

GREAT MARSH COASTAL ADAPTATION PLAN

DECEMBER 2017



IPSWICH RIVER
WATERSHED ASSOCIATION
The Voice of the River

Great Marsh Coastal Adaptation Plan

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



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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.

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.

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.

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



Matt Poole/USFWS

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

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



United States Air Force

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

- 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.

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.

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.

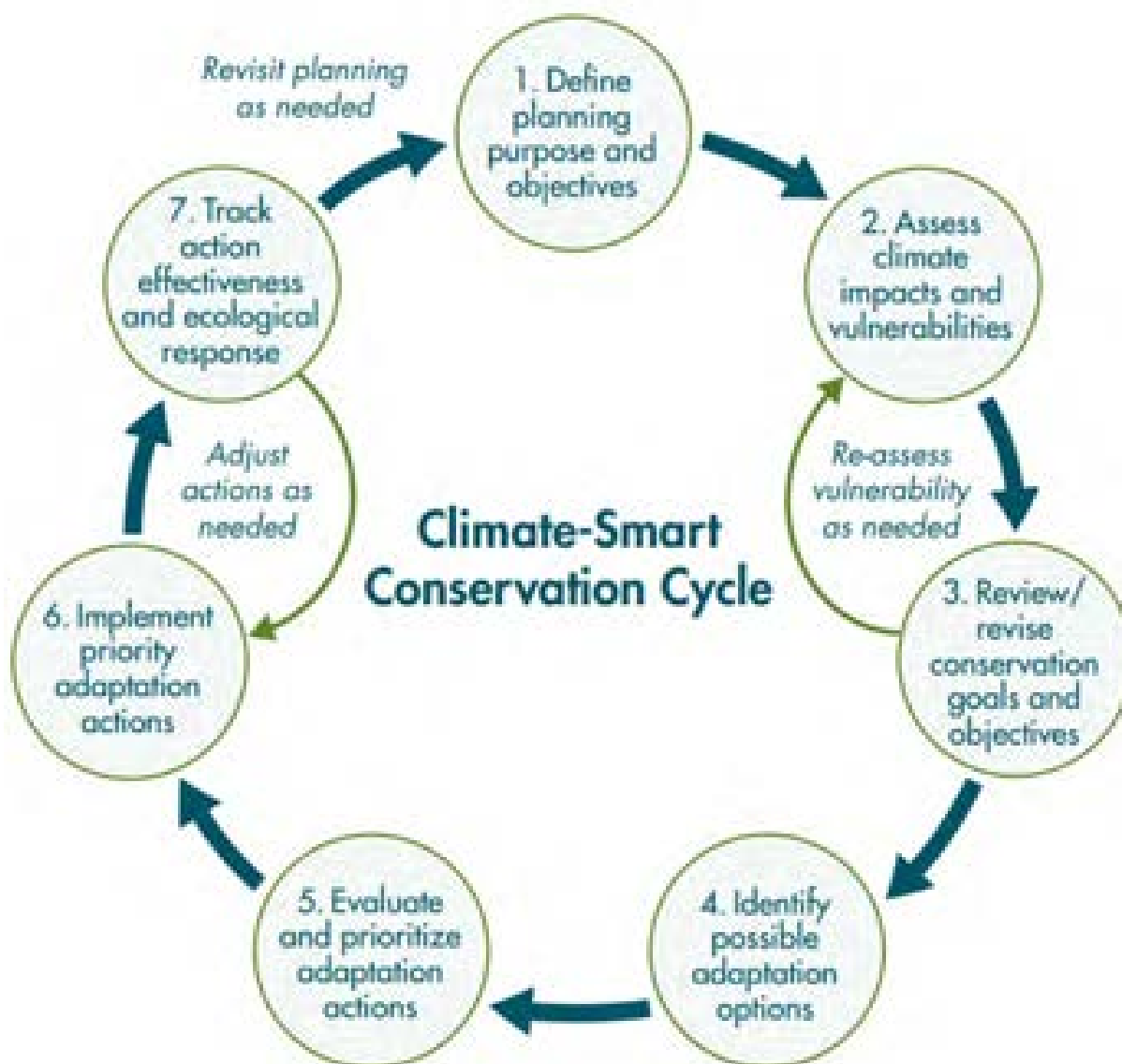


Figure 2.1. Climate-Smart Conservation Cycle. This cycle serves as the basis for this Community Adaptation Planning effort, and was used to help incorporate climate considerations throughout the planning process. *Source:* Stein, B.A., P. Glick, N. Edelson, and A. Staudt (eds.). 2014. *Climate-Smart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



NWF

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.”¹⁹In 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.²⁰Is 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.

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 Change²² 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%).

Hydrodynamic Model

Modeled Storm Events

Including hurricanes and nor'easters, as well as climatology projections

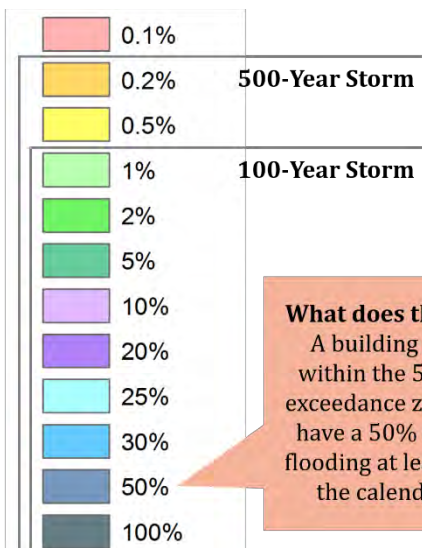
Sea Level Rise Projections

Consistent with both the US National Climate Assessment and projections specific to Massachusetts

Dynamic Coastal Processes

Driven by wave effects, wind, tides, and storm surge

Percent Risk of Coastal Flooding



What does this mean?

A building that lies within the 50% flood exceedance zone would have a 50% chance of flooding at least once in the calendar year.

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)°C from 1880 to 2012 (an increase

of 1.53°F).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}

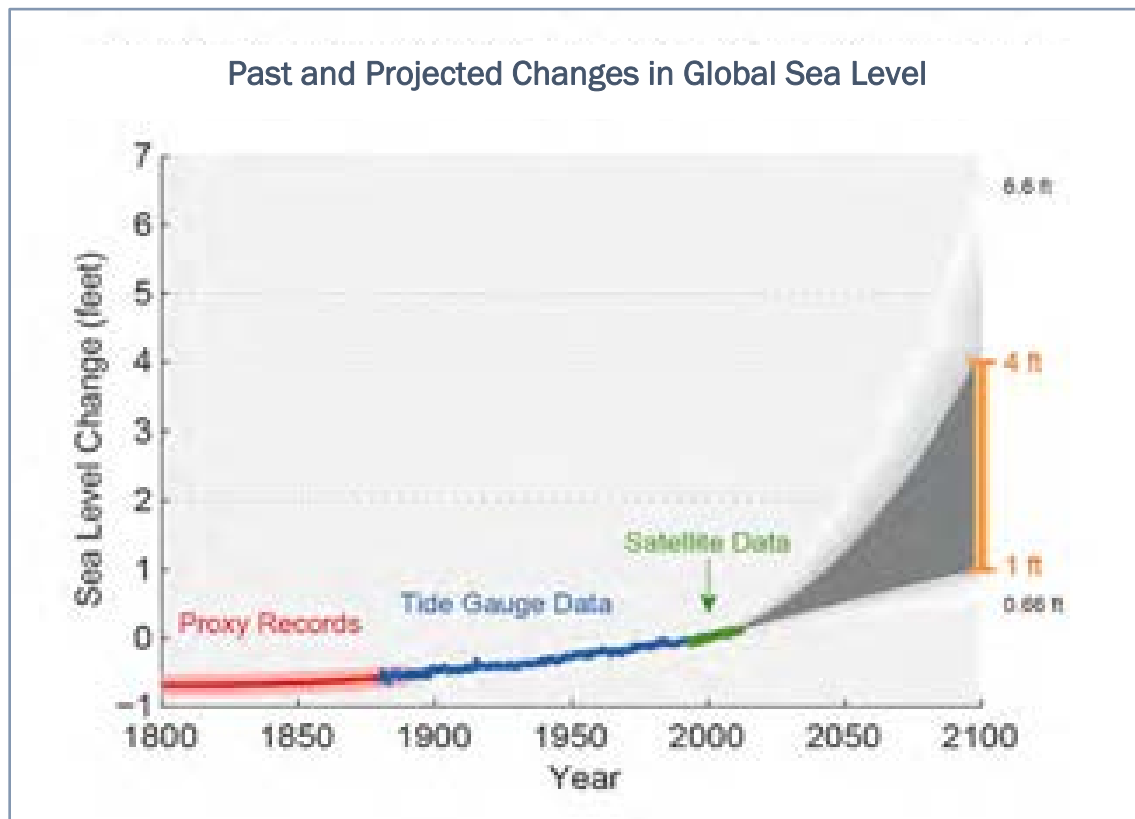


Figure 3.1-1. Estimated, observed, and possible future amounts of global sea level rise from 1800 to 2100, relative to the year 2000.²⁹

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°C (0.5°F) every decade – with most recent years showing the steepest rise in temperatures above the historical average.³²

Massachusetts, Average Temperature, January-December

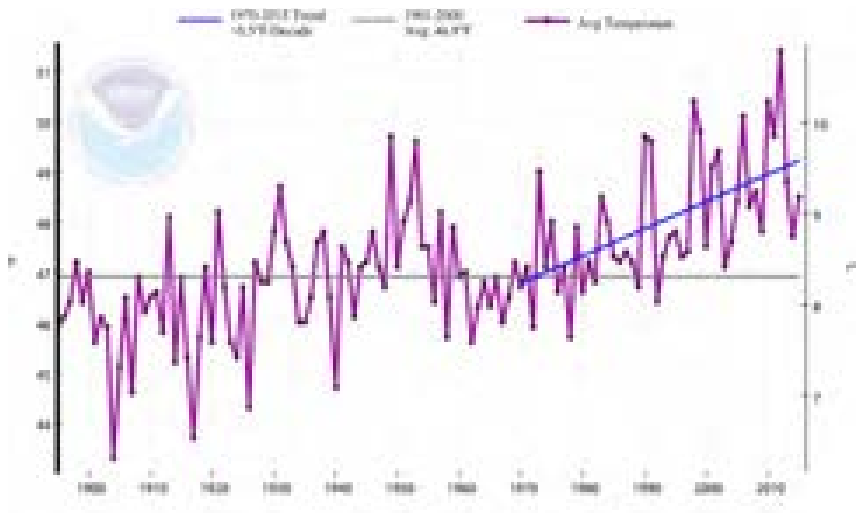


Figure 3.1-2. Average annual temperature in Massachusetts from 1895 to 2015. Trend line shows 0.5°F increase in temperature per decade from 1970-2015.³²

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.

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 in 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

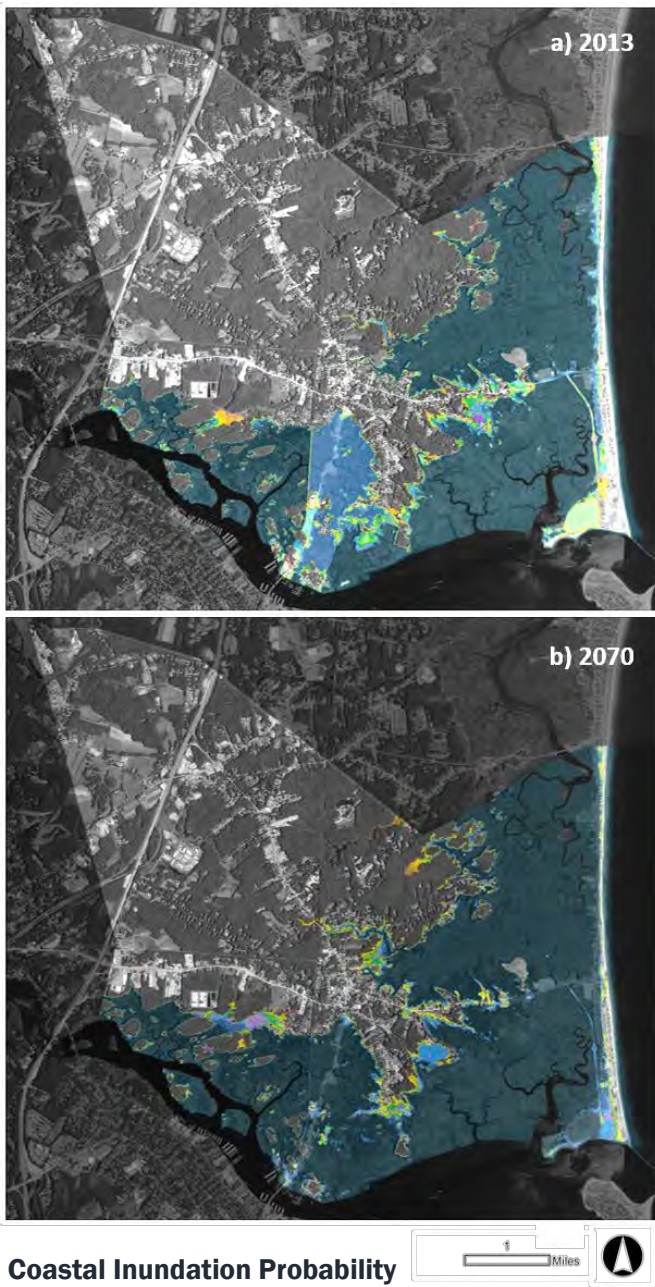


Figure 3.2-1. Salisbury, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

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.

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

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).

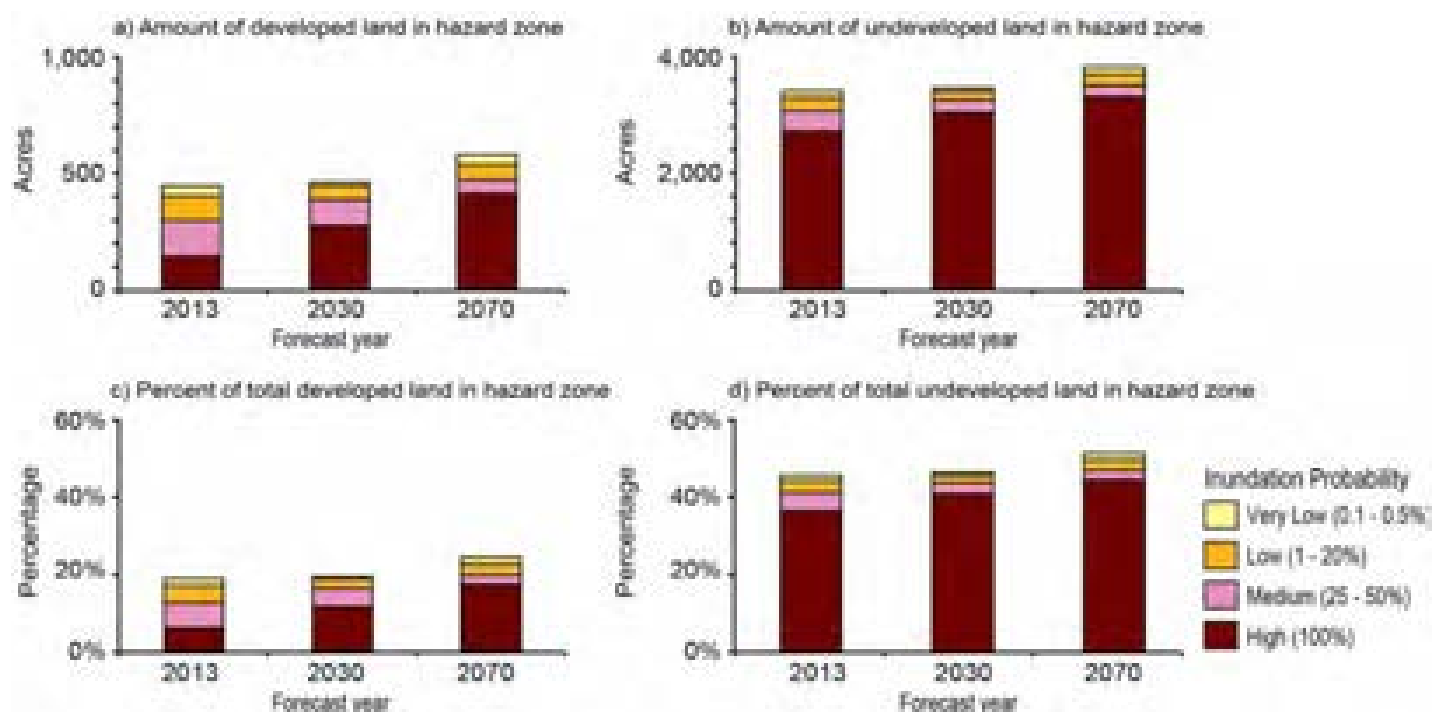


Figure 3.2-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Salisbury, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

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

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 analysis⁶⁸ 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 1 st 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 18 th 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

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).

