Strategies (now-2030)

- Replace culvert with structure designed to pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

Crossings on Elm Street, School Street, and Coleman Road

Location: Two unnamed tributaries to the Parker River flowing on the immediate east and west sides of the Triton Regional High School.
Description of hazard: One crossing under School Street and one under Coleman Road were identified as high risk by the hydraulic capacity screening tool. They are not expected to pass the flow associated with a 2-year (50% likelihood) storm.
Consequences of hazard: Potential flooding and road failure could reduce access to school.
Existing efforts underway: Conceptual designs for a total of six crossings on these two tributaries were completed as part of this project.

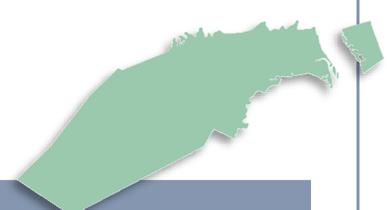
Short-term Strategies (now-2030)

- Replace problem structures as funding allows based on conceptual designs that will pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

4.2-4. TOWN OF ROWLEY: Adaptation Strategies and Recommendations for Selected Areas of Concern



Route 133 at Bachelder Brook *continued on next page*

Location: Northeast of 312 Haverhill St.
Description of hazard: Undersized culvert and riverine flooding is exacerbated by beaver activity.
Consequences of hazard: Route 133 floods and is unpassable. Traffic must detour around.
Existing efforts underway: Culvert cleaned out after Mother's Day flooding. Beaver deceiver installed. Preliminary design completed as part of barriers project.

Short-term Strategies (now-2030)

- Regularly remove woody debris that accumulates in and around the culverts.
- Actively remove beavers at bridge to restore flood storage potential of upstream floodplain.
- Replace culvert with bridge per design.

- Engage & educate business owners on future climate impacts.
- Encourage landscaping techniques for stormwater mitigation for nearby businesses and residences; e.g. rain gardens, pervious walkways & patios, infiltration trenches, and other green infrastructure techniques.

Long-term Strategies (2030-2070)

- Coordinate with DOT to plan for raising road adjacent to crossing.

Jewell Mill Dam

Location: On Mill River, west of the intersection between Mill St and Glen St, off of Route 1 near Newbury town line.
Description of hazard: Riverine flooding and risk of dam failure. Classified as Significant Hazard dam with Office of Dam Safety. High priority for removal based on screening for ecological impact and infrastructure risk.
Consequences of hazard: Glen Road bridge is at major risk if dam were to breach.
Existing efforts underway. Dam owner is currently not interested in removal due historical resources and current use.

Short-term Strategies (now-2030)

- Outreach & engagement with dam owner, educate about high hazard concerns and dam owner liability.
- Ensure that the dam is being inspected and maintained per Office of Dam Safety requirements.
- Work with dam owner to explore potential for structure removal or alteration to retain historic importance while removing risk and ecological impact.
- Upkeep and retrofits to reduce likelihood of failure.
- Identify opportunities for upstream water surge management.
- Educate neighborhood property owners on future risk.

Long-term Strategies (2030-2070)

- Remove dam.

Stackyard Road + Route 1A◊

Location: Stackyard Road and Route 1A from Stackyard Road north to town line (plus Newbury section of Route 1A to Parker River).
Description of hazard: Coastal flooding
Consequences of hazard: Roads flood and can be unpassable.
Existing efforts underway: Outer end of Stackyard Road has already been abandoned by FWS. Great Marsh Plan identified tidally restricted marsh caused by crossings under Route 1A near the Newbury town line. A rapid technical assessment was completed in 2005.

Short-term Strategies (now-2030)

- Create early warning system to alert residents when Route 1A is likely to be flooded or is flooded. Coordinate with evacuation planning for major storms.
- Assess culverts and water flow under the roadway. Increase culvert size if necessary to reduce likelihood of flooding and allow for the normal flow water and sediment throughout the system.
- Monitor flood frequency and depth to help with future road planning efforts; also require any redesign to take climate change into consideration.

Long-term Strategies (2030-2070)

- Work with State to raise 1A in low lying areas coupled with causeway "best practices" of increasing drainage under road & removing debris (mostly natural) along roadway to increase resiliency of marsh.
- Ultimately retreat from Stackyard Rd homes.
- Monitor and coordinate with railroad management because the railroad bed currently provides some flood protection.

Marina & Town Boat Launch◊

Location: Railroad Avenue/Warehouse Lane, off of Rt 1A.
Description of hazard: Coastal flooding
Consequences of hazard: Flooding impacts marina access and can cause property damage to boats and marina infrastructure.
Existing efforts underway: None

Short-term Strategies (now-2030)

- ☐ Property owner education, including the benefits of freeboard as well as specific building retrofits such as installing backflow valves on sew drains, elevating utilities to prevent flood damage, and breakaway walls to prevent structure collapse during storm surge.
- ☐ Consult with MBTA about resiliency planning for rail bed (this applies to Newbury, Rowley & Ipswich).

Long-term Strategies (2030-2070)

- ☐ Raise buildings seaward of RR tracks as feasible. Develop plan for Perley's Marina to adapt to SLR.
- ☐ Consider planned retreat.

Rowley Town Well #3 & well pumping station

Location: Along Mill River off of Boxford Road.
Description of hazard: Flooding, inundation of well pump station.
Consequences of hazard: Loss of municipal water supply
Existing efforts underway: None

Short-term Strategies (now-2030)

- ☐ Actively control beaver population to reduce chronic flooding.
- ☐ Elevate structure to protect facility from increased freshwater flooding.
- ☐ Explore retrofits (i.e. sealing interior conduits for water entry, elevating utilities, installing backup generator, etc.)
- ☐ Flood water diversion.

Long-term Strategies (2030-2070)

- ☐ Incorporate climate projections into long-term water infrastructure planning.

Crossing on Daniels Road

Location: Stream crossing under Daniels Road ~1,200 feet north of Haverhill Street intersection.
Description of hazard: The barriers study identified this crossing as a high priority, unable to pass the flow associated with a 2-year (50% likelihood) storm in addition to being a moderate barrier for fish and wildlife.
Consequences of hazard: Risk to road and property as well as ecological impact.
Existing efforts underway: The barriers study developed conceptual design for replacement of this structure.

Short-term Strategies (now-2030)

- ☐ Replace culvert with structure designed to pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- ☐ Continue to maintain and monitor structure for signs of flooding and failure.

Crossing of Mill River at Haverhill Street

Location: Mill River crossing under Haverhill Street ~400 feet west of Boxford Road intersection.
Description of hazard: The barriers study identified this crossing as a high priority, unable to pass the flow associated with a 2-year (50% likelihood) storm in addition to being a moderate barrier for fish and wildlife.
Consequences of hazard: Risk to road (major thoroughfare) and property as well as ecological impact.
Existing efforts underway: The barriers study developed conceptual design for replacement of this structure.

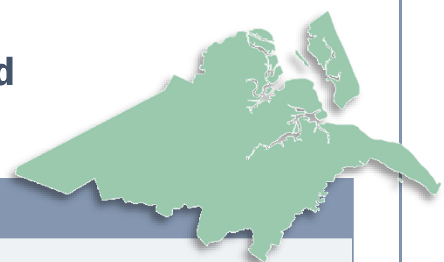
Short-term Strategies (now-2030)

- Replace culvert with structure designed to pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structure for signs of flooding and failure.

4.2-5. TOWN OF IPSWICH: Adaptation Strategies and Recommendations for Selected Areas of Concern



Jeffrey's Neck Road◊

Location: Beachview Ln northeast to 144 Jeffrey's Neck Rd
Description of hazard: Low elevation road floods during tidal storm surge events.
Consequences of hazard: Impacts access to recreational beaches and to 800 residences on Great Neck and Little Neck; this is an evacuation road so access is critical; police/fire can be cut off; Island Park, Hodges Way & Eagle Hill neighborhoods become islands.
Existing efforts underway: The Town has assessed flooding of the road[451] and is underway with plans to raise it 2 feet.

Short-term Strategies (now-2030)

- Regularly remove debris trapped along causeway that smothers the marsh and causes subsidence along roadbed.
- Study whether exchange of water under roadway (install culverts and/or increase sheet flow) would have environmental benefits or a negative impact due to Ipswich River flooding into Plum Island sound. Possibility of shellfish contamination and reduced salinity levels. Evaluate whether adjacent degraded salt marsh sites identified in this vulnerability assessment can be enhanced as part of project.
- Raise the road per results of flood assessment.

Long-term Strategies (2030-2070)

- Consider elevated causeway if long-term planning has neighborhoods remain and planned retreat is not an option.
- Incorporate climate projections into long-term infrastructure planning.

Ipswich Mills Dam *continued on next page*

Location: On Ipswich River in downtown Ipswich. Adjacent to EBSCO immediately upstream of Riverwalk footbridge.
Description of hazard: Downstream flooding/erosion risk if dam fails, contributes to upstream flooding, impoundment reduces upstream flood storage capacity, low head dam presents drowning risk
Consequences of hazard: Property damage to downtown businesses including EBSCO. Damage to Route 1A/133 at Choate Bridge
Existing efforts underway: Town is underway with the Ipswich Mills Dam Removal Feasibility Study to analyze the feasibility, cost, and effects of removing the downtown dam, including any impacts downstream.

[451] Parsons, R.A., *Final Technical Memorandum: Town of Ipswich Jeffrey's Neck Road Flood Assessment* (Boston, MA: CDM Smith, 2013), http://www.ipswichma.gov/documentcenter/view/514

Short-term Strategies (now-2030)

- Pending results of feasibility study, remove dam to restore upstream flood storage capacity, reduce upstream flooding and remove failure/drowning risk.
- While dam is in place, consider adding upstream signage to warn boaters of dam hazard and drowning risk.

Long-term Strategies (2030-2070)

- None if dam is removed.

Downtown Ipswich, including Choate Bridge and South Main Street

Location: Downtown along the Ipswich River, Route 133/1A.
Description of hazard: Riverine & coastal flooding; river bank erosion
Consequences of hazard: Includes EBSCO, businesses, housing (Rivercourt)
Existing efforts underway: Town is also studying river bank erosion between Ipswich Mills dam and Town Wharf and prioritizing green solutions.

Short-term Strategies (now-2030)

- Convene Downtown Ipswich resiliency working-group (business owners, town officials, and other partners) to consider long-term flooding risk and impacts. Focus on business owner engagement & education on building retrofits and general principles of resiliency.
- Encourage landscaping techniques for stormwater mitigation, e.g. rain gardens, pervious walkways & patios, infiltration trenches, and other green infrastructure techniques to reduce flooding.
- Create, enhance, and protect riparian buffer along the Ipswich River up and downstream of Town center to address current erosion and future climate impacts.

Long-term Strategies (2030-2070)

- Evaluate feasibility of river flood bypass through Veteran's Green/Elm Street area to accommodate flow from a 500-year flood.
- Incorporate climate projections, particularly increased freshwater flooding, into long-term infrastructure planning.

Crane Beach

Location: beach at end of Argilla Rd
Description of hazard: Beach and dune erosion.
Consequences of hazard: Erosion affects recreational use of property, causes widening of the mouth of the Essex River, and results in loss of critical wildlife habitat. Loss of buffering landmass could increase the vulnerability of inland areas in Essex Bay.
Existing efforts underway: The owners of Crane Beach, the Trustees of Reservations, have a beach management plan and are developing an enhanced Coastal Vulnerability Assessment. Dune restoration projects have been conducted and have worked well.

Short-term Strategies (now-2030)

- Support Trustees' beach management and implementation of the recommendations in their coastal adaptation plan, including monitoring erosion rates and allowing natural dynamic systems to evolve over time.
- Capitalize on the area's high visibility; opportunity for public education.

Long-term Strategies (2030-2070)

- Support Trustees' efforts to manage this undeveloped natural barrier beach.

Argilla Road, homes, and Crane Beach parking areas at end of road

Location: East end of Argilla Road
Description of hazard: Coastal flooding**.** Parking area owned by the Town floods a few times a year from marsh side. Sole access to beach and Castle Hill along Argilla Road has at least six places where the 100 yr. flood zone touches the road and currently floods.
Consequences of hazard: Flooding cuts off access to houses and beach and inundates the parking lot.
Existing efforts underway: The owners of Crane Beach, the Trustees of Reservations, are developing a Coastal Vulnerability Assessment with adaptation strategies for priority sites, which will be completed in 2017. The Trustees have recently completed improvements to the beach facilities to be more resilient to flooding.

Short-term Strategies (now-2030)

- Explore elevating road access - raising Argilla Road at entrance to Trustees' Castle Hill gate.

Long-term Strategies (2030-2070)

- Consider moving parking lot to higher ground and/or providing bus service to take residents to/from the beach.
- Consider planned retreat.

Pavilion Beach◊

Location: Beach connecting Great and Little Neck - beach & road access - only free public beach in Ipswich
Description of hazard: Erosion and coastal flooding. Tidal surge floods area during storm events. Extremely low-lying without dune system.
Consequences of hazard: At 3m storm surge model, Pavilion Playground/Park becomes beachfront; public beach will be lost; Little Neck access cut off; also need to take into account balance of Little Neck Road
Existing efforts underway: None.
Additional Notes: Adjacent coastal bank armoring appears to have affected sand supply to this beach.

Short-term Strategies (now-2030)

- Create early warning system for when the road is projected to flood; coordinate with evacuation planning.
- Conduct comprehensive beach nourishment/sediment composition study to increase short-term sustainability of beach.

Long-term Strategies (2030-2070)

- Elevate causeway/bridge if long-term planning indicates neighborhoods will remain and planned retreat is not an option.

Brown's Well (Ipswich drinking water supply) and Route 1A *continued on next page*

Location: Route 1A at Muddy Run /188 High Street.
Description of hazard: Riverine & coastal flooding. SLR projections indicate road and well will flood with saltwater. Area is in the AE Zone. Flooding from beaver activity exacerbates problem. The hydraulic capacity model flags this crossing as potentially unable to pass storm flows. It is transitional at 2-yr and fails at 10-yr.
Consequences of hazard: Asset and the surrounding area are subject to salt water infiltration as sea level rises.
Existing efforts underway: Town is looking for other well sites.

Short-term Strategies (now-2030)

- Engage with Water Department staff & Water Board to ensure that increasingly irregular precipitation patterns are considered in water supply management planning.
- Further study on the vulnerability of this site to the combined impacts of riverine and coastal flooding. Actively control beaver population to reduce chronic flooding.

- Replace water supply

Long-term Strategies (2030-2070)

- Raise road and install tide gate to protect future water supply that may be developed upstream from future saltwater intrusion.
- Incorporate climate projections into long-term infrastructure planning.

Ipswich River Bank from County St bridge to Sewage Pumping Station (Town Wharf)

Location: County Street bridge to Town Wharf at 68 East St.
Description of hazard: Riverine & coastal flooding.
Current solutions: Ipswich is planning educational signage about the river, including some discussion of climate impacts, to be posted on Sewage Pumping station at Town Wharf. The Town's CZM 2016 Resiliency grant investigated stormwater runoff, bank erosion, flooding, and recreational usage along river (completed June 2017). Area is also subject to several stormwater remediation studies.

Short-term Strategies (now-2030)

- Flood-proof pump station.
- Elevate critical utilities.
- Explore alternative pumping station locations.
- Consider impacts of sea level rise on stormwater remediation projects recommended for area.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term infrastructure planning. Relocate pumping station when needed.

Crossing at Topsfield Road and Gravelly Brook

Location: Gravelly Brook crossing of Topsfield Road ~100 feet east of Gravelly Brook Road.
Description of hazard: This crossing is deteriorating and eroding. If it fails the road will wash out.
Consequences of hazard: Road failure causing severely reduced access to and fro downtown Ipswich. Ecological impact to trout and other coldwater fish.
Existing efforts underway: The barriers study produced a conceptual design for the replacement of this structure. The Ipswich DPW has been seeking funding to initiate replacement.

Short-term Strategies (now-2030)

- Replace culvert with structure based on preliminary design which is more resilient to erosion and meets the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structure for signs of flooding and failure.

Crossings on Pineswamp Road *continued on next page*

Location: Two crossings Pineswamp Road. (1) ~500 feet west of Linebrook Road intersection and (2) ~300 feet west of Fox Run Road intersection.
Description of hazard: The hydraulic capacity screening tool identified both of these structures as vulnerable to flooding. Structure # 1 was replaced fairly recently, but does not meet the MA Stream Crossing Standards.
Consequences of hazard: Road flooding, possible road failure and ecological impacts.
Existing efforts underway: The associated barriers study produced conceptual designs for the replacement of these structures.

Crossing on Pineswamp Road continued

Short-term Strategies (now-2030)

- Replace culverts with structures designed to pass storm flows and meet the MA Stream Crossing standards.
- Conduct analysis at site #1 to identify whether downstream crossing at Linebrook Road needs to be upgraded at same time.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.
- Conserve adjacent land to allow marsh migration and to prevent additional development

4.2-6. TOWN OF ESSEX: Adaptation Strategies and Recommendations for Selected Areas of Concern

Main Street Causeway & Woodman's Landing

Location: 74 Main St. to 166 Main Street.
Description of hazard: Tidal and storm-driven flooding. Flooding occurs from both sides. Woodman's Beach is a possible breach point.
Consequences of hazard: Flooded road cuts off emergency services and impacts store-front economy.
Existing efforts underway: Flooding reduced since recent re-construction of the Causeway. Road was raised a few inches in 2011 as part of the Route 133 reconstruction project. Emergency vehicles are stationed on the east side of the Causeway when flooding is expected.

Short-term Strategies (now-2030)

- Create live video feed showing the Causeway so residents and travelers can go online and see in real-time if it's flooded/impassable. Track and monitor flow beneath Causeway.
- Convene Essex Causeway working-group (business owners and others) to begin considering long-term impacts and viability. Include representatives from local businesses, regional and state partners, and town officials.

Long-term Strategies (2030-2070)

- Raise road several feet at least and establish flow under roadway to restore hydrology and increase natural resiliency of marsh; investigate feasibility of a bridge.
- Incorporate climate projections into long-term infrastructure and business planning, including road maintenance and utilities running along the road.
- Ultimately if the road is to be raised substantially, some businesses will need to relocate; start business owner engagement early in the process (partial planned retreat).

Eastern Avenue at Ebben Creek◊ *continued on next page*

Location: 81 Eastern Ave to 97 Eastern Ave.
Description of hazard: Tidal and storm flooding. Flood map shows road within 100yr flood plain. Would be highly vulnerable to 6' of sea level rise.
Consequences of hazard: Reduced flow impacts the resiliency of the marsh and could eventually impact road stability and function. Restricted flow is causing erosion and scour is visible.
Existing efforts underway: None.

Eastern Avenue at Ebben Creek continued

Short-term Strategies (now-2030)

- Regularly monitor scouring to ensure road stability.
- Regularly remove debris caught in the culvert to ensure maximum flow.
- Update 2005 study of the restriction, focusing on impact to the marsh and flooding relative to updated inundation modeling data. Study should evaluate whether upgraded culvert would affect neighborhoods upstream.
- Re-evaluate flood hazard based on updated modeling and sea level rise estimates.

Long-term Strategies (2030-2070)

- Develop designs to raise causeway and/or bridge.
- Raise road elevation and/or install larger culvert or bridge.

Conomo Point Road & Robbins Road◊

Location: Low-lying portions of Conomo Point Road and Robbins Road (as shown by inundation maps)
Description of hazard: Tidal and storm-driven flooding.
Consequences of hazard: Flooded road blocks off homes, emergency access, and impacts boat launches, commercial clamming access and recreation areas.
Existing efforts underway: A Comprehensive Plan for Robbins Island and Northern Conomo Point was completed by the Town in March, 2016. The Plan addresses long-term disposition and management plans for certain properties.

Short-term Strategies (now-2030)

- Create early warning system to alert residents when the road is likely to be flooded or is flooded.
- Regularly evaluate evacuation plans, ensuring enough notice will be given prior to the road becoming impassible.
- Monitor flood frequency and depth to help with future road planning efforts.
- Require any redesign to take sea level rise and increased storm surge into consideration.
- Consider hybrid living shoreline near Clammers Beach to stabilize the shoreline and reduce wave energy.
- Ensure that long-term data for flooding and sea level rise is incorporated into town's Conomo Point planning and management strategies.

Long-term Strategies (2030-2070)

- Raise road at low pinch points where flooding is likely to occur, such as at Clammers Beach.
- Assess long-term outlook and viability of Conomo Point & Robbin's Island neighborhood plan road updates accordingly.
- Consider planned retreat.

Crane Beach (tip of point)◊ *continued on next page*

Location: 290 Argilla Rd, Ipswich
Description of hazard: Beach and dune erosion.
Consequences of hazard: Widening of the mouth of the Essex River. Loss of buffering landmass could increase the vulnerability of inland areas in Essex Bay.
Existing efforts underway: The owners of Crane Beach, The Trustees of Reservations, are developing a Coastal Vulnerability Assessment with adaptation strategies for priority sites, which will be completed in 2017.

Short-term Strategies (now-2030)

- Allow natural dynamic system to evolve over time
- Support efforts to educate the public concerning the natural processes and dynamics of a barrier beach system
- Continue monitoring erosion rates.
- Work with the Trustees to examine if active management to increase the resiliency of this area of the barrier is feasible and consistent with their coastal management and planning.

Long-term Strategies (2030-2070)

- Support Trustees' efforts to manage this undeveloped natural barrier beach.

Crossing at Lufkin Street

Location: Lufkin Creek crossing under Lufkin Street ~250 feet west of Harlow Street intersection.
Description of hazard: The barriers study identified this crossing as a high priority. The hydraulic capacity screening tool predicts that it is unable to pass the flow associated with a 2-year (50% likelihood) storm.
Consequences of hazard: Risk to property road and possible upstream flooding.
Existing efforts underway: The barriers study developed conceptual design for replacement of this structure.

