Ranger Poole/USFWS

CHAPTER 4

Adaptation Strategies for the Great Marsh Region

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

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

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

4.1 Regional Strategies and Recommendations

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

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

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

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

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

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

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

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

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

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

NWF

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

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

Best Practices

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

Establish and maintain a permanent Municipal Resiliency Task Force or committee

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

Set clear goals for addressing existing and projected vulnerability

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Collaborate across municipal departments

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

Collaborate across municipal boundaries

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

Sandy Tilton

Protect and enhance biodiversity

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

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

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

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

Reduce non-climate stressors

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

Peter Phippen

Evaluate effectiveness of adaptation strategies at regular intervals

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

Monitor coastal hazards and maintain strong research initiatives

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

Promote economic diversity

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

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

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

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

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

Natural and Nature-Based Strategies

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

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

Ensure and restore connectivity of river and coastal systems

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

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[387] Ibid

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

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

Use living shorelines to stabilize shoreline edges, where appropriate

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

Partnership for the Delaware Estuary/Flickr

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

[389] Small-Lorenz, S.L., W.P. Shadel, and P. Glick., *Building Ecological Solutions to Coastal Community Hazards* (Washington, DC: National Wildlife Federation, 2017), 74

[390] Ibid

[391] Ibid

[392] Miller, J.K., A. Rella, A. Williams, and E. Sproule, *Living Shorelines Engineering Guidelines*, prepared for New Jersey Department of Environmental Protection (Hoboken, NJ: Stevens Institute of Technology, 2016), http://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf

[393] NOAA Living Shorelines Workgroup, *Guidance for Considering the Use of Living Shorelines* (2012), (http://www.habitat.noaa.gov/pdf/noaa_guidance_for_considering_the_use_of_living_shorelines_2015.pdf

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

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

Lynnhaven River NOW

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

Protect and restore barrier beaches and dunes through renourishment and revegetation

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

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

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

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

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

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

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

Gregg Moore/UNH

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

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

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

Explore opportunities to beneficially reuse dredged material

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

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

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

[400] Ibid 59

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

Restore submerged-aquatic vegetation

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

Restore degraded salt marshes

Margie Brenner/USFWS

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

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

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

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

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

Facilitate marsh migration

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

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

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

Enhance land conservation efforts

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

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

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

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

Specific land conservation strategies include:

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

Matt Poole/USFWS

[409] Ibid
[410] "Greenbelt: Essex County's Land Trust," http://www.ecga.org/
[411] "Land Conservation," Mass Audubon, http://www.massaudubon.org/our-conservation-work/land-conservation
[412] "Land," Trustees, http://www.thetrustees.org/what-we-care-about/land/
[413] "Land Protection Program," MA Executive Office of Energy and Environmental Affairs, http://www.mass.gov/eea/agencies/dfg/dfw/wildlife-habitat-conservation/land-acquisition-and-protection.html

Gray Infrastructure and Retrofits

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

Remove unnecessary dams

Ipswich River Watershed Association

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

Upgrade road-stream crossings

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

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

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

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

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

Retrofit buildings to be more flood resilient

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

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

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

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

Specific strategies are to:

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

Pursue retrofits and planning for Massachusetts Bay Transportation Authority railroad

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


University of Florida

Land-Use Planning and Policy

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

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

Update municipal policies

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

Prioritize low-impact development (LID) practices

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

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

Revise local wetlands protection bylaws and regulations

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

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

Move development away from the coast and from wetlands

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

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

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

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

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

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

Create "freeboard incentive" for residential and commercial buildings

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

Use transferable development credits to reduce risky coastal development

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

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

[423] "Freeboard," Federal Emergency Management Agency (FEMA), https://www.fema.gov/freeboard
[424] Schechtman, J. and M. Brady, *Cost-Efficient Climate Change Adaptation in the North Atlantic*, 68
[425] Grannis, J., *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use*, 57-59
[426] Ibid
[427] "Smart Growth/Smart Energy Toolkit," MA EEA, http://www.mass.gov/envir/smart_growth_toolkit/bylaws/TDR-Bylaw.pdf
[428] MA EEA, *Smart Growth/Smart Energy Toolkit Bylaw: Transfer of Development Rights* (Boston, MA), 2, http://www.mass.gov/envir/smart_growth_toolkit/bylaws/TDR-Bylaw.pdf

While this strategy is described relatively succinctly and may seem straightforward, it is in fact one of the more complicated policy strategies to prevent or disincentive risky coastal development. It combines municipal policy changes along with the creation of market-based credits that can be purchased and sold. While it is an effective strategy, communities should be aware of the complexities associated with implementing a TDC/TDR program.

Institute comprehensive water resources management

The way in which human society has disrupted the natural water cycle is among the largest anthropogenic stressors on the natural world. The built environment often increases flooding, exacerbates drought, and disrupts the water cycle. Stormwater and wastewater are the one of the greatest threats to clean water in the United States and our region.[429] Water withdrawals for domestic, landscaping, and agricultural use dramatically affect both surface and groundwater hydrology. Historically, society has dealt with these interconnected and related issues separately, thereby exacerbating the problem and multiplying their negative impacts. Comprehensive water resources management is an effective tool to minimize these impacts on the environment while increasing the resiliency of human society.

To achieve comprehensive water resources management, Great Marsh communities and their partners should pursue the following activities:

Stormwater

- Implement EPA stormwater regulations[430] and monitor implementation progress;
- Expand local stormwater regulations to all areas of coastal communities outside of the mandatory EPA-regulated areas;[431]
- Incorporate and adopt CZM's *Assessment of Climate Change Impacts on Stormwater BMPs and Recommended BMP Design Considerations in Coastal Communities*;[432]
- Prioritize the identification and elimination of illicit discharges to municipal storm drain systems.

Wastewater

- Implement septic system management programs in each community;
- Pursue tertiary treatment for municipal and private wastewater plant discharges with a focus on reducing nitrogen and phosphorous discharges, including but not limited to the Town of Salisbury's discharge to the Merrimack River, the City of Newburyport's discharge to the Merrimack River, Governor's Academy's discharge to the Mill River in Newbury, and the Town of Ipswich's discharge to Greenwood Creek);
- Review all permitted point sources of pollution under the National Pollution Discharge Elimination System[433] (NPDES) and seek conditions to minimize their impact to the environment;

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[429] "Soak Up the Rain: What's the Problem?," EPA, https://www.epa.gov/soakuptherain/soak-rain-whats-problem
[430] "NPSED Stormwater Permit Program in New England," EPA, https://www.epa.gov/npdes-permits/npdes-stormwater-permit-program-new-england
[431] "Regulated MS4 in Massachusetts Communities,: EPA, https://www.epa.gov/npdes-permits/regulated-ms4-massachusetts-communities
[432] "Report on Climate Change Impacts to Coastal Stormwater Best Management Practices (BMPs)," MA CZM, http://www.mass.gov/eea/agencies/czm/program-areas/coastal-water-quality/cpr/climate-change-stormwater-bmps.html
[433] "Regulated MS4 in Massachusetts Communities,: EPA, https://www.epa.gov/npdes-permits/regulated-ms4-massachusetts-communities

- Increase frequency of the Massachusetts Division of Marine Fisheries estuarine Shoreline Surveys (to identify pollution sources) and expand surveys to first order freshwater streams;
- Implement boatyard and marina waste management[434] and expand/maintain boat pump-out programs.[435]

Public Drinking Water

- Pursue sustainable development without increasing overall water demands;
- Use the Net Blue Ordinance Toolkit[436] to develop water-neutral growth ordinances to either require or incentivize residential and commercial developments to offset their projected additional water demand through water-efficient retrofits of existing development;
- Implement comprehensive enhanced water conservation measures in each community;
- Broaden regional and town-specific water conservation outreach programs utilizing existing programs such as the Greenscapes North Shore Coalition[437] and others;
- Change local rate structures to de-incentivize the sale of non-essential water;
- Implement local bylaws to regulate private wells consistent with regulated municipal withdrawals, using Massachusetts Rivers Alliance resources[438] and bylaws in neighboring towns (Ipswich, Topsfield, and Wenham) as a model;
- Work with stakeholders to implement sustainable water management regulations at the state level to cover all water withdrawals.

Outreach and Engagement

As outlined elsewhere in this report, maximizing the resiliency of the communities and ecosystems of the Great Marsh will require collaboration, coordination, and funding over a sustained period. Communities should work in collaboration with neighboring communities, citizens groups, and regional partners to increase public awareness of climate-driven threats and solutions through implementation of a comprehensive, coordinated program. In addition, it will be incredibly important to get support from the general public and municipal officials in order to success in implementing resiliency and adaptation strategies. Therefore, municipalities and their regional partners should:

Develop municipal strategies for enhanced outreach and education

Individual communities should develop and enhance municipal education and outreach initiatives by these strategies among others:

- Identifying trusted neighborhood and citizens groups (such as Storm Surge or the Salisbury Beach Citizens for Change) to champion awareness of climate-driven threats and solutions to their unique audiences;
- Educating and reaching out to all sectors of the community, including cross-sector outreach initiatives with realtors, emergency management officials, public health workers, and business associations, among others;

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434 "Marina Management – Massachusetts Office of Coastal Zone Management," MA CZM, http://www.mass.gov/eea/agencies /czm/program-areas/coastal-water-quality/marina-management/

435 "Clean Boating – Massachusetts Office of Coastal Zone Management," MA CZM, http://www.mass.gov/eea/agencies/czm/ program-areas/coastal-water-quality/clean-boating/

436 "Net Blue: Supporting Water-Neutral Community Growth," Alliance for Water Efficiency, http://rivernetwork.us9.list-manage.com/track/click?u=37451e588b04a942f75ed66d3&id=d516bfeabe&e=806966bd0a

437 "Landscapes for Clean and Plentiful Water," Greenscapes Massachusetts North Shore Coalition, http://greenscapes.org/

438 "Resources," Massachusetts River Alliance, http://massriversalliance.org/resources/

- Using traditional and innovative media with informative content for public consumption;
- Developing high-visibility interpretative signage and installations in prominent public locations such as the Essex Causeway, the Newburyport Waterfront, and the Ipswich River Walk;
- Working with student groups, teachers, schools, and parents to educate and engage them in climate awareness programs, including adaptation strategies they can participate in on both private and public properties.

Strengthen existing regional outreach and education programs

Regional partners working in the Great Marsh should enhance collaborative outreach efforts across the region, including:

- Supporting and expanding the work of the Great Marsh Coalition,[439] including the Great Marsh Symposium, and developing messaging to reach broader audiences;
- Supporting the efforts of the Gulf of Maine Institute's Climate Café programs;[440]
- Expanding the efforts of Storm Surge,[441] the Merrimack Valley Coastal Adaptation Workgroup;
- Promoting the valuation of ecosystem services and functions and publicize the environmental, economic, and social benefits of doing so (triple bottom line);
- Expanding individual organizational outreach efforts, such as those run by Mass Audubon,[442] PIE-Rivers Partnership,[443] and others, to include a more specific focus on the recommendations of the *Great Marsh Coastal Regional Adaptation Plan*, including emphases on nature-based solutions.
- Promoting the valuation of ecosystem services and functions and publicize the environmental, economic, and social benefits of doing so (triple bottom line).

Support and develop opportunities for citizen science

There are few better ways for the general public to develop a sense of ownership of resiliency efforts than by directly engaging them in citizen science projects. There are many opportunities that currently exist in the Great Marsh and that could be further developed, including:

- Expanding use of the "MyCoast Massachusetts" web site[444] to document flooding and erosion;
- Establishing citizen groups on Plum Island to help track and document erosion rates;
- Engaging more local residents in the University of New Hampshire habitat restoration work[445] on the barrier beaches;
- Support and expand environmental education programs for K-12 students, such as those offered by Mass Audubon's Joppa Flats Education Center[446] and Ipswich River Wildlife Sanctuary;[447]

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[439] The Great Marsh Coalition, http://www.greatmarsh.org/
[440] "Climate Cafe," Gulf of Maine Institute, www.gulfofmaineinstitute.org/climatecafe
[441] Storm Surge, https://storm-surge.org/
[442] "Addressing the Challenges of Climate Change," Mass Audubon, www.massaudubon.org/our-conservation-work/climate-change
[443] Parker-Ipswich-Essex Rivers Restoration Partnership, www.pie-rivers.org
[444] "MyCoast: Massachusetts," MA CZM, https://mycoast.org/ma
[445] "Coastal Habitat Restoration," University of New Hampshire, New Hampshire Sea Grant, https://seagrant.unh.edu/Coastal-HabitatRestoration
[446] "Joppa Flats Education Center," Mass Audubon, http://www.massaudubon.org/get-outdoors/wildlife-sanctuaries/joppa-flats/programs-classes-activities/schools-groups/schools
[447] "Ipswich River Wildlife Sanctuary," Mass Audubon, http://www.massaudubon.org/get-outdoors/wildlife-sanctuaries/ipswich-river/programs-classes-activities/schools-groups/schools

- Maintaining and expanding the Great Marsh Revitalization Task Force[448] invasive *Phragmites* control program;
- Maintaining and expanding the Perennial Pepperweed Control Project,[449] led by Mass Audubon, and US Fish and Wildlife Service;
- Expanding the RiverWatch Volunteer Monitoring Program;[450]
- Assessing and creating additional Citizen Science programs

Implementation of the strategies identified within these five categories (Best Practices, Natural and Nature-based Strategies, Gray Infrastructure and Retrofits, Land-use Planning and Policy, and Outreach and Engagement) will require ongoing regional collaboration among local municipalities and regional or state partners. However, it should be noted that in Massachusetts, local municipalities have almost complete control over land use planning. As such, action must happen at the local level and through cross-town collaboration. Local communities have primary control over the fate of the Great Marsh and its ability to provide risk-reduction services for the region.

Matt Poole/USFWS

[448] "Great Marsh Revitalization Task Force," The Great Marsh Coalition, http://www.greatmarsh.org/resources/scientific-studies/80-resources/95-great-marsh-revitalization-task-force
[449] "Perennial Pepperweed Control Project," Mass Audubon, http://www.massaudubon.org/learn/nature-wildlife/invasive-plants/pepperweed/project
[450] "RiverWatch Volunteer Monitoring Program," Ipswich River Watershed Association, http://www.ipswichriver.org/riverwatch/

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4.2. Town-specific Strategies and Recommendations

This section highlights specific adaptation strategies and recommendations for the town-specific assets and areas of concern identified in Chapter 3: *Assessing Climate Impacts and Vulnerabilities*. The following town-specific strategies and recommendations were generated across three stages. To begin, the Project Team worked with the Municipal Task Forces to create a catalog (hereinafter "adaptation catalog") of over 90 potential adaptation options that communities could use to address vulnerabilities of specific assets, as well as more general coastal vulnerabilities and climate-related threats. A wide-range of physical and non-physical tools, strategies, and approaches applicable to the Great Marsh Region were explored and organized into categories. With the adaptation catalog in hand, the Project Team worked with the Municipal Task Forces, regional agencies, and NGO partners to evaluate the range of strategies based on those likely to (a) be most effective, (b) provide the most co-benefits, and (c) be operationally feasible from a social, technical, financial, and regulatory perspective. These strategies were further vetted through direct consultation with individuals and entities with professional and technical expertise in the planning, design, and implementation of adaptation strategies in the Great Marsh geography.

The following town-specific strategies and recommendations outlined below describe each Vulnerable Area of Concern (as identified by the Task Forces; ◊ = Within the Great Marsh Area of Critical Environmental Concern (ACEC)), Short-term Adaptation Strategies (now-2030), and Long-term Adaptation Strategies (2030-2070; inclusive of Short-term Adaptation Strategies).

4.2-1. TOWN OF SALISBURY: Adaptation Strategies and Recommendations for Selected Areas of Concern

Route 1A (Beach Road)

Location: Intersection with North End Blvd and west 0.5 miles.
Description of hazard: Tidal flooding and storm surge, especially around 191 Beach Road. Coastal inundation of marsh/back bay. Beach Road traps flood waters from dispersing across marsh.
Consequences of hazard: Flooding blocks the only evacuation route from the beach to the center of town. There is an alternate route via Route 286 thru Seabrook but Salisbury has no control of that route. The population of the beach is approx. 4000 year-round residents which swells to 20,000 in summer months, plus 1000s of daily visitors.
Existing efforts underway: The town has discussed the flooding and consequences with the Army Corps of Engineers and Mass DOT for studies to possibly raise Beach Road, but no funding for such studies or projects has materialized.