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

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

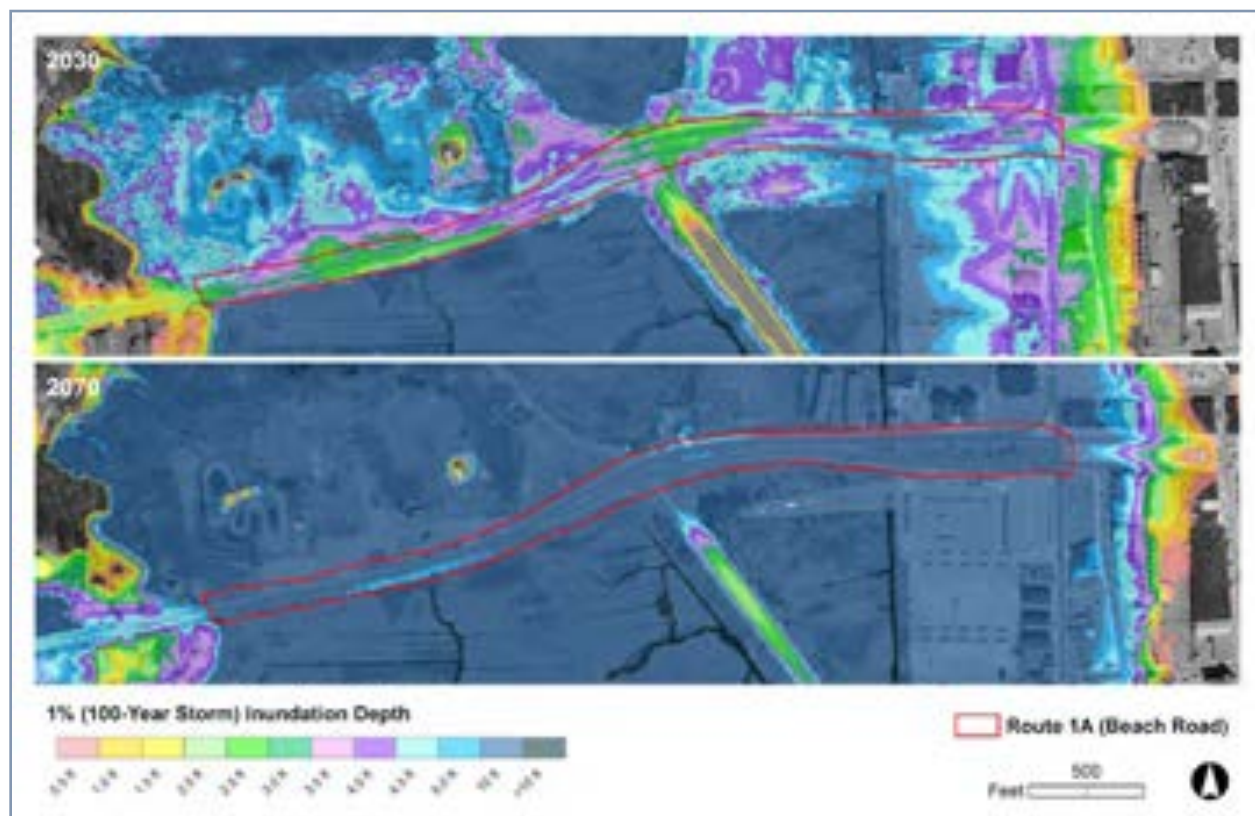


Figure 3.2-3. Route 1A/Beach Road, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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.

DEMOGRAPHICS⁷⁹

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.

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-ECONOMIC⁸⁰

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

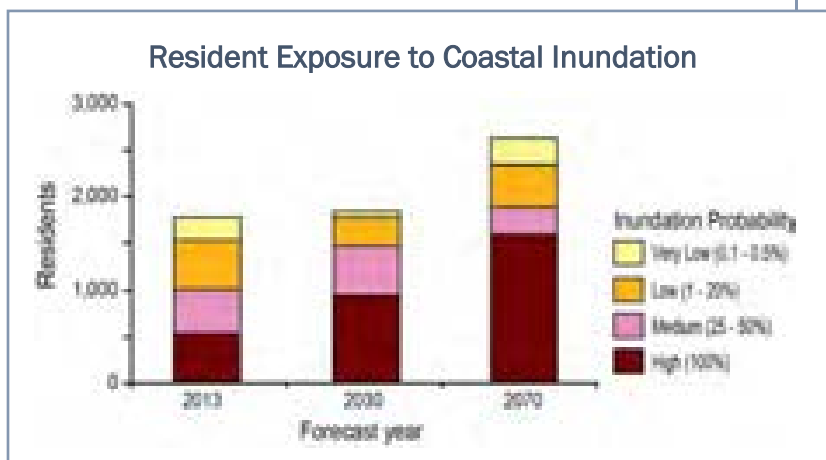


Figure 3.2-5. Resident exposure in the Town of Salisbury, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

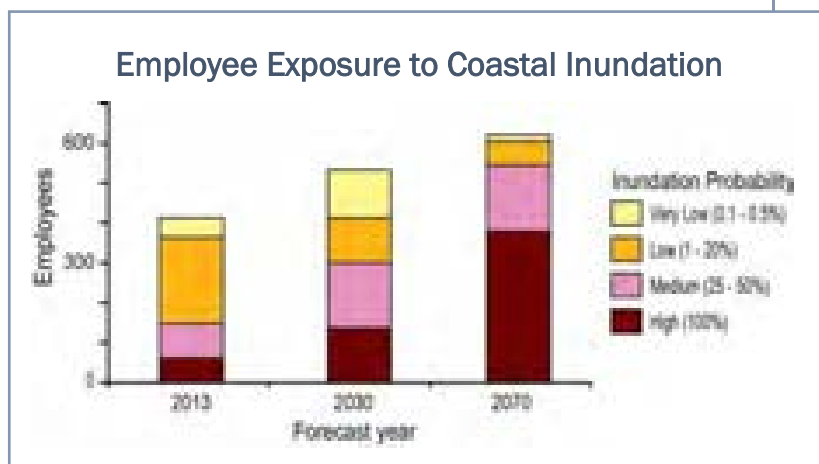


Figure 3.2-6. Employee exposure in Salisbury, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

⁷⁹ Ibid 10-11

⁸⁰ Ibid 11-12

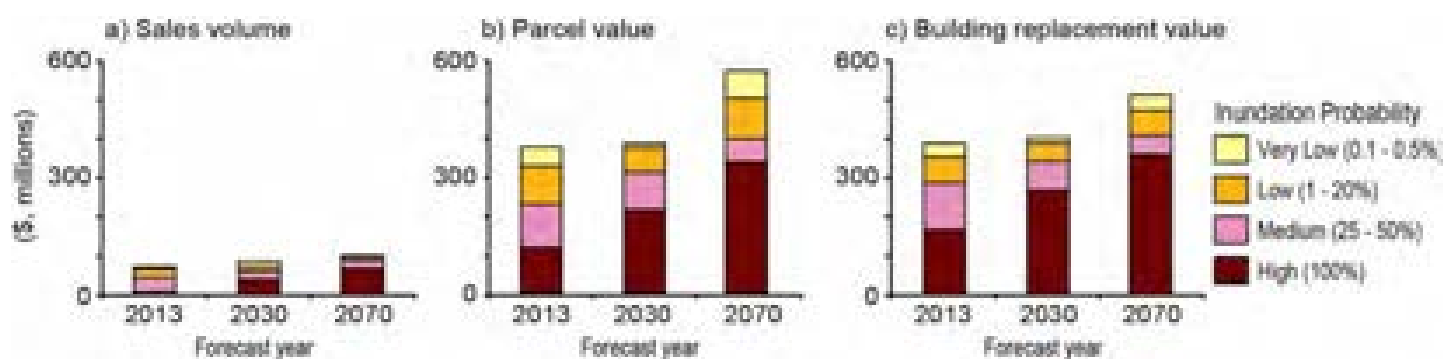


Figure 3.2-7. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Salisbury, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

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

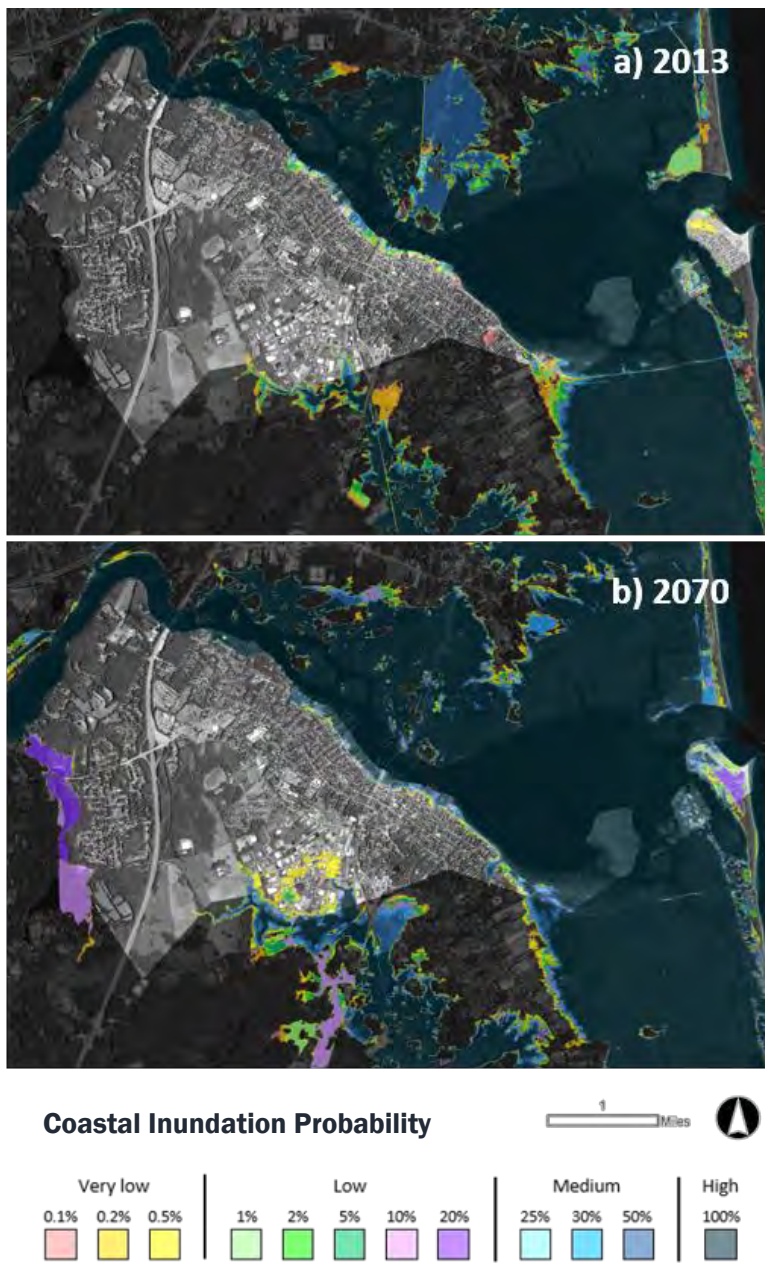


Figure 3.3-1. Newburyport, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

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

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

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.

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

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

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

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

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).

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

¹¹⁶Ibid 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

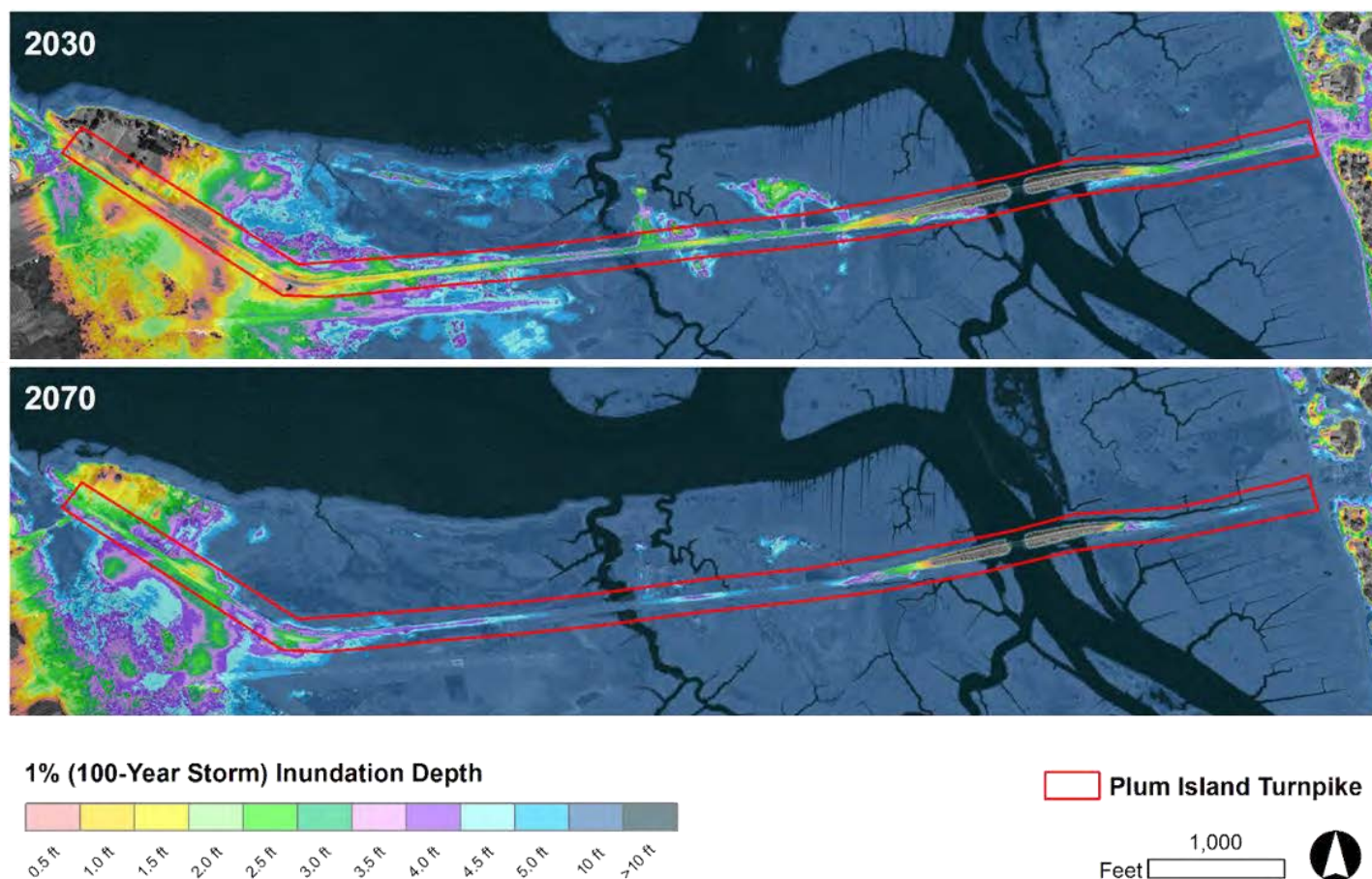


Figure 3.3-2. Plum Island Turnpike, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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

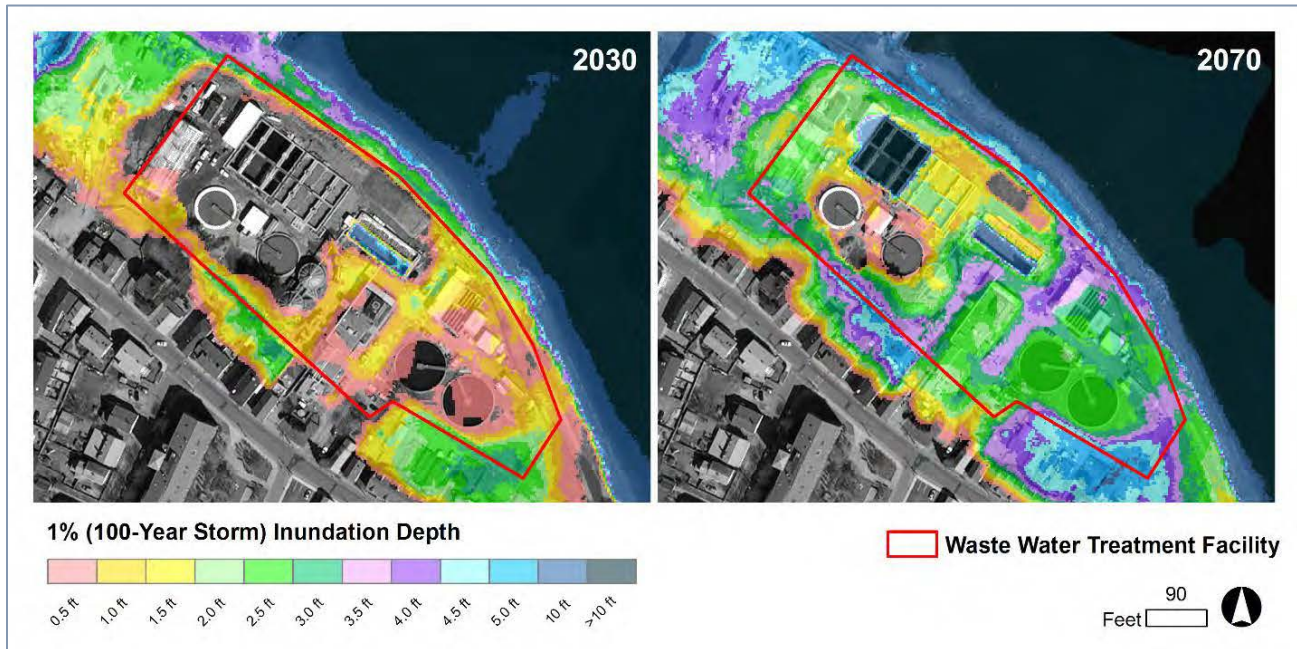


Figure 3.3-3. Wastewater Treatment Facility, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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