Short-term Strategies (now-2030)

- Replace culvert with structure designed to pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

Crossing at Story Street/Western Ave

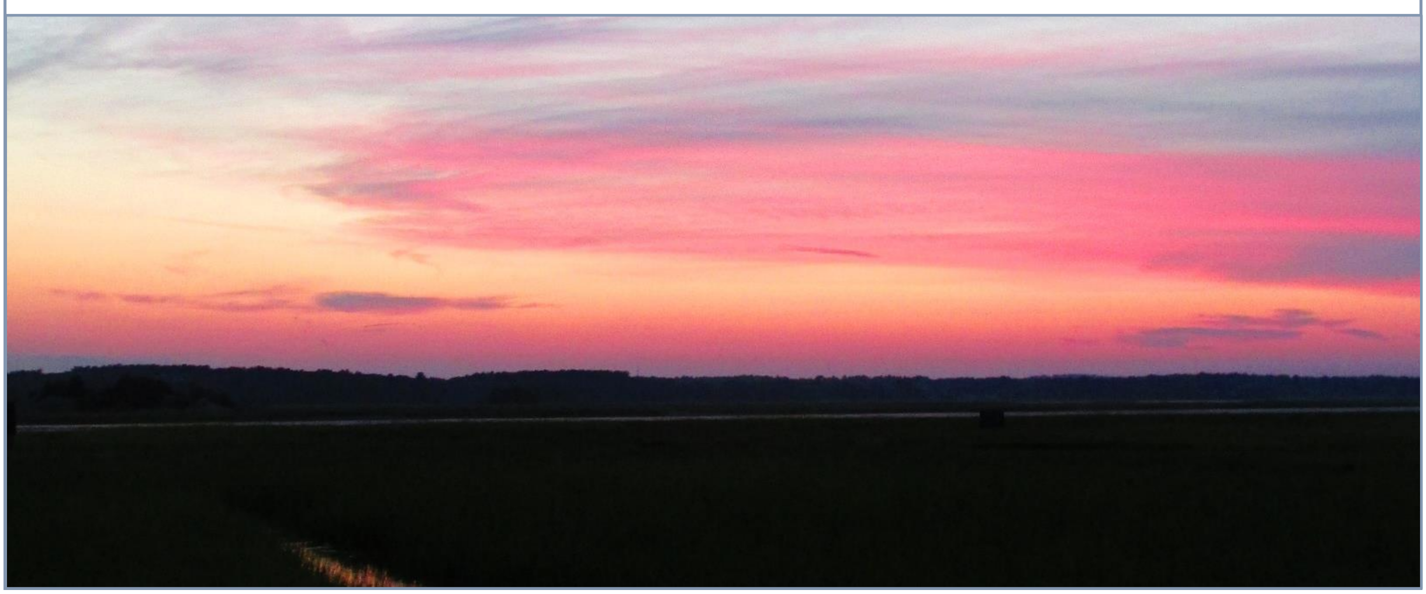
Location: Tributary to Alewife Brook crossing underneath intersection of Story Street and Western Avenue.
Description of hazard: The barriers study identified this crossing as a high priority, ranking in the top 35 across the entire study region for combined infrastructure risk and ecological impact.
Consequences of hazard: Risk to property and high replacement cost. Ecological impact.
Existing efforts underway: The barriers study developed conceptual design for replacement of this structure.

Short-term Strategies (now-2030)

- Replace culvert with structure based on conceptual design which will pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.



Sandy Tilton

Northeast Massachusetts Mosquito Control and Wetlands Management District

CHAPTER 5

Recommendations for Advancing the Implementation of Nature-based Strategies in the Great Marsh

Conducting vulnerability assessments and identifying adaptation strategies are both critically important steps in building coastal resilience, but they are only the first steps. Moving from assessing and planning activities to then implementing strategies that measurably reduce risk can be challenging. However, without implementation, resources and energy put into planning will amount to little; no measurable reduction in vulnerability will occur – in fact vulnerability will only continue to increase.

Transitioning from planning to implementing "on-the-ground" projects, and more specifically natural and nature-based strategies, can be difficult for a variety of reasons. The following pages summarize some of the major challenges associated with implementing adaptation strategies, and offer guidance and recommendations on how to address each challenge. When left unaddressed, these challenges can significantly impede the direction and effectiveness of adaptation projects. For this reason, promoting an informed understanding and awareness of how to navigate such challenges is key to moving the Great Marsh Region towards a wider adoption and implementation of natural and nature-based strategies.

RECOMMENDATION

Understand site-specific considerations

It's important to understand the physical site conditions when implementing most adaptation strategies, whether it's gray infrastructure, green infrastructure, or simply helping bolster existing natural defenses. Projects will perform successfully if they are designed to function within the specific biological and geophysical characteristics of the project site. If not properly sited and designed, projects have a higher likelihood of failing, which can ultimately contribute to public uncertainty about the viability of certain approaches and in particular, nature-based solutions.

Although it can be time consuming, it's important to consider site-specific factors before moving into the implementation phase. For projects that include a structural component, the first step is often a feasibility assessment and siting. Done correctly, these steps will help assess the site-specific conditions and put the project on a path towards success, reducing likelihood of unforeseen hurdles arising during the permitting, and eventual construction and installation of a project. Qualified contractors and MA CZM's North Shore Regional Coordinator[452] can help guide towns through this process, ensuring relevant data is acquired and analyzed appropriately. In addition, there are a number of existing resources available that provide guidance on how to assess a site to determine which project type(s) and/or approach(es) may be most appropriate for a given location and/or habitat.

Sandy Tilton

Available Resources:

- *Guidance for Considering the Use of Living Shorelines*[453]
- *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features*[454]
- *Living Shorelines Engineering Guidelines*[455]
- *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*[456]
- *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*[457]

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452 "North Shore Region," MA CZM, http://www.mass.gov/eea/agencies/czm/ regional-offices/north-shore/

453 NOAA Living Shorelines Workgroup, *Guidance for Considering the Use of Living Shorelines* (2012), 15, http://www.habitat.noaa.gov/pdf/noaa_guidance_for_considering_the_use_of_living_shorelines_2015.pdf

454 Cunniff, S. and A. Schwartz, *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features* (New York, NY: Environmental Defense Fund, 2015), http://www.edf.org/sites/default/files/summary_ni_literature_ compilation_0.pdf

455 Miller, J.K., A. Rella, A. Williams, and E. Sproule, *Living Shorelines Engineering Guidelines*, prepared for New Jersey Department of Environmental Protection (Hoboken, NJ: Stevens Institute of Technology, 2016), http://www.nj.gov/dep/cmp/ docs/living-shorelines-engineering-guidelines-final.pdf

456 Bridges, T.S. et al., *Use of natural and nature-based features (NNBF) for coastal resilience*, ERDC SR-15-1 (Vicksburg, MS: USACE, 2015), http://cdm16021.contentdm.oclc.org/cdm/ref/collection/p266001coll1/id/ 3442

457 Bridges, T.S. et al., *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*, CWTS 2013-3 (Washington, DC: USACE, 2013), http://www.corpsclimate.us/docs/USACE_Coastal_Risk_Reduction_final_CWTS_2013-3.pdf

RECOMMENDATION

Understand the permitting process early on

Most adaptation and coastal resilience projects that include a physical alteration of the environment will require one or more permits from federal and state agencies. In addition, many projects will require approval from municipal boards and commissions such as a Conservation Commission. Completing the permitting process can be time consuming and seem daunting. However following the permitting process is both legally required and reduces the likelihood that a project will have unintended negative consequences.

It is important to engage relevant state and federal regulators early in the development of a project for two main reasons: (1) a project may not be feasible from a regulatory perspective and it's better to make that determination before too much time and resources are invested; and (2) regulatory staff have expertise that can help inform project design, ensure best practices are used, and can recommend design changes to help the project move more swiftly through the permitting process. Knowing which regulators to reach out to can be difficult, but MA CZM and MassBays Program both employ regional coordinators who can liaise between project proponents and regulators.

When considering an adaptation or coastal resilience project, these regional coordinators should be consulted as early in the process as possible:

- MassBays North Shore Coastal Resources Coordinator[458]
- CZM's North Shore Regional Coordinator[459]

RECOMMENDATION

Work with partners to access creative resources and funding

Proactive risk-reduction projects can be cost-effective and save significant money over the lifespan of the project. The Federal Emergency Management Agency highlights an often cited statistic that every dollar spent on mitigation saves an average of four dollars.[460] Finding funding for mitigation projects and proactive management can be challenging, but there are a variety of resources and dedicated funding streams to support coastal resilience projects (see below). There is also a growing field exploring alternative financing mechanisms, such as public-private partnerships,[461] "pay for success" environmental impact bonds,[462] green bonds,[463] insurance-based resilience bonds,[464] and blended finance.[465]

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458 "Upper North Shore Region," Massachusetts Office of Coastal Zone Management, http://www.mass.gov/eea/agencies/mass-bays-program/regions/upper-north-shore.html

459 "North Shore Region," MA CZM, http://www.mass.gov/eea/agencies/czm/regional-offices/north-shore/

460 FEMA, *Mitigation's Value to Society* (Washington, DC: 2008), https://www.fema.gov/pdf/hazard/hurricane/2008/gustav/mitigations_value_factsheet2008.pdf

461 GZA Environmental, Inc., *Financing Resilience: The Big Challenge* (2017), 12, http://www.gza.com/sites/default/files/FINAL_Financing%20Resiliency%20The%20Big%20Challenge_1_31_17.pdf

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464 Re:focus Partners, LLC., *Leveraging catastrophe bonds as a mechanism for resilient infrastructure project finance* (2015), 39, http://www.refocuspartners.com/wp-content/uploads/2017/02/RE.bound-Program-Report-December-2015.pdf

465 "Blending Finance for (Climate) Resilience," Climate Finance Advisors, https://climatefinanceadvisors.com/2016/08/blending-finance-climate-resilience/

IMPORTANT TIP: Once a "Request for Proposal" (RFP) is announced, the funder is typically unable to communicate with applicants, answer questions, or provide input on project design. Before an RFP comes out, however, many funders will gladly review project concepts and provide advice. Engaging a funder prior to the funding announcement, and taking their advice into consideration, will generally increase the competitiveness of your proposal.

Federal Funding Sources:

- ☐ NOAA Coastal Resilience Grants Program[466]
- ☐ FEMA Hazard Mitigation Grant Program[467]
- ☐ North American Wetlands Conservation Act Standard Grants[468]

Browse Funding Opportunities:

- ☐ U.S. Climate Resilience Toolkit[469]
- ☐ U.S. DOI Climate Change Funding[470]
- ☐ Environmental Protection Agency climate Change Adaptation Resource Center[471]

State Funding Sources:

- ☐ MA CZM Coastal Resilience Grant Program[472]
- ☐ Culvert Replacement Grant Program[473]
- ☐ MassBays Grants Program[474]
- ☐ Municipal Vulnerability Preparedness Program[475]
- ☐ Dam and Seawall Repair or Removal Program[476]

Other Funding Sources:

- ☐ NFWF Resilient Communities Program[477]
- ☐ WCS Climate Adaptation Fund[478]

EPA

466 "2017 NOAA Coastal Resilience Grants," NOAA, https://www.coast.noaa.gov/resilience-grant/
467 "Hazard Mitigation Grant Program," FEMA, https://www.fema.gov/hazard-mitigation-grant-program
468 "Standard Grants," US Fish & Wildlife Service, https://www.fws.gov/birds/grants/north-american-wetland-conservation-act/standard-grants.php
469 "Funding Opportunities," US Climate Resilience Toolkit, https://toolkit.climate.gov/content/funding-opportunities
470 "Climate Change Funding Opportunities," US DOI, https://www.doi.gov/oia/climate-change/funding-opportunities
471 "Federal Funding and Technical Assistance for Climate Adaptation," EPA, https://www.epa.gov/arc-x/federal-funding-and-technical-assistance-climate-adaptation
472 "Coastal Resilience Grant Program," MA CZM, http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/grants/
473 "Municipal Assistance for Replacement of High Ecological Value Culverts, MA Dept. of Fish & Game, http://www.mass.gov /eea/agencies/dfg/der/technical-assistance/culvert-replacement-grant-rfr.html
474 "MassBays Grant Program," MA EEA, http://www.mass.gov/eea/agencies/mass-bays-program/grants/
475 "Municipal Vulnerability Preparedness Program," MA EEA, http://www.mass.gov/eea/air-water-climate-change/climate-change/massachusetts-global-warming-solutions-act/municipal-vulnerability-preparedness-program.html
476 "Damn and Seawall Repair or Removal Program," MA EEA, http://www.mass.gov/eea/waste-mgnt-recycling/water-resources/preserving-water-resources/water-laws-and-policies/water-laws/draft-regs-re-dam-and-sea-wall-repair-or-removal-fund.html
477 "Resilient Communities Program," National Fish and Wildlife Foundation, http://www.nfwf.org/resilient-communities/Pages/home.aspx
478 "Climate Adaptation Fund," Wildlife Conservation Society, http://wcsclimateadaptationfund.org/

RECOMMENDATION

Develop and enhance support from the general population to address long-term challenges

Craig Guillot

For resiliency enhancement efforts to succeed at the local level, there typically needs to be widespread community buy-in and a sense of shared ownership of the work that is occurring or that is proposed. The first step is to educate stakeholders and the general public on the threats facing the asset, resource, or geographic area. As the need for action becomes apparent and broadly understood, then the emphasis shifts towards solutions. In general, seawalls, bulkheads, and other gray infrastructure techniques have historically been a common approach to stabilizing sediment, preventing erosion, and providing flood protection.

Given the prevalence and use of coastal armoring, particularly in major coastal cities, gray infrastructure techniques tend to be more familiar to the general public, which further perpetuates their use as a dominant tactic. Natural and nature-based solutions could however be implemented more widely if the full scope of benefits and costs of such approaches were better communicated to, and understood by, contractors, residents, private landowners, and decision-makers. The content is important (i.e. the reasons why natural and nature-based solutions should be chosen over gray infrastructure), but the messengers delivering the content are also important. According to national polling, fire fighters, Red Cross, health professionals, and water quality scientists are the most effective and trusted "front-line" messengers to communicate concepts of resilience and nature-based solutions.[479] In the Great Marsh, health professionals, emergency management officials, police and fire fighters should be engaged to join implementation efforts alongside critical citizens groups such as Storm Surge and others.

Resources to help make the case for nature-based strategies:

- *A Comparative Cost Analysis of Ten Shore Protection Approaches at Three Sites Under Two Sea Level Rise Scenarios*[480]
- *Natural Defenses in Action*[481]
- *Improved Use and Understanding of NNBF in the Mid-Atlantic*[482]
- *Nature-based Solutions in Action*[483]

[479] The Nature Conservancy, How to Communicate Successfully Regarding Nature-Based Solutions: Key Lessons from Research with American Voters and Elites (2015), https://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd_284438.pdf

[480] Rella, A.J. and Miller, J.K., *A Comparative Cost Analysis of Ten Shore Protections Approaches at Three Sites Under Two Sea Level Rise Scenarios*, prepared for Hudson River National Estuarine Research Reserve (Hoboken, NJ: Stevens Institute of Technology, 2012), https://s3.amazonaws.com/nyclimatescience.org/240186100-A-Comparative-Cost-Analysis-of-Ten-ShoreProtection-Approaches-at-Three-Sites-Under-Two-Sea-Level-Rise-Scenarios.pdf

[481] Small-Lorenz, S.L. et al., Natural Defenses in Action: Harnessing Nature to Protect our Communities (Washington, DC: National Wildlife Federation, 2016), www.nwf.org/nature-in-action

[482] Schrass, K., and A.V. Mehta, *Improved Use and Understanding of NNBF in the Mid-Atlantic* (Annapolis, MD: National Wildlife Federation, 2017), http://midatlanticocean.org/wp-content/uploads/2017/03/Improved-Use-and-Understanding-of-NNBF-in-the-Mid-Atlantic.pdf

[483] "Nature Based Solutions in Action," Coastal Resilience, http://coastalresilience.org/nature-based-solutions-in-action/

David Stone

CHAPTER 6

Looking to the Future

As this project comes to a close, the communities and the Great Marsh Resiliency Partnership are at a crossroads. The list of challenges and associated recommendations noted in this Adaptation Plan are by no means intended to be exhaustive. Bridging the gap between planning and implementation is difficult, and coastal communities throughout the country are facing similar hurdles as they pursue adaptation strategies. In the Great Marsh, implementation efforts have already begun, many of them highly successful, others running into some of the challenges noted above. The Great Marsh Coastal Adaptation Plan is designed to directly support and guide both new and existing implementation efforts. It will help communities prioritize investments and strategies so as to maximize positive outcomes.

Each community in the Great Marsh should work within its existing planning and governing structures to further its resiliency work. Master planning, hazard mitigation planning, climate action committees, and other municipal planning efforts—that communities are already doing and that they will continue to do—should adopt and incorporate the adaptation strategies and recommendations outlined in this document.

Specifically, the Great Marsh Resiliency Partnership,[484] comprised of regional, governmental, municipal, and NGO partners working in the Great Marsh, will serve as an umbrella resource for moving strategies forward. Each community's Municipal Resiliency Task Force, convened for this planning process, should become a permanent committee, charged with the implementation of this Adaptation Plan. The first task of each municipal committee should be to work with the Great Marsh Resiliency Partnership to develop a detailed Action Plan.

484 "Great Marsh Resiliency Partnership," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_21/

Above all, the Great Marsh Coastal Adaptation Plan serves as a guide for taking a holistic and integrated approach to building coastal resiliency in the Great Marsh by combining natural resource enhancement with community risk reduction on a regional scale. The goal of this plan is to reduce the growing vulnerability of communities within the Great Marsh from coastal storms, sea level rise, flooding, and erosion by strengthening the resiliency of the ecological systems upon which those communities depend.

As a result of their coordinated planning, the coastal communities of the Great Marsh are poised to make large, measurable gains in reducing community vulnerability and enhancing coastal resiliency. Strategies include natural and nature-based solutions, building retrofits, policy measures, and outreach and education initiatives—all of which are operationally feasible and can be implemented in the near to moderate term. Shovel-ready projects have been identified and vetted, relevant municipal policy measures have been identified that incentivize climate-smart development and/or prohibit development in hazard-prone locations, best practices are ready to be incorporated into public and private development initiatives, and public support for implementation has grown.

To date, partners and municipalities in the Great Marsh have been successful in coordinating planning efforts at the regional scale, working across sectors and jurisdictions to engage relevant stakeholders. The challenge now is to build off the success of this regional planning effort and transition to coordinated regional implementation.

Dave Rimmer

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APPENDIX A:
Methodology for USGS Geospatial Exposure Analysis

Community exposure to coastal-inundation hazards was characterized by integrating geospatial data of scenario-hazard zones with various socioeconomic data to estimate the amount and relative percentage of a specific societal asset in a hazard zone. Societal assets were chosen based on USGS recommendations, discussions with NWF, and by vetting preliminary asset lists with project stakeholders in the six coastal communities. This section describes the geospatial data and geoprocessing assumptions for societal assets related to land cover and land use, populations, economic assets, and critical facilities and infrastructure. All socioeconomic data and subsequent exposure estimates reflect current distributions of people and assets, and do not include projections of future community growth. Socioeconomic data from the various sources described in this section were considered authoritative and no additional field verification or map corrections were conducted.

Prior to analysis, all geospatial data were re-projected to share the same datum (North American Datum of 1983, State Plane, Massachusetts, FIPS 2001 Feet) and projection (Lambert Conformal Conic) to conform to existing GIS data from the State of Massachusetts's GIS database (Office of Geographic Information, 2016). Spatial analysis of vector data (for example, Census block polygons and business points) focused on determining whether or not an asset was inside a hazard zone. Slivers of polygons that overlap administrative boundaries and a hazard zone were taken into account during analysis, and final values were adjusted proportionately. The results summarized in this report should be considered first approximations of community exposure and not exhaustive inventories or loss estimates.

Coastal-inundation-hazard zones used in this study were developed and are summarized in geospatial data provided by the Woods Hole Group. Methods to develop the various scenario-based hazard zones are described in Kleinfelder (2015).[1] Water-elevation modeling in their analysis was based on a fully optimized Monte Carlo approach to simulate the influence of climate change on sea level, tides, waves, and the track and intensities of tropical (hurricanes) and extra-tropical (nor'easters) storms. The spatial resolution of modeling efforts varied, ranging from 1 to 10 meters, based on data availability. Sea level rise assumptions for 2030 and 2070 hazard zones were 0.66 and 3.39 feet relative to mean sea level, respectively, which represent global sea level rise projections for the "highest" scenario by the Intergovernmental Panel on Climate Change[2] and Parris et al. (2012).[3]

Inundation modeling from Woods Hole Group include scenarios for 2013 (representing present day and hereafter referred to as "current" hazard zones), 2030, and 2070.[4] For each time scenario, mapped inundation-probability values ranged from 0.1% to 100% with 12 discrete classes. A percentage refers to the likelihood that coastal inundation will occur in a certain area during a 365 day period. Coastal inundation is defined as flood water (at a depth greater than or equal to 2 inches (5 cm)) encroaching on the surface at a particular location. USGS grouped the inundation probability values into four categories:

[1] Kleinfelder, *Coastal climate change vulnerability assessment and adaptation plan: City of Gloucester, MA* (Cambridge, MA: 2015), http://gloucester-ma.gov/DocumentCenter/View/3416

[2] IPCC, Climate Change 2014, 59

[3] Parris, A. et al., *Global Sea Level Rise Scenarios for the United States National Climate Assessment*, NOAA Tech Memo OAR CPO-1 (Silver Spring, MD: National Oceanic and Atmospheric Administration, 2012), 37

[4] Famely, J. et al., *Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA)*, Prepared by Woods Hole Group for National Wildlife Federation and U.S. Geological Survey, (Falmouth, MA: 2016)

high probability (100%), medium probability (25%, 30%, and 50%), low probability (1%, 2%, 5%, 10%, and 20%), and very low probability (0.1%, 0.2%. and 0.5%).

USGS also used flood-water depth data, from Woods Hole Group, that were summarized in 1-foot increments for all three time periods and for 1% and 0.2% inundation probabilities (which correspond to 100-year and 500-year storm likelihoods). Depth data shows how deep the water is likely to be in a certain area if a 1% or 0.2% storm occurs. Hazard-zone data provided by the Woods Hole Group were considered authoritative and no additional field verification, model verification, or map corrections were conducted.

For more information on the methodology used by the USGS, see the full report published online.[5]

[5] Abdollahian, N. et al., *Community exposure to potential climate-driven changes to coastal-inundation hazards for six communities in Essex County, Massachusetts*, U.S. Geological Survey open-file report (Reston, VA: USGS, 2016), https://pubs.usgs.gov/of/2016/1187/ofr20161187.pdf

APPENDIX B:
Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed

As part of the Great Marsh Resiliency Planning Project, the Ipswich River Watershed Association conducted a comprehensive inventory and assessment of man-made barriers to flow based on original research and a synthesis of previous studies to assess the vulnerability of these structures in the Great Marsh region. Four categories of barriers were considered in this assessment: non-tidal road-stream crossings (culverts and bridges), tidal road-stream crossings, dams, and gray infrastructure/coastal stabilization structures (seawalls, revetments, etc.).

By definition, all barriers can be considered vulnerable since they are the category of community infrastructure most routinely impacted by water. These assessments were reviewed by the project team and combined with barriers also identified by the local task forces to contribute to the list of high priority Vulnerable Areas of Concern (see Appendix C).