Short-term Strategies (now-2030)

- Remove debris from marsh and dunes along the causeway to increase resiliency of marsh (focus on natural debris which is trapped by structure and currently smothers marsh).
- Create early warning system to alert residents when the road is likely to be flooded or is flooded.
- Monitor flood frequency and depth to help with future road planning efforts.
- Coordinate with state DOT that manages this road to complete studies to possibly raise road.
- Require any road redesign to take climate change into consideration; explore green redesign, such as sustainable "Complete Streets."[450]
- Investigate option of improving culverts & removing tidal restriction on adjacent Old County Road to improve drainage.
- Explore green infrastructure opportunities throughout abutting properties and neighborhoods, such as bioswales and rain gardens.

Long-term Strategies (2030-2070)

- Working with the State, raise road, build bridge, and/or add culvert(s) to reduce flooding and establish flow under roadway to restore hydrology and increase natural resiliency of marsh.

Salisbury Beach at Broadway *continued on next page*

Location: East of Broadway Mall, stretching 200ft north and south
Description of hazard: Chronic and storm-related erosion; storm surge flooding.
Consequences of hazard: Intersection is not drivable during peak of flood; requires access via Route 286 in northern part of town. Debris cleanup and maintenance from storms is regular and costly to town.
Existing efforts underway: MA DCR recently acquired land (a former building site, just south of Beach Center) to enlarge beach area to compensate for erosion from storms. Dune nourishment and sand fencing underway. Boardwalk above dunes is being built.

Short-term Strategies (now-2030)

- Continue public acquisition of land for open space, if/when available, and installation and restoration of dunes.
- Continue dune grass planting & fencing.
- Local enforcement of existing state barrier beach regulations.
- Create freeboard incentive.

[450] National Complete Streets Coalition, *Implementing Complete Streets: Sustainable Complete Streets* (Washington, DC) https://smartgrowthamerica.org/app/uploads/2016/08/cs-greenstreets.pdf

- Educate property owners on projected sea level rise estimates and adaptation strategies, including the benefits of freeboard as well as specific building retrofits Engage with town staff, committees, residents, and business owners including Salisbury Beach Partnership, Merrimack River Beach Alliance, and the "Project for Public Spaces" to assure that long-term climate projections are being incorporated into the effort to redesign Broadway Mall.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the beach and associated infrastructure located along and directly behind the beach.
- Explore incorporating natural features and a seawall to enhance flood protection.

Low-lying Houses along the Salt Marsh west of Salisbury Beach

Location: Multiple neighborhoods abutting salt marsh north and south of Beach Road, including Cable Avenue neighborhood east of the road to Salisbury Reservation, and homes along 9th, 10th, 11th, 12th, Florence, and Lewis Avenues west of North End Boulevard.

Description of Hazard: Current & projected coastal inundation. Regular flooding from Blackwater River north of Beach Road and from Black Rock Creek south of Beach Road.

Consequences of hazard: Flooded houses and impacts to health of salt marsh.

Existing efforts underway: 3-4 foot high sheet pile sea wall has been recently built along neighborhood near 11th and 12th Avenues.

Short-term Strategies (now-2030)

- Property owner education, including the benefits of freeboard as well as specific building retrofits such as installing backflow valves on sewer drains, elevating utilities to prevent flood damage, and breakaway walls to prevent structure collapse during storm surge.
- Create municipal freeboard incentive (see Hull case study) & state freeboard policy/regulations.
- Establish conservancy district - zoning overlay to prevent future development in flood-prone areas and to create a permanent buffer between development and flooding (see Chatham case study.)
- Investigate whether restoring more natural tidal exchange through culvert improvements along State Reservation Road would decrease or increase flood risk in the Cable Ave neighborhood.
- Improve resilience of surrounding salt marsh by mapping and maintaining blocked ditches.

Long-term Strategies (2030-2070)

- Consider rolling easements to facilitate planned retreat: Town or state pays some amount to landowners in vulnerable locations today; when house eventually floods, town takes ownership.

US Route 1 & Associated Infrastructure *continued on next page*

Location: At Town Creek & surrounding area.

Description of hazard: Tidal flooding, culvert is small and in need of repair.

Consequences of hazard: Floods road cutting off primary transportation corridor. Floods businesses causing economic harm. Tidal restriction at Route 1impacts marsh; could be contributing to its degradation.

Existing efforts underway: Tide gate installed a few years ago at nearby bike path crossing (downstream of Route) has dramatically reduced flooding of Route 1 while improving tidal conditions.

Short-term Strategies (now-2030)

- Restore hydrology where possible after considering potential upstream impacts. Conceptual design for improved crossing at Route 1 was developed as part of this project.
- Engage/educate business community about current/future risk and adaptation options.
- Encourage landscaping techniques for stormwater mitigation, e.g. rain gardens, pervious walkways & patios, infiltration trenches, and other green infrastructure techniques.

- Provide part-time flood storage through open space planning.
- Renovate or retrofit buildings for resiliency.

Long-term Strategies (2030-2070)

- Raise road and establish flow under roadway to restore hydrology and increase natural resiliency of marsh.
- Use Ferry Road and Railroad bed for temporary tidal protection - evaluate if feasible.
- Incorporate climate projections into long-term planning.
- Move businesses to other business centers in town (Salisbury Square, Route 110) and demolish Route 1 buildings.

March Road, First Street, and Ferry Road

Description of hazard: Tidal flooding at two separate culverts (March Road and First Street), culverts are small & in need of repair. A separate tidal connection at Ferry Road is also restricting tidal exchange and is in disrepair.
Consequences of hazard: Floods yards, has flooded Ferry Road & homes. Tidal restrictions are degrading the marsh. Scouring is visible at Ferry Road culvert.
Existing Efforts Underway: Tidal restriction may provide some protection to low lying houses and businesses upstream. High restoration potential identified in the Great Marsh Plan Rapid assessment and tidal survey conducted in 2005.

Short-term Strategies (now-2030)

- Conduct comprehensive assessment of Ferry Road culverts and elevation as a potential means to mitigate this hazard.
- Upgrade March Road and First Street culverts.
- Implement marsh restoration plan.

Long-term Strategies (2030-2070)

- Monitor and continue marsh restoration efforts as needed.

4.2-2. CITY OF NEWBURYPORT: Adaptation Strategies and Recommendations for Selected Areas of Concern

Plum Island Turnpike◊ *continued on next page*

Location: Joppa Flats Nature Center east to Sunset Drive.
Description of hazard: Tidal and storm-driven roadway flooding, ice cakes, high winds, zero visibility during nor'easters.
Consequences of hazard: Road closure and access to and from the island is cut off.
Existing efforts underway: Hydrodynamic sediment transport model is focusing on the PI Turnpike area, including Bascule Bridge, to better understand water and sediment flow in this area. The Great Marsh Plan identifies degraded salt marsh south of PI Turnpike near the Plum Island Airport; potential for salt marsh restoration here and other locations in this area.
Additional Notes: Newburyport & Newbury are both affected. Turnpike traps flood waters from dispersing across marsh. Need joint solution as issues and solutions are common.

Short-term Strategies (now-2030)

- Recognizing shared vulnerability, create joint Newbury and Newburyport working group to address these issues.
- Create early warning system to alert residents when the road is likely to be flooded or is flooded.
- Monitor flood frequency and depth to help with future road planning efforts.
- To increase public safety, install plastic road reflectors to show the road during storms when it's flooded and/or during blizzards.

Long-term Strategies (2030-2070)

- Raise road elevation based on detailed analysis of current and future conditions.
- Develop long-term master plan for Plum Island and redesign road accordingly, taking climate change into consideration.

Waste Water Treatment Facility

Location: 157 Water Street
Description of hazard: Flooding from storm surge and sea level rise. Critical equipment located just above 100-year flood elevation. Could be inundated by sea level rise alone.
Consequences of hazard: Flooding of the facility could have catastrophic impacts across the community.
Existing efforts underway: Is a priority focus for the Newburyport Resiliency Committee

Short-term Strategies (now-2030)

- Elevate critical utilities.
- Flood-proof areas of the facility likely to flood.
- Pursue a feasibility study to assess the effectiveness of a seawall and/or berm with natural components to protect the facility.
- Consider living shoreline to attenuate wave energy.
- Assess the impacts if the outflow is to become entirely submerged/flooded.
- Have temporary inflatable berm available for deployment during storms.

Long-term Strategies (2030-2070)

- Plan for relocation.

North End of Plum Island *continued on next page*

Location: Reservation Terrace & Old Point neighborhood
Description of hazard: (1) Projected coastal inundation and (2) beach/dune erosion. Flooding when river basin is full of trapped flood waters & particularly during storms with W/NW winds. Erosion along Reservation Terrace.
Consequences of hazard: Flooding of heavily populated bayside neighborhoods, erosion threatens populated ocean-front neighborhoods.
Existing efforts underway: City received 2016 CZM Resiliency grant to address erosion from foot traffic over the dunes. Has conducted dune nourishment and installed sand fencing.

Short-term Strategies (now-2030)

- Continue installation & maintenance of sacrificial dunes.
- Continue dune grass planting & fencing.
- Reduce foot traffic on dunes.
- Ensure local enforcement of existing state barrier beach regulations.
- Create municipal freeboard incentive (see Hull case study).
- Review, evaluate, and revise Plum Island zoning and regulations using new climate projections.
- Explore instituting a voluntary buyback and financing program.
- Continue to work with Department of Conservation and Recreation and the Merrimack River Beach Alliance to closely monitor storm damage and erosion rates within the Reservation Terrace dune system to support decisions regarding dune protection and potential emergency response actions.
- Develop an emergency response plan for potential inundation of Reservation Terrace during extreme storm damage and erosion events.

North End of Plum Island continued

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the beach and associated infrastructure located along and directly behind the beach.
- Consider planned retreat.

Business Park

Location: 104 Parker Street/Scotland Road.
Description of hazard: Flooding from the Little River exacerbated by stormwater runoff. The hydraulic capacity screening model shows poor performance of crossings at Scotland Road and Hale Street as well as a few other crossings on tributaries to the Little River within the Business Park.
Consequences of hazard: Flooding could disperse on-site hazardous materials and can cut off access to and from businesses.
Existing efforts underway: City is coordinating with Newbury on barrier assessments (entire Little River watershed) & flood resiliency planning. Newburyport is planning replacement of the culvert at Scotland Road. This project is developing conceptual designs for the replacement of two at-risk crossings at Hale Street.
Additional Notes: Newburyport & Newbury are affected.

Short-term Strategies (now-2030)

- Business owner engagement and education
- Review possible building retrofits including drop-in flood barriers & longer term flood proofing.
- Install improved culverts where needed to restore hydrology and reduce flooding. Create flood-storage opportunities through open space planning.
- Consider creating a city-wide stormwater utility & implement BMPs across the Business Park.
- Ensure updated emergency response plans for dealing with chemicals on site if flooding occurs
- Encourage/require Low Impact Development standards for any new buildings or upgrades.
- Plant trees that are particularly well suited to absorbing water (such as willows).

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the Business Park and associated access routes.
- Renovate for resiliency.

Lower Artichoke Reservoir *continued on next page*

Location: Between Storey Ave & Middle Rd.
Description of hazard: Salt-water intrusion. The Mother's Day Storm of 2006 caused the Merrimack River to reach the top of the dam at the Lower Artichoke Reservoir and almost contaminated the public water supply with pollutants and saltwater. An equal or more intense storm, combined with sea level rise, could result in a breach of the water supply.
Consequences of hazard: Would contaminate the city’s drinking water supply.
Existing efforts underway: Proposed FY18 budget has a Capital Improvement Project to fund a feasibility study to determine if this dam should be raised or if improvements should be made to another dam downstream of this one.

Short-term Strategies (now-2030)

- Raise the elevation of the dam to prevent overtopping.
- Assess additional possible breach points.
- Increase flood-storage options using surrounding natural area.
- Install overflow pumping.
- Control new development projects to be water neutral so as not to increase water demand.
- Set up monitoring and response plan to deal with a possible breach and the influx of contaminants from the Merrimack River.

Long-term Strategies (2030-2070)

- Pursue new and additional drinking water supplies, particularly new groundwater supplies (i.e. wells) that are not hydrologically connected to the Artichoke or Bartlett Spring Pond.

Bartlett Spring Pond

Location: 742 Spring Ln

Description of hazard: Salt-water intrusion. Safe from near-term sea level rise, however ancillary structures and the piping network may be vulnerable to sea level rise and will need to be evaluated further.

Consequences of hazard: Would contaminate the city's drinking water supply.

Existing efforts underway: None.

Short-term Strategies (now-2030)

- Set up monitoring and response plan to deal with a possible breach and the influx of contaminants from the Merrimack River.
- Raise the road which rests on a natural floodwall (berm).
- Enhance existing berm, raising and terracing it while also including a drainage outlet.

Long-term Strategies (2030-2070)

- Pursue alternative drinking water supply and new back-up or emergency water supplies, particularly new groundwater supplies (i.e. wells), that are not hydrologically connected to the Artichoke or Bartlett Spring Pond.

Central Waterfront *see also Water Street & Cashman Park categories*

Location: East of Merrimac/Water Street, between Green Street and the Harbor Master Shack.

Description of hazard: Flooding during astronomical tides that coincide with multi-day storm events. . Storm surge on ocean raises sea level above river, not allowing river to discharge. Plum Island Turnpike & Beach Rd in Salisbury trap/concentrate flood waters.

Consequences of hazard: Waterfront and park become inaccessible. Flooding at the Rivers Edge condos well as waterfront businesses**.** Over time, usefulness of parks will be impacted & businesses may be significantly impacted.

Existing efforts underway: City is currently in the planning phase of redevelopment, including exploring raising the elevation of the park and associated parking lots.

Short-term Strategies (now-2030)

- Engage and educate central waterfront committees, associations, property owners, waterfront trust and redevelopment authority so that future development/planning incorporates climate projections.
- Raise the ground elevations of the park and parking lots.
- Create flood-storage opportunities/dual purpose parking lots.
- Review possible building retrofits including drop-in flood barriers & longer term flood proofing.
- For large businesses, consider additional retrofits such as sealing interior conduits for water entry, elevating utilities, installing backup generator.
- Incentivize climate-smart development away from flood-prone areas; consider Transfer of Development Credits to create a "sending" and "giving" area.

Long-term Strategies (2030-2070)

- Renovate for resiliency or demolish.
- Consider raising seawall coupled with new flood walls at open end of streets - should include natural components.

Water Street (part 1)

Location: Junction of Water and Union St. to Ocean Ave
Description of hazard: Coastal & freshwater flooding. Road is too low & floods during storms with rain and E/NE winds.
Consequences of hazard: Road becomes impassable.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Resident/business owner engagement and education.
- Investigate benefits of establishing a natural living shoreline/offshore reef to attenuate wave energy.
- Consider a hybrid living shoreline to reduce flooding and reduce erosion.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning.
- Raise buildings and the road.
- Raise seawall coupled with new flood walls at open end of streets.

Water Street (part 2)

Location: Seawall, Joppa Park Boat Ramp, Hale Park area to Union St.
Description of hazard: Coastal inundation during storms. During storms, water splashes over the seawall, becoming trapped and flooding residences. Sedimentation along Joppa park has attenuated wave energy a bit, as has marsh grass that has begun to establish itself in front of the seawall.
Consequences of hazard: Flooded residences, roads, and potential property loss.
Existing efforts underway: Seawall is in disrepair and needs to be updated/replaced. Town has set aside limited funds for this.

Short-term Strategies (now-2030)

- Resident/business owner engagement and education.
- Install openings (or scuppers) in the seawall to allow water to drain back into river after it splashes over.
- Investigate benefits of establishing a natural living shoreline/reef offshore.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning.
- Raise seawall coupled with new flood walls at open end of streets.

Cashman Park

Location: Cashman Park, west-northwest of waterfront
Description of hazard: Flooding during astronomical tides that coincide with multi-day storm events. Storm surge on ocean raises sea level above river, not allowing river to discharge. Plum Island Turnpike & Beach Rd in Salisbury may also trap flood waters.
Consequences of hazard: Waterfront and park become inaccessible due to flooding. Rivers Edge condos flood as well as waterfront businesses.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Consider living shoreline to replace existing armored shoreline. Presents a good opportunity due to its high visibility and open area.
- Explore incorporating drainage improvements to speed up removing flood waters after storms.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning.
- Raise the fields, but keep it an open space.