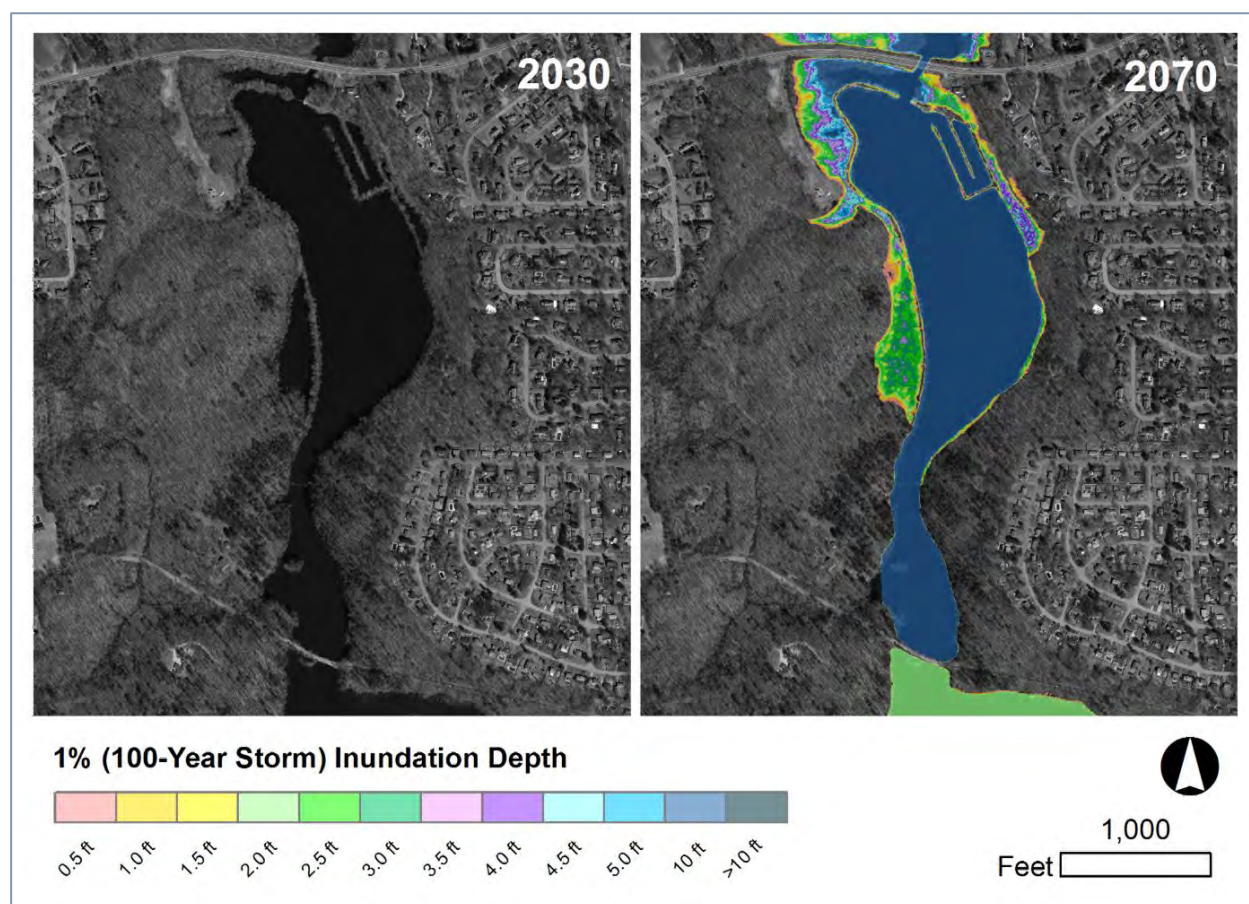


Figure 3.3-4. Lower Artichoke Reservoir, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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

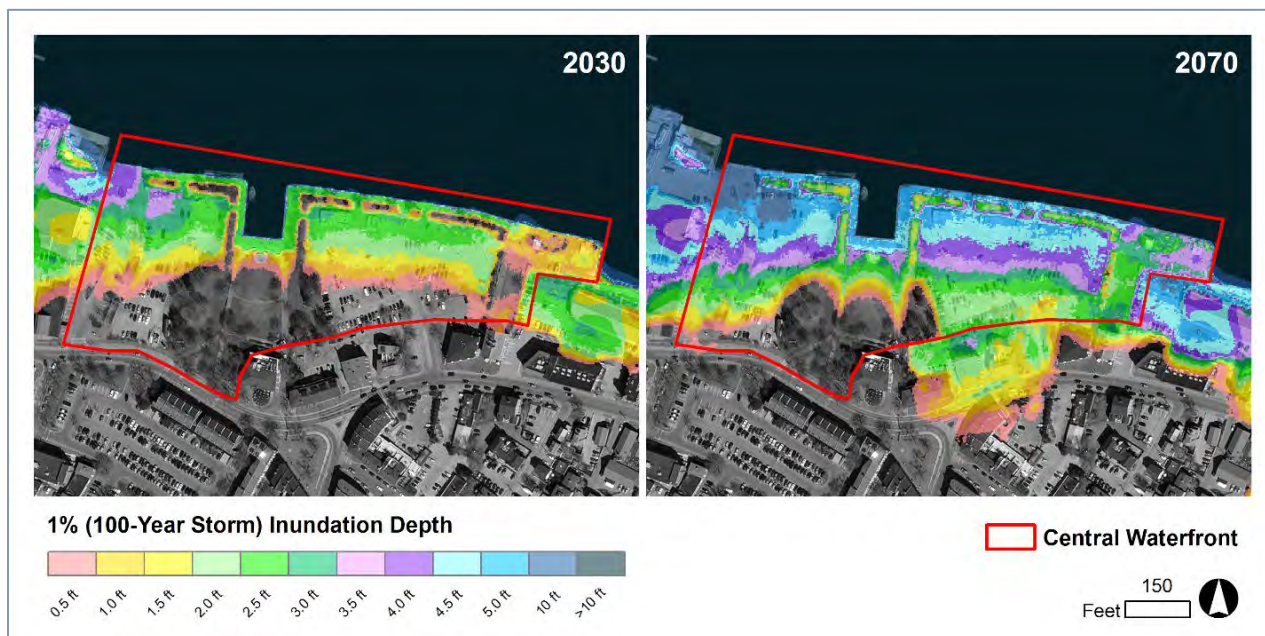


Figure 3.3-5. Central Waterfront, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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-year flood 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.

DEMOGRAPHICS¹⁴¹

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%).

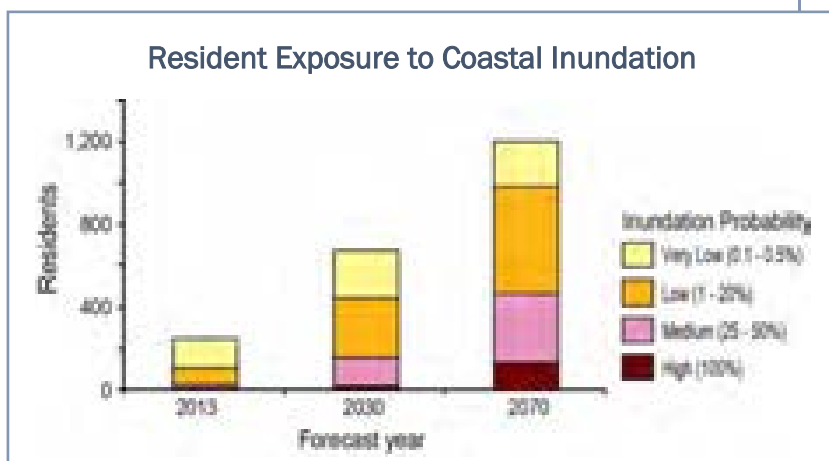


Figure 3.3-6. Resident exposure in the City of Newburyport, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

ECONOMIC & SOCIO-ECONOMIC¹⁴²

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

Employee Exposure to Coastal Inundation

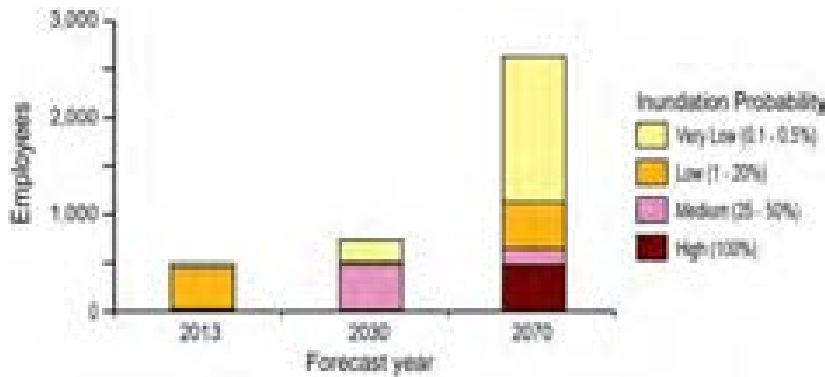


Figure 3.3-7. Employee exposure in Newburyport, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

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.

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

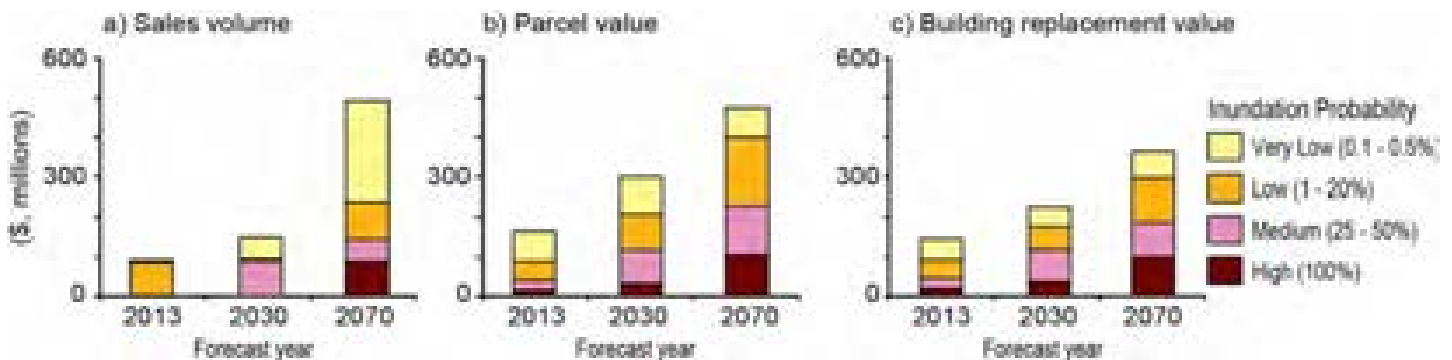


Figure 3.3-8. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Newburyport, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

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

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

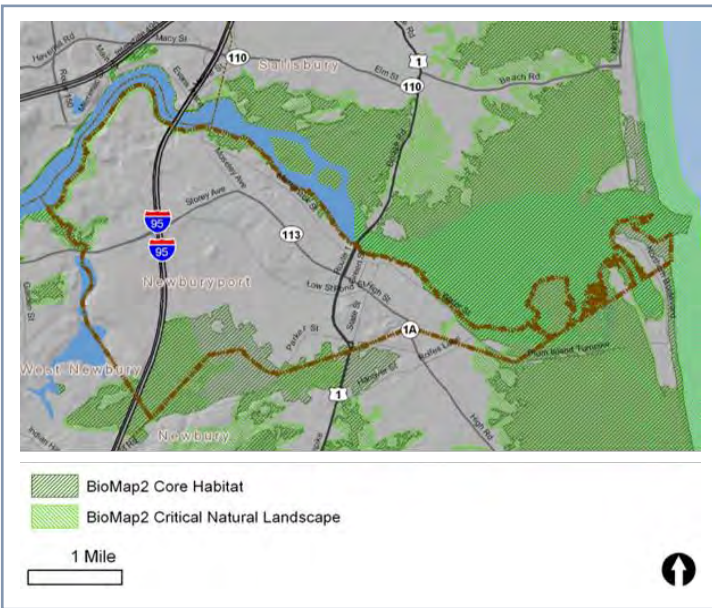


Figure 3.3-9. BioMap2 Core Habitats & critical natural landscapes in Newburyport.

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

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

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.

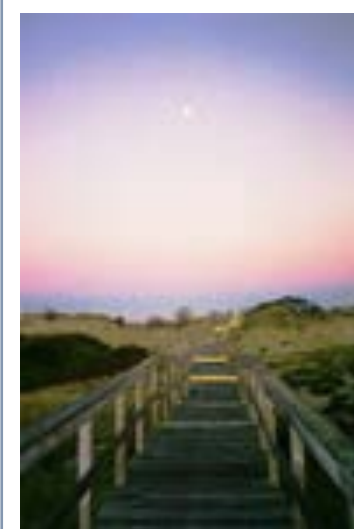
Newburyport beaches and dunes on Plum Island provide critical foraging habitat to the federally threatened Piping Plover, among other species. This habitat is however disappearing as erosion rates are further accelerated by increased storm frequency and intensity, and sea level rise. Like all barrier 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.

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.