Methodology

To assess the relative vulnerability of barriers, screening-level assessments were conducted as follows for the four categories of potential barriers considered:

Non-tidal road-stream crossings

Field assessments were conducted and an infrastructure risk model was run to test whether non-tidal crossings are likely to successfully pass flood flows based on watershed characteristics and crossing design/dimensions at five different return interval storms: 1%, 2%, 4%, 10% and 50%. Crossings that did not pass at the 4% level or above were deemed highly vulnerable.

The crossing infrastructure risk assessment builds upon the PIE-Rivers Road-Stream Crossing Inventory and Risk Assessment,[6] an earlier assessment of ecological connectivity at the region's stream crossings. This earlier work was conducted by Ipswich River Watershed Association utilizing a rapid assessment protocol developed by the North Atlantic Aquatic Connectivity Collaborative (NAACC). Between 2006 and 2014, more than 700 of the region's crossings were surveyed, assessing whether the designs of the bridges and culverts are suitable for the movement of fish and wildlife, or whether they present partial or complete barriers to migration for a variety of species.[7]

Data from the aforementioned PIE-Rivers Assessment was used to conduct an additional analysis of infrastructure risk using a hydraulic capacity (HC) screening model developed and applied by Trout Unlimited[8]. The HC screening model estimates whether a bridge or culvert will be able to pass instream flows during the 1%, 2%, 4%, 10% and 50% annual chance storms. This tool utilizes a combination of site specific measurements taken at each crossing, GIS data characterizing upstream watershed characteristics, and rainfall predictions to make these estimates. Crossings that are unable to pass flood flows are more likely to have catastrophic failure and used as an initial screening tool to assess their

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[6] "Continuity and Infrastructure Assessment," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_20/

[7] Kelder, B., *PIE-Rivers Stream Continuity Survey – Final Report* (Ipswich, MA: Ipswich River Watershed Association, 2014), http://www.pie-rivers.org/wp-content/uploads/2015/03/PIE_CrossingsFinalReport_12312014.pdf

[8] Trout Unlimited, *Piscataquog River Watershed Stream Crossing Vulnerability Assessment Project - Final Report* (Concord, NH, 2014), http://www.snhpc.org/pdf/PiscataquogHydrologyStudy2014.pdf

vulnerability for this report. The remainder of this study further assessed and prioritized structures in each community and regionally taking into consideration both infrastructure risk and ecological impact. Preliminary designs for 103 of the high priority structures in the region were produced to guide implementation work. The results of this more comprehensive analysis of risk and impact are summarized in the final Great Marsh Resiliency Plan. Full results for the entire study region can be found in the Great Marsh Barriers Report.

Tidal road-stream crossings

The results of a previously conducted study by the Massachusetts Division of Ecological Restoration, combined with site visits and local knowledge, were used to identify highly vulnerable sites. All tidal crossings under a public way that were associated with a tidally restricted marsh identified in the Draft Great Marsh Coastal Wetlands Restoration Plan[9] were assumed to be highly vulnerable.

The Great Marsh Coastal Wetlands Restoration Plan (hereinafter "Draft Plan"), developed by the Massachusetts Office of Coastal Zone Management's Wetlands Restoration Program (now part of the MA Division of Ecological Restoration) and partners, was drafted as a tool to help communities in the Great Marsh region identify and restore degraded and former coastal wetland habitats. The Draft Plan was initially developed in 2006 and is currently (2017) being updated and revised. It presents maps and descriptions of 121 potential and completed salt marsh restoration sites in the Great Marsh. In the future, the Division of Ecological Restoration and other partners will be updating and expanding the data to provide timely information on the status and progress of specific sites, and to incorporate new restoration opportunities as they emerge. These data are currently in the process of being published.[10]

For our analysis, we considered marshes that were located partly or completely within the town of interest and were classified as tidal restrictions. Through a combination of desktop GIS analysis and local knowledge, we identified tidal road-stream crossings in each town. Road-stream crossings under a public way that are associated with one of the marshes the Draft Plan identified as tidally restricted were considered to be highly vulnerable. The Draft Plan also included more detailed "rapid technical assessments" of a subset of the sites it considered. These reports include more detail on the degree of tidal restriction, including information such as measurements of tidal range over month-long periods that may be of use if these sites are further explored.

Dams

The most current data from the Massachusetts Office of Dam Safety (ODS) Inventory[11] were reviewed and dams rated as either high or significant hazard potential were deemed highly vulnerable due to the public safety ramifications. ODS[12] maintains records of dams located throughout the Commonwealth of Massachusetts and ensures compliance with acceptable practices pertaining to dam inspection, maintenance, operation and repair of dams. The database also contains location information for dams that are small enough to not be covered under the jurisdiction of the ODS. These dams were mapped, but

[9] Contact the Massachusetts Division of Ecological Restoration for more information: http://www.mass.gov/eea/agencies/dfg/der/

[10] Ibid

[11] "MassGIS Data – Dams," MA Executive Office for Administration and Finance, http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/dams.html

[12] "Dam Safety," MA EEA, http://www.mass.gov/eea/agencies/dcr/conservation/dam-safety/

not considered highly vulnerable because they are small enough to not reach risk thresholds to concern ODS. Dams are categorized as follows:

> *High Hazard Potential dam* refers to dams located where failure will likely cause loss of life and serious damage to home(s), industrial or commercial facilities, important public utilities, main highway(s) or railroad(s).
>
> *Significant Hazard Potential dam* refers to dams located where failure may cause loss of life and damage home(s), industrial or commercial facilities, secondary highway(s) or railroad(s) or cause interruption of use or service of relatively important facilities.
>
> *Low Hazard Potential dam* refers to dams located where failure may cause minimal property damage to others. Loss of life is not expected.

Gray infrastructure/coastal stabilization structures

Data from the Massachusetts Coastal Structure Inventory and Assessment Project,[13] prepared by the Infrastructure Plan Working Group of the Coastal Hazards Commission for Massachusetts Departments of Coastal Zone Management (CZM) and Conservation and Recreation (DCR), was used to review and assess shoreline stabilization structures and their ability to resist major coastal storms and prevent damage due to flooding and erosion. The data and summary report includes condition ratings and estimated repair or reconstruction costs for publicly-owned coastal structures inventoried from 2006-2009. The condition of coastal structures was characterized through on-site evaluation and ranged from excellent (A) to critical (F). The majority of the structures were either in good (B) or fair (C) condition. Publicly owned, man-made structures with condition scores graded D and F were deemed highly vulnerable.

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[13] "StormSmart Coasts – Inventories of Seawalls and Other Coastal Structures," MA CZM, http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/seawall-inventory/

Town-Specific Results

The following pages include tables and maps displaying the town-specific summary results of the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed.

Table B-1. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Salisbury, MA.

Data Set		Structure Count	Structures by Category		
Non-Tidal Stream Crossings		20*	**Priority**	**Storm Return Interval**	**Initial Hydraulic Screen Fail**
			Low	Pass all	5
				100 year (1%)	
				50 year (2%)	
			High	25 year (4%)	1
				10 year (10%)	
				2 Year (50%)	
Tidal Stream Crossings		15	**Priority**	**Count**	
			Low	5	
			High	10	
Dams		0	**Priority**	**Hazard Class**	**Count**
			Low	Non-Jurisdictional	
				Low Hazard	
			High	Significant Hazard	
Shoreline Stabilization Structures	Public	7	**Priority**	**Condition**	**Count**
			Low	A - Excellent	
				B - Good	6
				C - Fair	1
			High	D - Poor	
				F - Critical	
	Private	2	Not Prioritized		

* There are a total of 20 non-tidal stream crossings in the Salisbury data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

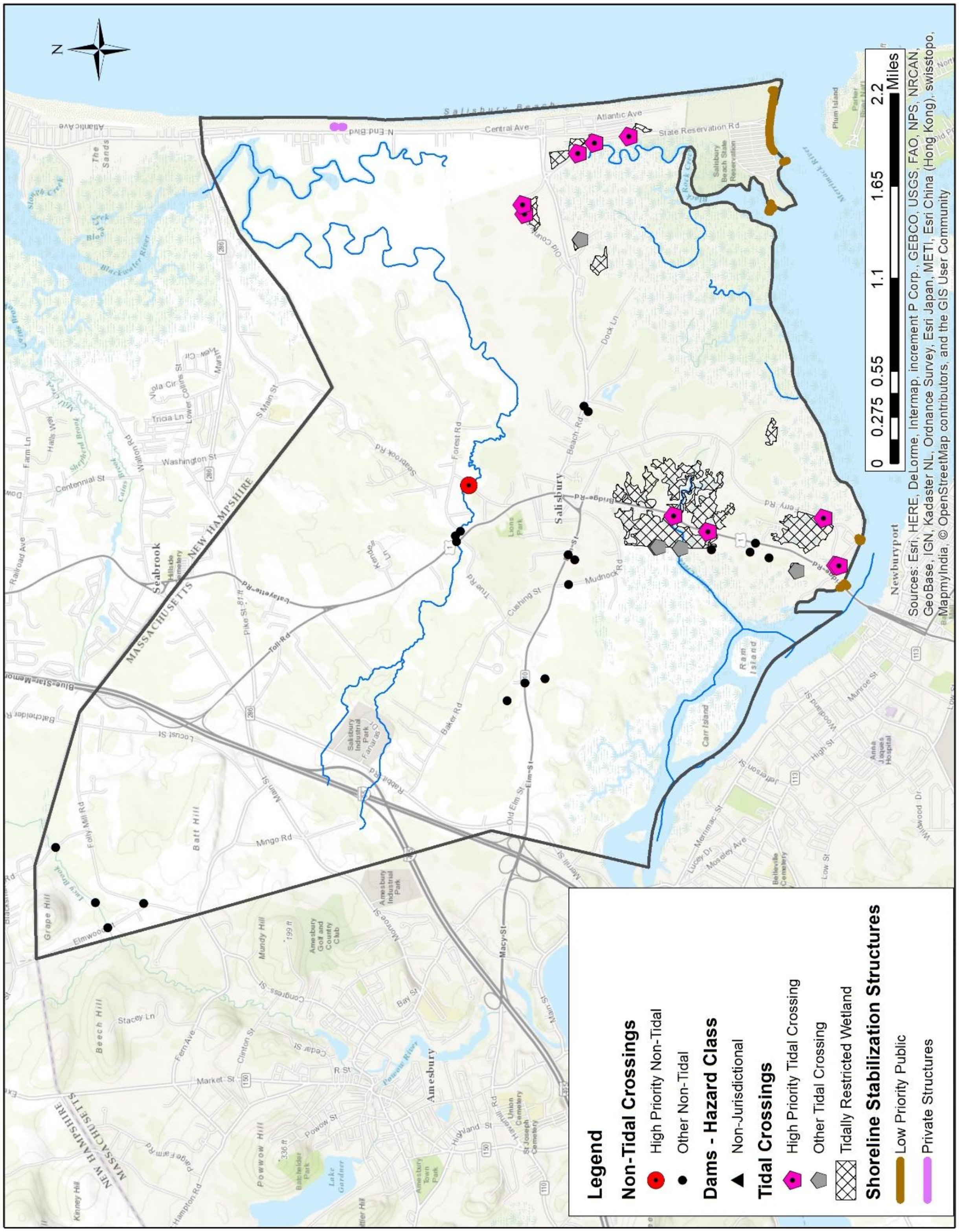

Figure B-1. Map and summary of results the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Salisbury, Massachusetts

Table B-2. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the City of Newburyport, MA.

Data Set		Structure Count	Structures by Category		
Non-Tidal Stream Crossings		35*	Priority	Storm Return Interval	Initial Hydraulic Screen Fail
			Low	Pass all	1
				100 year (1%)	1
				50 year (2%)	1
			High	25 year (4%)	2
				10 year (10%)	2
				2 Year (50%)	3
Tidal Stream Crossings		4	Priority	Count	
			Low	4	
			High		
Dams		4	Priority	Hazard Class	Count
			Low	Non-Jurisdictional	
				Low Hazard	4
			High	Significant Hazard	
Shoreline Stabilization Structures	Public	17	Priority	Condition	Count
			Low	A - Excellent	1
				B - Good	9
				C - Fair	7
			High	D - Poor	
				F - Critical	
	Private	14	Not Prioritized		

* There are a total of 35 non-tidal stream crossings in the Newburyport data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

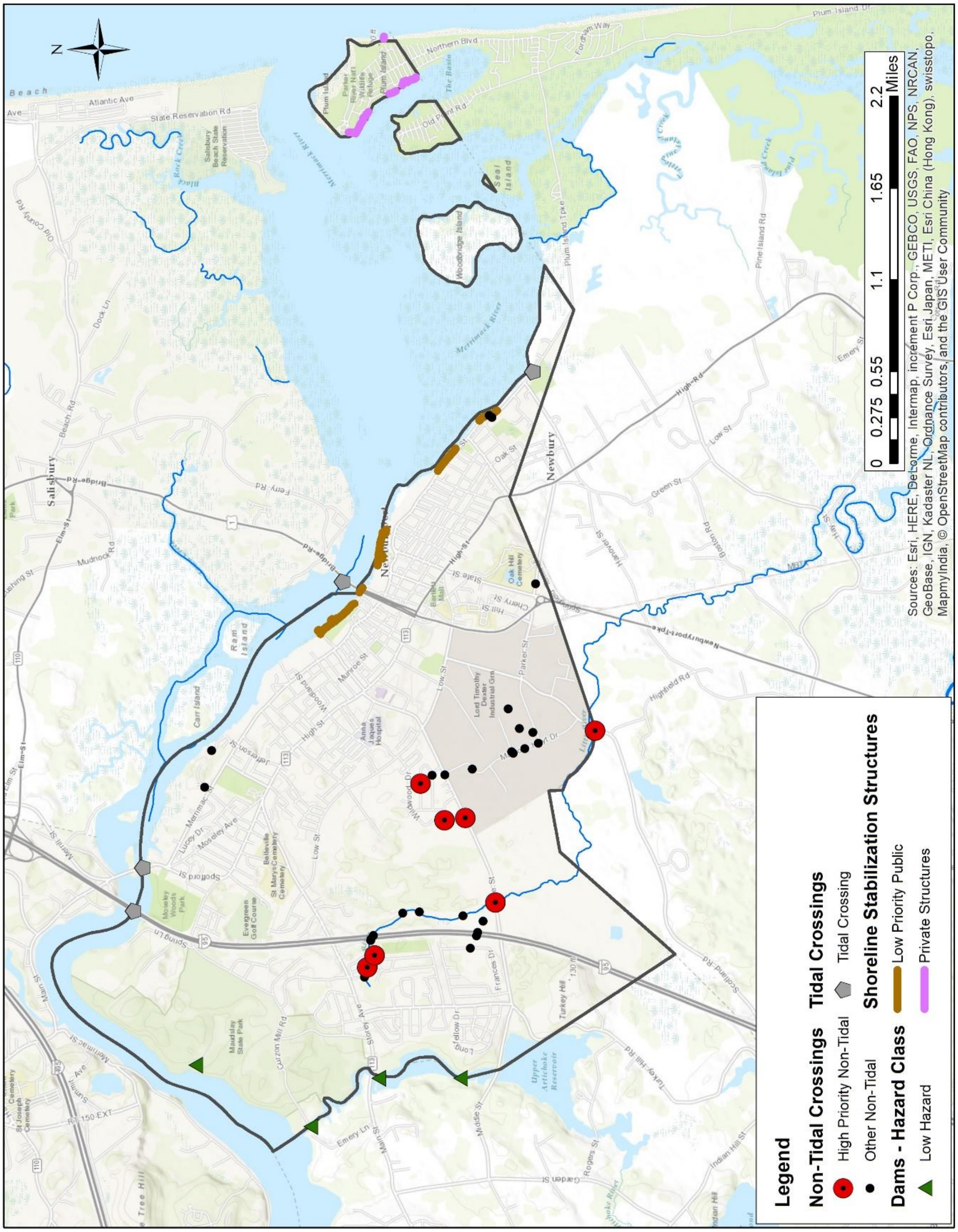

Figure B-2. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the City of Newburyport, MA.

Table B-3. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Newbury, MA.

Data Set		Structure Count	Structures by Category		
			Priority	**Storm Return Interval**	**Initial Hydraulic Screen Fail**
Non-Tidal Stream Crossings		80*	Low	Pass all	11
				100 year (1%)	
				50 year (2%)	
			High	25 year (4%)	1
				10 year (10%)	5
				2 Year (50%)	9
			Priority	**Count**	
Tidal Stream Crossings		27	Low	19	
			High	8	
			Priority	**Hazard Class**	**Count**
Dams		9	Low	Non-Jurisdictional	6
				Low Hazard	3
			High	Significant Hazard	
			Priority	**Condition**	**Count**
Shoreline Stabilization Structures	**Public**	2	Low	A - Excellent	
				B - Good	1
				C - Fair	
			High	D - Poor	1
				F - Critical	
	Private	19	Not Prioritized		

* There are a total of 80 non-tidal stream crossings in the Newbury data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

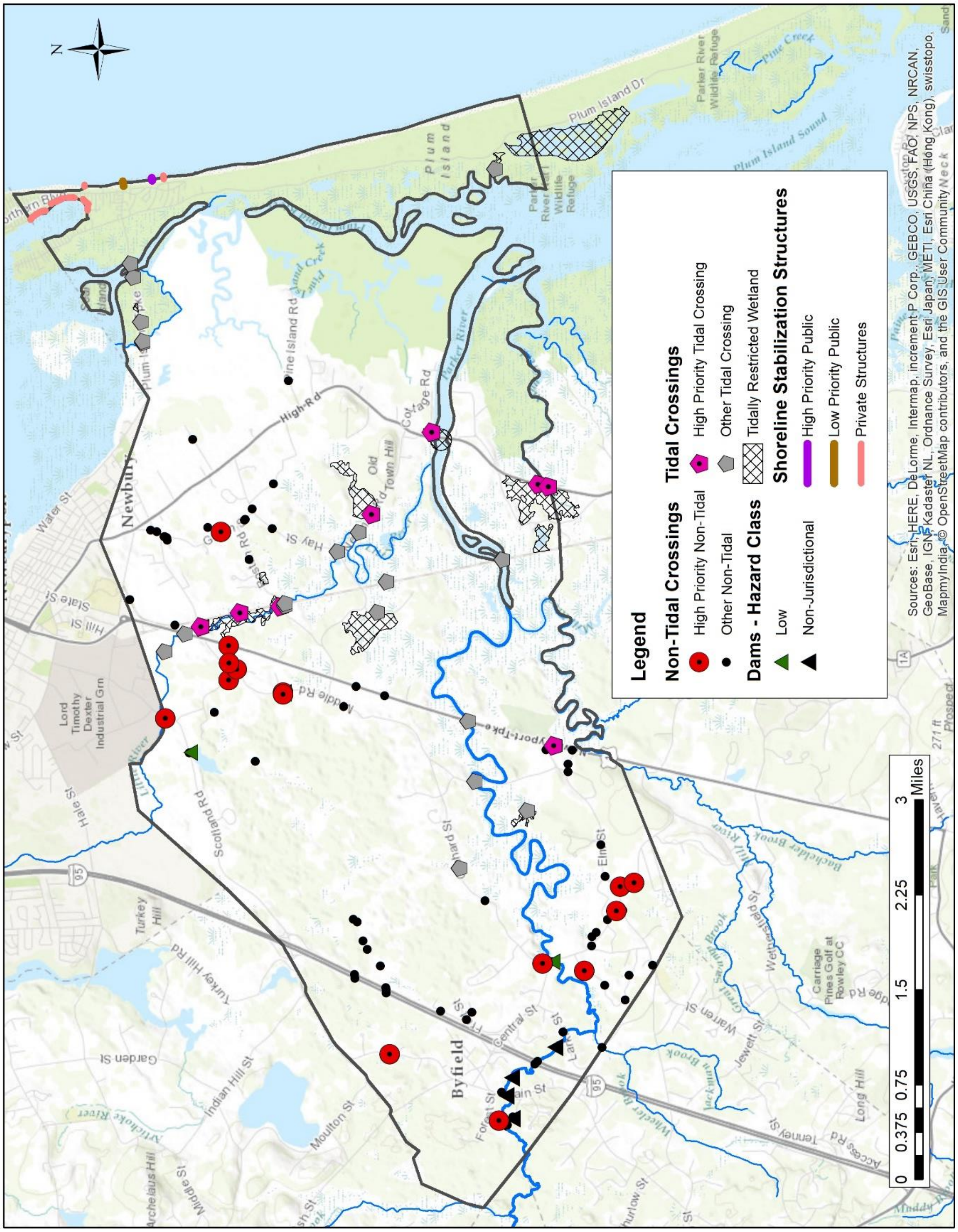

Figure B-3. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Newbury, MA.

Table B-4. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Rowley, MA.