Plum Island & Beach

Location: Barrier beach and dunes along Plum Island.
Description of hazard: Erosion on beach shore and on northern river shore near jetties. Retreating shoreline is encroaching on residences. The ocean shore seems to erode when the Merrimack River Jetty degrades, and the inside river shore erodes when the jetty is repaired.
Consequences of hazard: Erosion threatens residential houses, impacts beach access, and results in loss of critical wildlife habitat.
Existing efforts underway: City is in communication with Army Corps of Engineers to address erosion issues.

Short-term Strategies (now-2030)

- Continue installation & maintenance of sacrificial dunes.
- Continue dune grass planting & fencing.
- Reduce foot traffic.
- Ensure local enforcement of existing state barrier beach regulations.
- Create municipal freeboard incentive (see Hull case study).

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the beach and associated infrastructure located along and directly behind the beach.
- Consider planned retreat.

4.2-3. TOWN OF NEWBURY: Adaptation Strategies and Recommendations for Selected Areas of Concern

Plum Island Turnpike◊

Location: Joppa Flats Nature Center east to Sunset Drive.
Description of hazard: Tidal and storm-driven roadway flooding, ice cakes, high winds, zero visibility during nor'easters.
Consequences of hazard: Road closure and access to and from the island is cut off.
Existing efforts underway: Hydrodynamic sediment transport model is focusing on the PI Turnpike area, including Bascule Bridge, to better understand water and sediment flow in this area. The Great Marsh Plan identifies degraded salt marsh south of PI Turnpike near the Plum Island Airport; potential for salt marsh restoration here and other locations in this area.
Additional Notes: Newburyport & Newbury are both affected. Turnpike traps flood waters from dispersing across marsh.

Short-term Strategies (now-2030)

- Recognizing shared vulnerability, create joint Newbury and Newburyport working group to address these issues.
- Create early warning system to alert residents when the road is likely to be flooded or is flooded.
- Monitor flood frequency and depth to help with future road planning efforts.
- To increase public safety, install plastic road reflectors to show the road during storms when it's flooded and/or during blizzards.

Long-term Strategies (2030-2070)

- Raise road elevation based on detailed analysis of current and future conditions.
- Consider planned retreat from Plumbush Downs.
- Assess long-term master plan for Plum Island and redesign road accordingly, taking climate change into consideration.

Low-lying houses along bayside of Plum Island

Location: Basin Harbor neighborhood located between Old Point Road and Northern Boulevard, north of Plum Island turnpike.
Description of hazard: Tidal and storm-driven coastal flooding.
Consequences of hazard: Residential houses are flooded as are side streets.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Property owner education, including the benefits of freeboard as well as specific building retrofits such as installing backflow valves on sew drains, elevating utilities to prevent flood damage, and breakaway walls to prevent structure collapse during storm surge.
- Create municipal freeboard incentive (see Hull case study).

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term infrastructure planning.
- Consider rolling easements to facilitate planned retreat: town or state pays some amount to landowners in vulnerable locations today; when house eventually floods, town or state takes ownership.
- Consider planned retreat

Plumbush Downs◊

Location: Plum Bush Downs Road.
Description of hazard: Tidal and storm-driven flooding.
Consequences of hazard: Residential houses are flooded.
Existing Efforts Underway: The Great Marsh Plan identifies degraded salt marsh within Plumbush Downs development; potential for salt marsh restoration. Houses being rebuilt at Plumbush are being built on stilts.

Short-term Strategies (now-2030)

- Property owner education, including the benefits of freeboard as well as specific building retrofits such as installing backflow valves on sewer drains, elevating utilities to prevent flood damage, and breakaway walls to prevent structure collapse during storm surge.
- Create municipal freeboard incentive (see Hull case study) & state freeboard policy/regulations.

Long-term Strategies (2030-2070)

- Consider planned retreat

Sewage Pumping Station on Plum Island *continued on next page*

Location: Webbers Ct. & Olga Way
Description of hazard: Near area subject to overtopping**.** Building is relatively flood proof but surrounding area could flood cutting off access.
Consequences of hazard: Plum Island sewage system is vulnerable due to the way the system is segmented. If sewage system goes down, residents have to relocate until issue is fixed.
Existing efforts underway: Tried to remedy problem with a one-way valve but system got backed up with sediment; it didn't work. Study underway to reduce sewer system vulnerability in winter, but still vulnerable to storm surge.

Short-term Strategies (now-2030)

- Explore retrofits such as sealing interior conduits for water entry, elevating utilities, installing backup generator, etc. to allow the facility to continue operating during a storm.
- Consider a vegetated berm surrounding the plant.
- Explore alternate sites for sewage pumping station.

Long-term Strategies (2030-2070)

- Plan for possible future relocation depending on the level of risk the Newburyport and Newbury are willing to accept at the current location.
- Consider planned system shutdown in times of emergency & evacuating island until flooding recedes and you can turn system back on.

Plum Island & Beach

Location: Barrier beach and dunes along Plum Island.
Description of hazard: Erosion on beach shore and on northern river shore near jetties. Retreating shoreline is encroaching on residences. The ocean beach shore seems to erode when the Merrimack River Jetty degrades, and the inside river shore erodes when the jetty is repaired.
Consequences of hazard: Erosion threatens residential houses, impacts beach access, and results in loss of critical wildlife habitat.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Install & maintain sacrificial dunes.
- Conduct dune restoration, planting dune grass and installing sand fencing.
- Coordinate with Newburyport to develop strategies to reduce foot traffic over the dunes.
- Create municipal freeboard incentive (see Hull case study).
- Review, evaluate, and revise Plum Island zoning and regulations using new climate projections.
- Public and resident outreach and education

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term planning for the beach and associated infrastructure located along and directly behind the beach.
- Consider rolling easements to facilitate planned retreat: town or state pays some amount to landowners in vulnerable locations today; when house eventually floods, town or state takes ownership.

Newburyport Turnpike/Rt. 1◊

Location: Rt.1 at Parker River
Description of hazard: Tidal and storm flooding. Flooding north of Old Newbury Golf Course near the Plum Island Ecosystems Long Term Ecological Research Center.
Consequences of hazard: Major roadway can close during flooding.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Increase communication between state agency (that manages the road) and local officials.
- Create early warning system to alert residents when the road is likely to be flooded or is flooded, and to notify residents of alternate routes.
- Coordinate with evacuation planning for major storms.
- Monitor flood frequency and depth to help with future road planning efforts.

Long-term Strategies (2030-2070)

- Make plan to raise road in low lying areas coupled with causeway "best practices" of increasing drainage under road & removing debris along roadway to increase resiliency of marsh.
- Require any redesign or upgrade to road to take climate projections into consideration.

Newman Road

Location: Low-lying portions of Newman Rd. at Little River between The Trustees' Old Town Hill Reservation & Hay St.
Description of hazard: Approximately half mile of the western end of the road is often overtopped at high tide. Tidal flooding is a regular event, not just a storm occurrence, and will worsen with sea level rise and storm surge.
Consequences of hazard: Flooding impacts travel between Route 1 and 1A and is an inconvenience, but doesn't leave anyone stranded. Road is the access the Trustees have to the Adams Pasture parcel of Old Town Hill Reservation.
Existing efforts underway: Tidal restrictions have been identified in Barriers report (see Appendix B).

Short-term Strategies (now-2030)

- Create early warning system to alert residents when the road is likely to be flooded or is flooded, and to notify residents of alternate routes.
- Monitor flood frequency and depth to help with future road planning efforts.

Long-term Strategies (2030-2070)

- Make plan to raise road in low lying areas coupled with causeway "best practices" of increasing drainage under road & removing debris along roadway to increase resiliency of marsh.
- Require any redesign or upgrade to road to take climate projections into consideration.

Hanover Street at Little River◊

Location: 99-85 Hanover St.
Description of hazard: Flooding at Little River.
Consequences of hazard: Flooding impacts businesses, school bus parking lot, train tracks, several homes; not an impact on Elementary School which is higher elevation and has Newburyport water/sewer. Access road to school when it is needed as an emergency shelter could be cut off from the west side.
Existing efforts underway: Task force members are exploring relocating emergency shelter site to Triton Middle/High School on Elm St, Newbury. The Great Marsh Plan identified a tidally restricted marsh between Boston Road and Hanover Street on the Little River that may be affecting this site.

Short-term Strategies (now-2030)

- Work with emergency management personnel to relocate emergency shelter (find location that is free from flooding and accessible from all directions).
- Assess cost/benefit of raising road and new bridge crossing over Little River.

Crossings on Middle Road and Highfield Street

Location: Unnamed tributary to Little River that crosses under Route 1 ~1000 feet south of Hanover Street
Description of hazard: A number of crossings upstream (west) of and including the crossing under Route 1 were identified as high hazard by the hydraulic capacity screen. Four of these are not expected to pass the flow associated with a 2-year (50% likelihood) storm.
Consequences of hazard: Possible culvert failure and threat to roadways, including Route 1.
Existing efforts underway: Conceptual designs for the replacement of two crossings (Highfield Road and Middle Road) were developed as part of this project.

Short-term Strategies (now-2030)

- Replace existing undersized culverts with structures designed to meet pass higher flows and meet the MA Stream Crossing standards
- After consideration of possible downstream impacts of upgrading structures it may be necessary to design and replace structures beginning at the Route 1 crossing.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

Crossing on Orchard Street north of Central Street

Location: Tributary to Parker River that crosses under Orchard Street ~250 feet north of Central Street intersection.
Description of hazard: The barriers study identified this crossing as a high priority, ranking in the top 35 across the entire study region for combined infrastructure risk and ecological impact. The hydraulic capacity screening tool predicts that it is unable to pass the flow associated with a 25-year (4% likelihood) storm in addition to being an extreme barrier for fish and wildlife.
Consequences of hazard: Risk to property and road during floods. High ecological impact.
Existing efforts underway: The associated barriers study produced a conceptual design for the replacement of this structure.

Short-term Strategies (now-2030)

- Replace culvert with structure designed to pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

Crossings on Elm Street, School Street, and Coleman Road

Location: Two unnamed tributaries to the Parker River flowing on the immediate east and west sides of the Triton Regional High School.
Description of hazard: One crossing under School Street and one under Coleman Road were identified as high risk by the hydraulic capacity screening tool. They are not expected to pass the flow associated with a 2-year (50% likelihood) storm.
Consequences of hazard: Potential flooding and road failure could reduce access to school.
Existing efforts underway: Conceptual designs for a total of six crossings on these two tributaries were completed as part of this project.

Short-term Strategies (now-2030)

- Replace problem structures as funding allows based on conceptual designs that will pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

4.2-4. TOWN OF ROWLEY: Adaptation Strategies and Recommendations for Selected Areas of Concern

Route 133 at Bachelder Brook *continued on next page*

Location: Northeast of 312 Haverhill St.
Description of hazard: Undersized culvert and riverine flooding is exacerbated by beaver activity.
Consequences of hazard: Route 133 floods and is unpassable. Traffic must detour around.
Existing efforts underway: Culvert cleaned out after Mother's Day flooding. Beaver deceiver installed. Preliminary design completed as part of barriers project.

Short-term Strategies (now-2030)

- Regularly remove woody debris that accumulates in and around the culverts.
- Actively remove beavers at bridge to restore flood storage potential of upstream floodplain.
- Replace culvert with bridge per design.

Route 133 at Bachelder Brook continued

- Engage & educate business owners on future climate impacts.
- Encourage landscaping techniques for stormwater mitigation for nearby businesses and residences; e.g. rain gardens, pervious walkways & patios, infiltration trenches, and other green infrastructure techniques.

Long-term Strategies (2030-2070)

- Coordinate with DOT to plan for raising road adjacent to crossing.

Jewell Mill Dam

Location: On Mill River, west of the intersection between Mill St and Glen St, off of Route 1 near Newbury town line.
Description of hazard: Riverine flooding and risk of dam failure. Classified as Significant Hazard dam with Office of Dam Safety. High priority for removal based on screening for ecological impact and infrastructure risk.
Consequences of hazard: Glen Road bridge is at major risk if dam were to breach.
Existing efforts underway. Dam owner is currently not interested in removal due historical resources and current use.

Short-term Strategies (now-2030)

- Outreach & engagement with dam owner, educate about high hazard concerns and dam owner liability.
- Ensure that the dam is being inspected and maintained per Office of Dam Safety requirements.
- Work with dam owner to explore potential for structure removal or alteration to retain historic importance while removing risk and ecological impact.
- Upkeep and retrofits to reduce likelihood of failure.
- Identify opportunities for upstream water surge management.
- Educate neighborhood property owners on future risk.

Long-term Strategies (2030-2070)

- Remove dam.

Stackyard Road + Route 1A◊

Location: Stackyard Road and Route 1A from Stackyard Road north to town line (plus Newbury section of Route 1A to Parker River).
Description of hazard: Coastal flooding
Consequences of hazard: Roads flood and can be unpassable.
Existing efforts underway: Outer end of Stackyard Road has already been abandoned by FWS. Great Marsh Plan identified tidally restricted marsh caused by crossings under Route 1A near the Newbury town line. A rapid technical assessment was completed in 2005.

Short-term Strategies (now-2030)

- Create early warning system to alert residents when Route 1A is likely to be flooded or is flooded. Coordinate with evacuation planning for major storms.
- Assess culverts and water flow under the roadway. Increase culvert size if necessary to reduce likelihood of flooding and allow for the normal flow water and sediment throughout the system.
- Monitor flood frequency and depth to help with future road planning efforts; also require any redesign to take climate change into consideration.

Long-term Strategies (2030-2070)

- Work with State to raise 1A in low lying areas coupled with causeway "best practices" of increasing drainage under road & removing debris (mostly natural) along roadway to increase resiliency of marsh.
- Ultimately retreat from Stackyard Rd homes.
- Monitor and coordinate with railroad management because the railroad bed currently provides some flood protection.

Marina & Town Boat Launch◊

Location: Railroad Avenue/Warehouse Lane, off of Rt 1A.
Description of hazard: Coastal flooding
Consequences of hazard: Flooding impacts marina access and can cause property damage to boats and marina infrastructure.
Existing efforts underway: None

Short-term Strategies (now-2030)

- Property owner education, including the benefits of freeboard as well as specific building retrofits such as installing backflow valves on sew drains, elevating utilities to prevent flood damage, and breakaway walls to prevent structure collapse during storm surge.
- Consult with MBTA about resiliency planning for rail bed (this applies to Newbury, Rowley & Ipswich).

Long-term Strategies (2030-2070)

- Raise buildings seaward of RR tracks as feasible. Develop plan for Perley's Marina to adapt to SLR.
- Consider planned retreat.

Rowley Town Well #3 & well pumping station

Location: Along Mill River off of Boxford Road.
Description of hazard: Flooding, inundation of well pump station.
Consequences of hazard: Loss of municipal water supply
Existing efforts underway: None

Short-term Strategies (now-2030)

- Actively control beaver population to reduce chronic flooding.
- Elevate structure to protect facility from increased freshwater flooding.
- Explore retrofits (i.e. sealing interior conduits for water entry, elevating utilities, installing backup generator, etc.)
- Flood water diversion.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term water infrastructure planning.

Crossing on Daniels Road

Location: Stream crossing under Daniels Road ~1,200 feet north of Haverhill Street intersection.
Description of hazard: The barriers study identified this crossing as a high priority, unable to pass the flow associated with a 2-year (50% likelihood) storm in addition to being a moderate barrier for fish and wildlife.
Consequences of hazard: Risk to road and property as well as ecological impact.
Existing efforts underway: The barriers study developed conceptual design for replacement of this structure.

Short-term Strategies (now-2030)

- Replace culvert with structure designed to pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structure for signs of flooding and failure.

Crossing of Mill River at Haverhill Street

Location: Mill River crossing under Haverhill Street ~400 feet west of Boxford Road intersection.
Description of hazard: The barriers study identified this crossing as a high priority, unable to pass the flow associated with a 2-year (50% likelihood) storm in addition to being a moderate barrier for fish and wildlife.
Consequences of hazard: Risk to road (major thoroughfare) and property as well as ecological impact.
Existing efforts underway: The barriers study developed conceptual design for replacement of this structure.