Kay Bice/MA Office of Travel & Tourism

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

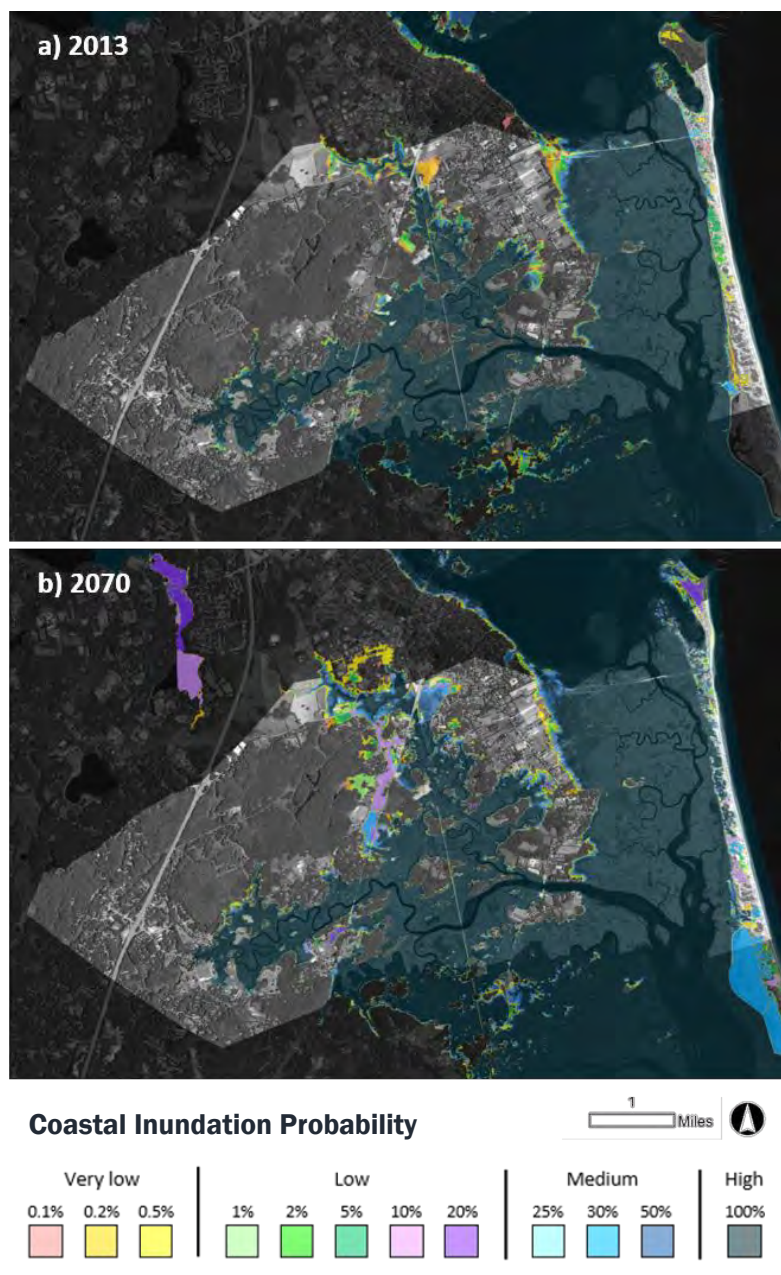


Figure 3.4-1. Newbury, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

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

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

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

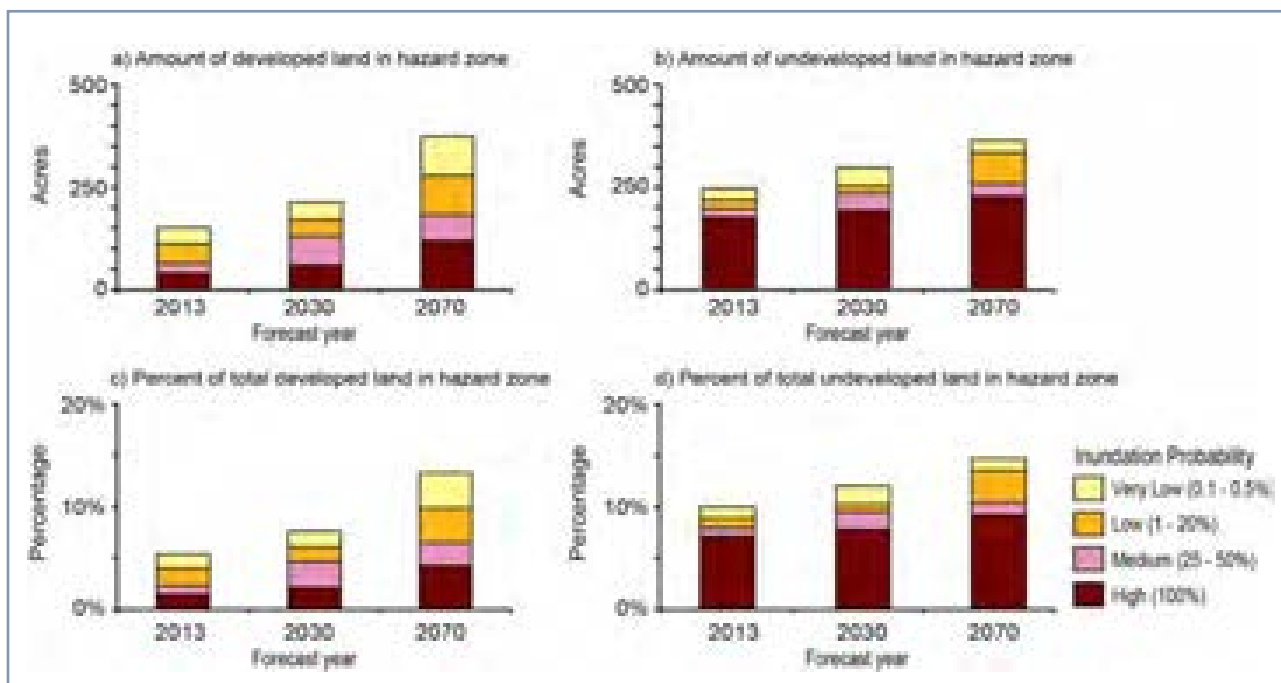


Figure 3.4-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Newbury, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

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.

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



Sandy Tilton

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}

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

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

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

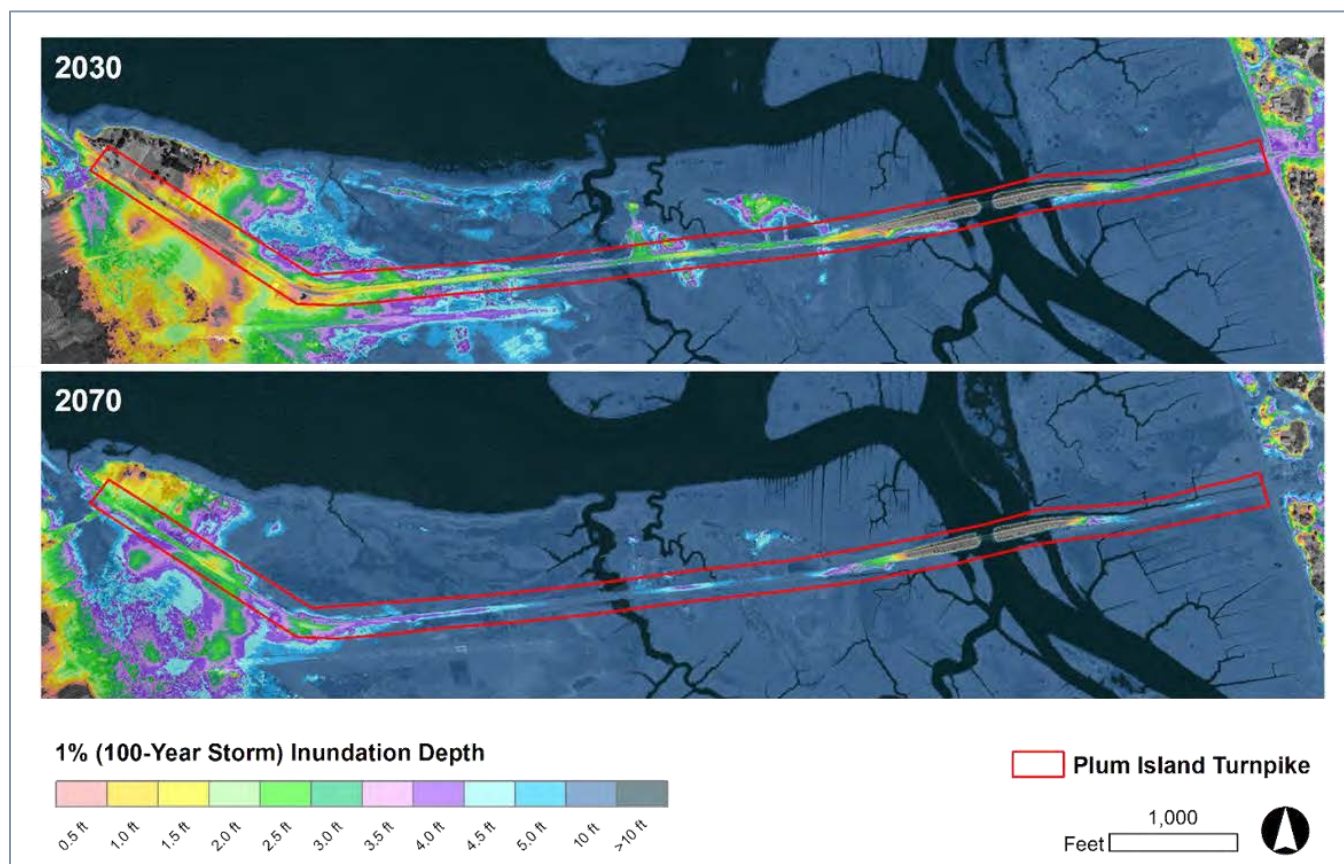


Figure 3.4-3. Plum Island Turnpike, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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

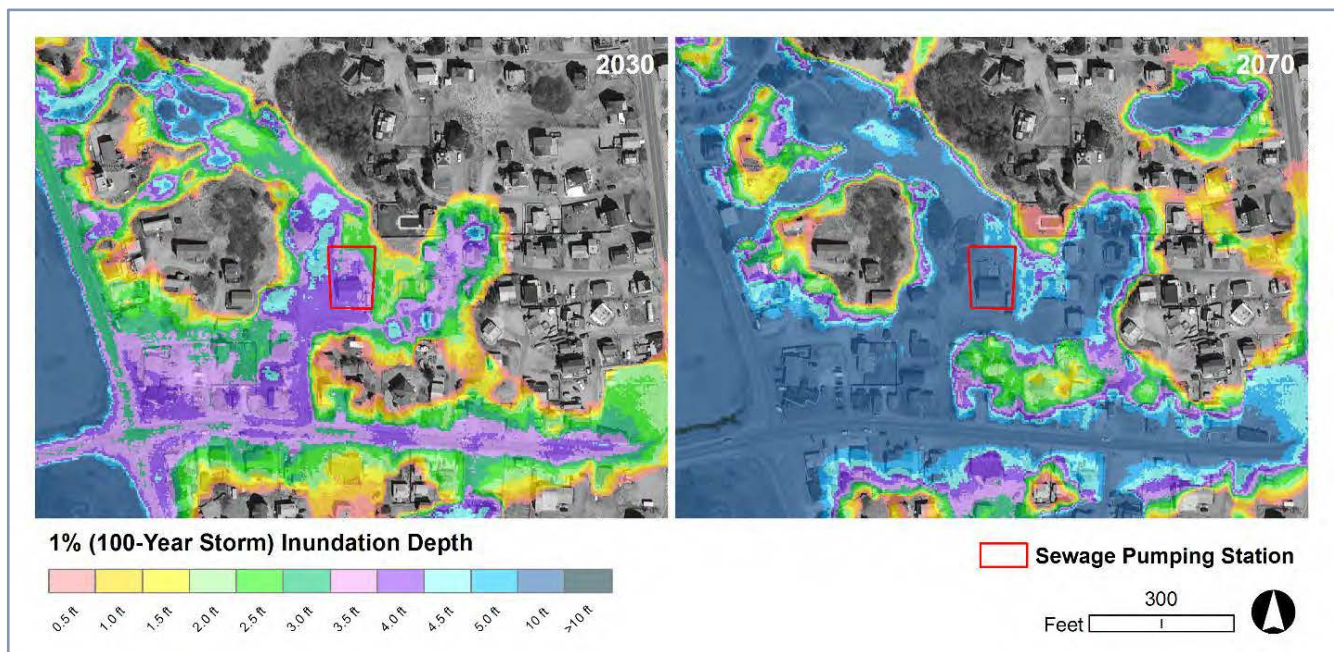


Figure 3.4-4. The Plum Island sewage pumping station, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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

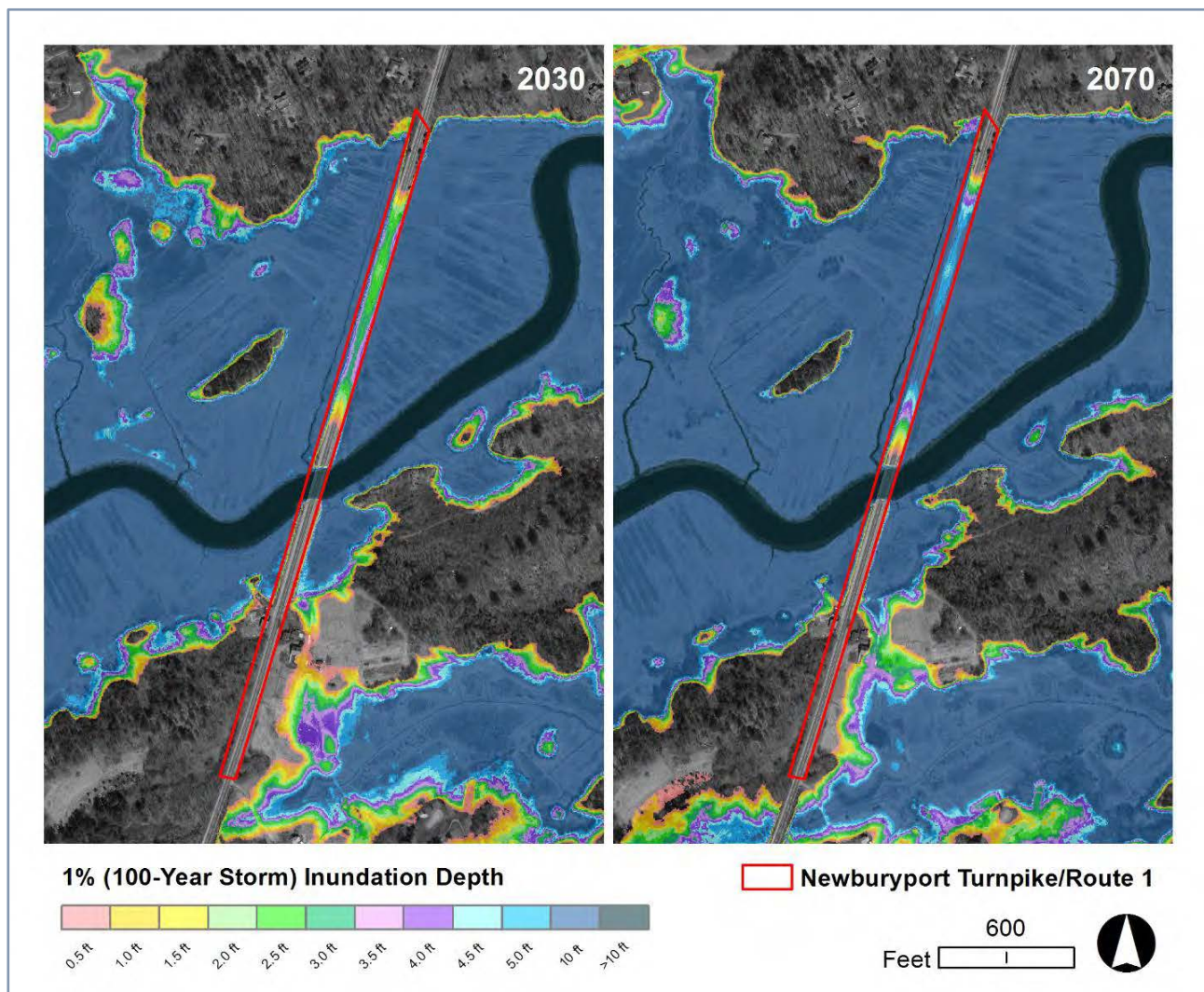


Figure 3.4-5. Newburyport Turnpike/Route 1, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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

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



Ron Stelline/MyCoast

areas.¹⁸⁹ In addition, according to the Hydro-barrier Assessment (see Appendix B), a public shoreline structure along the beach is in poor condition.

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

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.

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

DEMOGRAPHICS¹⁹⁴

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.

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-ECONOMIC¹⁹⁵

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.

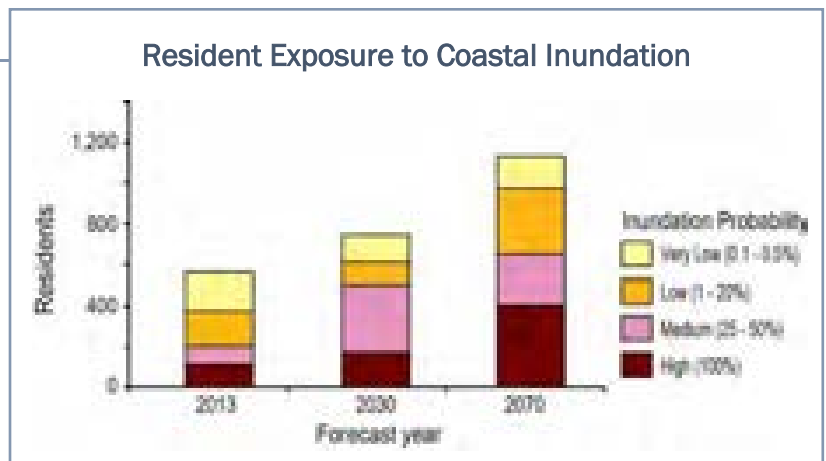


Figure 3.4-7. Resident exposure in the Town of Newbury, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

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.