Data Set		Structure Count	Structures by Category		
Non-Tidal Stream Crossings		76*	**Priority**	**Storm Return Interval**	**Initial Hydraulic Screen Fail**
			Low	Pass all	15
				100 year (1%)	
				50 year (2%)	1
			High	25 year (4%)	1
				10 year (10%)	6
				2 Year (50%)	15
Tidal Stream Crossings		9	**Priority**	**Count**	
			Low	7	
			High	2	
Dams		6	**Priority**	**Hazard Class**	**Count**
			Low	Non-Jurisdictional	3
				Low Hazard	2
			High	Significant Hazard	1
Shoreline Stabilization Structures	**Public**	0	**Priority**	**Condition**	**Count**
			Low	A - Excellent	
				B - Good	
				C - Fair	
			High	D - Poor	
				F - Critical	
	Private	0	Not Prioritized		

* There are a total of 76 non-tidal stream crossings in the Rowley data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

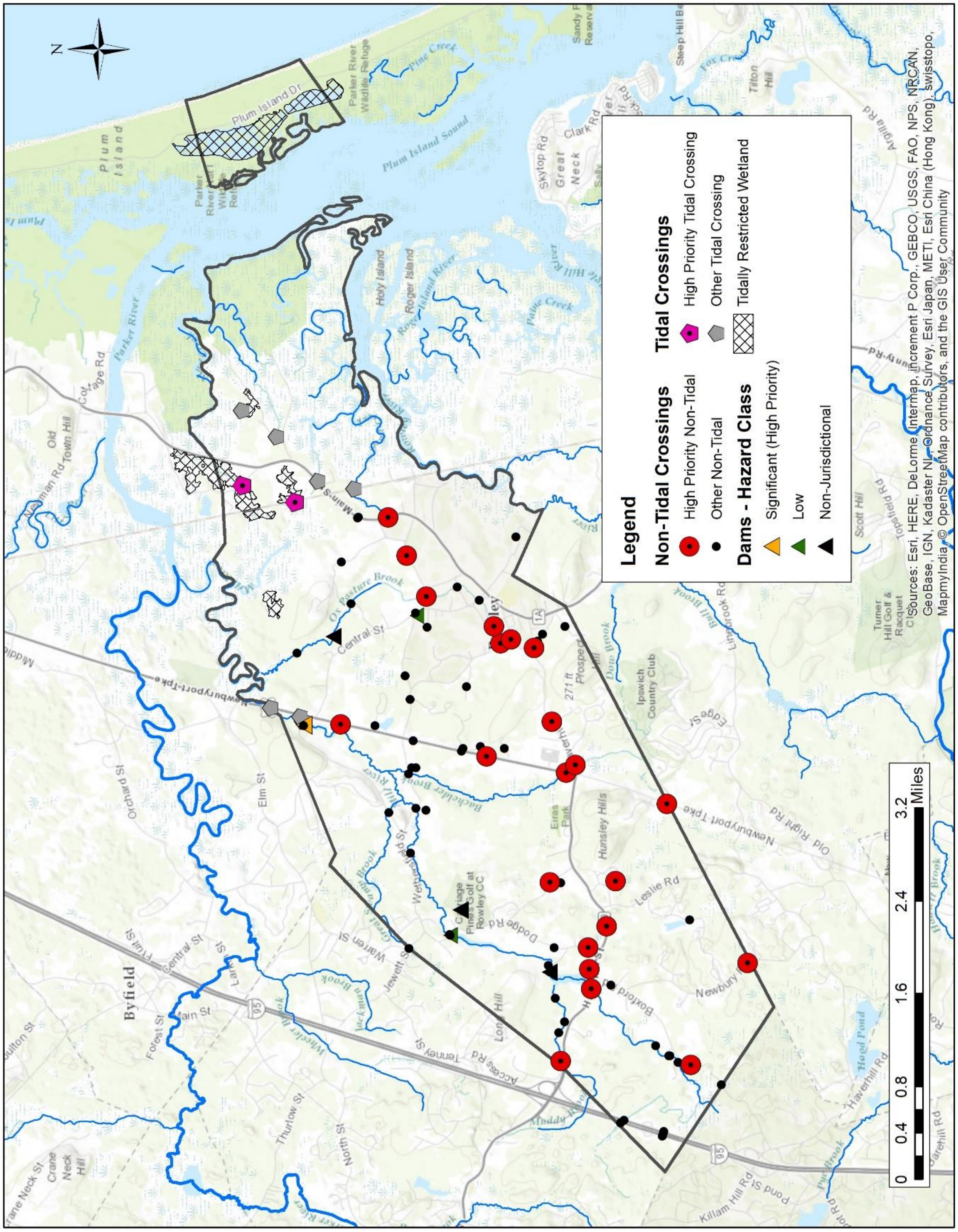

Figure B-4. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Rowley, MA.

Table B-5. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Ipswich, MA.

<table>
<tr><th colspan="2">Data Set</th><th>Structure Count</th><th colspan="3">Structures by Category</th></tr>
<tr><td colspan="2" rowspan="7">Non-Tidal Stream Crossings</td><td rowspan="7">87*</td><th>Priority</th><th>Storm Return Interval</th><th>Initial Hydraulic Screen Fail</th></tr>
<tr><td rowspan="3">Low</td><td>Pass all</td><td>12</td></tr>
<tr><td>100 year (1%)</td><td>2</td></tr>
<tr><td>50 year (2%)</td><td>1</td></tr>
<tr><td rowspan="3">High</td><td>25 year (4%)</td><td>1</td></tr>
<tr><td>10 year (10%)</td><td>5</td></tr>
<tr><td>2 Year (50%)</td><td>16</td></tr>
<tr><td colspan="2" rowspan="3">Tidal Stream Crossings</td><td rowspan="3">17</td><th>Priority</th><th colspan="2">Count</th></tr>
<tr><td>Low</td><td colspan="2">10</td></tr>
<tr><td>High</td><td colspan="2">7</td></tr>
<tr><td colspan="2" rowspan="4">Dams</td><td rowspan="4">6</td><th>Priority</th><th>Hazard Class</th><th>Count</th></tr>
<tr><td rowspan="2">Low</td><td>Non-Jurisdictional</td><td>2</td></tr>
<tr><td>Low Hazard</td><td>3</td></tr>
<tr><td>High</td><td>Significant Hazard</td><td>1</td></tr>
<tr><td rowspan="7">Shoreline Stabilization Structures</td><td rowspan="6">Public</td><td rowspan="6">1</td><th>Priority</th><th>Condition</th><th>Count</th></tr>
<tr><td rowspan="3">Low</td><td>A - Excellent</td><td></td></tr>
<tr><td>B - Good</td><td></td></tr>
<tr><td>C - Fair</td><td>1</td></tr>
<tr><td rowspan="2">High</td><td>D - Poor</td><td rowspan="2"></td></tr>
<tr><td>F - Critical</td></tr>
<tr><td>Private</td><td>24</td><td colspan="3">Not Prioritized</td></tr>
</table>

* There are a total of 87 stream crossings in the Ipswich data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

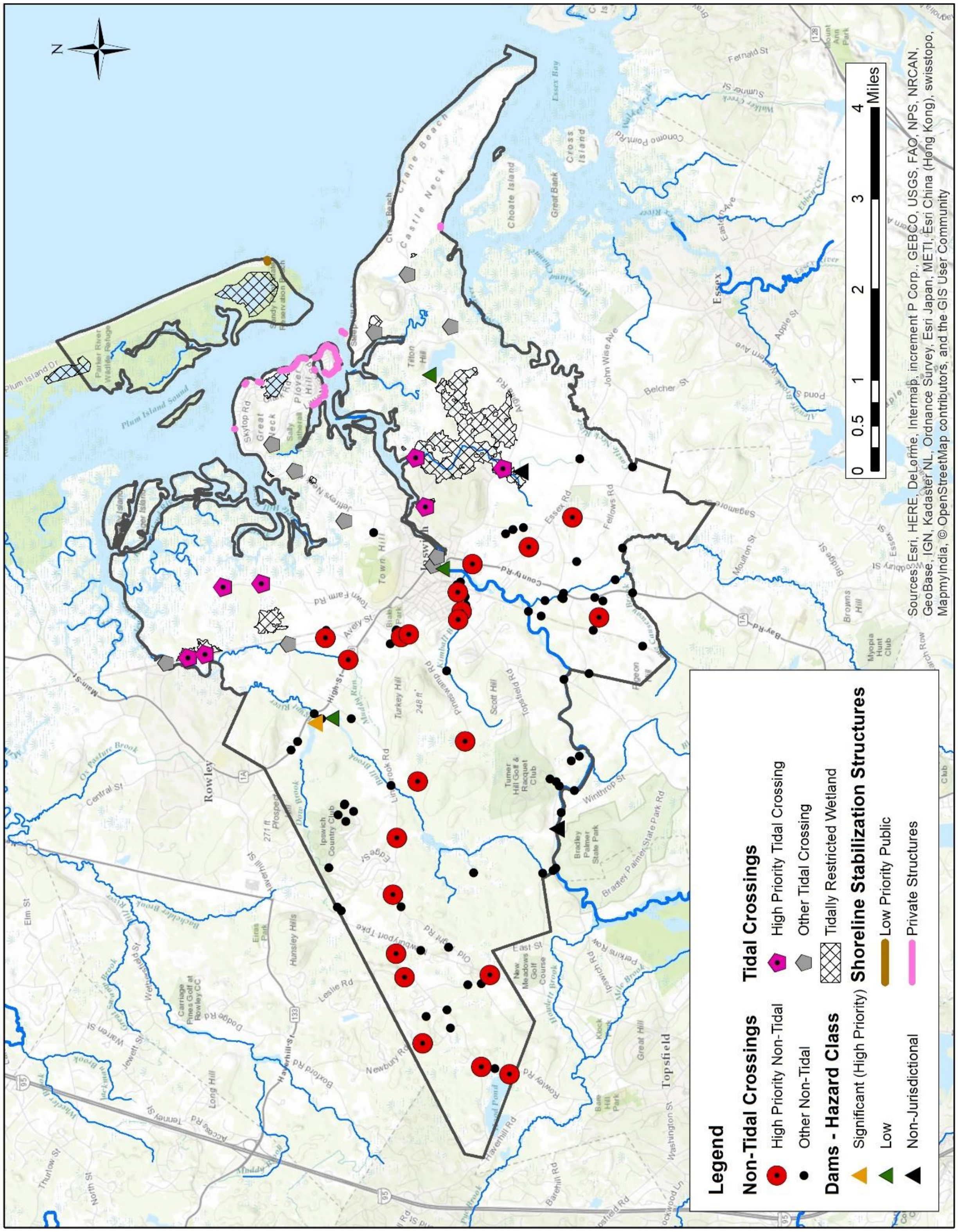

Figure B-5. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Ipswich, MA.

Table B-6. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Essex, MA.

<table>
<tr><th colspan="2">Data Set</th><th>Structure Count</th><th colspan="3">Structures by Category</th></tr>
<tr><td colspan="2" rowspan="7">Non-Tidal Stream Crossings</td><td rowspan="7">38*</td><td>Priority</td><td>Storm Return Interval</td><td>Initial Hydraulic Screen Fail</td></tr>
<tr><td rowspan="3">Low</td><td>Pass all</td><td>7</td></tr>
<tr><td>100 year (1%)</td><td>0</td></tr>
<tr><td>50 year (2%)</td><td>0</td></tr>
<tr><td rowspan="3">High</td><td>25 year (4%)</td><td>3</td></tr>
<tr><td>10 year (10%)</td><td>2</td></tr>
<tr><td>2 Year (50%)</td><td>3</td></tr>
<tr><td colspan="2" rowspan="3">Tidal Stream Crossings</td><td rowspan="3">12</td><td>Priority</td><td colspan="2">Count</td></tr>
<tr><td>Low</td><td colspan="2">7</td></tr>
<tr><td>High</td><td colspan="2">5</td></tr>
<tr><td colspan="2" rowspan="4">Dams</td><td rowspan="4">0</td><td>Priority</td><td>Hazard Class</td><td>Count</td></tr>
<tr><td rowspan="2">Low</td><td>Non-Jurisdictional</td><td></td></tr>
<tr><td>Significant Hazard</td><td></td></tr>
<tr><td>High</td><td>Non-Jurisdictional</td><td></td></tr>
<tr><td rowspan="7">Shoreline Stabilization Structures</td><td rowspan="6">Public</td><td rowspan="6">0</td><td>Priority</td><td>Condition</td><td>Count</td></tr>
<tr><td rowspan="3">Low</td><td>A - Excellent</td><td></td></tr>
<tr><td>B - Good</td><td></td></tr>
<tr><td>C - Fair</td><td></td></tr>
<tr><td rowspan="2">High</td><td>D - Poor</td><td></td></tr>
<tr><td>F - Critical</td><td></td></tr>
<tr><td>Private</td><td>0</td><td colspan="3">Not Prioritized</td></tr>
</table>

*There are a total of 38 non-tidal stream crossings in the Essex data set including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

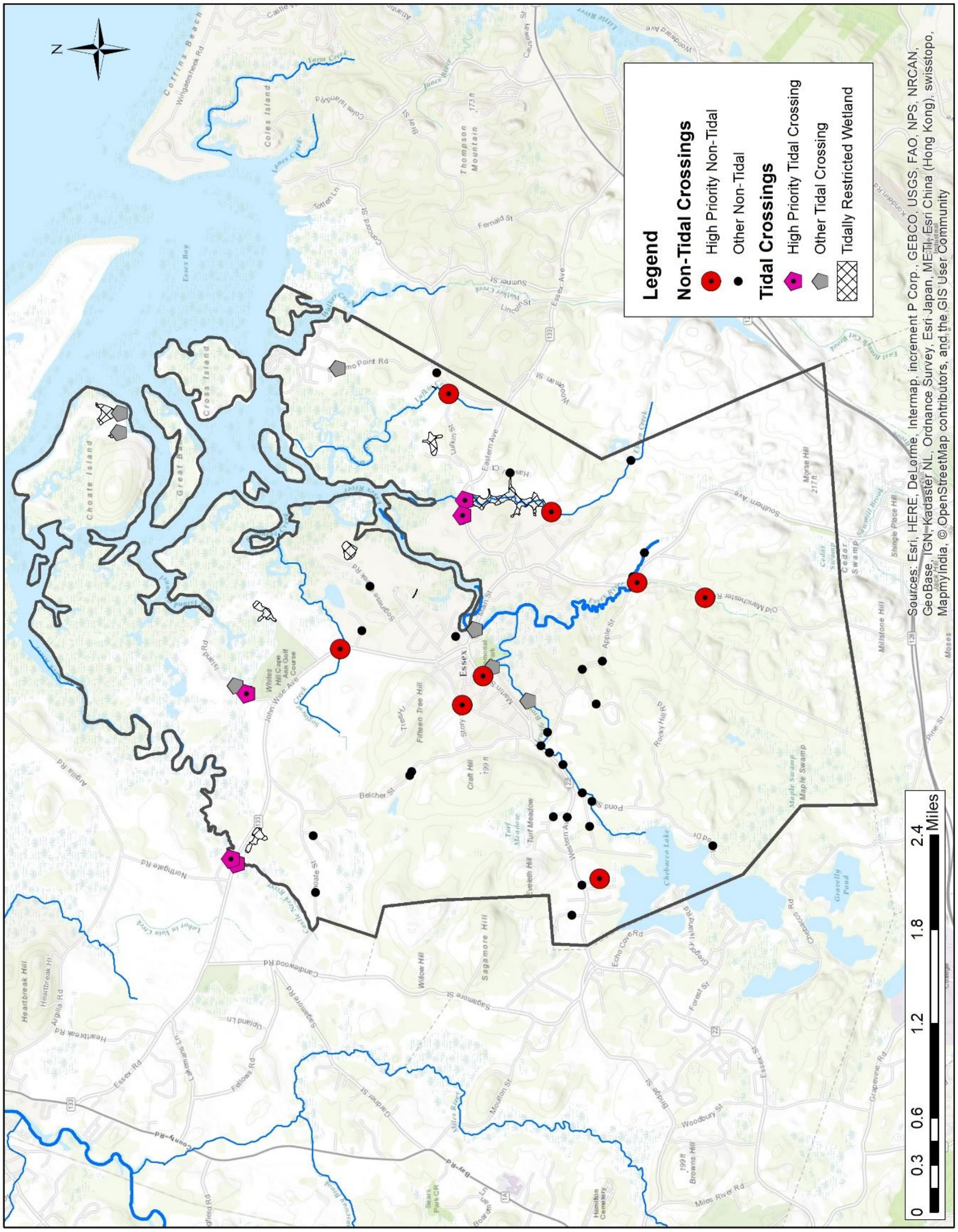

Figure B-6. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Essex, MA.

APPENDIX C:
Vulnerable Areas of Special Concern

During the planning process, the following assets were identified as areas of special concern due to their current and future vulnerability and the consequences if the area/asset is impacted by flooding or erosion. The Municipal and Regional Resiliency Task Forces contributed extensive local knowledge to inform the identification of these areas. A geospatial analysis also helped identify areas vulnerable to future inundation.

Table C-1. Identified vulnerable areas of special concern by town; (*) = identified by the Resiliency Task Force as an area of primary concern; (◊) = Located in a state designated Area of Critical Environmental Concern (ACEC)

Town	Area of Concern	Location	Hazard Type
Essex	Main Street Causeway & Woodman's Landing*	74 to 166 Main Street	Flooding
Essex	Eastern Avenue at Ebben Creek*◊	81 Eastern Ave to 97 Eastern Ave	Flooding
Essex	Conomo Point Road*◊	All of Conomo Point Road	Flooding
Essex	Crane Beach (tip of point)* ◊	290 Argilla Rd, Ipswich	Erosion
Essex	Eastern Ave and Grove St	Intersection of Eastern Ave and Grove Street	Flooding
Essex	Richdale's Gas Station	156 Main Street	Flooding
Essex	Ball fields behind town hall and playground	30 Martin Street	Flooding
Essex	Landing Road culvert	9 Landing Road	Flooding
Essex	Apple Street culvert near Andrews Street	Essex River culvert at Apple Street	Flooding
Ipswich	Downtown Ipswich (including Choate Bridge and South Main Street)*	Downtown along the Ipswich River, Route 133/1A	Flooding
Ipswich	Sewage Pumping Station	Town Wharf at 68 East St.	Flooding
Ipswich	Jeffrey's Neck Road*◊	Beachview Lane northeast to 144 Jeffrey's Neck Rd	Flooding
Ipswich	Crane Beach (including parking lots/beach facility)*◊	290 Argilla Rd, Ipswich	Erosion, coastal flooding
Ipswich	Pavilion Beach◊	Beach connecting Great and Little Neck	Erosion
Ipswich	Massachusetts Bay Transportation Authority (MBTA) Newburyport Train Line◊	Ipswich portion of train tracks	Storm surge and sea level rise; tracks act as a barrier to natural coastal flowage patterns
Ipswich	Brown's well (Ipswich drinking water supply)	Route 1A at Muddy Run /188 High St	Flooding, salt water infiltration due to sea level rise

Town	Area of Concern	Location	Hazard Type
Ipswich	Clark Beach◊	Beach bordering Clark Pond	Erosion
Ipswich	Clark Pond◊	Great Neck	Coastal flooding
Newbury	Plum Island Turnpike/Plum Island Airport/Plumbush Downs*◊	MA Audubon's Joppa Flats Education Center East to Sunset Dr.	Tidal and storm flooding
Newbury	Sewage Pumping Station on Plum Island*	Webbers Ct. & Olga Way, in Basin Harbor neighborhood	Near area subject to overtopping, projected coastal inundation
Newbury	Low-lying houses along bayside of Plum Island	Basin Harbor neighborhood located between Old Point Road and Northern Boulevard, north of Plum Island turnpike.	Projected coastal inundation
Newbury	Newbury Elementary School (Little River @ Hanover St)*◊	63 Hanover St.	Emergency shelter – access point from west side floods
Newbury	Newburyport Turnpike/Rt. 1*◊	Rt.1 at Parker River bridge	Tidal and storm flooding
Newbury	Low-lying houses along bayside of Plum Island	Basin Harbor neighborhood located between Old Point Road and Northern Boulevard, north of Plum Island turnpike.	Projected coastal inundation
Newbury	Route 1A at Rowley border, including Old Rowley Road	Route 1A at Rowley border	Flooding of roads & residences
Newbury	Lord Timothy Dexter Industrial Green ("Business Park")	Parker St, Scotland Rd)	Flooding caused by small culverts
Newbury	Triton Middle & High School	112 Elm St	Possible future flooding of ball fields
Newbury	Newburyport MBTA Train Station	Route 1 rotary near Little River & back end of Parker St	Flooding
Newbury	Pine Island Road	All of Pine Island Road that is along the marsh	Flooding, ice cakes, high winds, zero visibility
Newbury	Refuge Road	From the Plum Island Turnpike south into Parker River NWR	Flooding
Newbury	Governor's Academy	Campus and waste water treatment plant located between Mill River, Elm St, Route 1, and Parker River	Tidal and storm flooding from Parker River and floodplain
Newbury	Cottage Road, off of 1A near Parker River	Boat ramp at the end of Cottage Road	Flooding from Parker River
Newbury	Central St. dam	70 Central St	Flooding, possible dam failure

Town	Area of Concern	Location	Hazard Type
Newbury	River St./Forest St. dam	Just north of intersection between West St and Main St	Flooding, possible dam failure
Newbury	Plum Island Beach and groins/jetties	East from the end of Plum Island Turnpike and south on beach next to Southern Boulevard	Flooding, erosion, jetties deteriorate over time
Newburyport	Plum Island Beach and groins/jetties	East from the end of Plum Island Turnpike and south on beach next to Southern Boulevard	Flooding, erosion, jetties deteriorate over time
Newburyport	Merrimack River Jetty System*	Mouth of the Merrimack River	Deteriorates over time; potentially increases erosion, jetty design is a concern
Newburyport	North End of Plum Island*	Reservation Terrace Old Point Neighborhood	Projected coastal inundation
Newburyport	Plum Island Turnpike (including Plum Island Airport)*◊	Joppa Flats Nature Center East to Sunset Dr.	Tidal and storm flooding
Newburyport	Waste Water Treatment Facility*	157 Water Street	Flooding from storm surge and sea level rise
Newburyport	Central Waterfront (historic downtown)	East of Merrimac/Water Street, between Green Street and the Harbor Master Shack	Flooding
Newburyport	Water Street (including Salvation Army & Coast Guard Station)	Plum Island Turnpike to Merrimac Street	Flooding
Newburyport	Cashman Park	West of Route 1 bridge, between Merrimac River and Merrimac Street	Flooding
Newburyport	Lower Artichoke Reservoir*	Between Storey Ave (Rt 113) & Middle Rd., West Newbury	Salt-water intrusion
Newburyport	Bartlett Spring Pond*	742 Spring Ln	Salt-water intrusion
Newburyport	Lord Timothy Dexter Industrial Green (Business Park)	104 Parker Street/Scotland Road	Flooding at Little River
Rowley	Route 133 at Bachelder Brook*	Northeast of 312 Haverhill St	Flooding
Rowley	Jewel Mill Dam*	west of the intersection between Mill St and Glen St	Dam failure/flooding

Town	Area of Concern	Location	Hazard Type
Rowley	Rowley Town Well # 3*	Along Mill River off of Boxford Road	Flooding, inundation of well pump station
Rowley	13 acres of beach on Parker River National Wildlife Refuge*◊	Plum Island	Erosion, coastal flooding
Rowley	Hillside St culvert at tributary to Mill River*	Great Swamp Brook at Hillside Street	Flooding
Rowley	Stackyard Road + Route 1A◊	Stackyard Road and Route 1A from Stackyard Road north to town line (plus Newbury section of Route 1A to Parker River)	Flooding
Rowley	Marina & town boat launch◊	Railroad Avenue/Warehouse Lane, off of Rt 1A	Flooding
Rowley	Massachusetts Bay Transporta-tion Authority (MBTA) Newburyport Train Line◊	Rowley portion of train tracks	Storm surge and sea level rise; tracks act as a barrier to natural coastal flowage patterns
Salisbury	Route 1A (Beach Road)*	North End Blvd intersection west .5 miles	Flooding
Salisbury	Salisbury Beach at Broadway*	East of the Broadway Mall, stretching 200ft north and south	Erosion, flooding
Salisbury	Salisbury Barrier Beach	3.8 mile long beach from NH Border to Merrimack River, including jetty and dunes.	Erosion, flooding
Salisbury	Route 1 and Associated Infrastructure	From downtown to the Merrimack bridge, particularly low-lying areas near 54 and 93 Bridge Road and at the Merrimack River Bridge.	Projected coastal inundation
Salisbury	Low-lying houses along the bayside of Salisbury Beach	- Neighborhood east of road to Salisbury reservation - Low-lying residential area north of Beach Center, west of 1A that surround the Blackwater river	Projected coastal inundation
Salisbury	North End Boulevard	from Old Town Way to 18th street	Flooding
Salisbury	Sewage Pumping Station	228 Beach Rd	Flooding
Salisbury	Town Pier	32 1st Street	Erosion, coastal flooding

Town	Area of Concern	Location	Hazard Type
Salisbury	Beach Rose RV Park	147 Beach Road	Projected coastal inundation
Salisbury	Rings Island neighborhood & marina	1st St neighborhood between Route 1 and Merrimack River	Projected coastal inundation
Salisbury	Access Road to Salisbury Beach State Park	State Beach Road, State Reservation Road	Projected coastal inundation
Salisbury	Hayes Street neighborhood	Off of Beach Road near 163 Beach Rd	Projected coastal inundation
Salisbury	Salisbury Police Station	175 Beach Road	Projected coastal inundation

APPENDIX D:
Town-specific Inundation Maps

The following maps illustrate current (2013) and future (2070) probability of coastal inundation in the six shore-front communities (listed north to south). Coastal inundation data was produced by the Woods Hole Group[14] using a hydrodynamic model developed for the Massachusetts Department of Transportation[15] (Figure D-1). It's important to note that this model does not take into account inland freshwater flooding. Present day (considered 2013) results incorporate existing sea level conditions. 2070 results incorporate 3.4 feet of sea level rise, which is also approximately the "Intermediate-High" scenario for 2090.