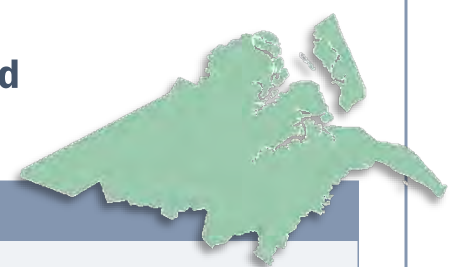
Short-term Strategies (now-2030)

- Replace culvert with structure designed to pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structure for signs of flooding and failure.

4.2-5. TOWN OF IPSWICH: Adaptation Strategies and Recommendations for Selected Areas of Concern



Jeffrey's Neck Road◊

Location: Beachview Ln northeast to 144 Jeffrey's Neck Rd
Description of hazard: Low elevation road floods during tidal storm surge events.
Consequences of hazard: Impacts access to recreational beaches and to 800 residences on Great Neck and Little Neck; this is an evacuation road so access is critical; police/fire can be cut off; Island Park, Hodges Way & Eagle Hill neighborhoods become islands.
Existing efforts underway: The Town has assessed flooding of the road[451] and is underway with plans to raise it 2 feet.

Short-term Strategies (now-2030)

- Regularly remove debris trapped along causeway that smothers the marsh and causes subsidence along roadbed.
- Study whether exchange of water under roadway (install culverts and/or increase sheet flow) would have environmental benefits or a negative impact due to Ipswich River flooding into Plum Island sound. Possibility of shellfish contamination and reduced salinity levels. Evaluate whether adjacent degraded salt marsh sites identified in this vulnerability assessment can be enhanced as part of project.
- Raise the road per results of flood assessment.

Long-term Strategies (2030-2070)

- Consider elevated causeway if long-term planning has neighborhoods remain and planned retreat is not an option.
- Incorporate climate projections into long-term infrastructure planning.

Ipswich Mills Dam *continued on next page*

Location: On Ipswich River in downtown Ipswich. Adjacent to EBSCO immediately upstream of Riverwalk footbridge.
Description of hazard: Downstream flooding/erosion risk if dam fails, contributes to upstream flooding, impoundment reduces upstream flood storage capacity, low head dam presents drowning risk
Consequences of hazard: Property damage to downtown businesses including EBSCO. Damage to Route 1A/133 at Choate Bridge
Existing efforts underway: Town is underway with the Ipswich Mills Dam Removal Feasibility Study to analyze the feasibility, cost, and effects of removing the downtown dam, including any impacts downstream.

[451] Parsons, R.A., *Final Technical Memorandum: Town of Ipswich Jeffrey's Neck Road Flood Assessment* (Boston, MA: CDM Smith, 2013), http://www.ipswichma.gov/documentcenter/view/514

Ipswich Mills Dam continued

Short-term Strategies (now-2030)

- Pending results of feasibility study, remove dam to restore upstream flood storage capacity, reduce upstream flooding and remove failure/drowning risk.
- While dam is in place, consider adding upstream signage to warn boaters of dam hazard and drowning risk.

Long-term Strategies (2030-2070)

- None if dam is removed.

Downtown Ipswich, including Choate Bridge and South Main Street

Location: Downtown along the Ipswich River, Route 133/1A.
Description of hazard: Riverine & coastal flooding; river bank erosion
Consequences of hazard: Includes EBSCO, businesses, housing (Rivercourt)
Existing efforts underway: Town is also studying river bank erosion between Ipswich Mills dam and Town Wharf and prioritizing green solutions.

Short-term Strategies (now-2030)

- Convene Downtown Ipswich resiliency working-group (business owners, town officials, and other partners) to consider long-term flooding risk and impacts. Focus on business owner engagement & education on building retrofits and general principles of resiliency.
- Encourage landscaping techniques for stormwater mitigation, e.g. rain gardens, pervious walkways & patios, infiltration trenches, and other green infrastructure techniques to reduce flooding.
- Create, enhance, and protect riparian buffer along the Ipswich River up and downstream of Town center to address current erosion and future climate impacts.

Long-term Strategies (2030-2070)

- Evaluate feasibility of river flood bypass through Veteran's Green/Elm Street area to accommodate flow from a 500-year flood.
- Incorporate climate projections, particularly increased freshwater flooding, into long-term infrastructure planning.

Crane Beach

Location: beach at end of Argilla Rd
Description of hazard: Beach and dune erosion.
Consequences of hazard: Erosion affects recreational use of property, causes widening of the mouth of the Essex River, and results in loss of critical wildlife habitat. Loss of buffering landmass could increase the vulnerability of inland areas in Essex Bay.
Existing efforts underway: The owners of Crane Beach, the Trustees of Reservations, have a beach management plan and are developing an enhanced Coastal Vulnerability Assessment. Dune restoration projects have been conducted and have worked well.

Short-term Strategies (now-2030)

- Support Trustees’ beach management and implementation of the recommendations in their coastal adaptation plan, including monitoring erosion rates and allowing natural dynamic systems to evolve over time.
- Capitalize on the area’s high visibility; opportunity for public education.

Long-term Strategies (2030-2070)

- Support Trustees’ efforts to manage this undeveloped natural barrier beach.

Argilla Road, homes, and Crane Beach parking areas at end of road

Location: East end of Argilla Road
Description of hazard: Coastal flooding**.** Parking area owned by the Town floods a few times a year from marsh side. Sole access to beach and Castle Hill along Argilla Road has at least six places where the 100 yr. flood zone touches the road and currently floods.
Consequences of hazard: Flooding cuts off access to houses and beach and inundates the parking lot.
Existing efforts underway: The owners of Crane Beach, the Trustees of Reservations, are developing a Coastal Vulnerability Assessment with adaptation strategies for priority sites, which will be completed in 2017. The Trustees have recently completed improvements to the beach facilities to be more resilient to flooding.

Short-term Strategies (now-2030)

- Explore elevating road access - raising Argilla Road at entrance to Trustees' Castle Hill gate.

Long-term Strategies (2030-2070)

- Consider moving parking lot to higher ground and/or providing bus service to take residents to/from the beach.
- Consider planned retreat.

Pavilion Beach◊

Location: Beach connecting Great and Little Neck - beach & road access - only free public beach in Ipswich
Description of hazard: Erosion and coastal flooding. Tidal surge floods area during storm events. Extremely low-lying without dune system.
Consequences of hazard: At 3m storm surge model, Pavilion Playground/Park becomes beachfront; public beach will be lost; Little Neck access cut off; also need to take into account balance of Little Neck Road
Existing efforts underway: None.
Additional Notes: Adjacent coastal bank armoring appears to have affected sand supply to this beach.

Short-term Strategies (now-2030)

- Create early warning system for when the road is projected to flood; coordinate with evacuation planning.
- Conduct comprehensive beach nourishment/sediment composition study to increase short-term sustainability of beach.

Long-term Strategies (2030-2070)

- Elevate causeway/bridge if long-term planning indicates neighborhoods will remain and planned retreat is not an option.

Brown's Well (Ipswich drinking water supply) and Route 1A *continued on next page*

Location: Route 1A at Muddy Run /188 High Street.
Description of hazard: Riverine & coastal flooding. SLR projections indicate road and well will flood with saltwater. Area is in the AE Zone. Flooding from beaver activity exacerbates problem. The hydraulic capacity model flags this crossing as potentially unable to pass storm flows. It is transitional at 2-yr and fails at 10-yr.
Consequences of hazard: Asset and the surrounding area are subject to salt water infiltration as sea level rises.
Existing efforts underway: Town is looking for other well sites.

Short-term Strategies (now-2030)

- Engage with Water Department staff & Water Board to ensure that increasingly irregular precipitation patterns are considered in water supply management planning.
- Further study on the vulnerability of this site to the combined impacts of riverine and coastal flooding. Actively control beaver population to reduce chronic flooding.

- Replace water supply

Long-term Strategies (2030-2070)

- Raise road and install tide gate to protect future water supply that may be developed upstream from future saltwater intrusion.
- Incorporate climate projections into long-term infrastructure planning.

Ipswich River Bank from County St bridge to Sewage Pumping Station (Town Wharf)

Location: County Street bridge to Town Wharf at 68 East St.
Description of hazard: Riverine & coastal flooding.
Current solutions: Ipswich is planning educational signage about the river, including some discussion of climate impacts, to be posted on Sewage Pumping station at Town Wharf. The Town's CZM 2016 Resiliency grant investigated stormwater runoff, bank erosion, flooding, and recreational usage along river (completed June 2017). Area is also subject to several stormwater remediation studies.

Short-term Strategies (now-2030)

- Flood-proof pump station.
- Elevate critical utilities.
- Explore alternative pumping station locations.
- Consider impacts of sea level rise on stormwater remediation projects recommended for area.

Long-term Strategies (2030-2070)

- Incorporate climate projections into long-term infrastructure planning. Relocate pumping station when needed.

Crossing at Topsfield Road and Gravelly Brook

Location: Gravelly Brook crossing of Topsfield Road ~100 feet east of Gravelly Brook Road.
Description of hazard: This crossing is deteriorating and eroding. If it fails the road will wash out.
Consequences of hazard: Road failure causing severely reduced access to and fro downtown Ipswich. Ecological impact to trout and other coldwater fish.
Existing efforts underway: The barriers study produced a conceptual design for the replacement of this structure. The Ipswich DPW has been seeking funding to initiate replacement.

Short-term Strategies (now-2030)

- Replace culvert with structure based on preliminary design which is more resilient to erosion and meets the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structure for signs of flooding and failure.

Crossings on Pineswamp Road *continued on next page*

Location: Two crossings Pineswamp Road. (1) ~500 feet west of Linebrook Road intersection and (2) ~300 feet west of Fox Run Road intersection.
Description of hazard: The hydraulic capacity screening tool identified both of these structures as vulnerable to flooding. Structure # 1 was replaced fairly recently, but does not meet the MA Stream Crossing Standards.
Consequences of hazard: Road flooding, possible road failure and ecological impacts.
Existing efforts underway: The associated barriers study produced conceptual designs for the replacement of these structures.

Crossing on Pineswamp Road continued

Short-term Strategies (now-2030)
☐ Replace culverts with structures designed to pass storm flows and meet the MA Stream Crossing standards. ☐ Conduct analysis at site #1 to identify whether downstream crossing at Linebrook Road needs to be upgraded at same time.
Long-term Strategies (2030-2070)
☐ Continue to maintain and monitor structures for signs of flooding and failure. ☐ Conserve adjacent land to allow marsh migration and to prevent additional development

4.2-6. TOWN OF ESSEX: Adaptation Strategies and Recommendations for Selected Areas of Concern

Main Street Causeway & Woodman's Landing

Location: 74 Main St. to 166 Main Street.
Description of hazard: Tidal and storm-driven flooding. Flooding occurs from both sides. Woodman's Beach is a possible breach point.
Consequences of hazard: Flooded road cuts off emergency services and impacts store-front economy.
Existing efforts underway: Flooding reduced since recent re-construction of the Causeway. Road was raised a few inches in 2011 as part of the Route 133 reconstruction project. Emergency vehicles are stationed on the east side of the Causeway when flooding is expected.

Short-term Strategies (now-2030)

- ☐ Create live video feed showing the Causeway so residents and travelers can go online and see in real-time if it’s flooded/impassable. Track and monitor flow beneath Causeway.
- ☐ Convene Essex Causeway working-group (business owners and others) to begin considering long-term impacts and viability. Include representatives from local businesses, regional and state partners, and town officials.

Long-term Strategies (2030-2070)

- ☐ Raise road several feet at least and establish flow under roadway to restore hydrology and increase natural resiliency of marsh; investigate feasibility of a bridge.
- ☐ Incorporate climate projections into long-term infrastructure and business planning, including road maintenance and utilities running along the road.
- ☐ Ultimately if the road is to be raised substantially, some businesses will need to relocate; start business owner engagement early in the process (partial planned retreat).

Eastern Avenue at Ebben Creek◊ *continued on next page*

Location: 81 Eastern Ave to 97 Eastern Ave.
Description of hazard: Tidal and storm flooding. Flood map shows road within 100yr flood plain. Would be highly vulnerable to 6' of sea level rise.
Consequences of hazard: Reduced flow impacts the resiliency of the marsh and could eventually impact road stability and function. Restricted flow is causing erosion and scour is visible.
Existing efforts underway: None.

Short-term Strategies (now-2030)

- Regularly monitor scouring to ensure road stability.
- Regularly remove debris caught in the culvert to ensure maximum flow.
- Update 2005 study of the restriction, focusing on impact to the marsh and flooding relative to updated inundation modeling data. Study should evaluate whether upgraded culvert would affect neighborhoods upstream.
- Re-evaluate flood hazard based on updated modeling and sea level rise estimates.

Long-term Strategies (2030-2070)

- Develop designs to raise causeway and/or bridge.
- Raise road elevation and/or install larger culvert or bridge.

Conomo Point Road & Robbins Road◊

Location: Low-lying portions of Conomo Point Road and Robbins Road (as shown by inundation maps)
Description of hazard: Tidal and storm-driven flooding.
Consequences of hazard: Flooded road blocks off homes, emergency access, and impacts boat launches, commercial clamming access and recreation areas.
Existing efforts underway: A Comprehensive Plan for Robbins Island and Northern Conomo Point was completed by the Town in March, 2016. The Plan addresses long-term disposition and management plans for certain properties.

Short-term Strategies (now-2030)

- Create early warning system to alert residents when the road is likely to be flooded or is flooded.
- Regularly evaluate evacuation plans, ensuring enough notice will be given prior to the road becoming impassible.
- Monitor flood frequency and depth to help with future road planning efforts.
- Require any redesign to take sea level rise and increased storm surge into consideration.
- Consider hybrid living shoreline near Clammers Beach to stabilize the shoreline and reduce wave energy.
- Ensure that long-term data for flooding and sea level rise is incorporated into town's Conomo Point planning and management strategies.

Long-term Strategies (2030-2070)

- Raise road at low pinch points where flooding is likely to occur, such as at Clammers Beach.
- Assess long-term outlook and viability of Conomo Point & Robbin's Island neighborhood plan road updates accordingly.
- Consider planned retreat.

Crane Beach (tip of point)◊ *continued on next page*

Location: 290 Argilla Rd, Ipswich
Description of hazard: Beach and dune erosion.
Consequences of hazard: Widening of the mouth of the Essex River. Loss of buffering landmass could increase the vulnerability of inland areas in Essex Bay.
Existing efforts underway: The owners of Crane Beach, The Trustees of Reservations, are developing a Coastal Vulnerability Assessment with adaptation strategies for priority sites, which will be completed in 2017.

Short-term Strategies (now-2030)

- Allow natural dynamic system to evolve over time
- Support efforts to educate the public concerning the natural processes and dynamics of a barrier beach system
- Continue monitoring erosion rates.
- Work with the Trustees to examine if active management to increase the resiliency of this area of the barrier is feasible and consistent with their coastal management and planning.

Crane Beach (tip of point) continued

Long-term Strategies (2030-2070)

- Support Trustees' efforts to manage this undeveloped natural barrier beach.

Crossing at Lufkin Street

Location: Lufkin Creek crossing under Lufkin Street ~250 feet west of Harlow Street intersection.
Description of hazard: The barriers study identified this crossing as a high priority. The hydraulic capacity screening tool predicts that it is unable to pass the flow associated with a 2-year (50% likelihood) storm.
Consequences of hazard: Risk to property road and possible upstream flooding.
Existing efforts underway: The barriers study developed conceptual design for replacement of this structure.

Short-term Strategies (now-2030)

- Replace culvert with structure designed to pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

Crossing at Story Street/Western Ave

Location: Tributary to Alewife Brook crossing underneath intersection of Story Street and Western Avenue.
Description of hazard: The barriers study identified this crossing as a high priority, ranking in the top 35 across the entire study region for combined infrastructure risk and ecological impact.
Consequences of hazard: Risk to property and high replacement cost. Ecological impact.
Existing efforts underway: The barriers study developed conceptual design for replacement of this structure.

Short-term Strategies (now-2030)

- Replace culvert with structure based on conceptual design which will pass higher flows and meet the MA Stream Crossing standards.

Long-term Strategies (2030-2070)

- Continue to maintain and monitor structures for signs of flooding and failure.