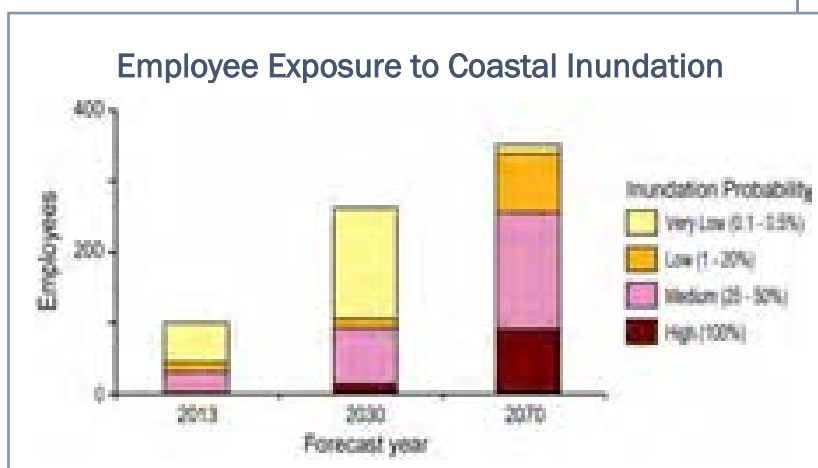


Figure 3.4-8. Employee exposure in Newbury, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

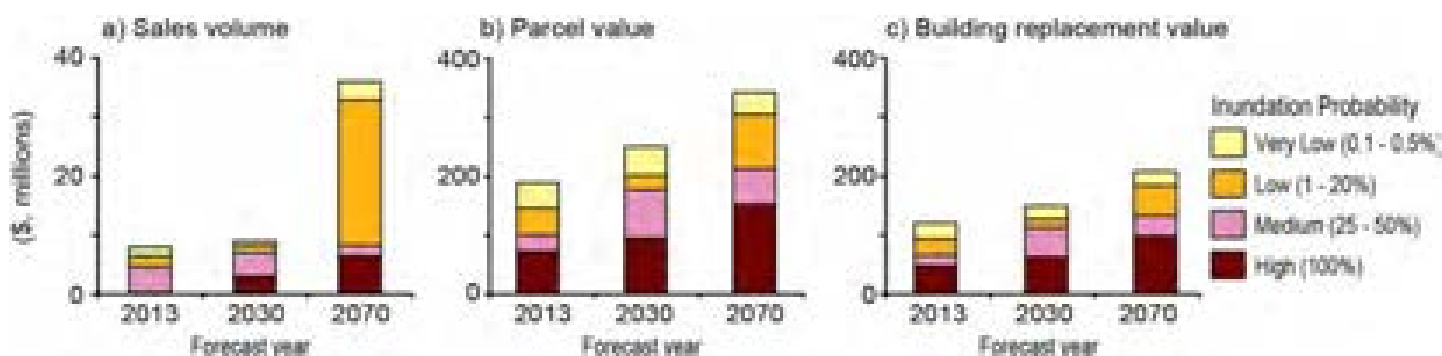


Figure 3.4-9. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Newbury, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

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

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



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

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

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

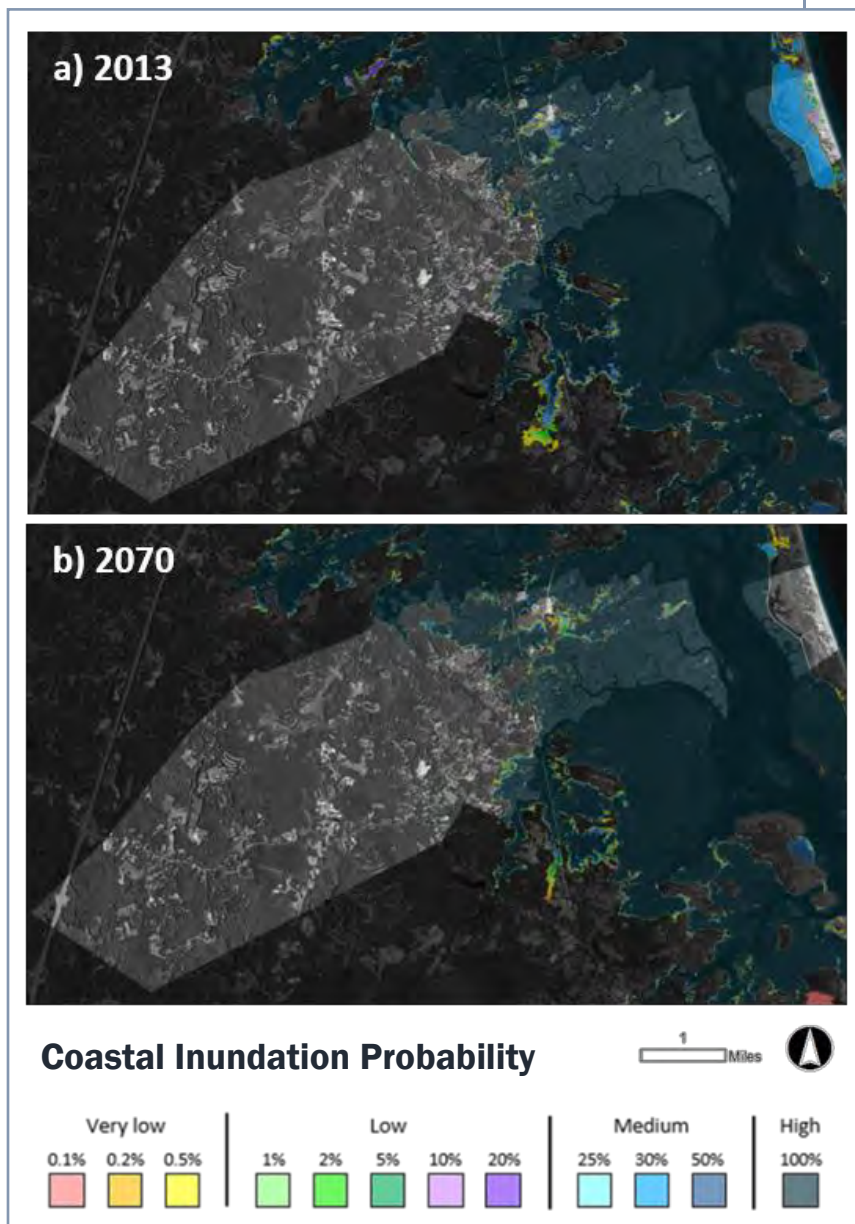


Figure 3.5-1. Rowley, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

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.

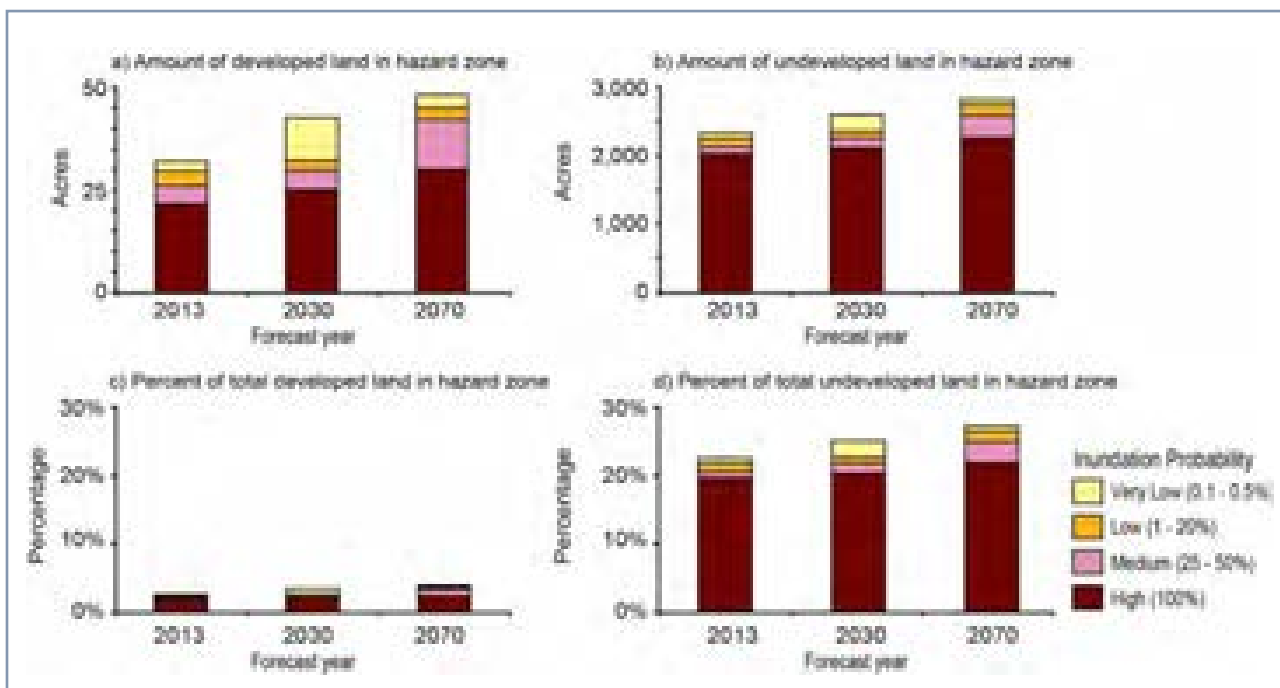


Figure 3.5-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Rowley, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

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 analysis²²² 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.

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).



A.D. Chandler

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

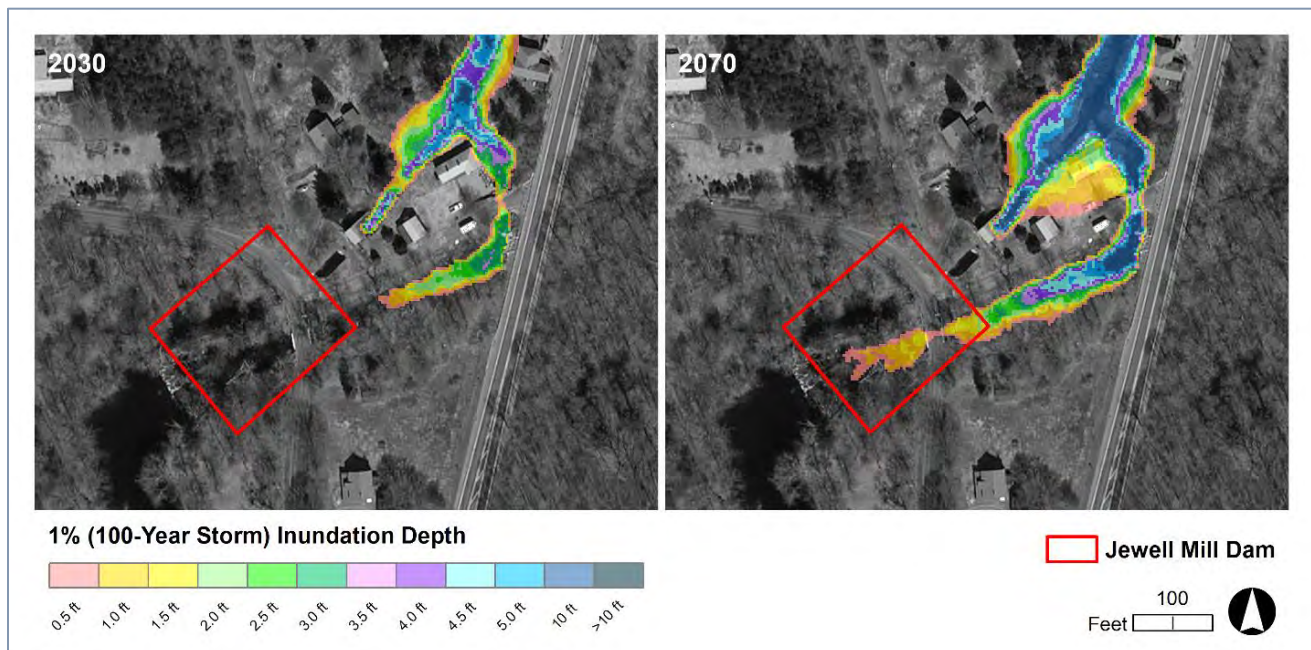


Figure 3.5-3. Jewel Mill Dam, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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.

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).

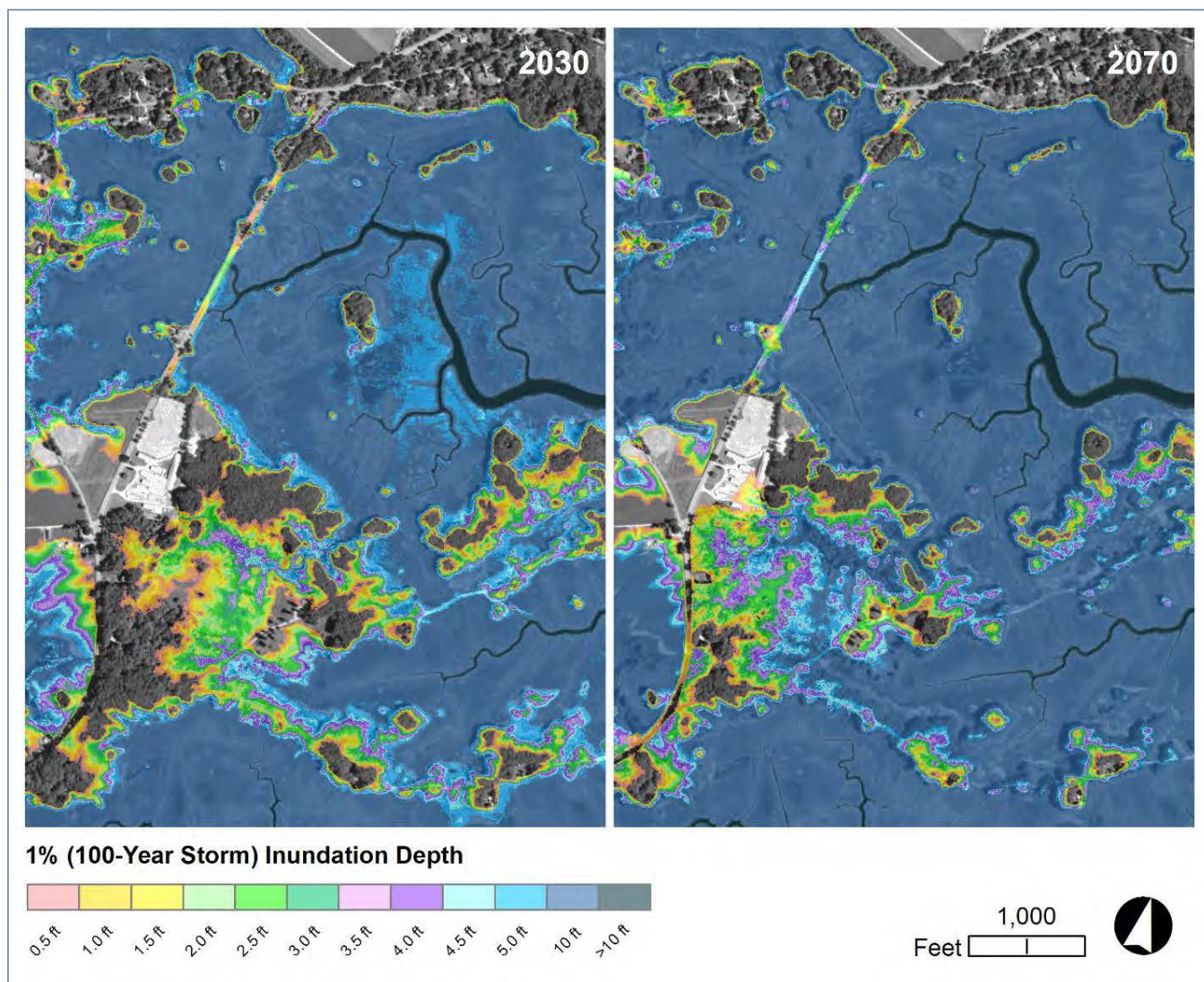


Figure 3.5-4. Stackyard Road at Route 1A, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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

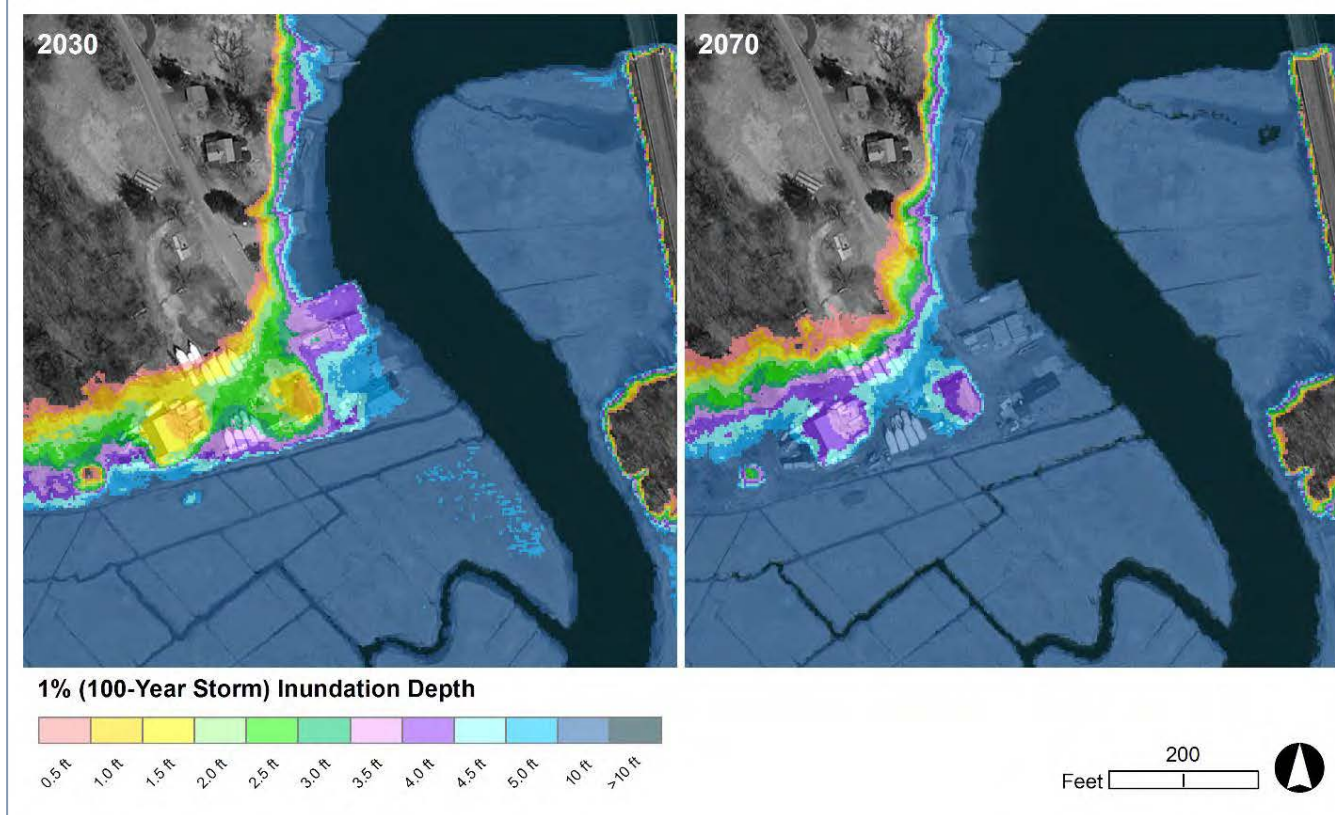


Figure 3.5-5. Rowley Marina and Boat Launch, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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.