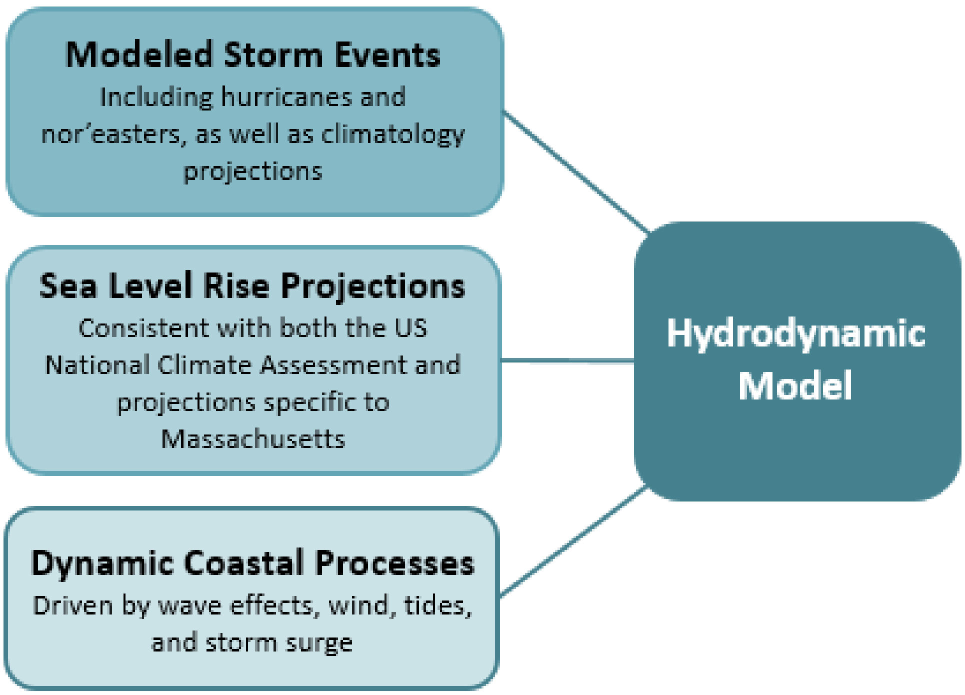

Figure D-1. Schematic summary of inputs built into the hydrodynamic model, as developed for the Massachusetts Department of Transportation (Bosma et al. 2016).

[14] Famely, J., K. Bosma and B. Hoffnagle, *Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA)*, Prepared for National Wildlife Federation and U.S. Geological Survey (East Falmouth, MA: Woods Hole Group, 2016).

[15] Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson, *MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery* (East Falmouth, MA: Woods Hole Group, 2016), https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_Report_MassDOT_FHWA.pdf

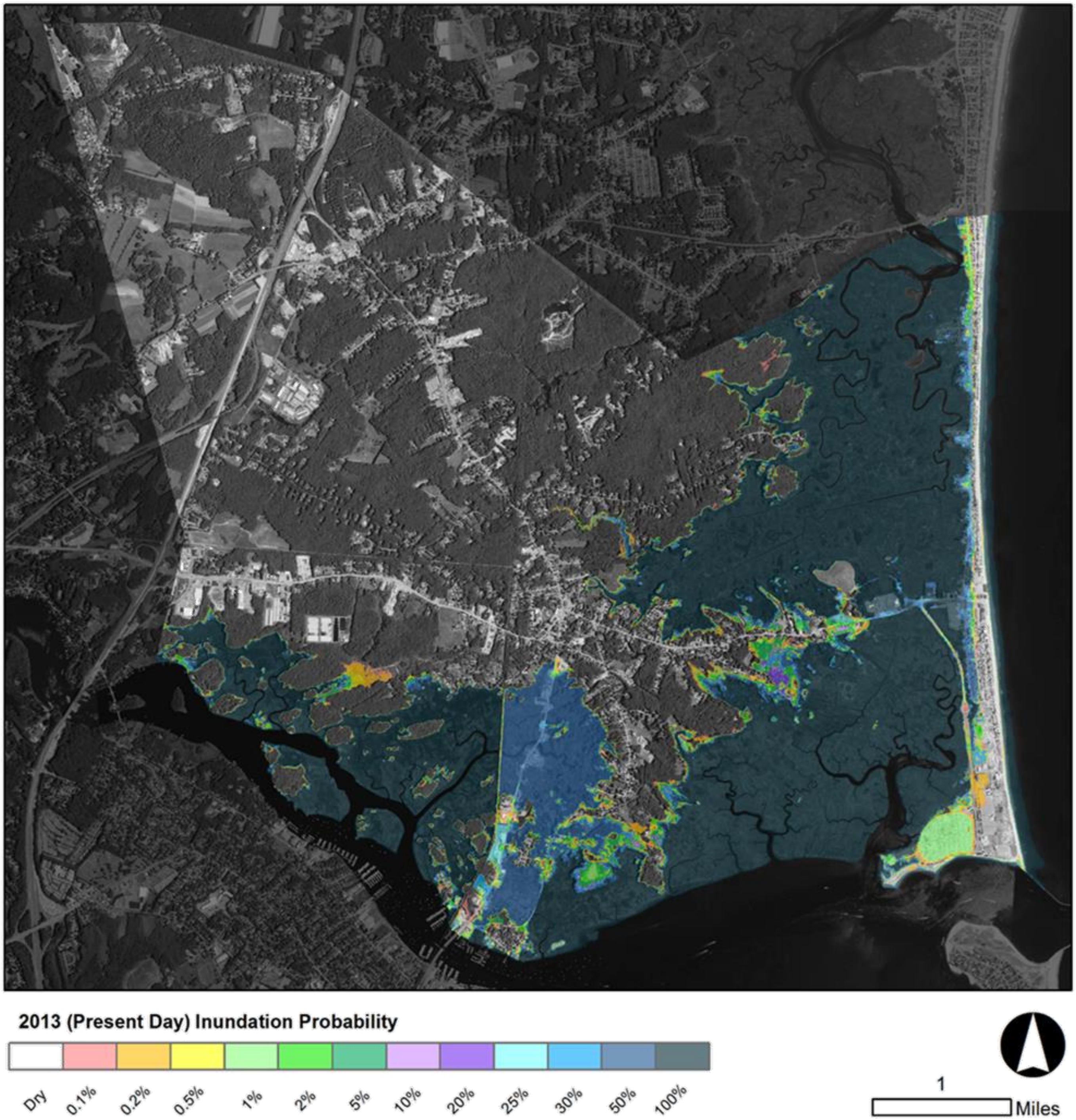

Figure D-1. Town of Salisbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

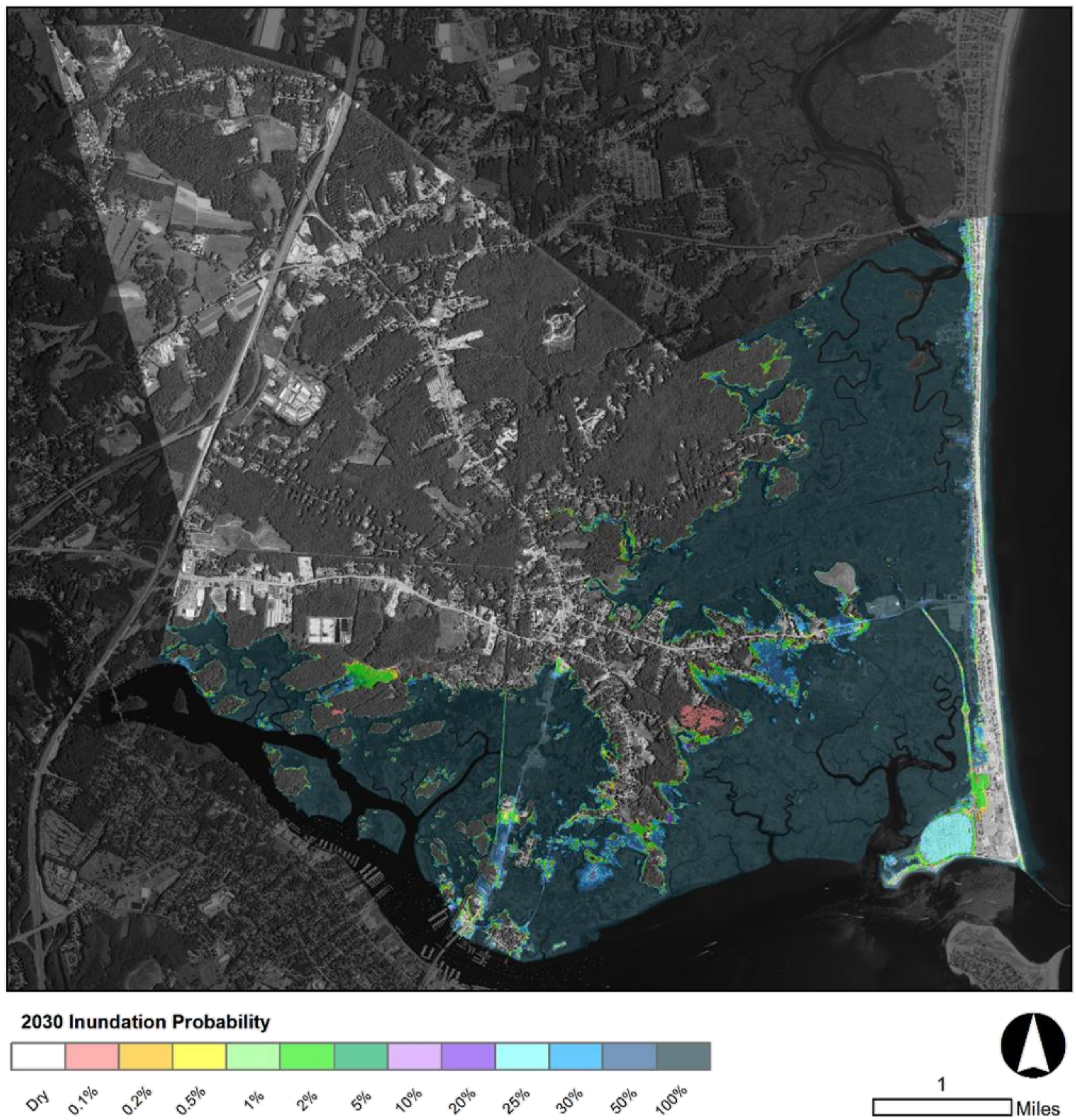

Figure D-2. Town of Salisbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

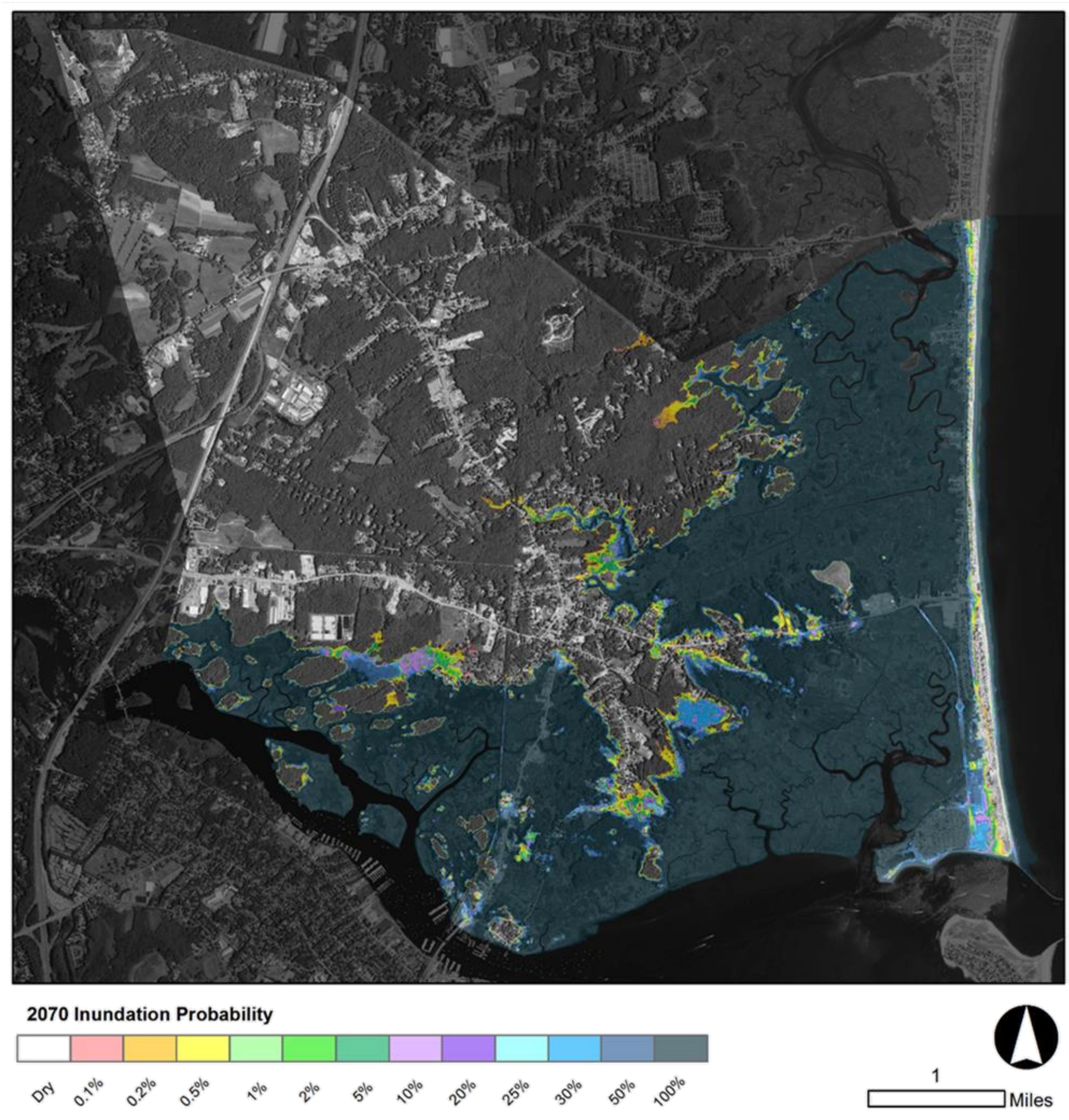

Figure D-3. Town of Salisbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

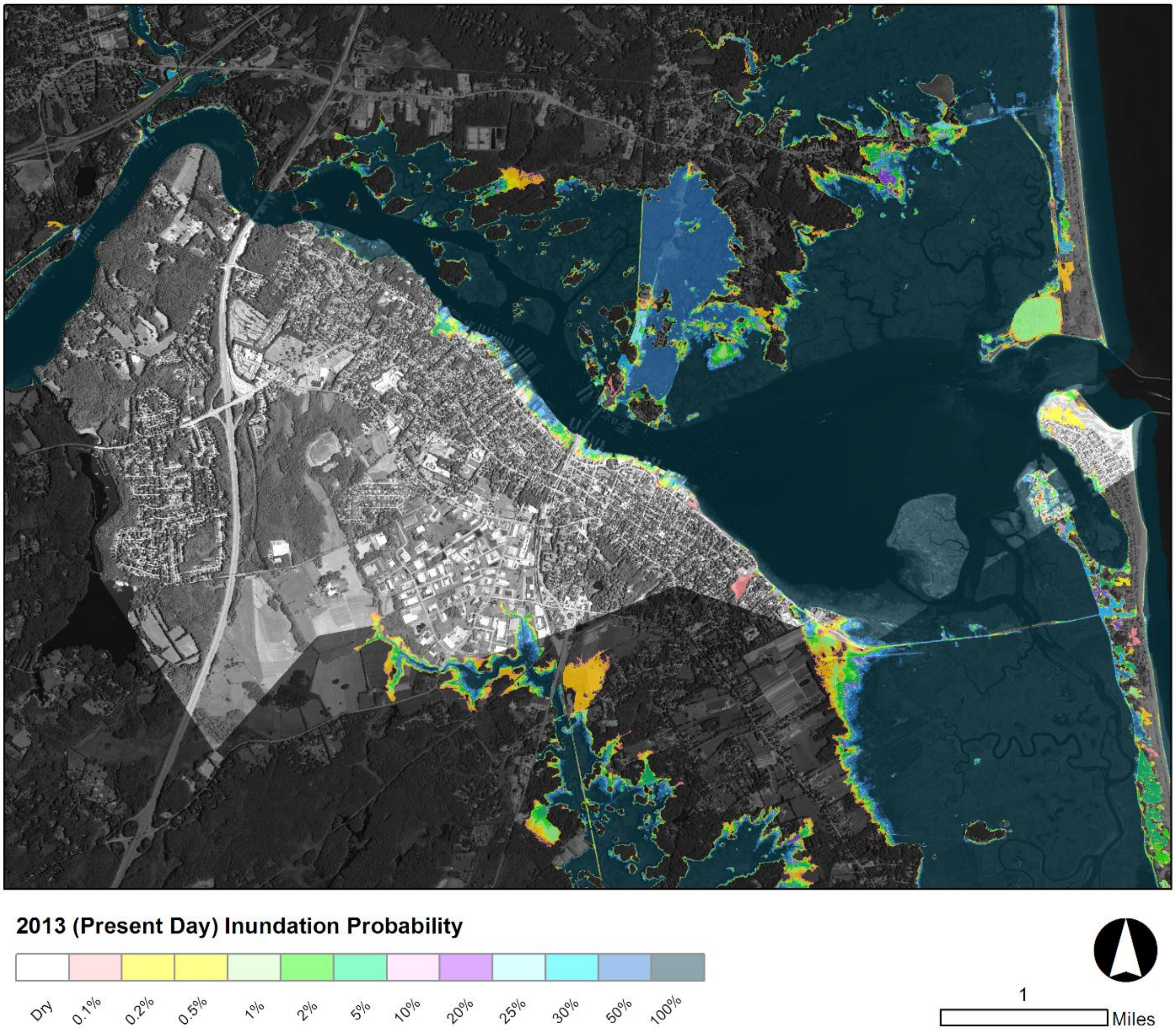

Figure D-4. City of Newburyport, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

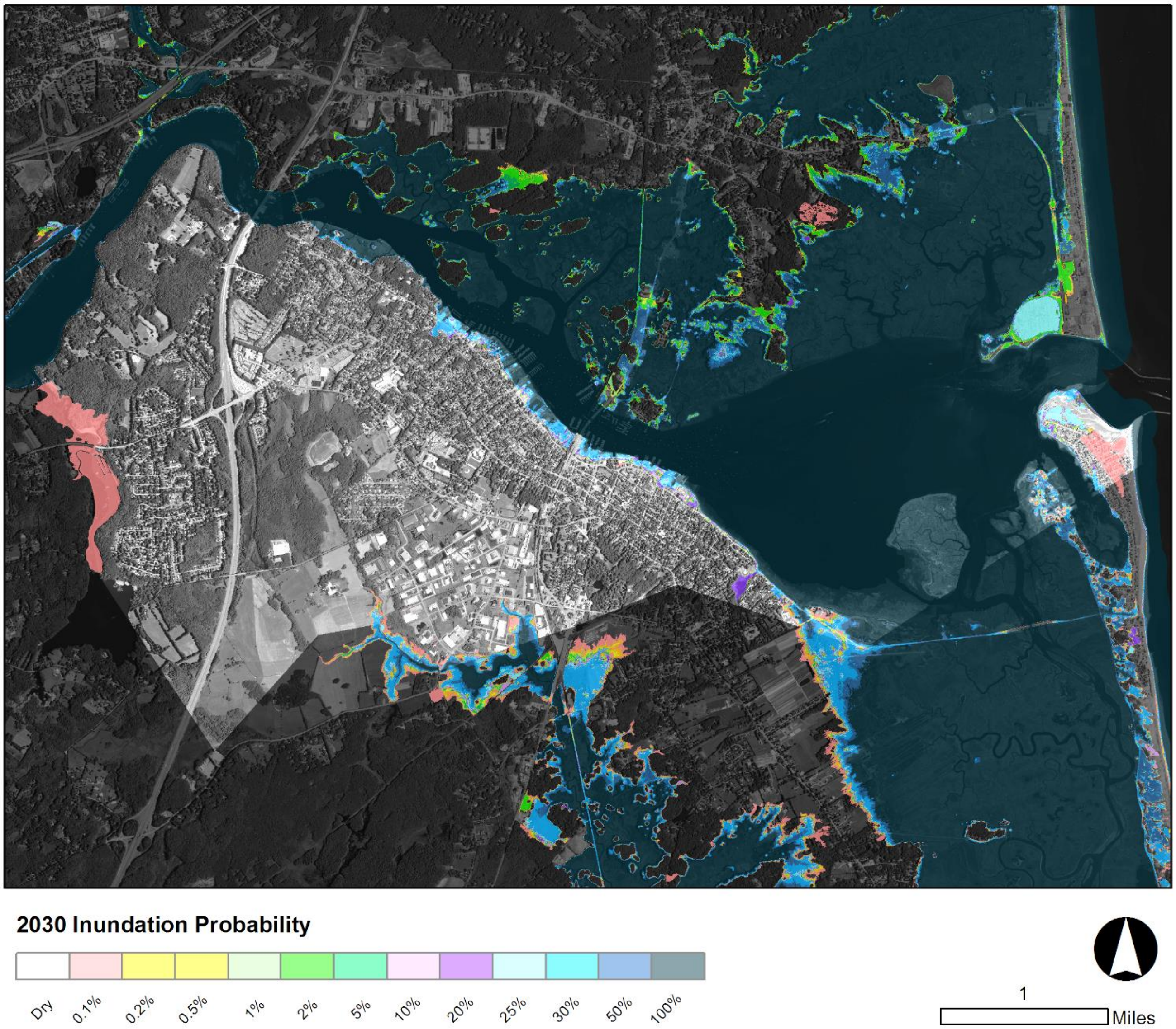

Figure D-5. City of Newburyport, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