Sandy Tilton

Northeast Massachusetts Mosquito Control and Wetlands Management District

CHAPTER 5

Recommendations for Advancing the Implementation of Nature-based Strategies in the Great Marsh

Conducting vulnerability assessments and identifying adaptation strategies are both critically important steps in building coastal resilience, but they are only the first steps. Moving from assessing and planning activities to then implementing strategies that measurably reduce risk can be challenging. However, without implementation, resources and energy put into planning will amount to little; no measurable reduction in vulnerability will occur – in fact vulnerability will only continue to increase.

Transitioning from planning to implementing "on-the-ground" projects, and more specifically natural and nature-based strategies, can be difficult for a variety of reasons. The following pages summarize some of the major challenges associated with implementing adaptation strategies, and offer guidance and recommendations on how to address each challenge. When left unaddressed, these challenges can significantly impede the direction and effectiveness of adaptation projects. For this reason, promoting an informed understanding and awareness of how to navigate such challenges is key to moving the Great Marsh Region towards a wider adoption and implementation of natural and nature-based strategies.

RECOMMENDATION
Understand site-specific considerations

It's important to understand the physical site conditions when implementing most adaptation strategies, whether it's gray infrastructure, green infrastructure, or simply helping bolster existing natural defenses. Projects will perform successfully if they are designed to function within the specific biological and geophysical characteristics of the project site. If not properly sited and designed, projects have a higher likelihood of failing, which can ultimately contribute to public uncertainty about the viability of certain approaches and in particular, nature-based solutions.

Although it can be time consuming, it's important to consider site-specific factors before moving into the implementation phase. For projects that include a structural component, the first step is often a feasibility assessment and siting. Done correctly, these steps will help assess the site-specific conditions and put the project on a path towards success, reducing likelihood of unforeseen hurdles arising during the permitting, and eventual construction and installation of a project. Qualified contractors and MA CZM's North Shore Regional Coordinator[452] can help guide towns through this process, ensuring relevant data is acquired and analyzed appropriately. In addition, there are a number of existing resources available that provide guidance on how to assess a site to determine which project type(s) and/or approach(es) may be most appropriate for a given location and/or habitat.

Sandy Tilton

Available Resources:

- *Guidance for Considering the Use of Living Shorelines*[453]
- *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features*[454]
- *Living Shorelines Engineering Guidelines*[455]
- *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*[456]
- *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*[457]

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452 "North Shore Region," MA CZM, http://www.mass.gov/eea/agencies/czm/ regional-offices/north-shore/

453 NOAA Living Shorelines Workgroup, *Guidance for Considering the Use of Living Shorelines* (2012), 15, http://www.habitat.noaa.gov/pdf/noaa_guidance_for_considering_the_use_of_living_shorelines_2015.pdf

454 Cunniff, S. and A. Schwartz, *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features* (New York, NY: Environmental Defense Fund, 2015), http://www.edf.org/sites/default/files/summary_ni_literature_compilation_0.pdf

455 Miller, J.K., A. Rella, A. Williams, and E. Sproule, *Living Shorelines Engineering Guidelines*, prepared for New Jersey Department of Environmental Protection (Hoboken, NJ: Stevens Institute of Technology, 2016), http://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf

456 Bridges, T.S. et al., *Use of natural and nature-based features (NNBF) for coastal resilience*, ERDC SR-15-1 (Vicksburg, MS: USACE, 2015), http://cdm16021.contentdm.oclc.org/cdm/ref/collection/p266001coll1/id/ 3442

457 Bridges, T.S. et al., *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*, CWTS 2013-3 (Washington, DC: USACE, 2013), http://www.corpsclimate.us/docs/USACE_Coastal_Risk_Reduction_final_CWTS_2013-3.pdf

RECOMMENDATION

Understand the permitting process early on

Most adaptation and coastal resilience projects that include a physical alteration of the environment will require one or more permits from federal and state agencies. In addition, many projects will require approval from municipal boards and commissions such as a Conservation Commission. Completing the permitting process can be time consuming and seem daunting. However following the permitting process is both legally required and reduces the likelihood that a project will have unintended negative consequences.

It is important to engage relevant state and federal regulators early in the development of a project for two main reasons: (1) a project may not be feasible from a regulatory perspective and it's better to make that determination before too much time and resources are invested; and (2) regulatory staff have expertise that can help inform project design, ensure best practices are used, and can recommend design changes to help the project move more swiftly through the permitting process. Knowing which regulators to reach out to can be difficult, but MA CZM and MassBays Program both employ regional coordinators who can liaise between project proponents and regulators.

When considering an adaptation or coastal resilience project, these regional coordinators should be consulted as early in the process as possible:

- MassBays North Shore Coastal Resources Coordinator[458]
- CZM's North Shore Regional Coordinator[459]

RECOMMENDATION

Work with partners to access creative resources and funding

Proactive risk-reduction projects can be cost-effective and save significant money over the lifespan of the project. The Federal Emergency Management Agency highlights an often cited statistic that every dollar spent on mitigation saves an average of four dollars.[460] Finding funding for mitigation projects and proactive management can be challenging, but there are a variety of resources and dedicated funding streams to support coastal resilience projects (see below). There is also a growing field exploring alternative financing mechanisms, such as public-private partnerships,[461] "pay for success" environmental impact bonds,[462] green bonds,[463] insurance-based resilience bonds,[464] and blended finance.[465]

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458 "Upper North Shore Region," Massachusetts Office of Coastal Zone Management, http://www.mass.gov/eea/agencies/mass-bays-program/regions/upper-north-shore.html

459 "North Shore Region," MA CZM, http://www.mass.gov/eea/agencies/czm/regional-offices/north-shore/

460 FEMA, *Mitigation's Value to Society* (Washington, DC: 2008), https://www.fema.gov/pdf/hazard/hurricane/2008/gustav/mitigations_value_factsheet2008.pdf

461 GZA Environmental, Inc., *Financing Resilience: The Big Challenge* (2017), 12, http://www.gza.com/sites/default/files/FINAL_Financing%20Resiliency%20The%20Big%20Challenge_1_31_17.pdf

462 Hierra, D., "Environmental impact bonds: Next big thing for green investments?," Environmental Defense Fund, https://www.edf.org/blog/2017/07/14/environmental-impact-bonds-next-big-thing-green-investments

463 Colgan, C.S. et al., *Financing Natural Infrastructure for Coastal Flood Damage Reduction* (London, England: Lloyd's Tercentenary Research Foundation, 2017), 12-14,

464 Re:focus Partners, LLC., *Leveraging catastrophe bonds as a mechanism for resilient infrastructure project finance* (2015), 39, http://www.refocuspartners.com/wp-content/uploads/2017/02/RE.bound-Program-Report-December-2015.pdf

465 "Blending Finance for (Climate) Resilience," Climate Finance Advisors, https://climatefinanceadvisors.com/2016/08/blending-finance-climate-resilience/

IMPORTANT TIP*:* Once a "Request for Proposal" (RFP) is announced, the funder is typically unable to communicate with applicants, answer questions, or provide input on project design. Before an RFP comes out, however, many funders will gladly review project concepts and provide advice. Engaging a funder prior to the funding announcement, and taking their advice into consideration, will generally increase the competitiveness of your proposal.

Federal Funding Sources:

- NOAA Coastal Resilience Grants Program[466]
- FEMA Hazard Mitigation Grant Program[467]
- North American Wetlands Conservation Act Standard Grants[468]

Browse Funding Opportunities:

- U.S. Climate Resilience Toolkit[469]
- U.S. DOI Climate Change Funding[470]
- Environmental Protection Agency climate Change Adaptation Resource Center[471]

State Funding Sources:

- MA CZM Coastal Resilience Grant Program[472]
- Culvert Replacement Grant Program[473]
- MassBays Grants Program[474]
- Municipal Vulnerability Preparedness Program[475]
- Dam and Seawall Repair or Removal Program[476]

Other Funding Sources:

- NFWF Resilient Communities Program[477]
- WCS Climate Adaptation Fund[478]

EPA

466 "2017 NOAA Coastal Resilience Grants," NOAA, https://www.coast.noaa.gov/resilience-grant/
467 "Hazard Mitigation Grant Program," FEMA, https://www.fema.gov/hazard-mitigation-grant-program
468 "Standard Grants," US Fish & Wildlife Service, https://www.fws.gov/birds/grants/north-american-wetland-conservation-act/standard-grants.php
469 "Funding Opportunities," US Climate Resilience Toolkit, https://toolkit.climate.gov/content/funding-opportunities
470 "Climate Change Funding Opportunities," US DOI, https://www.doi.gov/oia/climate-change/funding-opportunities
471 "Federal Funding and Technical Assistance for Climate Adaptation," EPA, https://www.epa.gov/arc-x/federal-funding-and-technical-assistance-climate-adaptation
472 "Coastal Resilience Grant Program," MA CZM, http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/grants/
473 "Municipal Assistance for Replacement of High Ecological Value Culverts, MA Dept. of Fish & Game, http://www.mass.gov /eea/agencies/dfg/der/technical-assistance/culvert-replacement-grant-rfr.html
474 "MassBays Grant Program," MA EEA, http://www.mass.gov/eea/agencies/mass-bays-program/grants/
475 "Municipal Vulnerability Preparedness Program," MA EEA, http://www.mass.gov/eea/air-water-climate-change/climate-change/massachusetts-global-warming-solutions-act/municipal-vulnerability-preparedness-program.html
476 "Damn and Seawall Repair or Removal Program," MA EEA, http://www.mass.gov/eea/waste-mgnt-recycling/water-resources/preserving-water-resources/water-laws-and-policies/water-laws/draft-regs-re-dam-and-sea-wall-repair-or-removal-fund.html
477 "Resilient Communities Program," National Fish and Wildlife Foundation, http://www.nfwf.org/resilient-communities/Pages/home.aspx
478 "Climate Adaptation Fund," Wildlife Conservation Society, http://wcsclimateadaptationfund.org/

RECOMMENDATION

Develop and enhance support from the general population to address long-term challenges

Craig Guillot

For resiliency enhancement efforts to succeed at the local level, there typically needs to be widespread community buy-in and a sense of shared ownership of the work that is occurring or that is proposed. The first step is to educate stakeholders and the general public on the threats facing the asset, resource, or geographic area. As the need for action becomes apparent and broadly understood, then the emphasis shifts towards solutions. In general, seawalls, bulkheads, and other gray infrastructure techniques have historically been a common approach to stabilizing sediment, preventing erosion, and providing flood protection.

Given the prevalence and use of coastal armoring, particularly in major coastal cities, gray infrastructure techniques tend to be more familiar to the general public, which further perpetuates their use as a dominant tactic. Natural and nature-based solutions could however be implemented more widely if the full scope of benefits and costs of such approaches were better communicated to, and understood by, contractors, residents, private landowners, and decision-makers. The content is important (i.e. the reasons why natural and nature-based solutions should be chosen over gray infrastructure), but the messengers delivering the content are also important. According to national polling, fire fighters, Red Cross, health professionals, and water quality scientists are the most effective and trusted "front-line" messengers to communicate concepts of resilience and nature-based solutions.[479] In the Great Marsh, health professionals, emergency management officials, police and fire fighters should be engaged to join implementation efforts alongside critical citizens groups such as Storm Surge and others.

Resources to help make the case for nature-based strategies:

- *A Comparative Cost Analysis of Ten Shore Protection Approaches at Three Sites Under Two Sea Level Rise Scenarios*[480]
- *Natural Defenses in Action*[481]
- *Improved Use and Understanding of NNBF in the Mid-Atlantic*[482]
- *Nature-based Solutions in Action*[483]

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479 The Nature Conservancy, How to Communicate Successfully Regarding Nature-Based Solutions: Key Lessons from Research with American Voters and Elites (2015), https://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd_284438.pdf

480 Rella, A.J. and Miller, J.K., *A Comparative Cost Analysis of Ten Shore Protections Approaches at Three Sites Under Two Sea Level Rise Scenarios*, prepared for Hudson River National Estuarine Research Reserve (Hoboken, NJ: Stevens Institute of Technology, 2012), https://s3.amazonaws.com/nyclimatescience.org/240186100-A-Comparative-Cost-Analysis-of-Ten-ShoreProtection-Approaches-at-Three-Sites-Under-Two-Sea-Level-Rise-Scenarios.pdf

481 Small-Lorenz, S.L. et al., Natural Defenses in Action: Harnessing Nature to Protect our Communities (Washington, DC: National Wildlife Federation, 2016), www.nwf.org/nature-in-action

482 Schrass, K., and A.V. Mehta, *Improved Use and Understanding of NNBF in the Mid-Atlantic* (Annapolis, MD: National Wildlife Federation, 2017), http://midatlanticocean.org/wp-content/uploads/2017/03/Improved-Use-and-Understanding-of-NNBF-in-the-Mid-Atlantic.pdf

483 "Nature Based Solutions in Action," Coastal Resilience, http://coastalresilience.org/nature-based-solutions-in-action/

David Stone

CHAPTER 6

Looking to the Future

As this project comes to a close, the communities and the Great Marsh Resiliency Partnership are at a crossroads. The list of challenges and associated recommendations noted in this Adaptation Plan are by no means intended to be exhaustive. Bridging the gap between planning and implementation is difficult, and coastal communities throughout the country are facing similar hurdles as they pursue adaptation strategies. In the Great Marsh, implementation efforts have already begun, many of them highly successful, others running into some of the challenges noted above. The Great Marsh Coastal Adaptation Plan is designed to directly support and guide both new and existing implementation efforts. It will help communities prioritize investments and strategies so as to maximize positive outcomes.

Each community in the Great Marsh should work within its existing planning and governing structures to further its resiliency work. Master planning, hazard mitigation planning, climate action committees, and other municipal planning efforts—that communities are already doing and that they will continue to do—should adopt and incorporate the adaptation strategies and recommendations outlined in this document.

Specifically, the Great Marsh Resiliency Partnership,[484] comprised of regional, governmental, municipal, and NGO partners working in the Great Marsh, will serve as an umbrella resource for moving strategies forward. Each community's Municipal Resiliency Task Force, convened for this planning process, should become a permanent committee, charged with the implementation of this Adaptation Plan. The first task of each municipal committee should be to work with the Great Marsh Resiliency Partnership to develop a detailed Action Plan.

[484] "Great Marsh Resiliency Partnership," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_21/

Above all, the Great Marsh Coastal Adaptation Plan serves as a guide for taking a holistic and integrated approach to building coastal resiliency in the Great Marsh by combining natural resource enhancement with community risk reduction on a regional scale. The goal of this plan is to reduce the growing vulnerability of communities within the Great Marsh from coastal storms, sea level rise, flooding, and erosion by strengthening the resiliency of the ecological systems upon which those communities depend.

As a result of their coordinated planning, the coastal communities of the Great Marsh are poised to make large, measurable gains in reducing community vulnerability and enhancing coastal resiliency. Strategies include natural and nature-based solutions, building retrofits, policy measures, and outreach and education initiatives—all of which are operationally feasible and can be implemented in the near to moderate term. Shovel-ready projects have been identified and vetted, relevant municipal policy measures have been identified that incentivize climate-smart development and/or prohibit development in hazard-prone locations, best practices are ready to be incorporated into public and private development initiatives, and public support for implementation has grown.

To date, partners and municipalities in the Great Marsh have been successful in coordinating planning efforts at the regional scale, working across sectors and jurisdictions to engage relevant stakeholders. The challenge now is to build off the success of this regional planning effort and transition to coordinated regional implementation.

Dave Rimmer

Literature Cited

Abdollahian, N., Jones, J., and N. Wood. *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: U.S. Geological Survey, 2016.

American Shore & Beach Preservation Association (ASBPA). "In Defense of Dunes." January 13, 2015. http://www.asbpa.org/news/newsroom_14BN0113_in_defense_of_dunes.htm

Barringer, P. *Downtown Assessment: Ipswich, Massachusetts*. Brookline, MA: FinePoint Associates, 2014.

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

Blake, Eric S., Todd B. Kimberlain, Robert J. Berg, John P. Cangialosi and John L. Beven II. *Tropical Cyclone Report Hurricane Sandy (AL182012)*. NOAA National Hurricane Center. February 12, 2013. http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf

Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. *MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery*. East Falmouth, MA: Woods Hole Group, 2016. https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_ Report_MassDOT_FHWA.pdf

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.