DEMOGRAPHICS²³⁷

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

Resident Exposure to Coastal Inundation

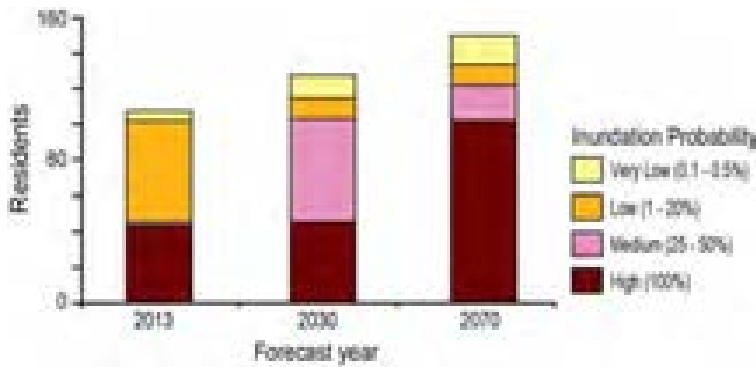


Figure 3.5-6. Resident exposure in the Town of Rowley, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

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-ECONOMIC²³⁸

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

Employee Exposure to Coastal Inundation

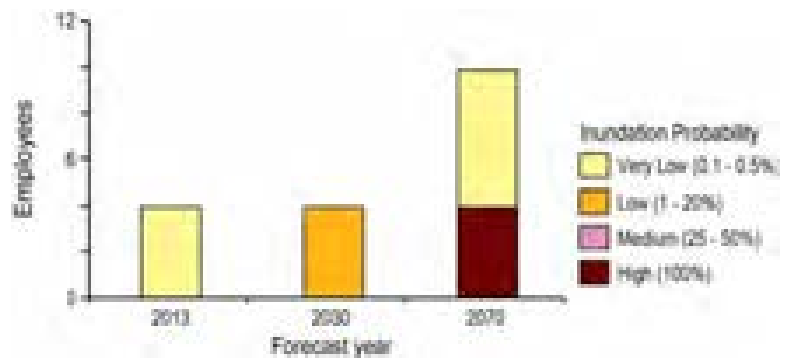


Figure 3.5-7. Employee exposure in Rowley, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

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.

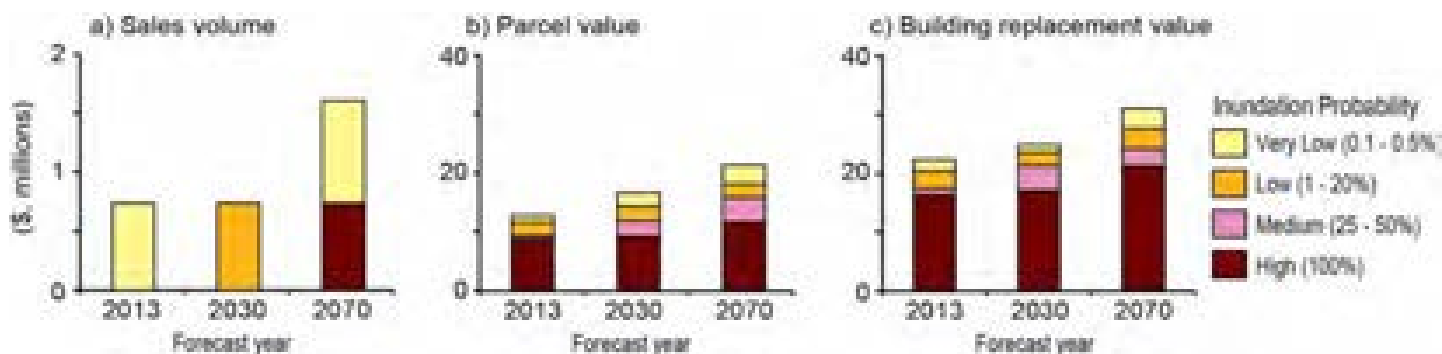


Figure 3.5-8. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Rowley, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

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

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



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

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.

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

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	Wet 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

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

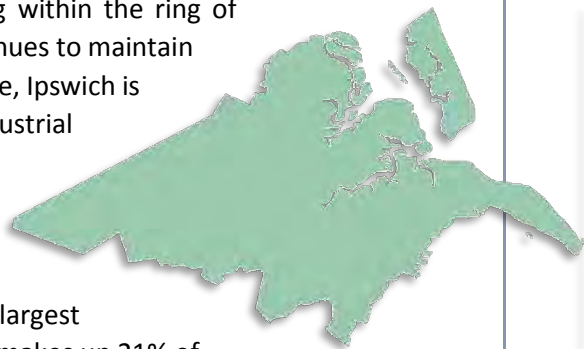


David Stone

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

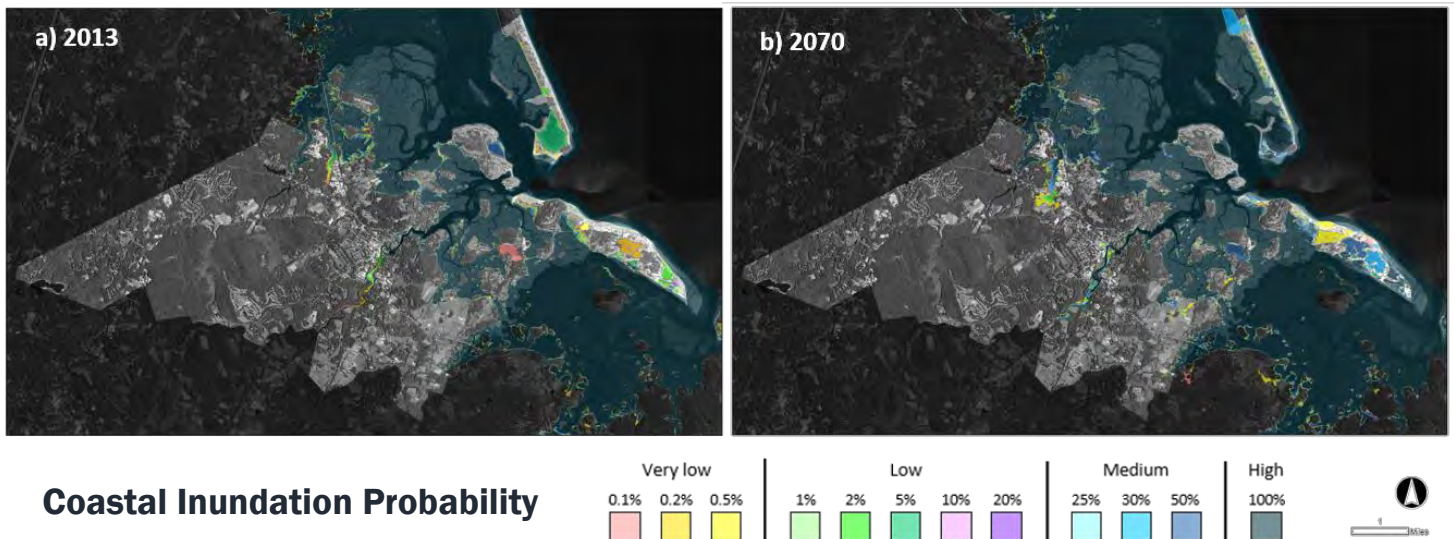


Figure 3.6-1. Ipswich, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

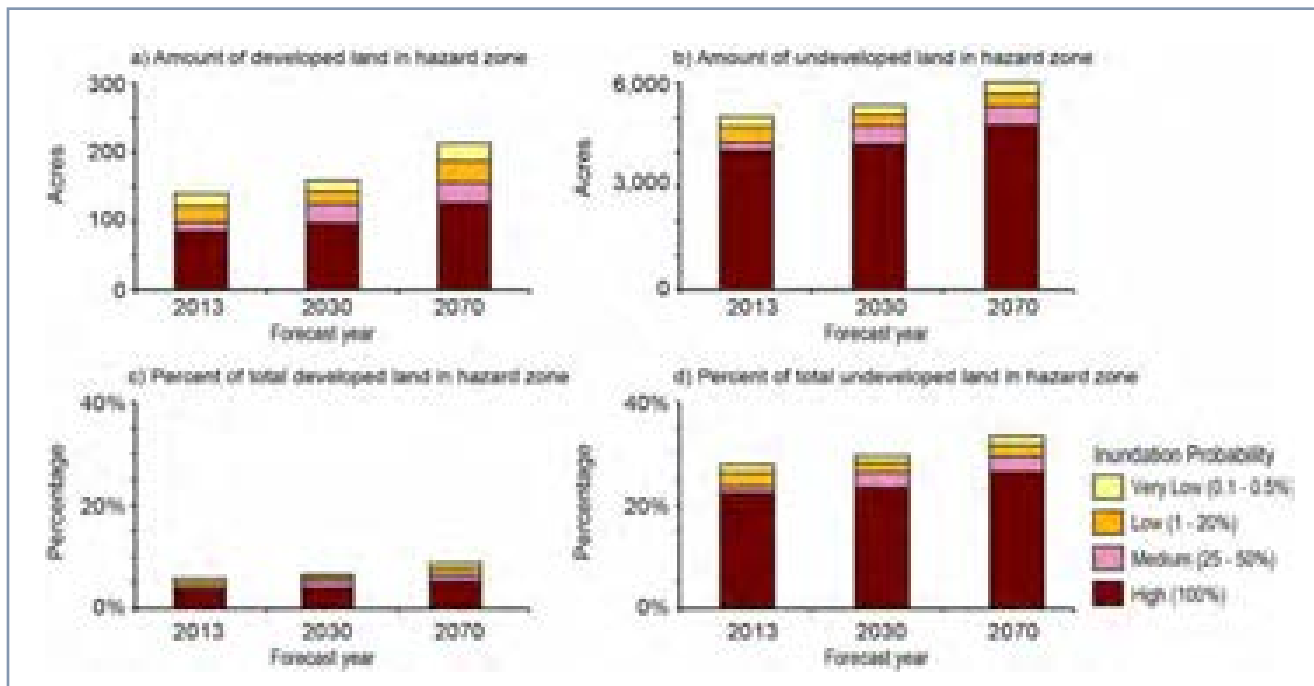


Figure 3.6-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Ipswich, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

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



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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

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



Kirk R. Williamson/Flickr

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.

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

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).



²⁸² Town of Ipswich, *Ipswich Community Development Plan*, 98

²⁸³ MAPC, *Town of Ipswich Hazard Mitigation Plan*, 11

David Stone

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

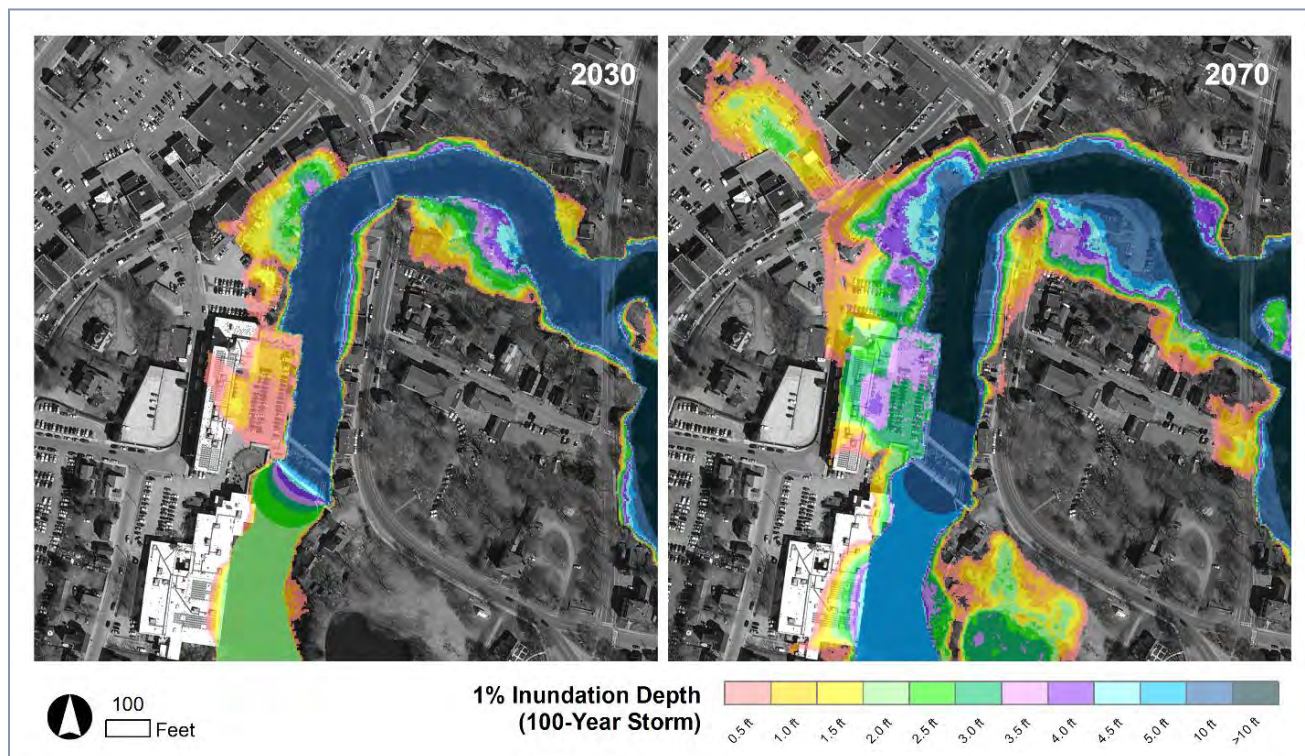


Figure 3.6-3. Downtown Ipswich, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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



cmh2315f/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

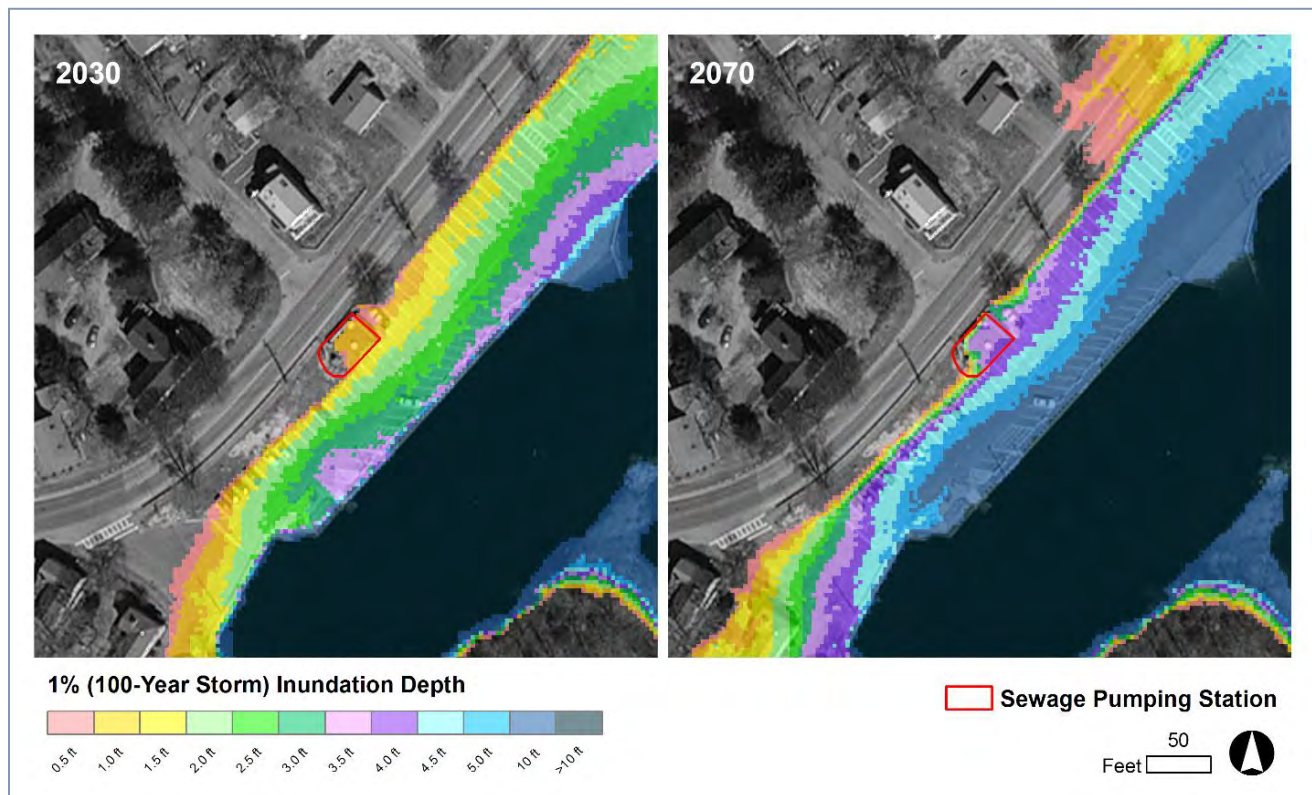


Figure 3.6-4. Sewage Pumping Station, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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.