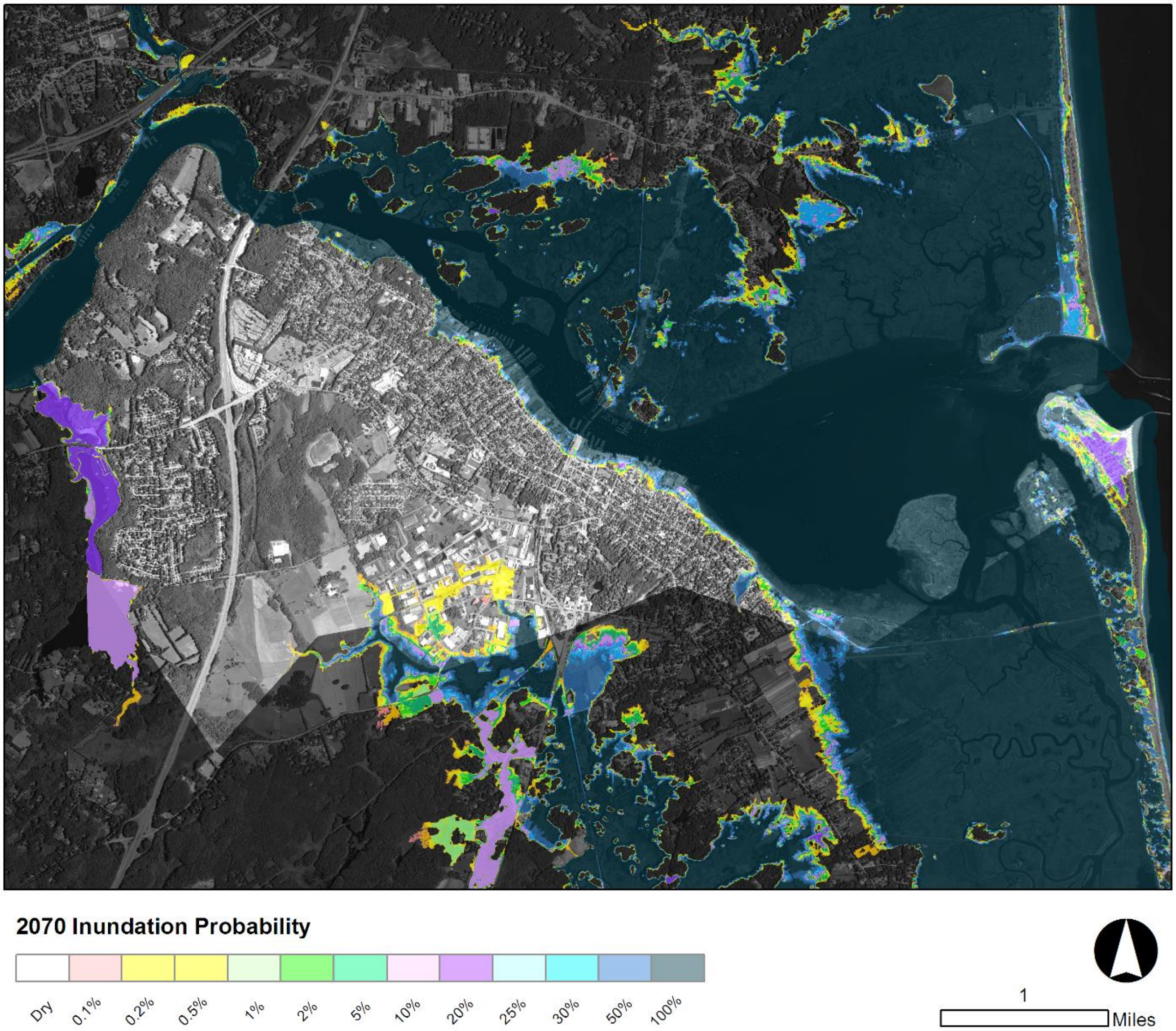

Figure D-6. City of Newburyport, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

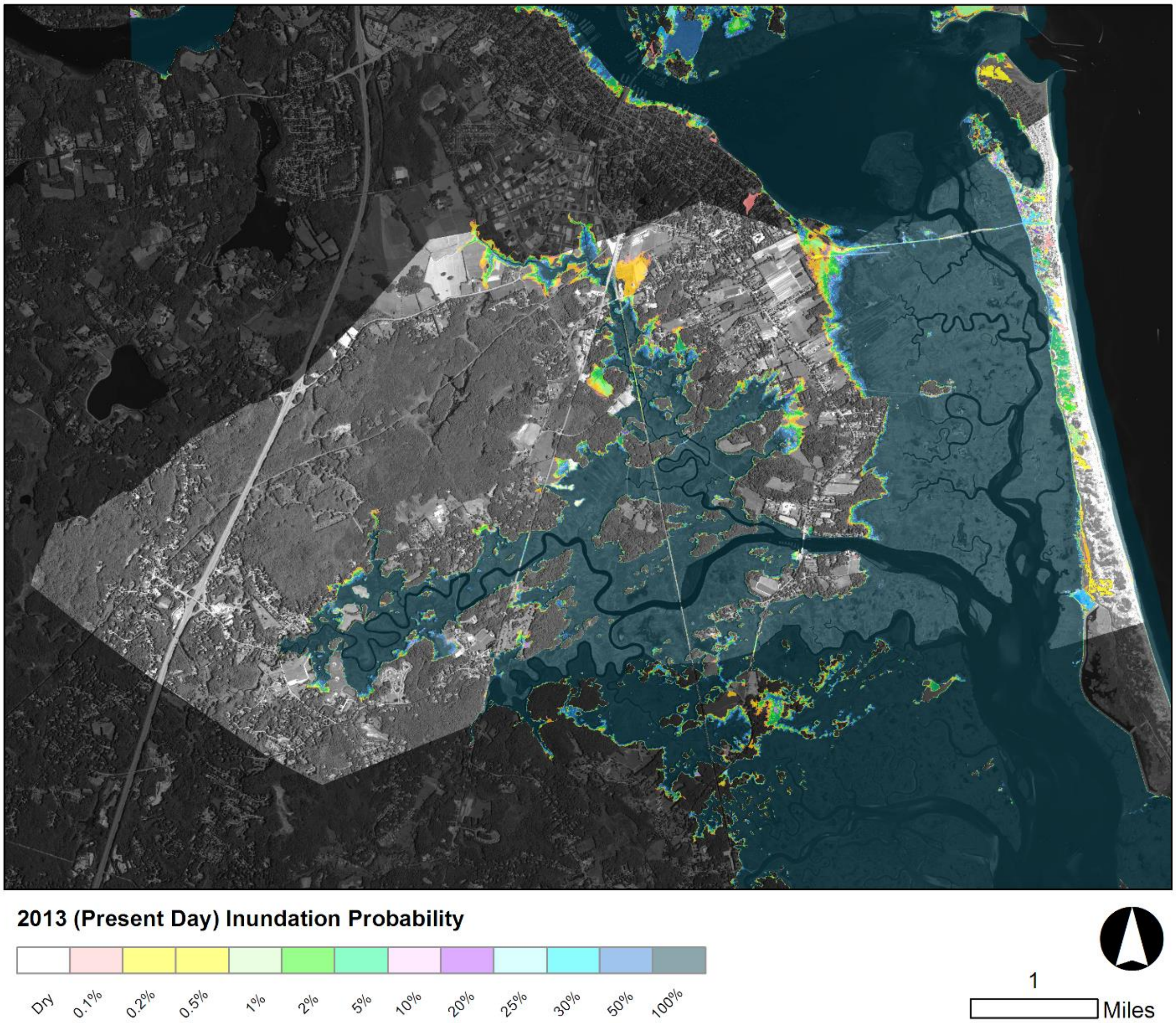

Figure D-7. Town of Newbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

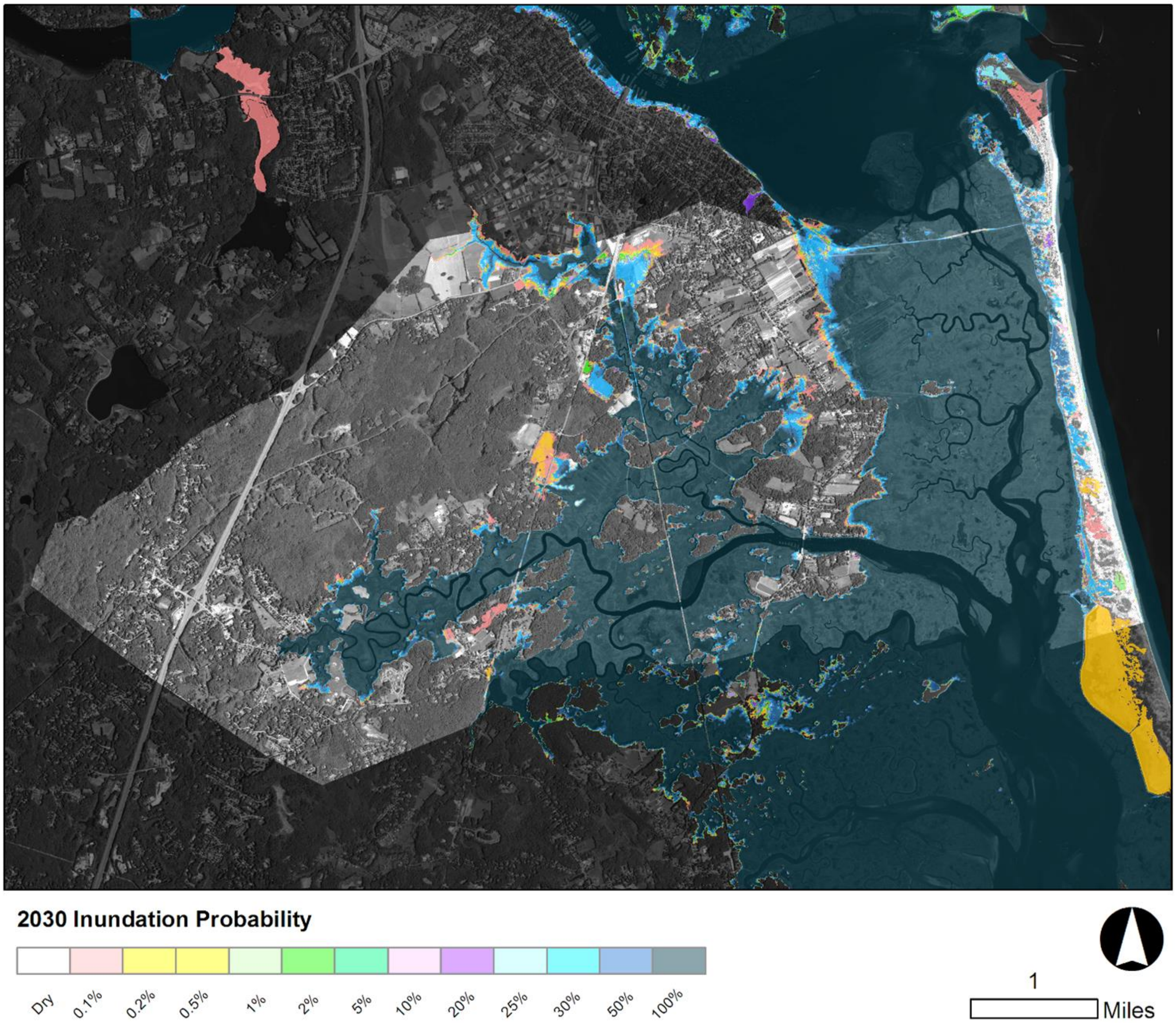

Figure D-8. Town of Newbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

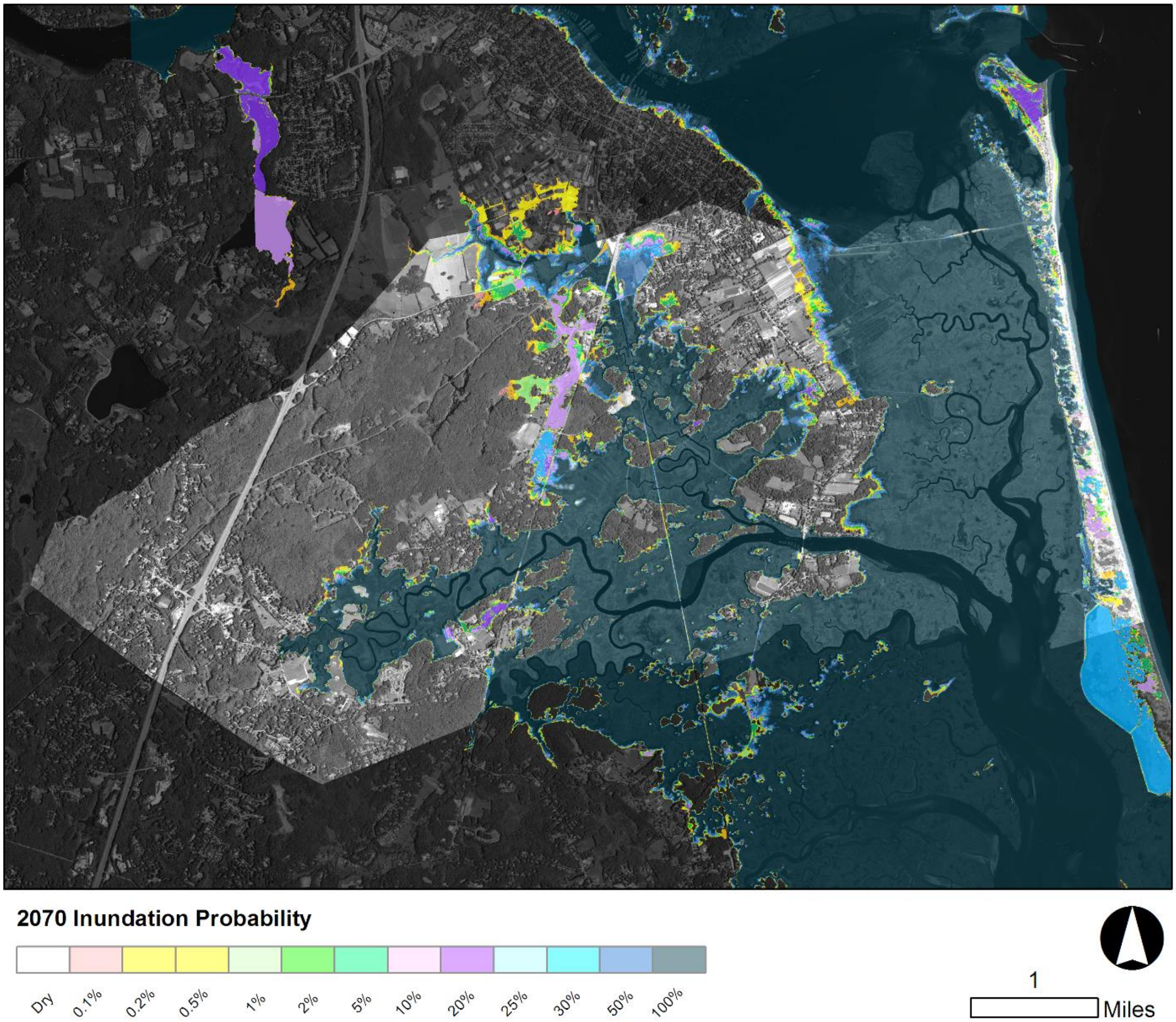

Figure D-9. Town of Newbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

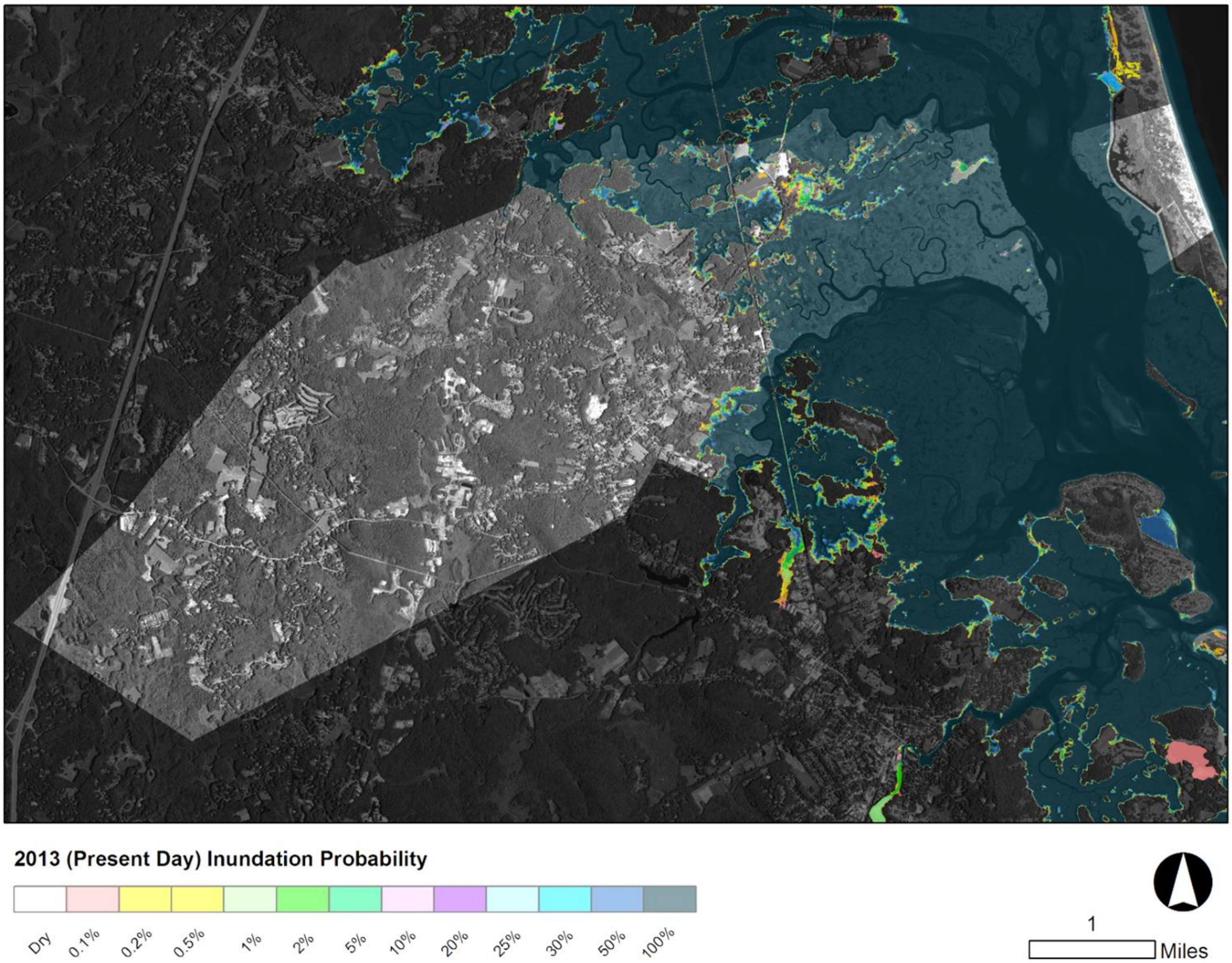

Figure D-10. Town of Rowley, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

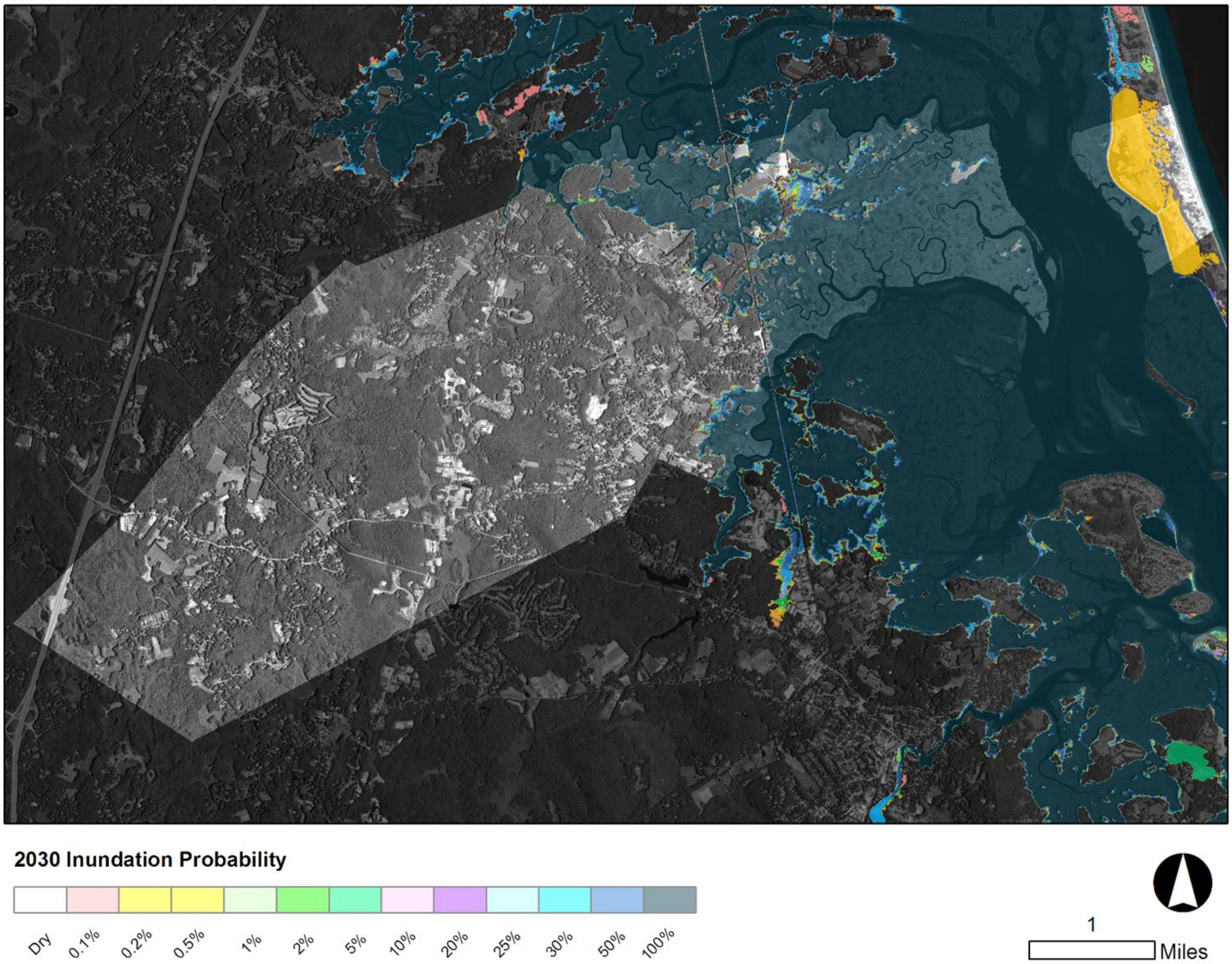

Figure D-11. Town of Rowley, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