Boston University. "Marsh Edge Erosion." Accessed August 2015. http://sites.bu.edu/novak/ research/marsh-edge-erosion/

Brady, P.D., K.E. Reback, K.D. McLaughlin, and C.G. Milliken. "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.

Bridges, T.S., K.A. Burks-Copes, M.E. Bates, Z.Collier, C.J. Fischenich, C.D. Piercy, E.J. Russo, D.J. Shafer, and B.C. Suedel. *Use of natural and nature-based features (NNBF) for coastal resilience*, ERDC SR-15-1. Vicksburg, MS: Directorate of Civil Works, US Army Corps of Engineers, 2015. http://cdm16021.contentdm.oclc.org/cdm/ref/collection/p266001coll1/id/ 3442

Bridges, T.S., R. Henn, S. Komlos, D. Scerno, T. Wamsley, and K. White. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*, CWTS 2013-3. Washington, DC: Directorate of Civil Works, US Army Corps of Engineers, 2013. http://www.corpsclimate.us/docs/USACE_Coastal_Risk_Reduction_final_CWTS_2013-3.pdf

Bu, N., J.F. Qu, G. Li, B. Zhao, R.J. Zhang, and C.M. Fang. "Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool." *Ecological Engineering*, 81 (2015): 335-339.

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

City of Newburyport. *DRAFT Newburyport Master Plan*. Newburyport, MA: 2015.

City of Newburyport. *Newburyport Master Plan*. Newburyport, MA: 2001.

City of Newburyport. *Open Space and Recreation Plan*. Newburyport, MA: 2012.

Climate Central. "Surging Seas: Risk Finder." Last updated April 2014. http://sealevel.climatecentral.org/ssrf/massachusetts

Colgan, C. S., M. W. Beck, S. Narayan. *Financing Natural Infrastructure for Coastal Flood Damage Reduction*. London, England: Lloyd's Tercentenary Research Foundation, 2017. https://conservationgateway.org/ConservationPractices/Marine/crr/library/Documents/FinancingNaturalInfrastructureReport.pdf

Cunniff, S. and A. Schwartz. *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features*. New York, NY: Environmental Defense Fund, 2015. http://www.edf.org/sites/default/files/summary_ni_literature_ compilation_0.pdf

Deegan, L.A., D.S. Johnson, R.S. Warren, B.J. Peterson, J.W. Fleeger, S. Fagherazzi, W.M. Wollheim. "Coastal eutrophication as a driver of salt marsh loss." *Nature*, 490 (18 October 2012): 388-392.

Famely, J., K. Bosma and B. Hoffnagle. *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.

Federal Emergency Management Agency (FEMA). *DRAFT Flood Risk Report: Essex County, MA*. FEMA 001. Washington, DC: 2013.

Federal Emergency Management Agency (FEMA). *Mitigation's Value to Society*. Washington, DC: 2008. https://www.fema.gov/pdf/hazard/hurricane/2008/gustav/mitigations_value_factsheet2008.pdf

Gittman, R.K., F.J. Fodrie, A.M. Popowich, D.A. Keller, J.F. Bruno, C.A. Currin, C.H. Peterson, and M.F. Piehler. "Engineering away our natural defenses: an analysis of shoreline hardening in the US." *Frontiers in Ecology and the Environment* 13, no.6 (2015): 301-307, doi: 10.1890/150065

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

Grannis, J. *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use*. Washington, DC: Georgetown Climate Science Center, 2001. http://www.georgetownclimate.org/files/report/Adaptation_Tool_Kit_SLR.pdf

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

GZA Environmental, Inc., *Financing Resilience: The Big Challenge*. 2017. http://www.gza.com/sites/default/files/FINAL_Financing%20Resiliency%20The%20Big%20Challenge_1_31_17.pdf

Haney, R., L. Kouloheras, V. Malkowski, J. Mahala, and Y. Unger. *Beach Nourishment: MassDEP's Guide to Best Management Practices for Projects in Massachusetts*. Boston, MA: Massachusetts Department of Environmental Protection & Office of Coastal Zone Management, 2007. http://www.mass.gov/eea/docs/dep/water/resources/a-thru-m/bchbod.pdf

Herrera, Diego. "Environmental impact bonds: Next big thing for green investments?" Environmental Defense Fund. July 14, 2017. https://www.edf.org/blog/2017/07/14/environmental-impact-bonds-next-big-thing-green-investments

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

Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, A. Whelchel, D. Wolfe, and F. Lipschultz. "Ch. 16: Northeast" in *Climate Change Impacts in the United States: The Third National Climate Assessment*, edited by J.M. Melillo, T.C. Richmond, and G.W. Yohe. U.S. Global Change Research Program. Washington, DC: 2014.

Intergovernmental Panel on Climate Change (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*, edited by M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E.Hanson. Cambridge, UK: Cambridge University Press, 2007.

Intergovernmental Panel on Climate Change (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*, edited by R.K. Pachauri and L.A. Meyer. Geneva, Switzerland: 2014.

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

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

Kelder, B. *PIE-Rivers Stream Continuity Survey – Final Report*. Ipswich, MA: Ipswich River Watershed Association, 2014. http://www.pie-rivers.org/wp-content/uploads/2015/03/PIE_Crossings FinalReport_12312014.pdf

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

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

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

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

Massachusetts Bay Transportation Authority (MBTA). "Chapter 4: Commuter Rail" in *Ridership and Service Statistics: Fourteenth Edition.* Boston, MA: 2014.

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

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.

Massachusetts Department of Conservation and Recreation (MA DCR). *Massachusetts Coastal Infrastructure Inventory and Assessment Project*. Boston, MA: 2009.

Massachusetts Department of Fish & Game (MA DFG) and The Nature Conservancy (TNC). 2012. *BioMap 2: Salisbury*. Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife. http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Salisbury.pdf.

Massachusetts Department of Fish & Game (MA DFG) and The Nature Conservancy (TNC). *BioMap 2: Essex.* Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012. http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Essex.pdf.

Massachusetts Department of Fish & Game (MA DFG) and The Nature Conservancy (TNC). *BioMap 2: Ipswich*. Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012. http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Ipswich.pdf.

Massachusetts Department of Fish & Game (MA DFG) and The Nature Conservancy (TNC). *BioMap 2: Newbury.* Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012. http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Newbury.pdf.

Massachusetts Department of Fish & Game (MA DFG) and The Nature Conservancy (TNC). *BioMap 2: Newburyport*. Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012. http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Newburyport.pdf.

Massachusetts Department of Fish & Game (MA DFG) and The Nature Conservancy (TNC). *BioMap 2: Rowley*. Westborough, MA: Commonwealth of Massachusetts Division of Fisheries & Wildlife, 2012. http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Rowley.pdf.

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

Massachusetts Executive Office of Energy and Environmental Affairs (MA EEA). *Massachusetts Climate Change Adaptation Report.* Boston, MA: 2011.

Massachusetts Executive Office of Energy and Environmental Affairs (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

Massachusetts Executive Office of Energy and Environmental Affairs (MA EEA). *Smart Growth/Smart Energy Toolkit Bylaw: Transfer of Development Rights*. Boston, MA. http://www.mass.gov/envir/smart_growth_toolkit/bylaws/TDR-Bylaw.pdf

Massachusetts Office of Coastal Zone Management (CZM). "MORIS: CZM's Online Mapping Tool." Last updated January 9, 2012. http://maps.massgis.state.ma.us/map_ol/moris.php

Massachusetts Office of Coastal Zone Management. *Massachusetts Office of Coastal Zone Management: Policy Guide*. Boston, MA: 2011. http://www.mass.gov/eea/docs/czm/fcr-regs/czm-policy-guide-october2011.pdf

Massachusetts Watershed Initiative. *Parker River Watershed: Year 3 Watershed Assessment Report*. Wilmington, MA: Massachusetts Department of Environmental Protection, 2002.

Massachusetts Wildlife Action Tool. "Restore natural coastal buffers: Beach and dune nourishment and restoration." Amherst, MA: University of Massachusetts Amherst, 2017. http://climateaction-tool.org/content/restore-natural-coastal-buffers-beach-and-dune-nourishment-and-restoration

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

Merrill, S.B. and A. Gray. "MAST Modeling for the Great Marsh in Coastal Massachusetts." In *Final Report to the National Wildlife Federation*. Portland, ME: GEI Consultants, Inc., 2015.

Merrimack Valley Planning Commission (MVPC). "MVMPO Current Transportation Projects Action Chart." Last updated September 18, 2012. Haverhill, MA: 2012. http://mvpc.org/wp-content/uploads/Transportation-Project-list-9-2012.pdf

Merrimack Valley Planning Commission (MVPC). "Newburyport Natural Hazard Risk Assessment." In *Draft Merrimack Valley Multi-Hazard Mitigation Plan*. Haverhill, MA: 2015.

Merrimack Valley Planning Commission (MVPC). "Town of Salisbury Natural Hazard Risk Assessment." In *Draft Merrimack Valley Multi-Hazard Mitigation Plan*. Haverhill, MA: 2015.

Merrimack Valley Planning Commission (MVPC). *Draft Merrimack Valley Multi-Hazard Mitigation Plan*. Haverhill, MA: 2015.

Metropolitan Area Planning Council (MAPC). *Essex Community Development Plan*. Boston, MA: 2004.

Metropolitan Area Planning Council (MAPC). *Town of Essex Hazard Mitigation Plan*. Adopted June 4, 2012. Boston, MA: 2012.

Metropolitan Area Planning Council (MAPC). *Town of Ipswich Hazard Mitigation Plan*. Adopted October 1, 2012. Boston, MA: 2012.

Miller, J.K., A. Rella, A. Williams, and E. Sproule. *Living Shorelines Engineering Guidelines*, prepared for New Jersey Department of Environmental Protection. Hoboken, NJ: Stevens Institute of

Technology, 2016. http://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf

Moser, S.C., M.A. Davidson, P. Kirshen, P. Mulvaney, J.F. Murley, J.E. Neumann, L. Petes, and D. Reed. "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.

National Aeronautics and Space Station (NASA). "NASA, NOAA Find 2014 Warmest Year in Modern Record." January 16, 2015. https://www.nasa.gov/press/2015/january/nasa-determines-2014-warmest-year-in-modern-record

National Complete Streets Coalition. *Implementing Complete Streets: Sustainable Complete Street*. Washington, DC. https://smartgrowthamerica.org/app/uploads/2016/08/cs-greenstreets.pdf

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

National Oceanic and Atmospheric Administration (NOAA) Hurricane Research Division. "The thirty costliest mainland United States tropical cyclones 1900-2013." Accessed September 2017. http://www.aoml.noaa.gov/hrd/tcfaq/costliesttable.html

National Oceanic and Atmospheric Administration (NOAA) Living Shorelines Workgroup. *Guidance for Considering the Use of Living Shoreline.* 2012. http://www.habitat.noaa.gov/pdf/noaa_guidance_for_considering_the_use_of_living_shorelines_2015.pdf

National Oceanic and Atmospheric Administration (NOAA). "Climate at a Glance." Accessed April 1, 2016. http://www.ncdc.noaa.gov/cag/

National Oceanic and Atmospheric Administration (NOAA). "Climate Monitoring Summary Information." Accessed March 3, 2016. http://www.ncdc.noaa.gov/sotc/summary-info/global/201512

National Oceanic and Atmospheric Administration (NOAA). "Coastal Blue Carbon." http://www.habitat.noaa.gov/coastalbluecarbon.html

National Oceanic and Atmospheric Administration (NOAA). "Mean Sea Level Trend 8443970 Boston, Massachusetts." Accessed March 6, 2016. http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8443970

National Oceanic and Atmospheric Administration (NOAA). "What percentage of the American population lives near the coast?" Last updated July 6, 2017. http://oceanservice.noaa.gov/facts/population.html

National Oceanic and Atmospheric Administration (NOAA). *The Economic Value of Resilient Coastal Communities.* Silver Spring, MD: 2012. http://www.performance.noaa.gov/wp-content/uploads/EconomicValueofResilientCoastalCommunities.pdf

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

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. *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.

Parsons, R.A. *Final Technical Memorandum: Town of Ipswich Jeffrey's Neck Road Flood Assessment*. Boston, MA: CDM Smith, 2013. http://www.ipswichma.gov/documentcenter/view/514

Re:focus Partners, LLC. Levera*ging catastrophe bonds as a mechanism for resilient infrastructure project finance.* 2015. http://www.refocuspartners.com/wp-content/uploads/2017/02/RE.bound-Program-Report-December-2015.pdf

Rella, A.J. and Miller, J.K. *A Comparative Cost Analysis of Ten Shore Protections Approaches at Three Sites Under Two Sea Level Rise Scenarios*, prepared for Hudson River National Estuarine Research Reserve. Hoboken, NJ: Stevens Institute of Technology, 2012. https://s3.amazonaws.com/nyclimatescience.org/240186100-A-Comparative-Cost-Analysis-of-Ten-ShoreProtection-Approaches-at-Three-Sites-Under-Two-Sea-Level-Rise-Scenarios.pdf

Rickards, B., K. Lund, and A. Cooper. 2002. *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.

Schechtman, J. and M. Brady, *Cost-Efficient Climate Change Adaptation in the North Atlantic*. New Brunswick, NJ: Rutgers University, 2013. http://www.regions.noaa.gov/north-atlantic/wp-content/uploads/2013/07/CEANA-Final-V11.pdf

Schrass, K., and A.V. Mehta. *Improved Use and Understanding of NNBF in the Mid-Atlantic*. Annapolis, MD: National Wildlife Federation, 2017. http://midatlanticocean.org/wp-content/uploads/2017/03/Improved-Use-and-Understanding-of-NNBF-in-the-Mid-Atlantic.pdf

Sexton, N. A.M. Dietsch, A.W. Don Carlos, L. Koontz, A.N. Solomon, and H.M. Miller. *National Wildlife Refuge Visitor Survey 2010/2011: Individual Refuge Results for Parker River National Wildlife Refuge*. Fort Collins, CO: United States Geological Survey, 2011.

Shaw, W. *Case Study – A Cape Cod Community Prevents New Residences in Floodplain*. Boston, MA: Massachusetts Office of Coastal Zone Management, 2008. http://www.mass.gov/eea/docs/czm/stormsmart/ssc/ssc3-chatham.pdf

Shepard, C.C., C.M. Crain, and M.W. Beck. "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.

Small-Lorenz, S.L., B. A. Stein, K. Schrass, D.N. Holstein, and A.V. Mehta. *Natural Defenses in Action: Harnessing Nature to Protect our Communities*. Washington, DC: National Wildlife Federation, 2016. www.nwf.org/nature-in-action

Small-Lorenz, S.L., W.P. Shadel, and P. Glick. *Building Ecological Solutions to Coastal Community Hazards.* Washington, DC: National Wildlife Federation, 2017. www.nwf.org/CoastalSolutions-GuideNJ

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.

The Nature Conservancy. *How to Communicate Successfully Regarding Nature-Based Solutions: Key Lessons from Research with American Voters and Elite*. 2015. https://www.nature.org/cs /groups/webcontent/@web/@lakesrivers/documents/ document/prd_284438.pdf

Town of Essex Long Term Planning Committee. *Essex Village Initiative*. Essex, MA: 2009.

Town of Essex. *Open Space and Recreation Plan*. Essex, MA: 2007.

Town of Ipswich. *Ipswich Community Development Plan*. Ipswich, MA: 2003.

Town of Ipswich. *Open Space and Recreation Plan*. Ipswich, MA: 2013.

Town of Newbury. "Newburyport Harbor Jetties." Newbury, MA. Accessed September 2015. http://www.townofnewbury.org/pages/history.pdf

Town of Newbury. *Master Plan*. Newbury, MA: 2006.

Town of Rowley. *Annual Drinking Water Quality Report*. Rowley, MA: Rowley Water Department, 2014.

Town of Rowley. *Rowley Master Plan*. Rowley, MA: 2003.

Town of Rowley. *Rowley Protective Zoning Bylaw*. Rowley, MA: 2013. http://www.townofrowley.net/pdf/130611%20Zoning%20ALL.pdf

Town of Salisbury. *Open Space and Recreation Plan 2006-2007*. Salisbury, MA: 2010.