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



Abby Manzi/DeRosa Environmental Consulting, Inc.

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

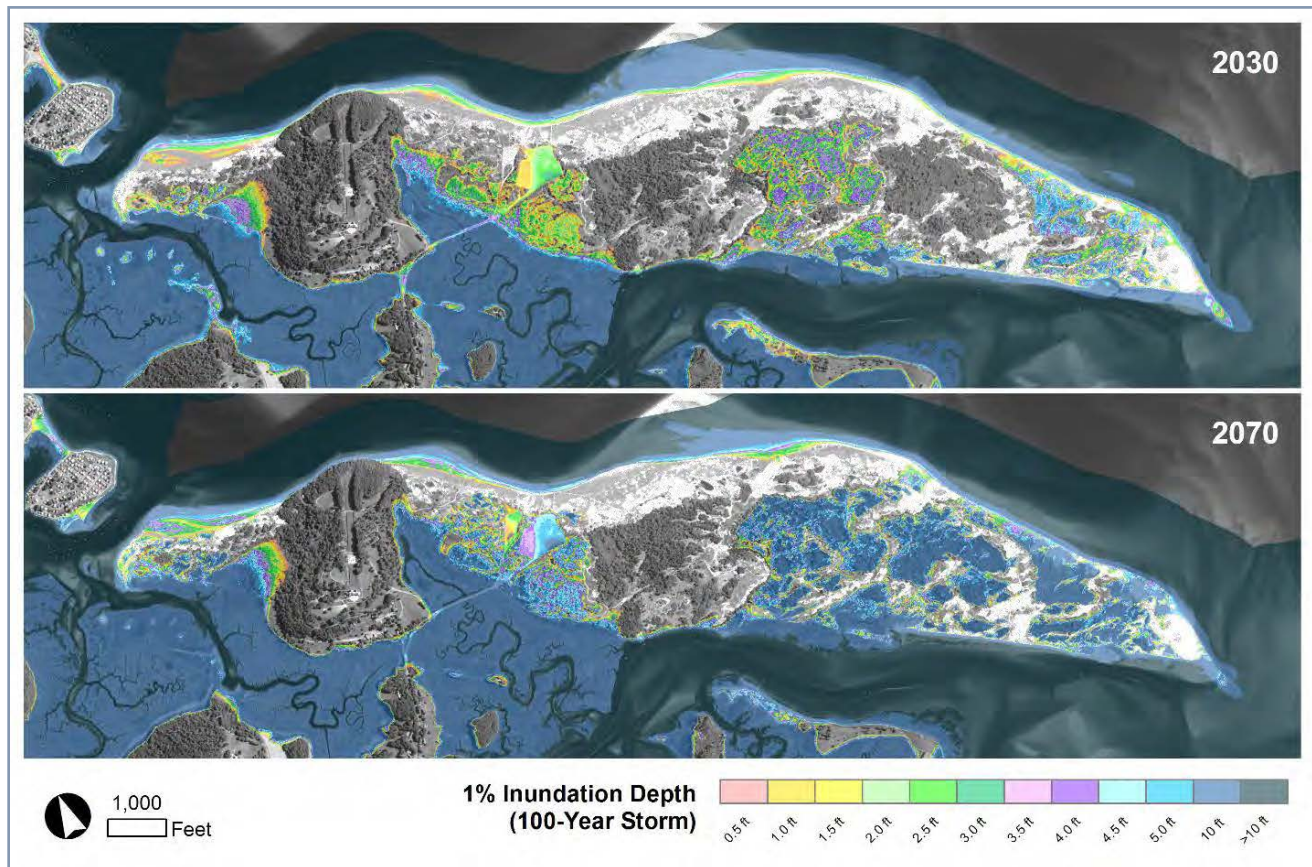


Figure 3.6-5. Crane Beach, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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,



David Stone

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.

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).

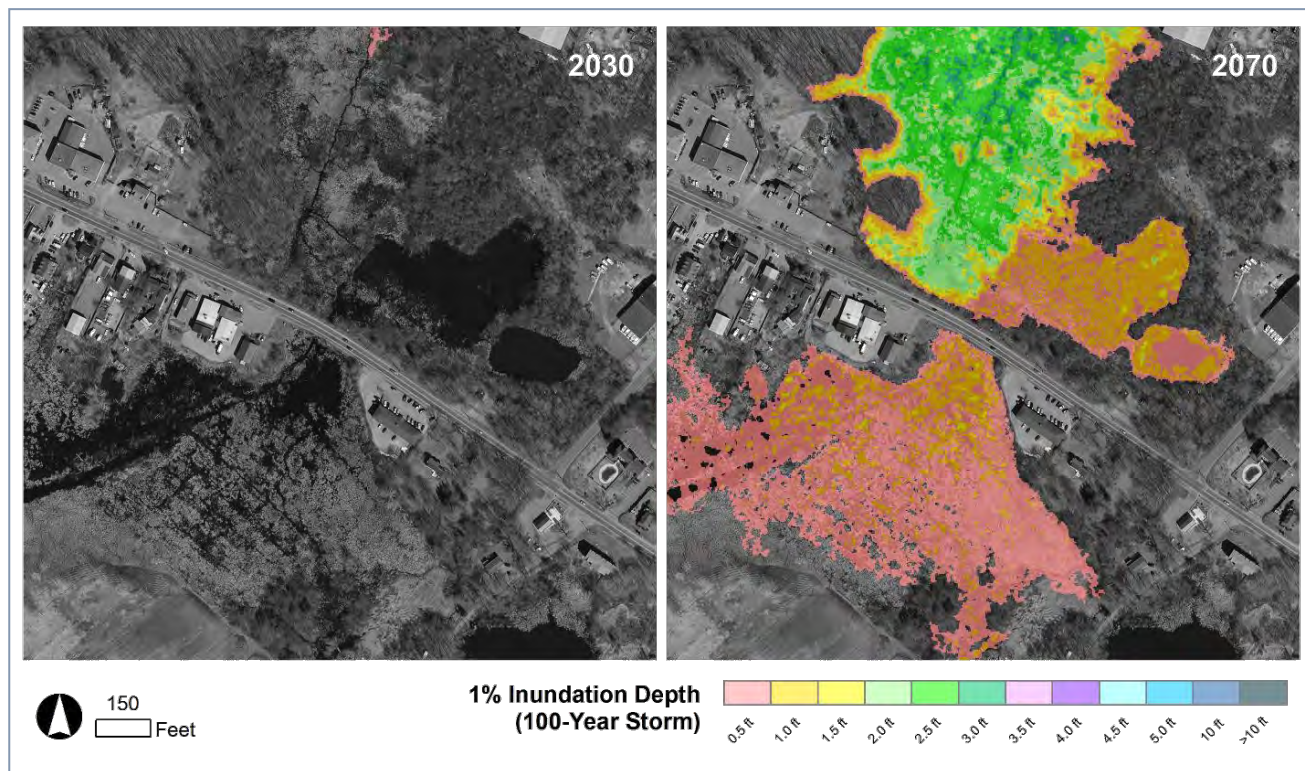


Figure 3.6-6. Brown's Well, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

DEMOGRAPHICS²⁹⁸

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

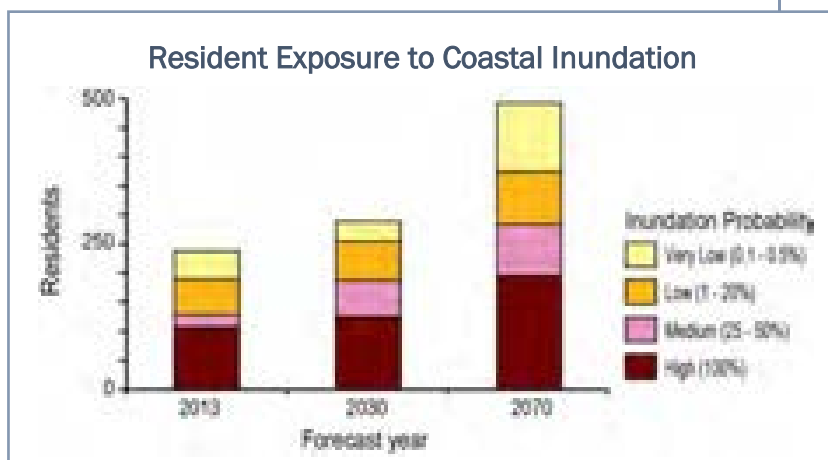


Figure 3.6-7. Resident exposure in the Town of Ipswich, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

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-ECONOMIC²⁹⁹

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.

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

Employee Exposure to Coastal Inundation

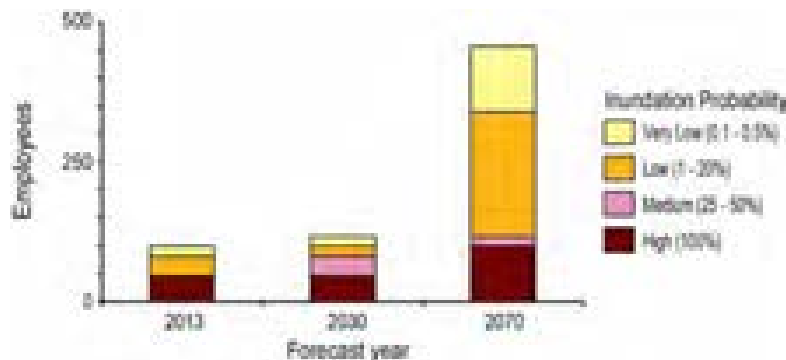


Figure 3.6-8. Employee exposure in Ipswich, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

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

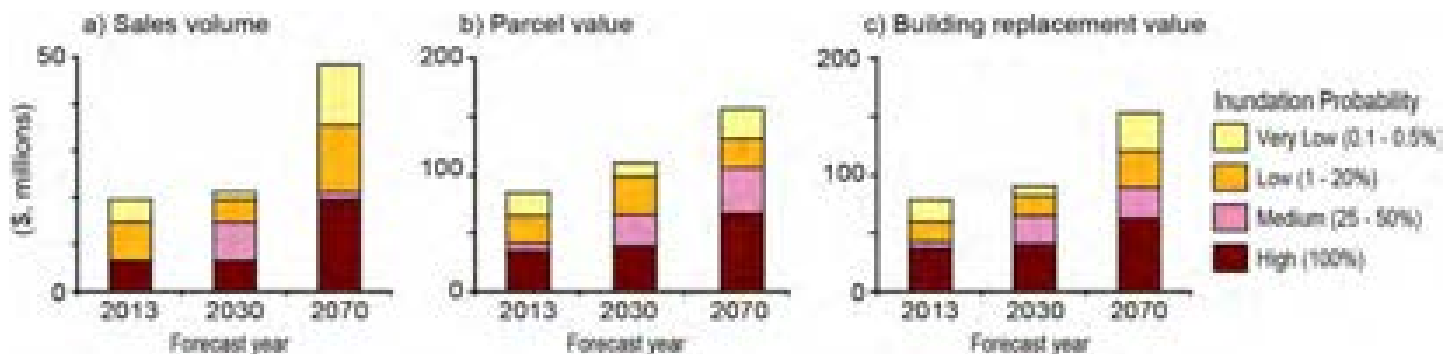


Figure 3.6-9. Cumulative value of (A) business sales volume, (B) total parcels, and (C) building replacement costs in coastal-hazard zones for Ipswich, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

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

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



John Phelan/Flickr



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

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

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

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.

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



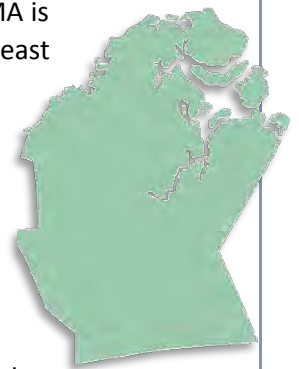
Abby Manzi/DeRosa Environmental Consulting, Inc.

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.

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%



Robert Barossi/MyCoast

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

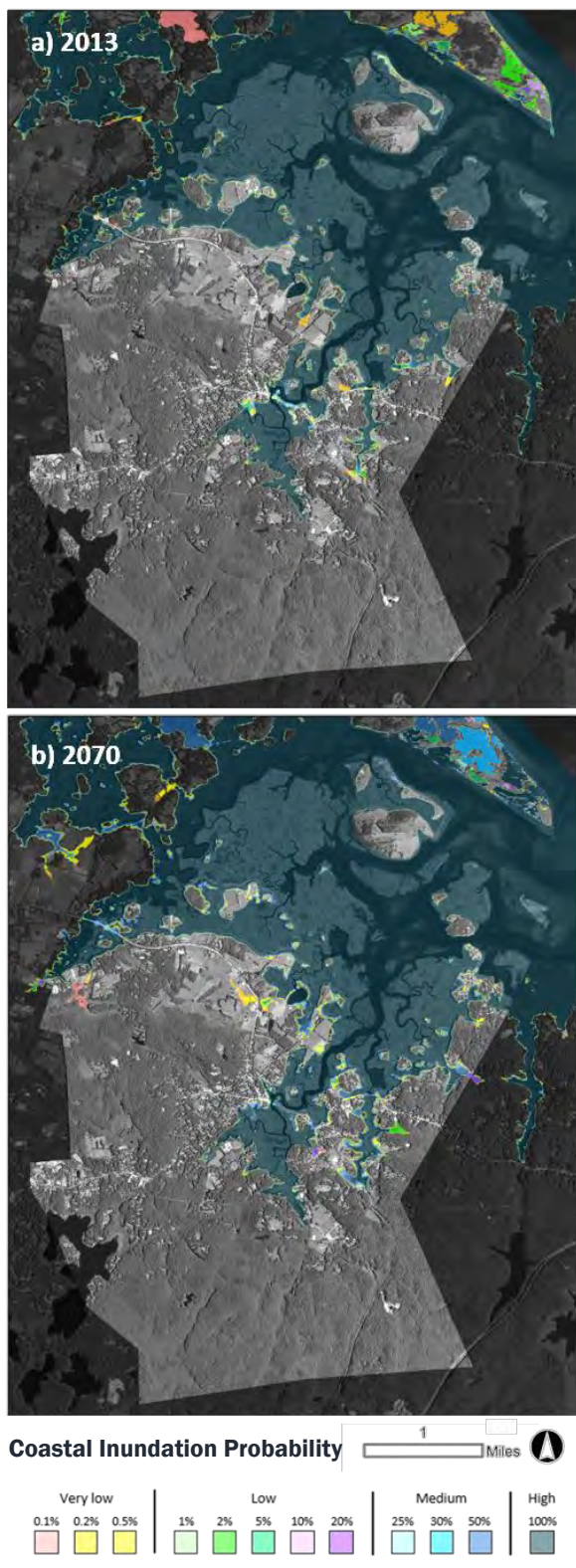


Figure 3.7-1. Essex, Massachusetts, coastal inundation-probability maps showing modeled hazard zones in (a) 2013 (present day) and (b) 2070.