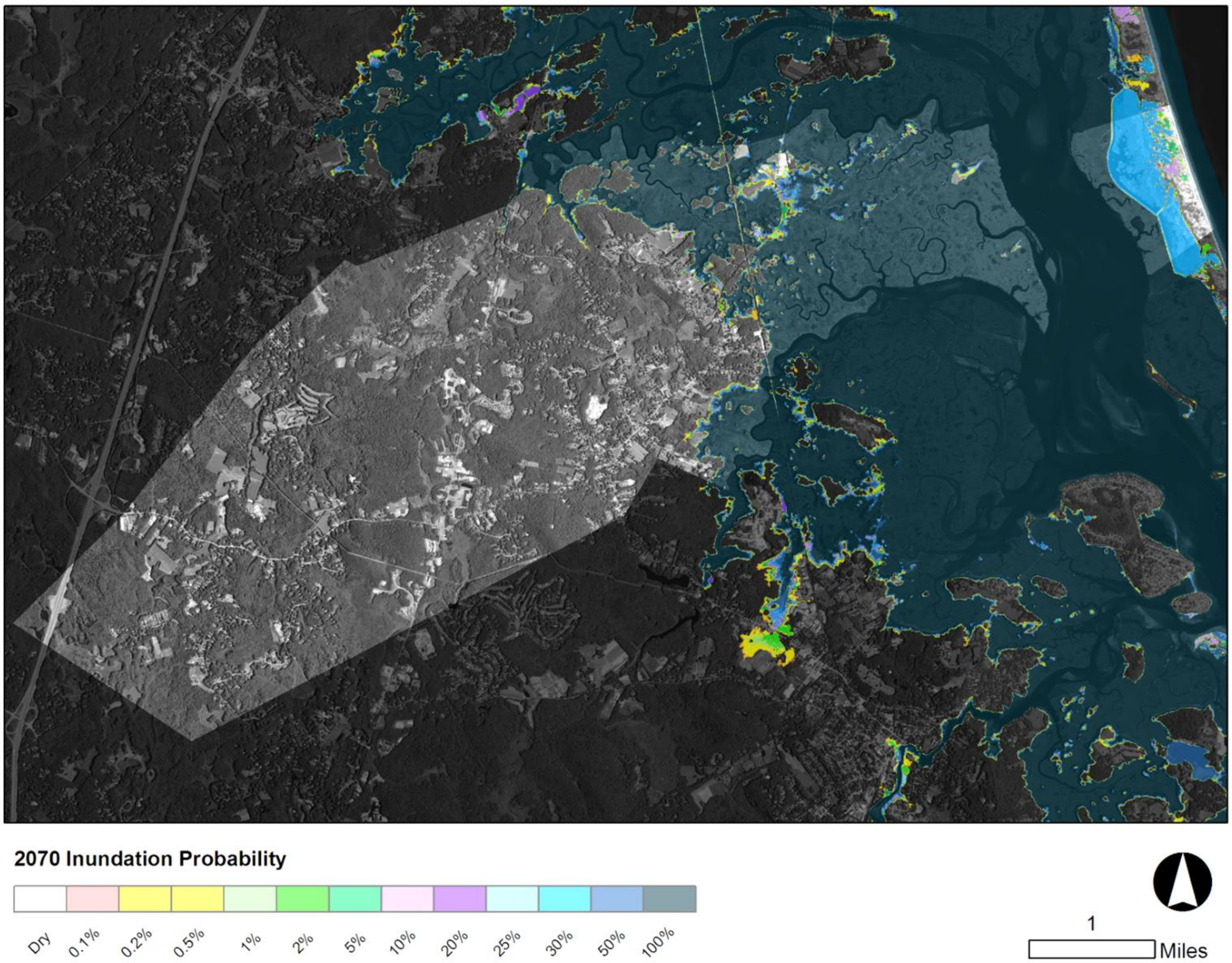

Figure D-12. Town of Rowley, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

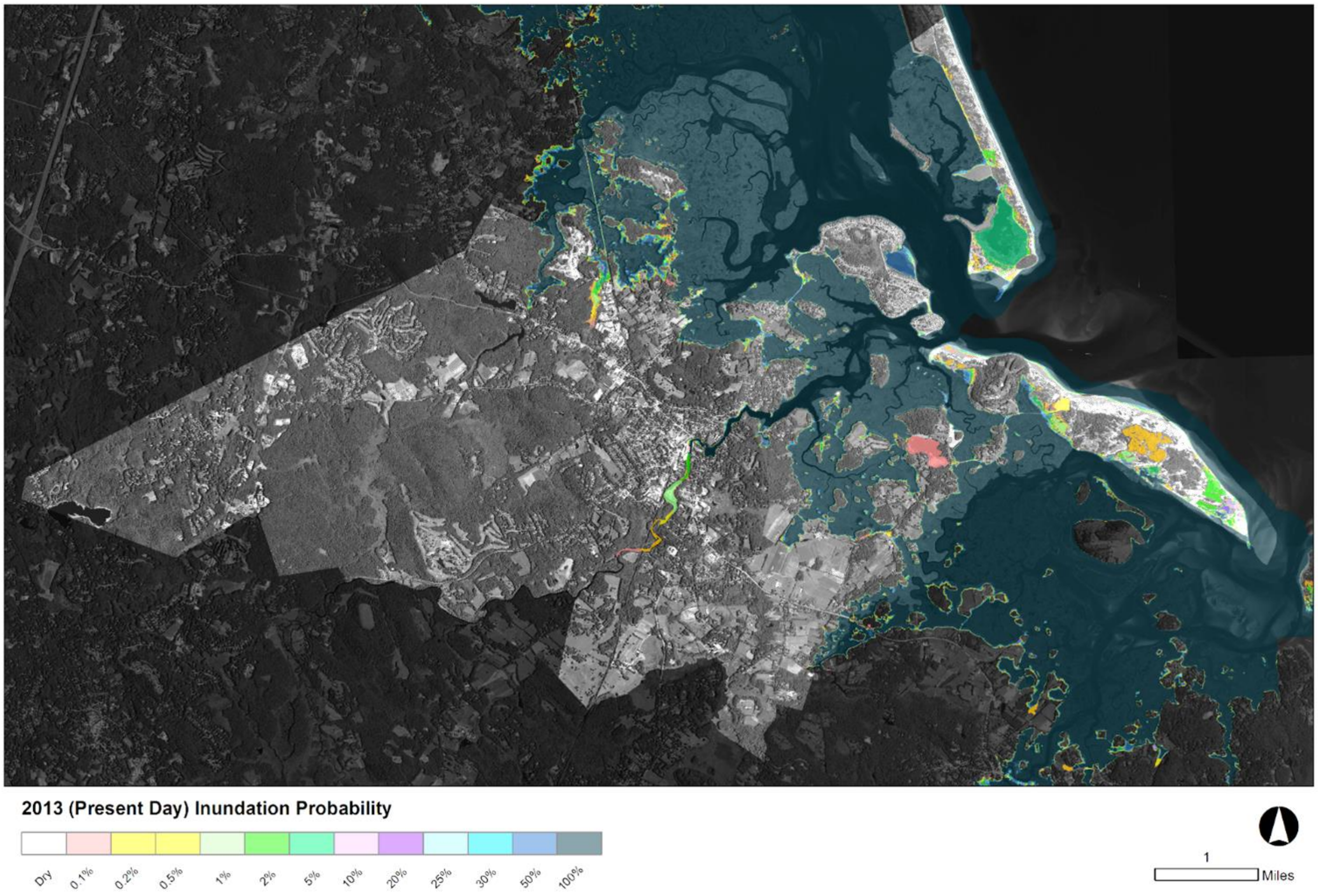

Figure D-13. Town of Ipswich, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

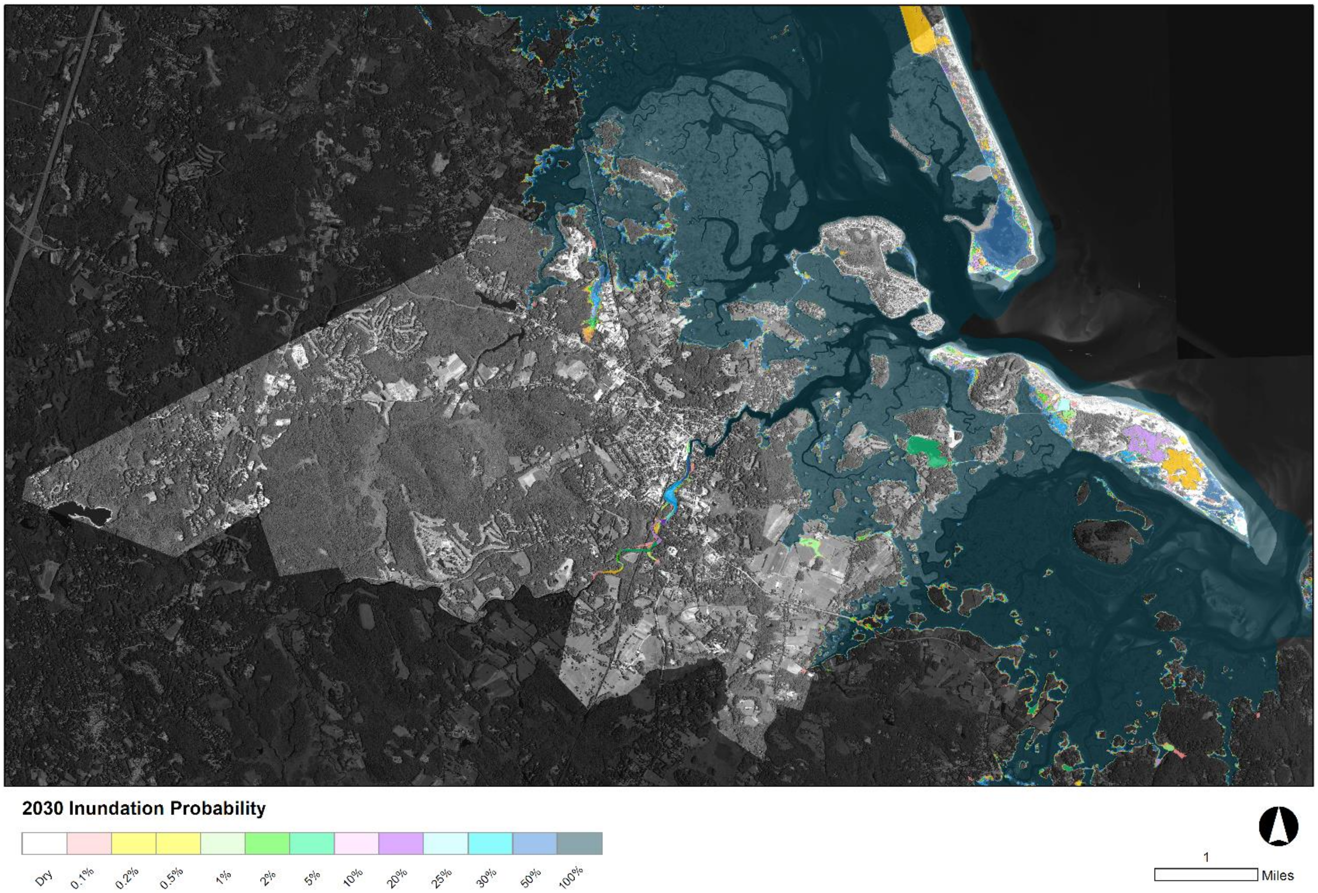

Figure D-14. Town of Ipswich, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

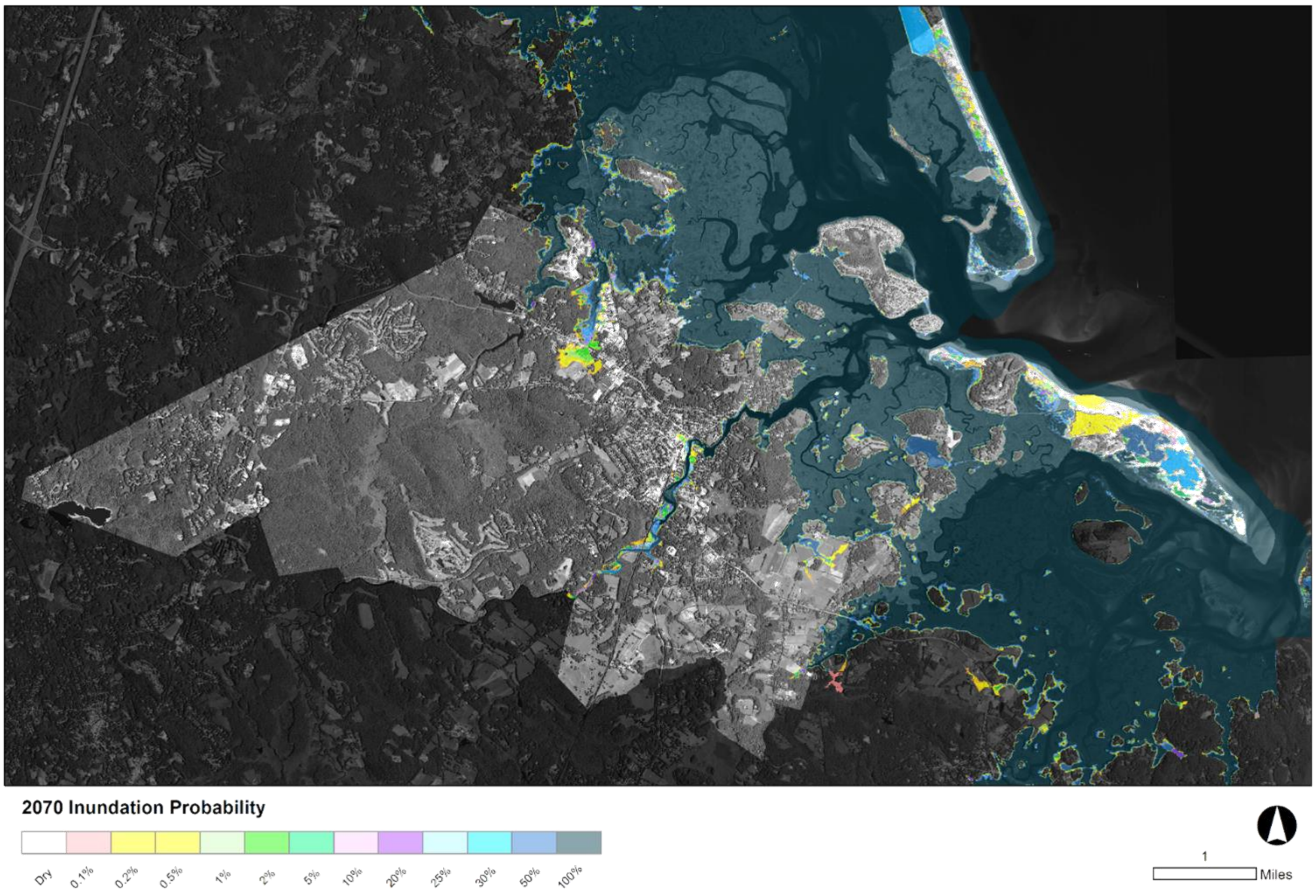

Figure D-15. Town of Ipswich, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