Trout Unlimited. *Piscataquog River Watershed Stream Crossing Vulnerability Assessment Project - Final Report*. Concord, NH: 2014. http://www.snhpc.org/pdf/PiscataquogHydrologyStudy2014.pdf

U.S. Army Corps of Engineers (USACE). "Hurricane Inundation Maps." Accessed August 2015. http://www.mass.gov/eopss/agencies/mema/hurricane-inundation-maps.html

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

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. "Ch. 2: Our Changing Climate" in *Climate Change Impacts in the United States: The Third National Climate Assessment,* edited by J. M. Melillo, T.C. Richmond, and G.W. Yohe. Washington, DC: U.S. Global Change Research Program, 2014. doi:10.7930/J0KW5CXT

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

APPENDIX A:
Methodology for USGS Geospatial Exposure Analysis

Community exposure to coastal-inundation hazards was characterized by integrating geospatial data of scenario-hazard zones with various socioeconomic data to estimate the amount and relative percentage of a specific societal asset in a hazard zone. Societal assets were chosen based on USGS recommendations, discussions with NWF, and by vetting preliminary asset lists with project stakeholders in the six coastal communities. This section describes the geospatial data and geoprocessing assumptions for societal assets related to land cover and land use, populations, economic assets, and critical facilities and infrastructure. All socioeconomic data and subsequent exposure estimates reflect current distributions of people and assets, and do not include projections of future community growth. Socioeconomic data from the various sources described in this section were considered authoritative and no additional field verification or map corrections were conducted.

Prior to analysis, all geospatial data were re-projected to share the same datum (North American Datum of 1983, State Plane, Massachusetts, FIPS 2001 Feet) and projection (Lambert Conformal Conic) to conform to existing GIS data from the State of Massachusetts's GIS database (Office of Geographic Information, 2016). Spatial analysis of vector data (for example, Census block polygons and business points) focused on determining whether or not an asset was inside a hazard zone. Slivers of polygons that overlap administrative boundaries and a hazard zone were taken into account during analysis, and final values were adjusted proportionately. The results summarized in this report should be considered first approximations of community exposure and not exhaustive inventories or loss estimates.

Coastal-inundation-hazard zones used in this study were developed and are summarized in geospatial data provided by the Woods Hole Group. Methods to develop the various scenario-based hazard zones are described in Kleinfelder (2015).[1] Water-elevation modeling in their analysis was based on a fully optimized Monte Carlo approach to simulate the influence of climate change on sea level, tides, waves, and the track and intensities of tropical (hurricanes) and extra-tropical (nor'easters) storms. The spatial resolution of modeling efforts varied, ranging from 1 to 10 meters, based on data availability. Sea level rise assumptions for 2030 and 2070 hazard zones were 0.66 and 3.39 feet relative to mean sea level, respectively, which represent global sea level rise projections for the "highest" scenario by the Intergovernmental Panel on Climate Change[2] and Parris et al. (2012).[3]

Inundation modeling from Woods Hole Group include scenarios for 2013 (representing present day and hereafter referred to as "current" hazard zones), 2030, and 2070.[4] For each time scenario, mapped inundation-probability values ranged from 0.1% to 100% with 12 discrete classes. A percentage refers to the likelihood that coastal inundation will occur in a certain area during a 365 day period. Coastal inundation is defined as flood water (at a depth greater than or equal to 2 inches (5 cm)) encroaching on the surface at a particular location. USGS grouped the inundation probability values into four categories:

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

[2] IPCC, Climate Change 2014, 59

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

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

high probability (100%), medium probability (25%, 30%, and 50%), low probability (1%, 2%, 5%, 10%, and 20%), and very low probability (0.1%, 0.2%. and 0.5%).

USGS also used flood-water depth data, from Woods Hole Group, that were summarized in 1-foot increments for all three time periods and for 1% and 0.2% inundation probabilities (which correspond to 100-year and 500-year storm likelihoods). Depth data shows how deep the water is likely to be in a certain area if a 1% or 0.2% storm occurs. Hazard-zone data provided by the Woods Hole Group were considered authoritative and no additional field verification, model verification, or map corrections were conducted.

For more information on the methodology used by the USGS, see the full report published online.[5]

[5] Abdollahian, N. et al., *Community exposure to potential climate-driven changes to coastal-inundation hazards for six communities in Essex County, Massachusetts*, U.S. Geological Survey open-file report (Reston, VA: USGS, 2016), https://pubs.usgs.gov/of/2016/1187/ofr20161187.pdf

APPENDIX B:
Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed

As part of the Great Marsh Resiliency Planning Project, the Ipswich River Watershed Association conducted a comprehensive inventory and assessment of man-made barriers to flow based on original research and a synthesis of previous studies to assess the vulnerability of these structures in the Great Marsh region. Four categories of barriers were considered in this assessment: non-tidal road-stream crossings (culverts and bridges), tidal road-stream crossings, dams, and gray infrastructure/coastal stabilization structures (seawalls, revetments, etc.).

By definition, all barriers can be considered vulnerable since they are the category of community infrastructure most routinely impacted by water. These assessments were reviewed by the project team and combined with barriers also identified by the local task forces to contribute to the list of high priority Vulnerable Areas of Concern (see Appendix C).

Methodology

To assess the relative vulnerability of barriers, screening-level assessments were conducted as follows for the four categories of potential barriers considered:

Non-tidal road-stream crossings

Field assessments were conducted and an infrastructure risk model was run to test whether non-tidal crossings are likely to successfully pass flood flows based on watershed characteristics and crossing design/dimensions at five different return interval storms: 1%, 2%, 4%, 10% and 50%. Crossings that did not pass at the 4% level or above were deemed highly vulnerable.

The crossing infrastructure risk assessment builds upon the PIE-Rivers Road-Stream Crossing Inventory and Risk Assessment,[6] an earlier assessment of ecological connectivity at the region's stream crossings. This earlier work was conducted by Ipswich River Watershed Association utilizing a rapid assessment protocol developed by the North Atlantic Aquatic Connectivity Collaborative (NAACC). Between 2006 and 2014, more than 700 of the region's crossings were surveyed, assessing whether the designs of the bridges and culverts are suitable for the movement of fish and wildlife, or whether they present partial or complete barriers to migration for a variety of species.[7]

Data from the aforementioned PIE-Rivers Assessment was used to conduct an additional analysis of infrastructure risk using a hydraulic capacity (HC) screening model developed and applied by Trout Unlimited[8]. The HC screening model estimates whether a bridge or culvert will be able to pass instream flows during the 1%, 2%, 4%, 10% and 50% annual chance storms. This tool utilizes a combination of site specific measurements taken at each crossing, GIS data characterizing upstream watershed characteristics, and rainfall predictions to make these estimates. Crossings that are unable to pass flood flows are more likely to have catastrophic failure and used as an initial screening tool to assess their

6 "Continuity and Infrastructure Assessment," PIE-Rivers, http://www.pie-rivers.org/portfolio-item/id_20/

7 Kelder, B., *PIE-Rivers Stream Continuity Survey – Final Report* (Ipswich, MA: Ipswich River Watershed Association, 2014), http://www.pie-rivers.org/wp-content/uploads/2015/03/PIE_CrossingsFinalReport_12312014.pdf

8 Trout Unlimited, *Piscataquog River Watershed Stream Crossing Vulnerability Assessment Project - Final Report* (Concord, NH, 2014), http://www.snhpc.org/pdf/PiscataquogHydrologyStudy2014.pdf

vulnerability for this report. The remainder of this study further assessed and prioritized structures in each community and regionally taking into consideration both infrastructure risk and ecological impact. Preliminary designs for 103 of the high priority structures in the region were produced to guide implementation work. The results of this more comprehensive analysis of risk and impact are summarized in the final Great Marsh Resiliency Plan. Full results for the entire study region can be found in the Great Marsh Barriers Report.

Tidal road-stream crossings

The results of a previously conducted study by the Massachusetts Division of Ecological Restoration, combined with site visits and local knowledge, were used to identify highly vulnerable sites. All tidal crossings under a public way that were associated with a tidally restricted marsh identified in the Draft Great Marsh Coastal Wetlands Restoration Plan[9] were assumed to be highly vulnerable.

The Great Marsh Coastal Wetlands Restoration Plan (hereinafter "Draft Plan"), developed by the Massachusetts Office of Coastal Zone Management's Wetlands Restoration Program (now part of the MA Division of Ecological Restoration) and partners, was drafted as a tool to help communities in the Great Marsh region identify and restore degraded and former coastal wetland habitats. The Draft Plan was initially developed in 2006 and is currently (2017) being updated and revised. It presents maps and descriptions of 121 potential and completed salt marsh restoration sites in the Great Marsh. In the future, the Division of Ecological Restoration and other partners will be updating and expanding the data to provide timely information on the status and progress of specific sites, and to incorporate new restoration opportunities as they emerge. These data are currently in the process of being published.[10]

For our analysis, we considered marshes that were located partly or completely within the town of interest and were classified as tidal restrictions. Through a combination of desktop GIS analysis and local knowledge, we identified tidal road-stream crossings in each town. Road-stream crossings under a public way that are associated with one of the marshes the Draft Plan identified as tidally restricted were considered to be highly vulnerable. The Draft Plan also included more detailed "rapid technical assessments" of a subset of the sites it considered. These reports include more detail on the degree of tidal restriction, including information such as measurements of tidal range over month-long periods that may be of use if these sites are further explored.

Dams

The most current data from the Massachusetts Office of Dam Safety (ODS) Inventory[11] were reviewed and dams rated as either high or significant hazard potential were deemed highly vulnerable due to the public safety ramifications. ODS[12] maintains records of dams located throughout the Commonwealth of Massachusetts and ensures compliance with acceptable practices pertaining to dam inspection, maintenance, operation and repair of dams. The database also contains location information for dams that are small enough to not be covered under the jurisdiction of the ODS. These dams were mapped, but

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[9] Contact the Massachusetts Division of Ecological Restoration for more information: http://www.mass.gov/eea/agencies/dfg/der/

[10] Ibid

[11] "MassGIS Data – Dams," MA Executive Office for Administration and Finance, http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/dams.html

[12] "Dam Safety," MA EEA, http://www.mass.gov/eea/agencies/dcr/conservation/dam-safety/

not considered highly vulnerable because they are small enough to not reach risk thresholds to concern ODS. Dams are categorized as follows:

High Hazard Potential dam refers to dams located where failure will likely cause loss of life and serious damage to home(s), industrial or commercial facilities, important public utilities, main highway(s) or railroad(s).

Significant Hazard Potential dam refers to dams located where failure may cause loss of life and damage home(s), industrial or commercial facilities, secondary highway(s) or railroad(s) or cause interruption of use or service of relatively important facilities.

Low Hazard Potential dam refers to dams located where failure may cause minimal property damage to others. Loss of life is not expected.

Gray infrastructure/coastal stabilization structures

Data from the Massachusetts Coastal Structure Inventory and Assessment Project,[13] prepared by the Infrastructure Plan Working Group of the Coastal Hazards Commission for Massachusetts Departments of Coastal Zone Management (CZM) and Conservation and Recreation (DCR), was used to review and assess shoreline stabilization structures and their ability to resist major coastal storms and prevent damage due to flooding and erosion. The data and summary report includes condition ratings and estimated repair or reconstruction costs for publicly-owned coastal structures inventoried from 2006-2009. The condition of coastal structures was characterized through on-site evaluation and ranged from excellent (A) to critical (F). The majority of the structures were either in good (B) or fair (C) condition. Publicly owned, man-made structures with condition scores graded D and F were deemed highly vulnerable.

[13] "StormSmart Coasts – Inventories of Seawalls and Other Coastal Structures," MA CZM, http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/seawall-inventory/

Town-Specific Results

The following pages include tables and maps displaying the town-specific summary results of the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed.

Table B-1. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Salisbury, MA.

<table>
<tr><th colspan="2">Data Set</th><th>Structure Count</th><th colspan="3">Structures by Category</th></tr>
<tr><td colspan="2" rowspan="7">Non-Tidal Stream Crossings</td><td rowspan="7">20*</td><td>Priority</td><td>Storm Return Interval</td><td>Initial Hydraulic Screen Fail</td></tr>
<tr><td rowspan="3">Low</td><td>Pass all</td><td>5</td></tr>
<tr><td>100 year (1%)</td><td></td></tr>
<tr><td>50 year (2%)</td><td></td></tr>
<tr><td rowspan="3">High</td><td>25 year (4%)</td><td>1</td></tr>
<tr><td>10 year (10%)</td><td></td></tr>
<tr><td>2 Year (50%)</td><td></td></tr>
<tr><td colspan="2" rowspan="3">Tidal Stream Crossings</td><td rowspan="3">15</td><td>Priority</td><td colspan="2">Count</td></tr>
<tr><td>Low</td><td colspan="2">5</td></tr>
<tr><td>High</td><td colspan="2">10</td></tr>
<tr><td colspan="2" rowspan="4">Dams</td><td rowspan="4">0</td><td>Priority</td><td>Hazard Class</td><td>Count</td></tr>
<tr><td rowspan="2">Low</td><td>Non-Jurisdictional</td><td></td></tr>
<tr><td>Low Hazard</td><td></td></tr>
<tr><td>High</td><td>Significant Hazard</td><td></td></tr>
<tr><td rowspan="7">Shoreline Stabilization Structures</td><td rowspan="6">Public</td><td rowspan="6">7</td><td>Priority</td><td>Condition</td><td>Count</td></tr>
<tr><td rowspan="3">Low</td><td>A - Excellent</td><td></td></tr>
<tr><td>B - Good</td><td>6</td></tr>
<tr><td>C - Fair</td><td>1</td></tr>
<tr><td rowspan="2">High</td><td>D - Poor</td><td></td></tr>
<tr><td>F - Critical</td><td></td></tr>
<tr><td>Private</td><td>2</td><td colspan="3">Not Prioritized</td></tr>
</table>

* There are a total of 20 non-tidal stream crossings in the Salisbury data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

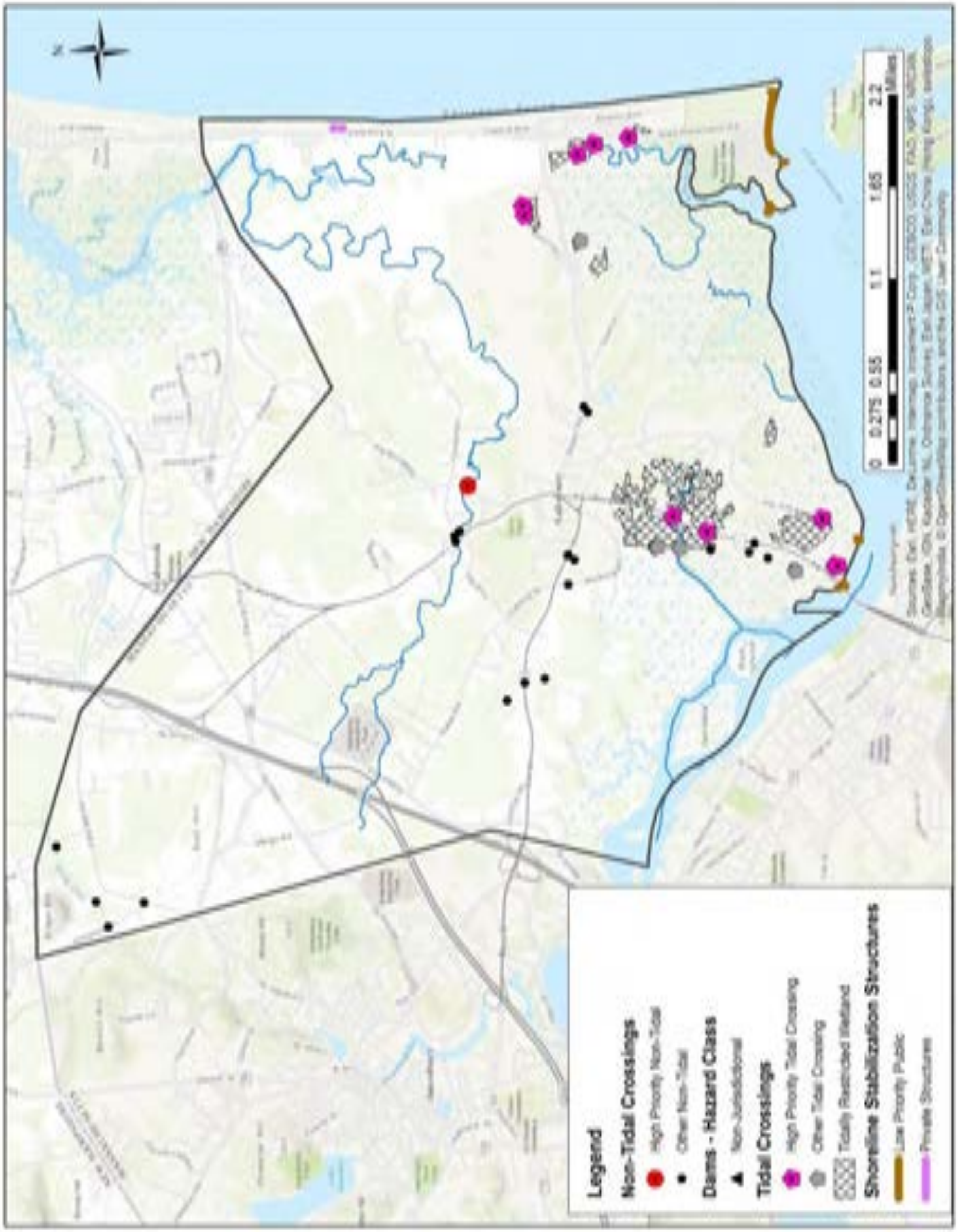

Figure B-1. Map and summary of results the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Salisbury, Massachusetts

Table B-2. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the City of Newburyport, MA.