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

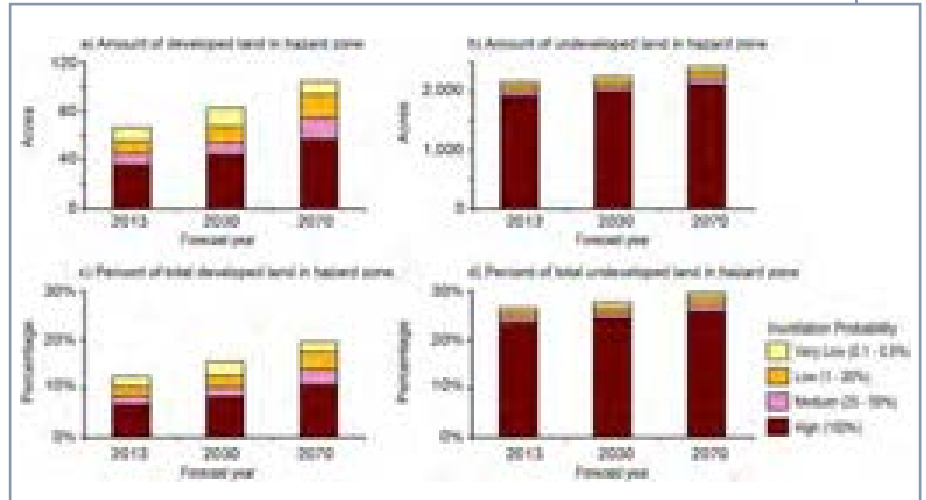


Figure 3.7-2. Amounts of (a) developed and (b) undeveloped land and total percentages of (c) developed and (d) undeveloped land in coastal-hazard zones of Salisbury, Massachusetts, expressed by inundation probability in 2013 (present day), 2030, and 2070.

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.

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 clambers 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.

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



NWF

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

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

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.

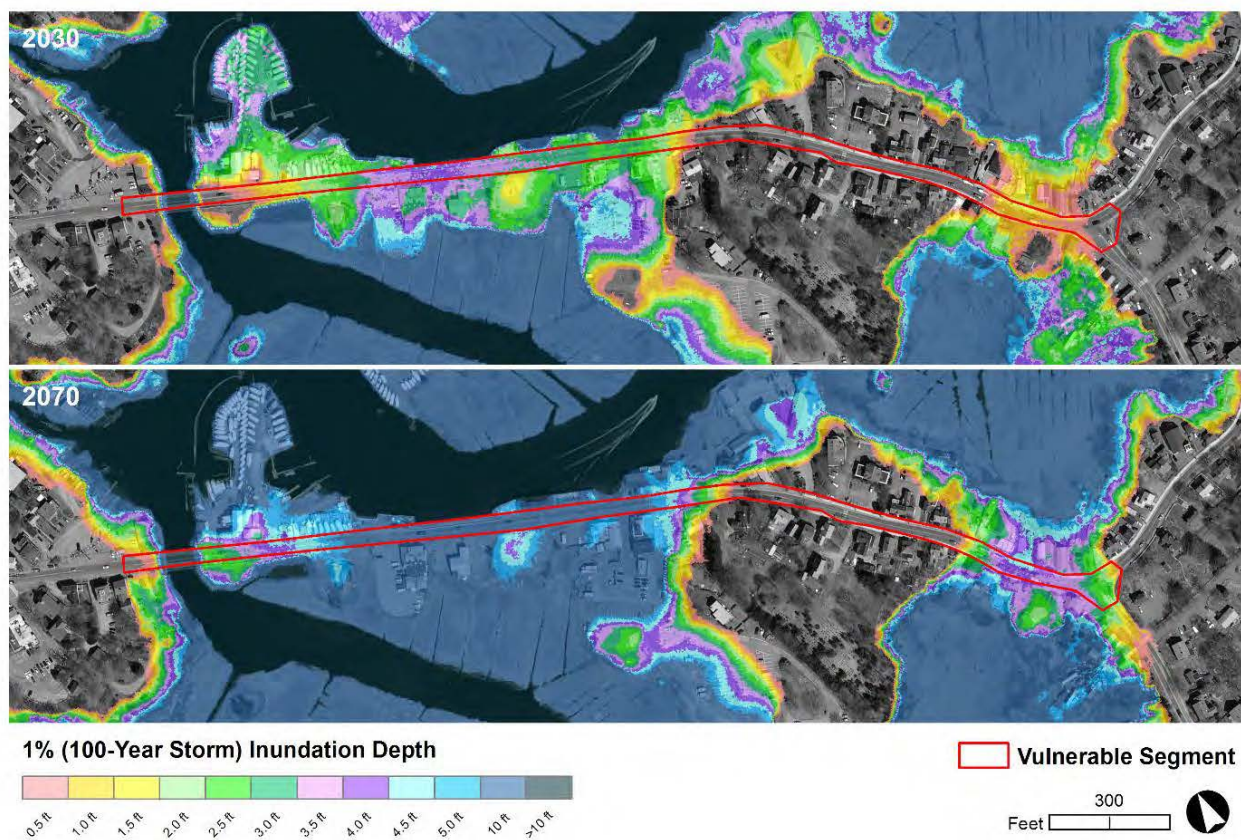


Figure 3.7-3. Essex Causeway and Woodman's Landing, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

³⁵¹ MAPC, *Town of Essex Hazard Mitigation Plan*, 16

³⁵² Abdollahian, N. et al., *Community Exposure*, 65

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



Abby Manzi/DeRosa Environmental Consulting, Inc.

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.

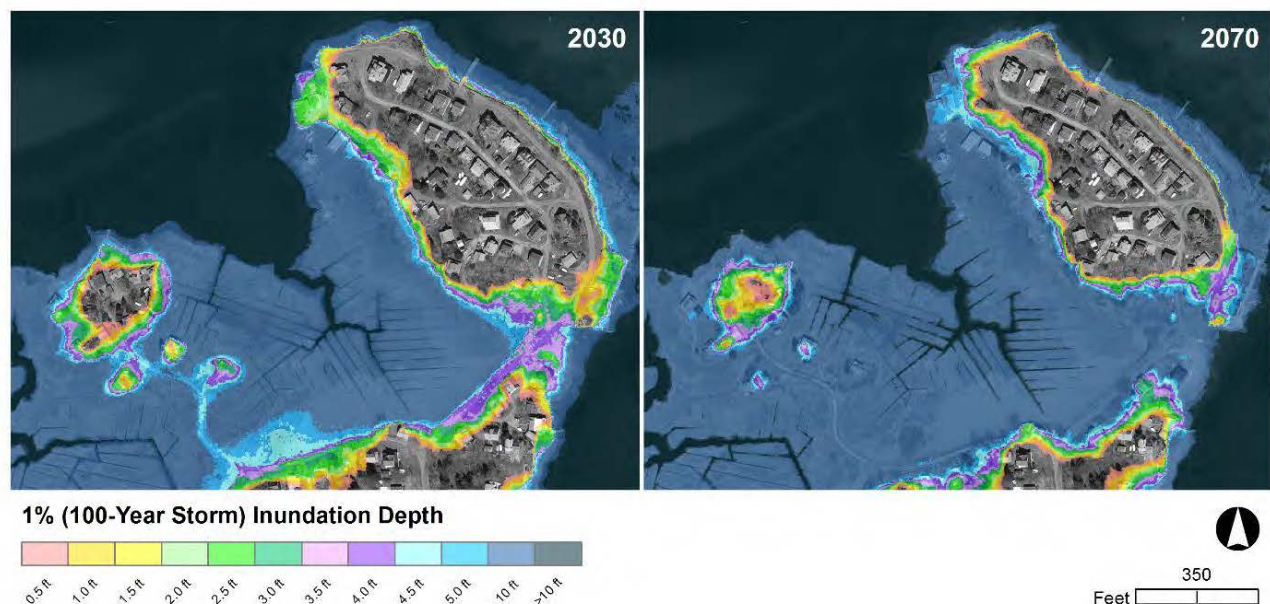


Figure 3.7-4. Conomo Point Road and Robbins Island Road, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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.

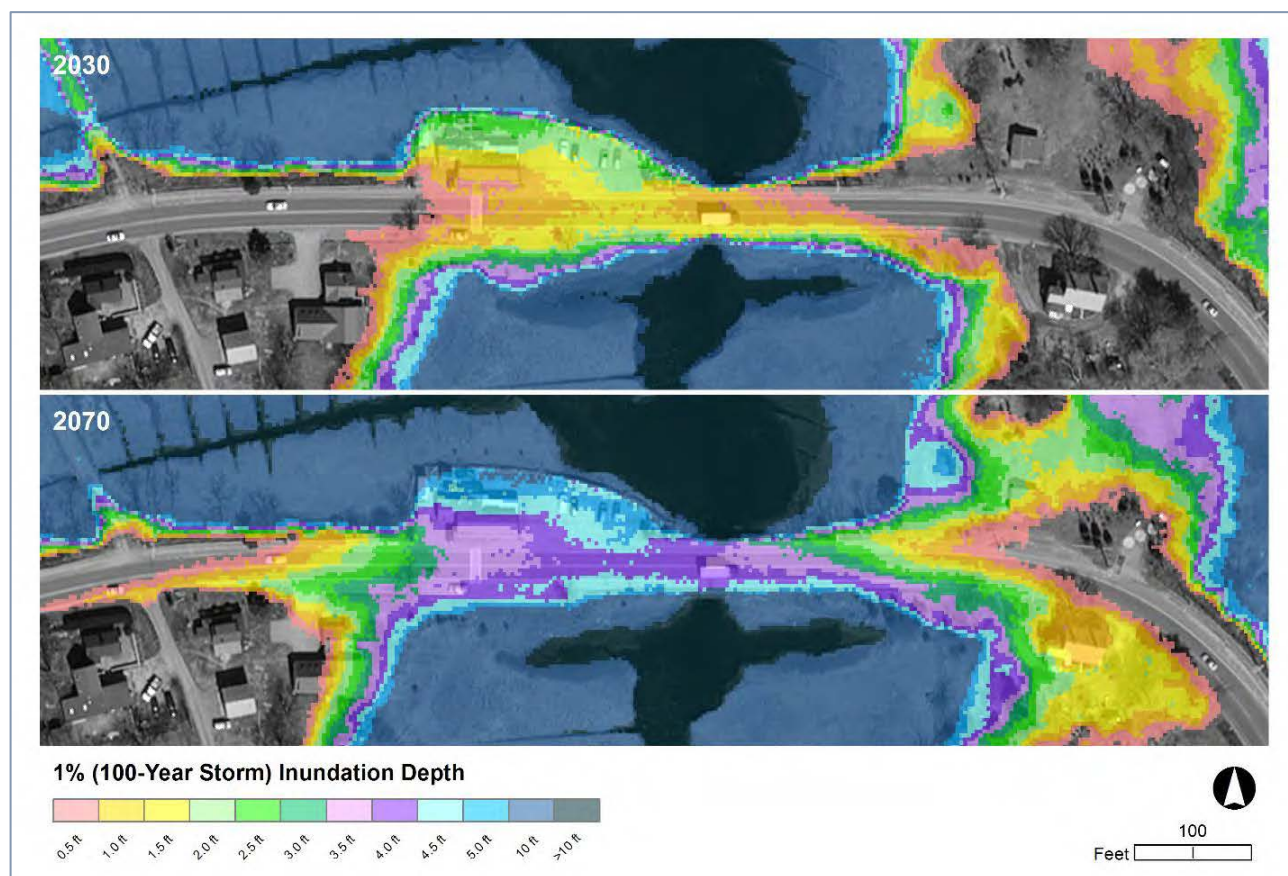


Figure 3.7-5. Eastern Avenue at Ebben Creek, 1% Flood Depth in 2030 and 2070 (includes projected storm surge).

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.*

DEMOGRAPHICS³⁶⁰

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%).

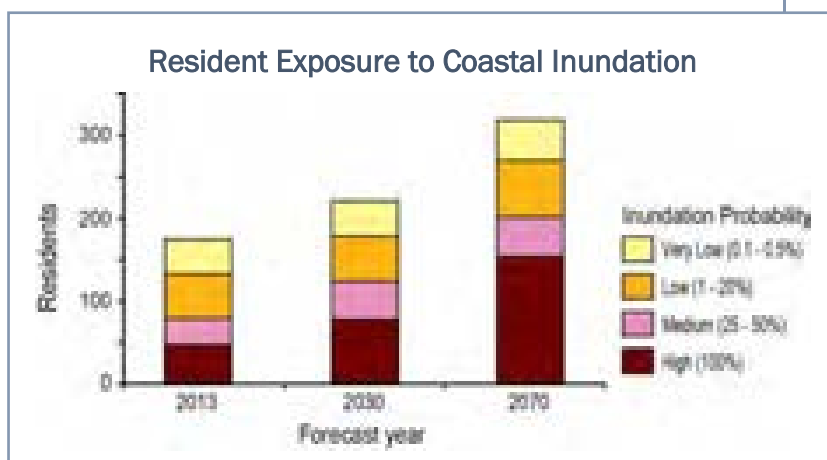


Figure 3.7-6. Resident exposure in the Town of Essex, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability percentage.

ECONOMIC & SOCIO-ECONOMIC³⁶¹

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 1,410 employees 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.

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.

Employee Exposure to Coastal Inundation

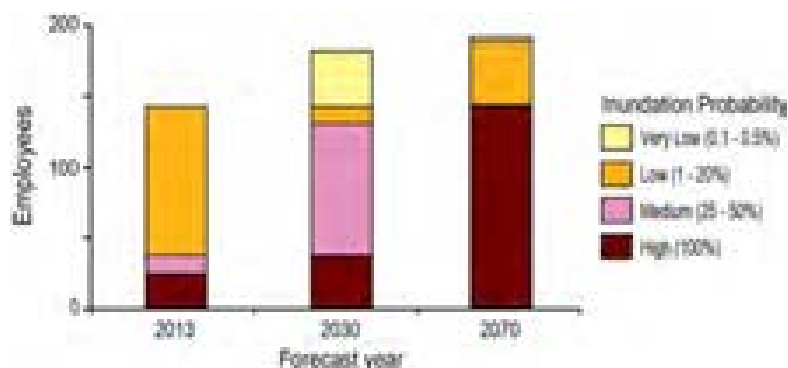


Figure 3.7-7. Employee exposure in Essex, Massachusetts, to storm surge scenarios for 2013 (present day), 2030, and 2070, organized by inundation probability. %, percent.

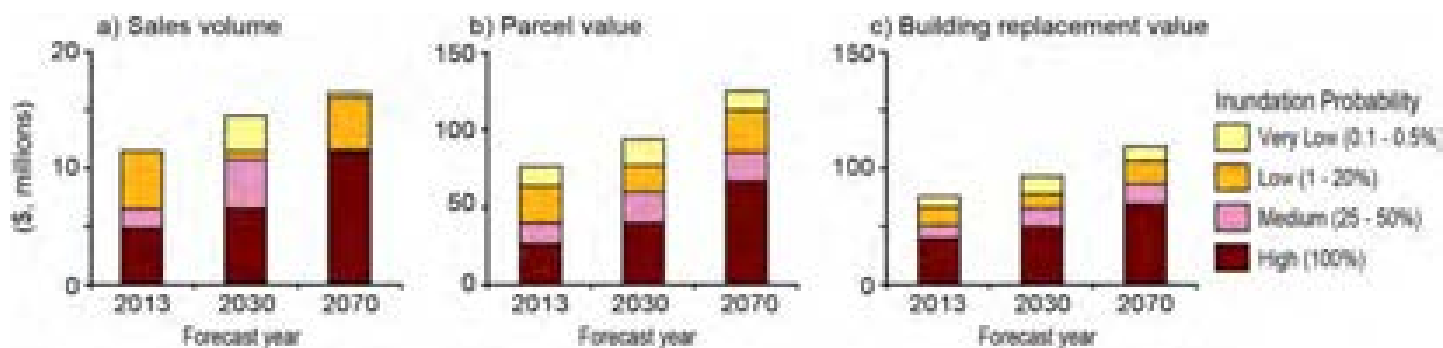


Figure 3.7-8. Cumulative value of (a) business sales volume, (b) total parcels, and (c) building replacement costs in coastal-hazard zones for Essex, Massachusetts for 2013 (present day), 2030, and 2070. Millions of dollars; %, percent.

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

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



Walter Seigmund/Flickr

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.

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.



Robin Lubbock/WBUR

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.

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.



NWF

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