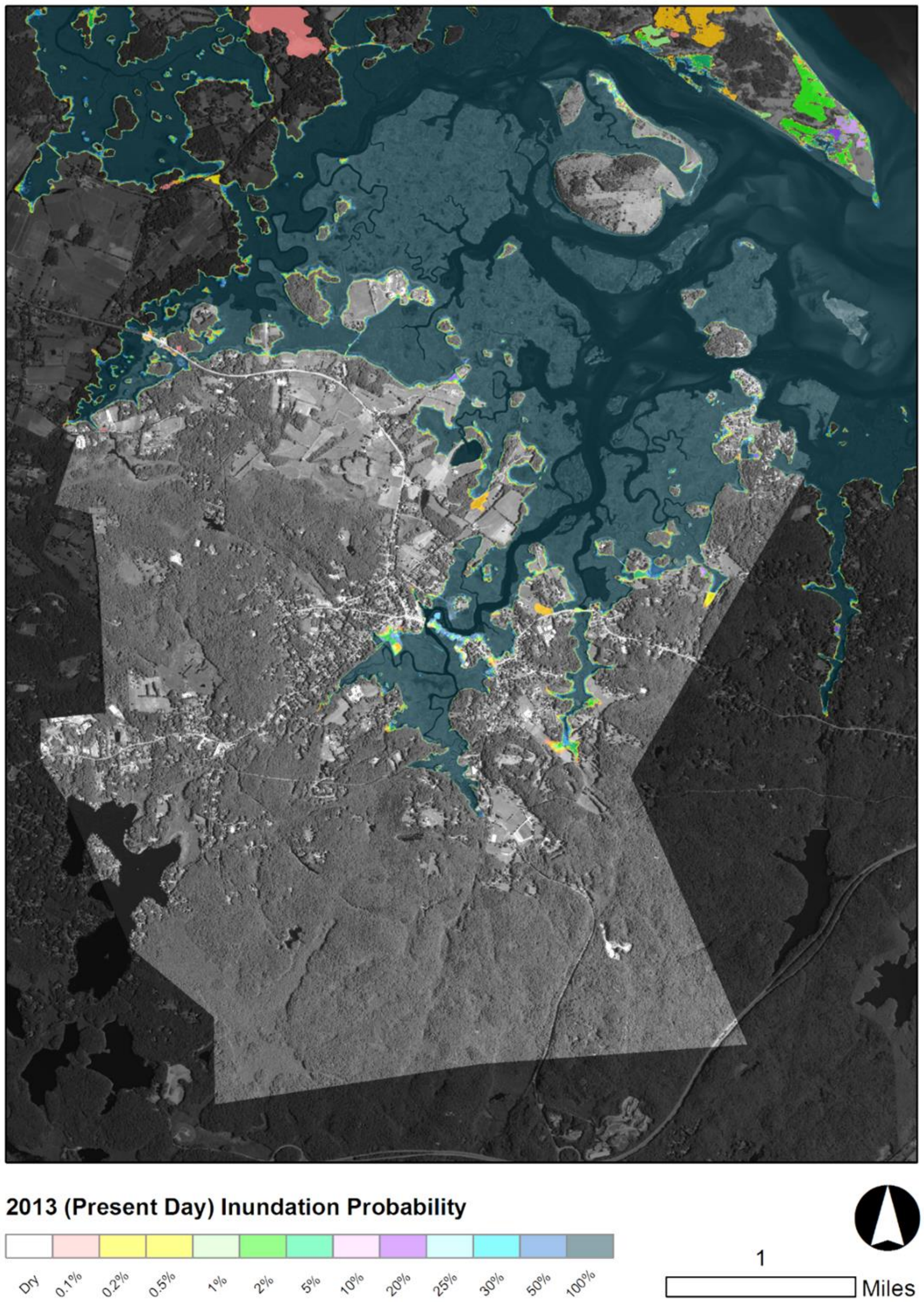

Figure D-16. Town of Essex, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

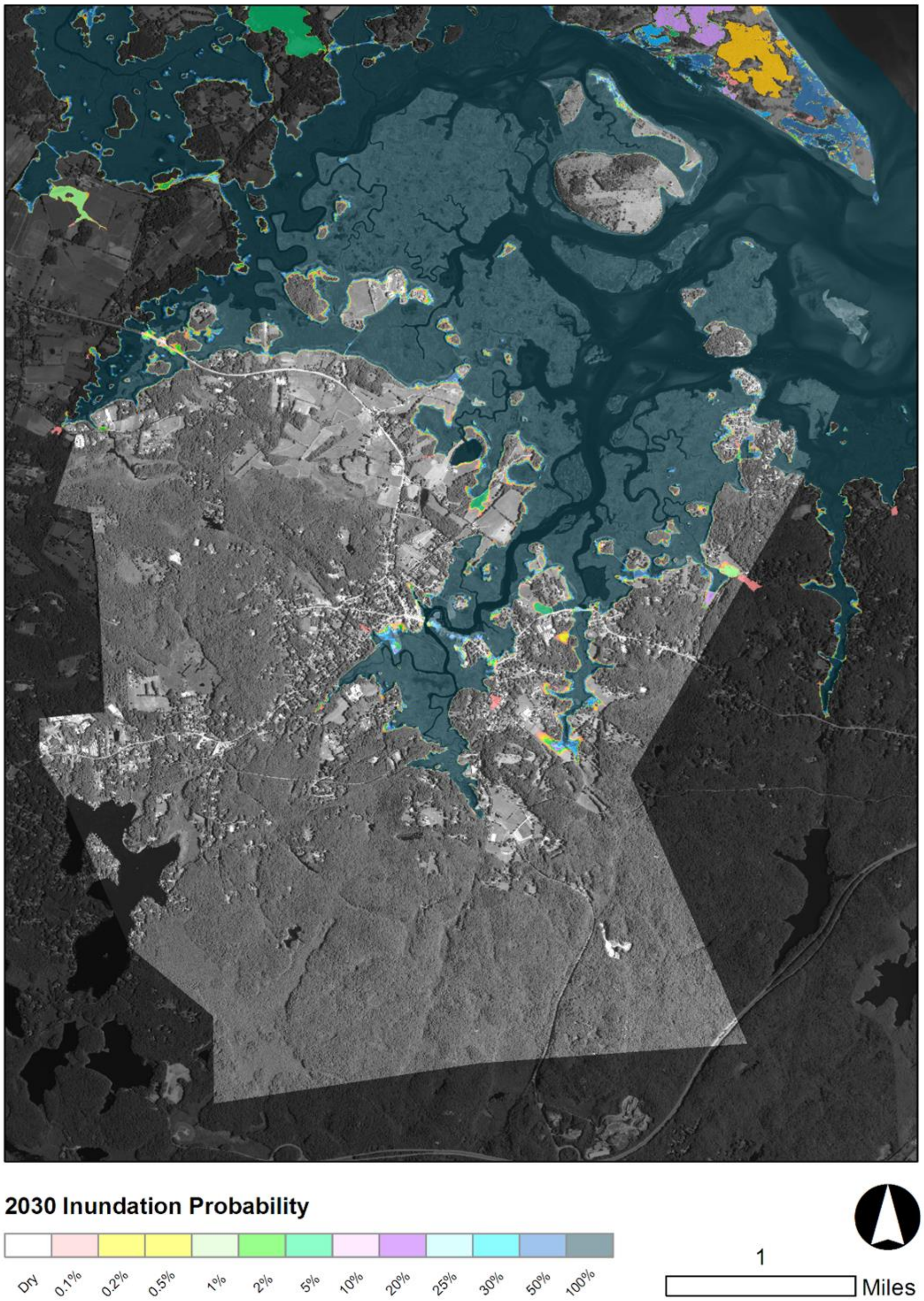

Figure D-17. Town of Essex, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

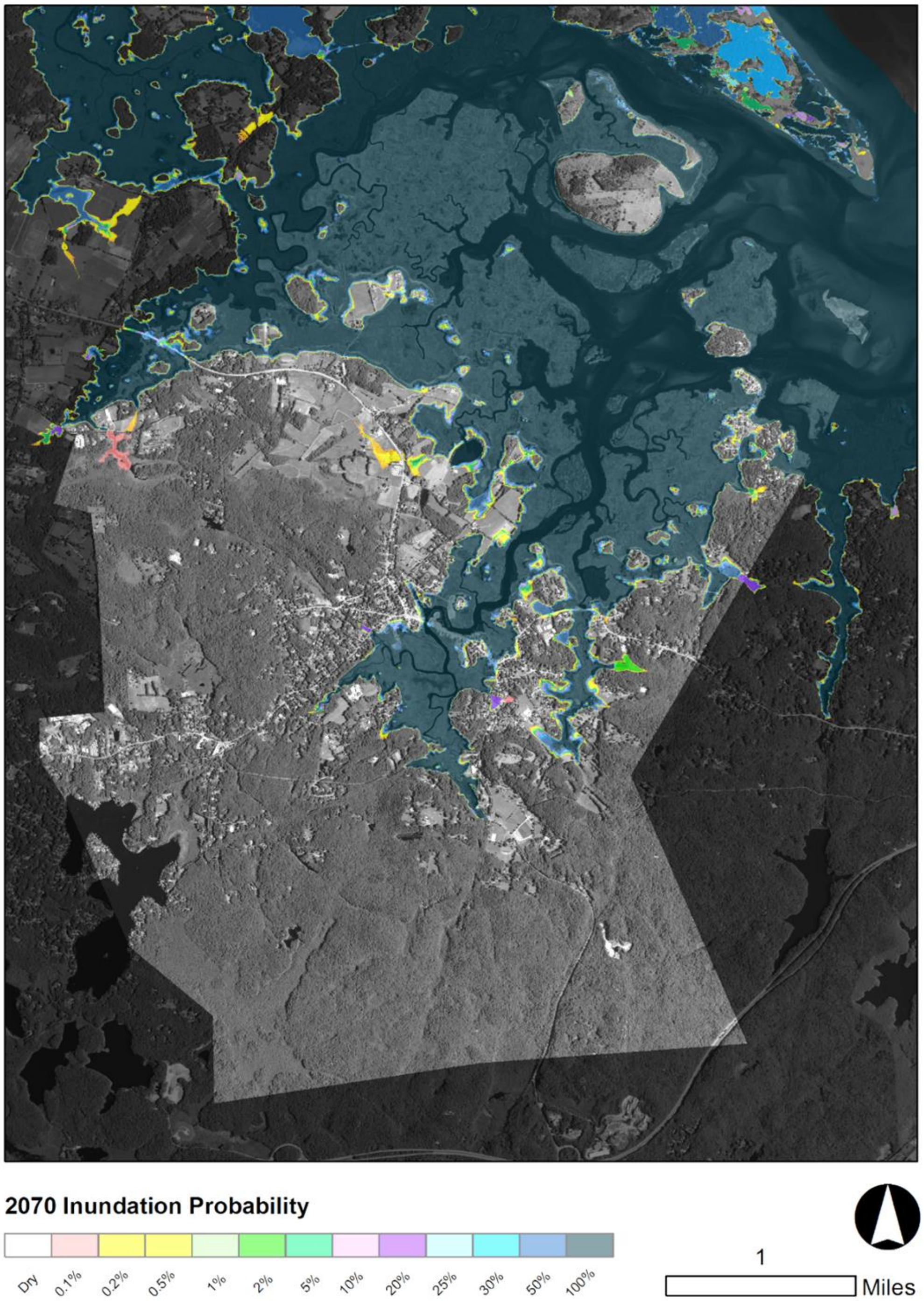

Figure D-18. Town of Essex, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

APPENDIX E:
Marsh Adaptation Strategy Tool (MAST)

GEI Consultants and the Project Team worked with 15 state and local land conservation professionals to apply the Marsh Adaptation Strategy Tool (MAST) to the Great Marsh region. MAST can help inform coastal land prioritization decisions in an era of marsh migration. Using the tool, the land conservation professionals ranked 11 high-priority coastal parcels (Figure E-1) in an auction process according to ecosystem services that they value. The software then gradually inundated each parcel according to identified sea level rise scenarios. Through topographic analysis in each year, in each of three sea level rise scenarios through 2100, and in reference to 13 benefit creation functions, the software then calculated cumulative ecosystem services that may be expected to emerge on each parcel over time.

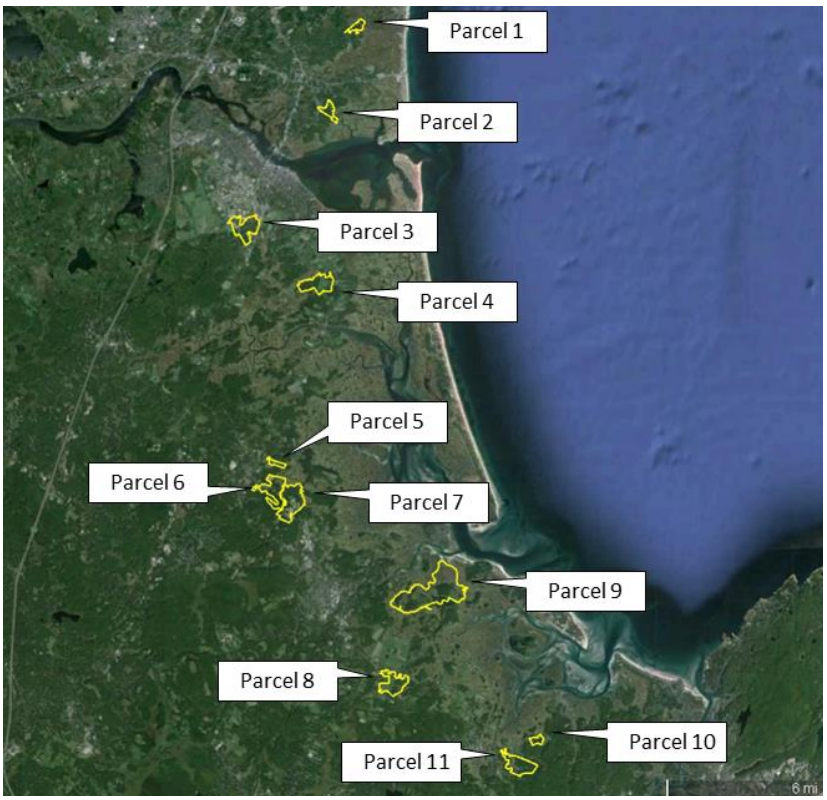

Figure E-1. Map of 11 high-priority coastal parcels analyzed using the Marsh Adaptation Strategy Tool (MAST).

Key findings of the MAST analysis are highlighted below. For more detailed results, see the final MAST report published online.[16]

[16] Merrill, S.B. and A. Gray, "MAST Modeling for the Great Marsh in Coastal Massachusetts," In *Final Report to the National Wildlife Federation*, (Portland, ME: GEI Consultants, Inc., 2015), http://www.pie-rivers.org/wp-content/uploads/2015/09/Great-Marsh-MAST-Report-Final-09282015.pdf

Table E-1. MAST survey results where experts subjectively ranked ecosystem services for each parcel.

	Parcels											
Services	1	2	3	4	5	6	7	8	9	10	11	**Totals**
1 Prevention of flood damages	50	30	100	75	6	100	30	75	100	25	20	611
2 Increased land values	20	50	18	10	16	20	10	16	40	10	10	220
3 Water quality	10	10	100	30	10	20	20	30	100	10	20	360
4 Drinking water supply	10	10	10	10	10	10	20	10	30	10	15	145
5 Recreation	10	25	20	50	10	50	25	40	100	15	10	355
6 Aesthetics	10	10	30	50	10	25	20	40	50	10	10	265
7 Carbon storage	20	25	20	20	10	30	25	10	50	10	40	260
8 Habitat connectivity	50	25	90	50	15	50	30	50	200	10	20	590
9 Habitat for commercial sp.	50	10	20	75	10	75	10	50	70	10	10	390
10 Habitat for biodiversity	25	15	15	75	20	50	25	50	50	10	20	355
11 Nutrient export for commercial sp.	8	25	20	10	10	15	10	10	30	5	10	153
12 Nutrient export for biodiversity	5	6	30	20	20	30	25	10	50	6	20	222
13 Research value	9	5	20	10	5	10	5	8	30	5	8	115
(acres)	*33*	*46*	*146*	*134*	*23*	*148*	*191*	*125*	*571*	*27*	*130*	
Totals	277	246	493	485	152	485	255	399	900	136	213	

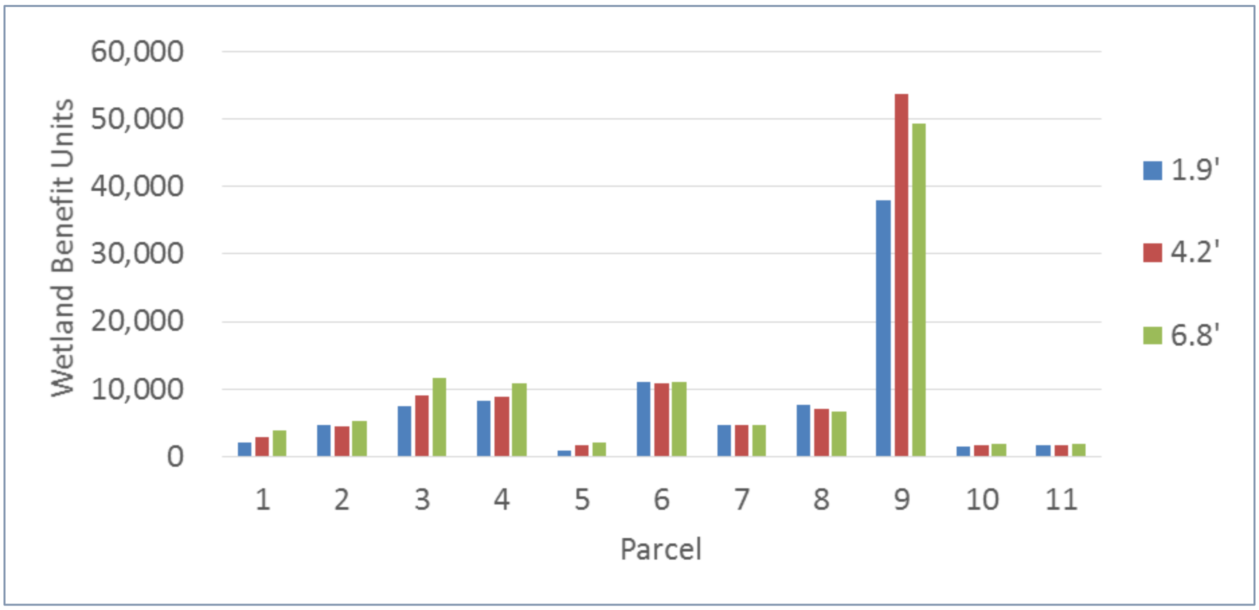

Figure E-2. Great Marsh MAST parcels and wetland benefits accrued in three sea level rise scenarios

APPENDIX F:
Coastal Adaptation to Sea Level Rise Tool (COAST)

GEI Consultants worked with NWF and Task Force members from the City of Newburyport to run the Coastal Adaptation to Sea Level Rise Tool (COAST). The Study area included parts of the downtown area of Newburyport along the Merrimack River (northwest and southeast of the U.S. Route 1 bridge), as well as parts of the industrial park adjacent to the Little River (Figure F-1). COAST analyzed potential damages to buildings from three sea level rise scenarios, both as single snapshots in time from a 100-year flood in 2030 and 2070; and as cumulative damages from all possible storms from 2015 to 2030 and from 2031 to 2070.

Key findings of the COAST analysis are highlighted below. **For more detailed results, see the final COAST report[17] published online.**

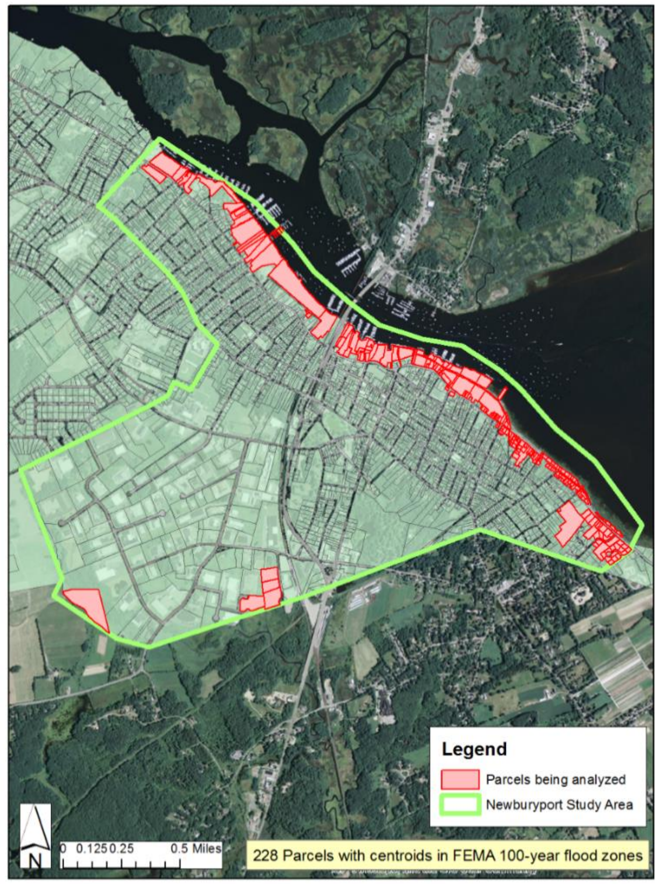

Figure F-1. Map of Newburyport COAST study area.

Table F-1. One-time damage estimates for a 100-year flood in 2030 and 2070 under low, medium, and high sea level rise scenarios. Damage estimates are to building structures only within the Newburyport, MA Study Area (does not include building contents).

Year	Sea Level Rise	Damage to Buildings
2030	Low (0.31 ft)	$14.1 Million
2030	Med (0.50 ft)	$14.9 Million
2030	High (0.72 ft)	$15.8 Million
2070	Low (1.09 ft)	$18.3 Million
2070	Med (2.19 ft)	$24.2 Million
2070	High (3.45 ft)	$32.4 Million

[17] Merrill, S.B. and A. Gray, "COAST Modeling for the City of Newburyport, Massachusetts." In *Final Report to the National Wildlife Federation* (Portland, ME: GEI Consultants, Inc., 2015), http://www.pie-rivers.org/wp-content/uploads/2015/02/Great-Marsh-COAST-Final-Report_10072015.pdf

Table F-2. Cumulative storm surge and sea level rise damage estimates for buildings in Newburyport study area between 2015 and 2030, 2031 and 2070, and 2015 and 2070. Damage estimates are to building structure only (does not include contents).

Year	Sea Level Rise	Damage to Buildings	Buildings Lost to SLR
2015-2030	Low (0 ft - 0.31 ft)	$3,222,783	$270,600
2015-2030	Med (0 ft - 0.50 ft)	$3,385,577	$424,600
2015-2030	High (0 ft - 0.72 ft)	$3,606,155	$424,600
2031-2070	Low (0.33 ft - 1.09 ft)	$9,876,800	$414,400
2031-2070	Med (0.53 ft - 2.19 ft)	$15,438,355	$2,279,000
2031-2070	High (0.76 ft - 3.45 ft)	$25,072,509	$4,702,800
2015-2070	Low (0 ft - 1.09 ft)	$13,099,584	$685,000
2015-2070	Med (0 ft - 2.19 ft)	$18,823,932	$2,703,600
2015-2070	High (0 ft - 3.45 ft)	$28,678,663	$5,127,400

Table F-3. Parcels, land, buildings, and total parcel values in the Newburyport study area that are lost to sea level rise by 2030 and 2070.

Year	Sea Level Rise	Parcels Lost to SLR	Land Value	Building Value	Total Value
2030	Low (0.31 ft)	1	$415,400	$270,600	$686,000
2030	Med (0.50 ft)	2	$841,100	$424,600	$1,265,700
2030	High (0.72 ft)	2	$841,100	$424,600	$1,265,700
2070	Low (1.09 ft)	3	$1,222,000	$685,000	$1,907,000
2070	Med (2.19 ft)	11	$5,753,700	$2,703,600	$8,457,300
2070	High (3.45 ft)	27	$15,775,800	$5,127,400	$20,903,200

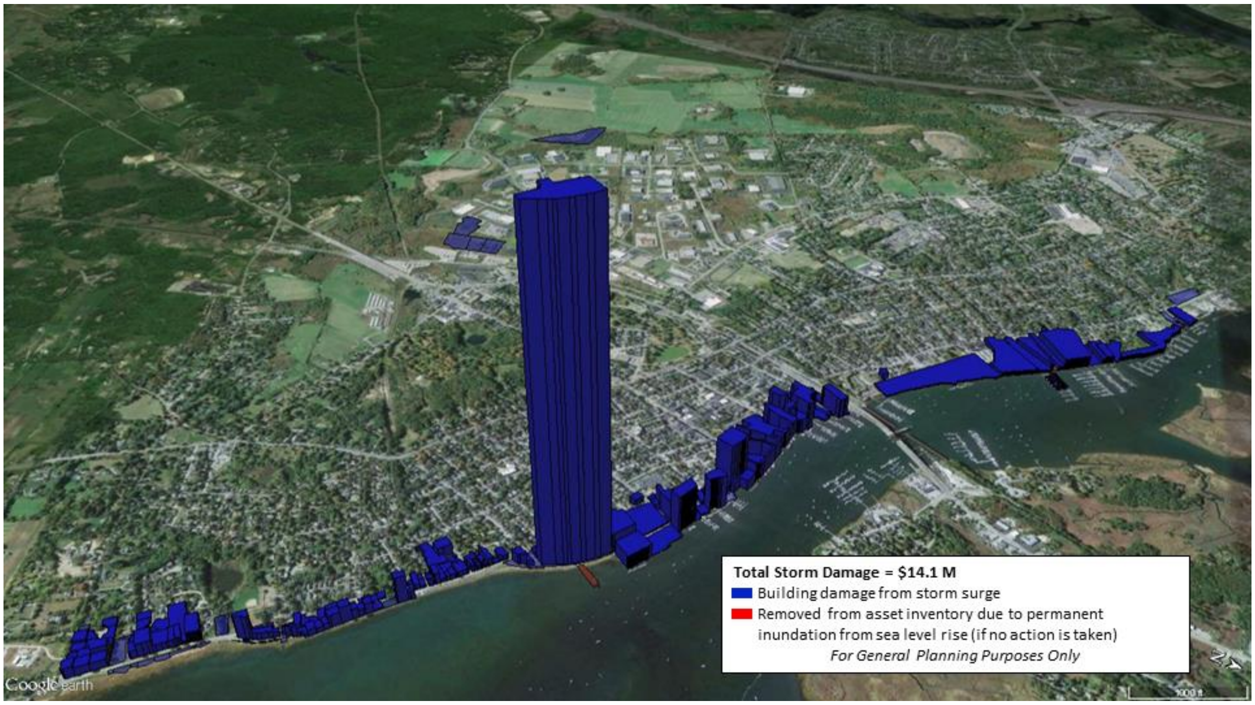

Figure F-2. Newburyport COAST Visual Results: 1% (100-year) flood in 2030 with 0.31 ft of sea level rise ("low" sea level rise scenario).

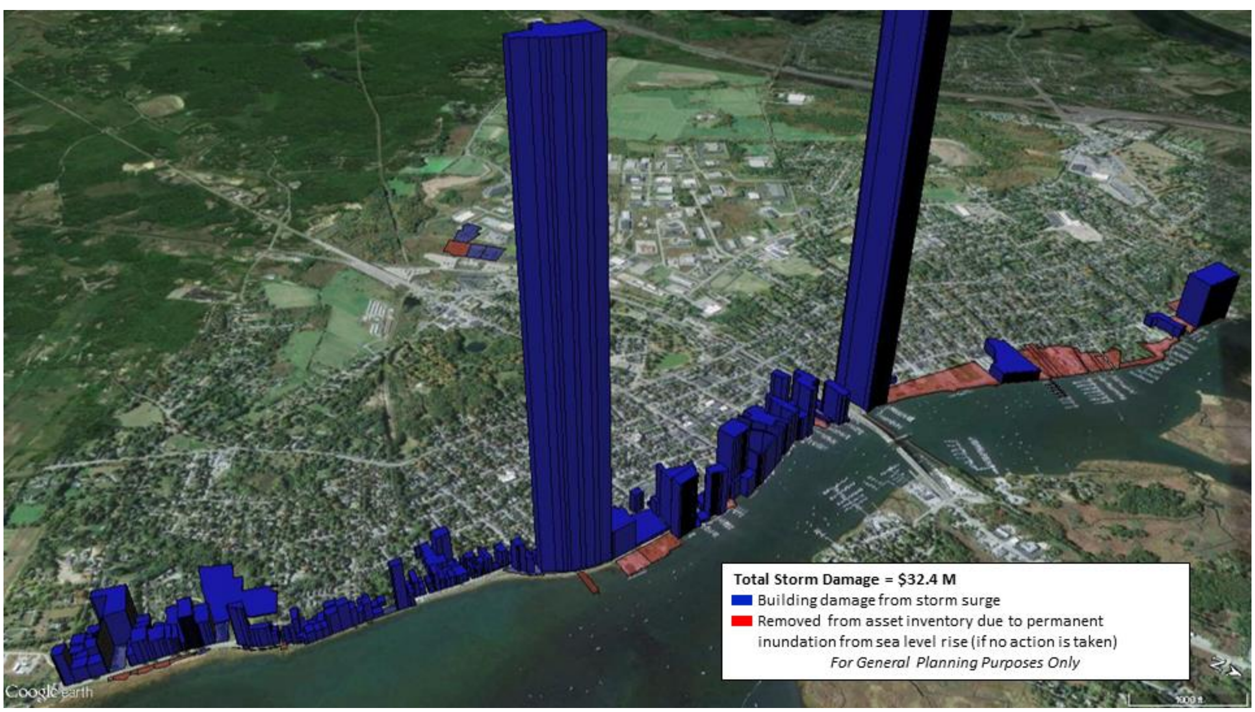

Figure F-3. Newburyport COAST Visual Results: 1% (100-year) flood in 2070 with 3.45 ft of sea level rise ("high" sea level rise scenario).