Data Set		Structure Count	Structures by Category		
Non-Tidal Stream Crossings		35*	Priority	Storm Return Interval	Initial Hydraulic Screen Fail
			Low	Pass all	1
				100 year (1%)	1
				50 year (2%)	1
			High	25 year (4%)	2
				10 year (10%)	2
				2 Year (50%)	3
Tidal Stream Crossings		4	Priority	Count	
			Low	4	
			High		
Dams		4	Priority	Hazard Class	Count
			Low	Non-Jurisdictional	
				Low Hazard	4
			High	Significant Hazard	
Shoreline Stabilization Structures	Public	17	Priority	Condition	Count
			Low	A - Excellent	1
				B - Good	9
				C - Fair	7
			High	D - Poor	
				F - Critical	
	Private	14	Not Prioritized		

* There are a total of 35 non-tidal stream crossings in the Newburyport data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

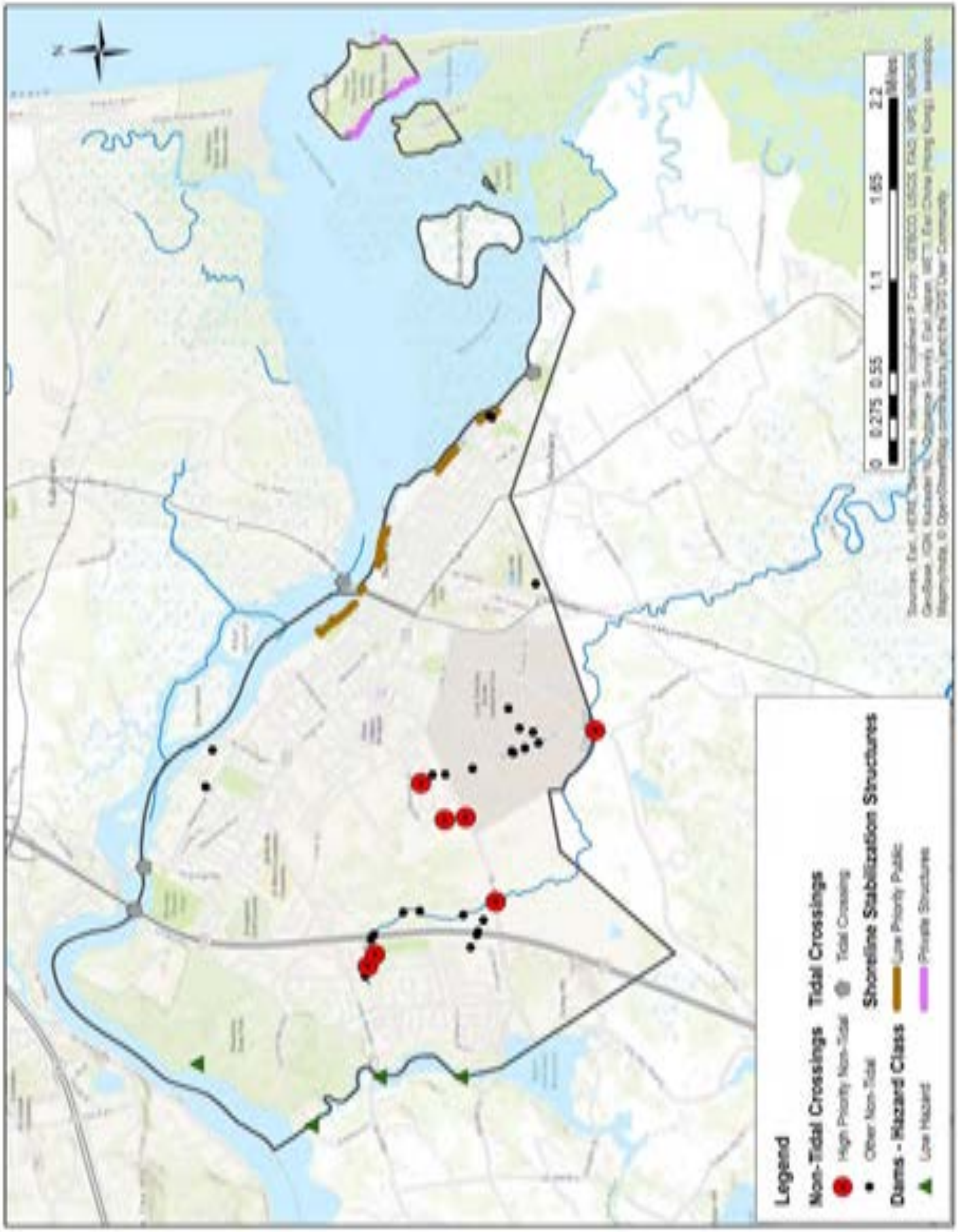

Figure B-2. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the City of Newburyport, MA.

Table B-3. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Newbury, MA.

Data Set		Structure Count	Structures by Category		
Non-Tidal Stream Crossings		80*	Priority	Storm Return Interval	Initial Hydraulic Screen Fail
			Low	Pass all	11
				100 year (1%)	
				50 year (2%)	
			High	25 year (4%)	1
				10 year (10%)	5
				2 Year (50%)	9
Tidal Stream Crossings		27	Priority	Count	
			Low	19	
			High	8	
Dams		9	Priority	Hazard Class	Count
			Low	Non-Jurisdictional	6
				Low Hazard	3
			High	Significant Hazard	
Shoreline Stabilization Structures	Public	2	Priority	Condition	Count
			Low	A - Excellent	
				B - Good	1
				C - Fair	
			High	D - Poor	1
				F - Critical	
	Private	19	Not Prioritized		

* There are a total of 80 non-tidal stream crossings in the Newbury data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

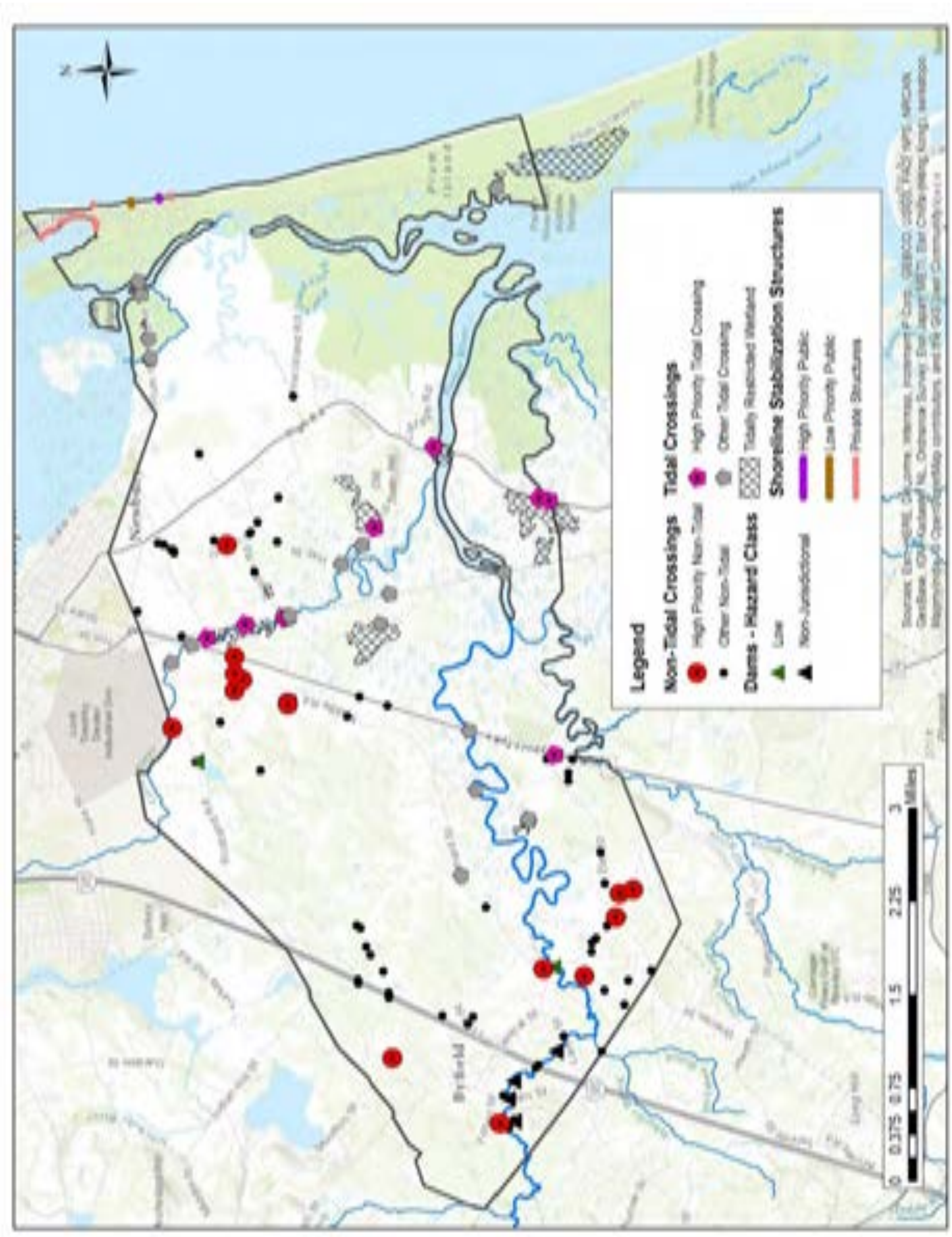

Figure B-3. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Newbury, MA.

Table B-4. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Rowley, MA.

Data Set		Structure Count	Structures by Category		
Non-Tidal Stream Crossings		76*	**Priority**	**Storm Return Interval**	**Initial Hydraulic Screen Fail**
			Low	Pass all	15
				100 year (1%)	
				50 year (2%)	1
			High	25 year (4%)	1
				10 year (10%)	6
				2 Year (50%)	15
Tidal Stream Crossings		9	**Priority**	**Count**	
			Low	7	
			High	2	
Dams		6	**Priority**	**Hazard Class**	**Count**
			Low	Non-Jurisdictional	3
				Low Hazard	2
			High	Significant Hazard	1
Shoreline Stabilization Structures	**Public**	0	**Priority**	**Condition**	**Count**
			Low	A - Excellent	
				B - Good	
				C - Fair	
			High	D - Poor	
				F - Critical	
	Private	0	Not Prioritized		

* There are a total of 76 non-tidal stream crossings in the Rowley data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

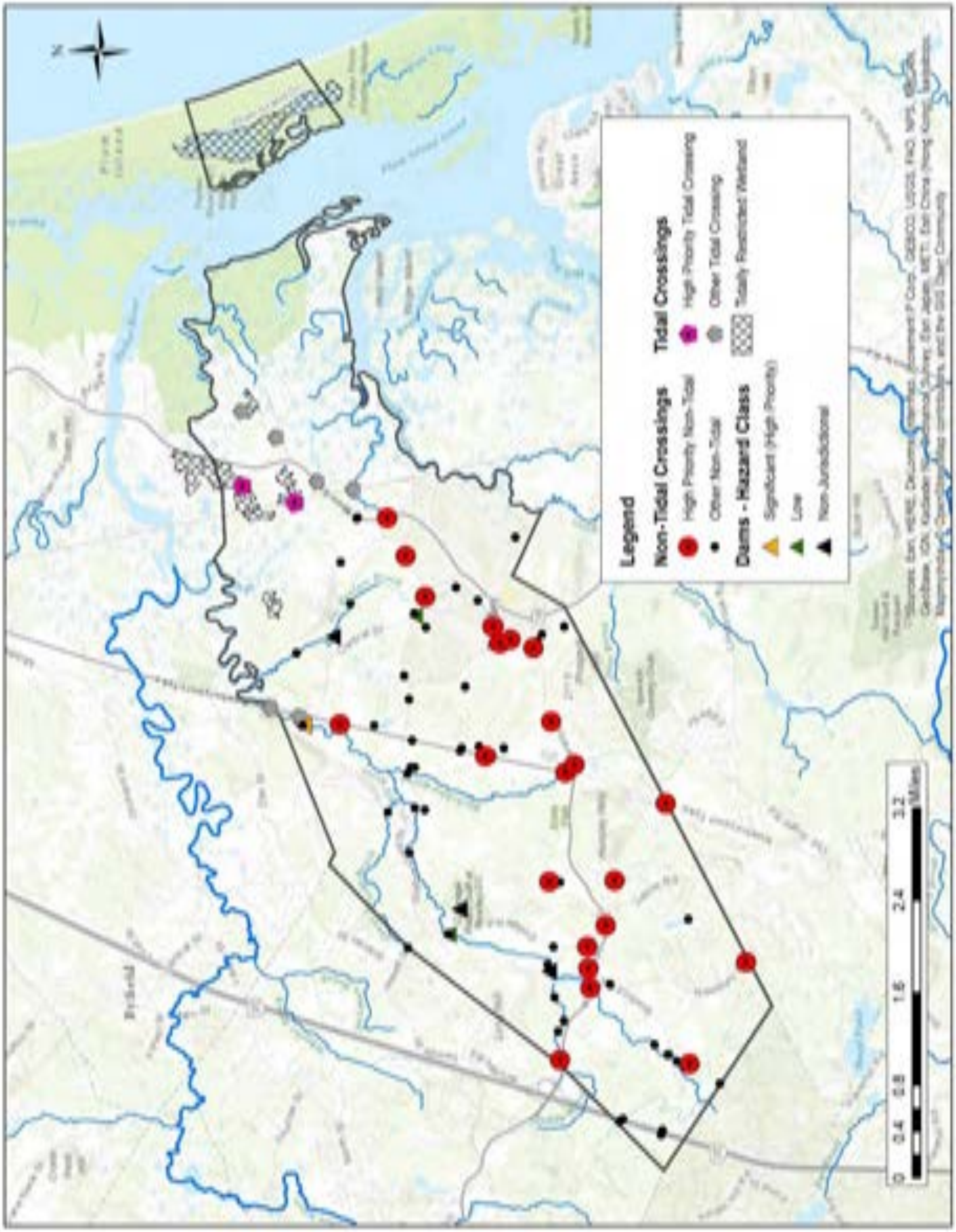

Figure B-4. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Rowley, MA.

Table B-5. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Ipswich, MA.

Data Set		Structure Count	Structures by Category		
Non-Tidal Stream Crossings		87*	Priority	Storm Return Interval	Initial Hydraulic Screen Fail
			Low	Pass all	12
				100 year (1%)	2
				50 year (2%)	1
			High	25 year (4%)	1
				10 year (10%)	5
				2 Year (50%)	16
Tidal Stream Crossings		17	Priority	Count	
			Low	10	
			High	7	
Dams		6	Priority	Hazard Class	Count
			Low	Non-Jurisdictional	2
				Low Hazard	3
			High	Significant Hazard	1
Shoreline Stabilization Structures	Public	1	Priority	Condition	Count
			Low	A - Excellent	
				B - Good	
				C - Fair	1
			High	D - Poor	
				F - Critical	
	Private	24	Not Prioritized		

* There are a total of 87 stream crossings in the Ipswich data set, including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

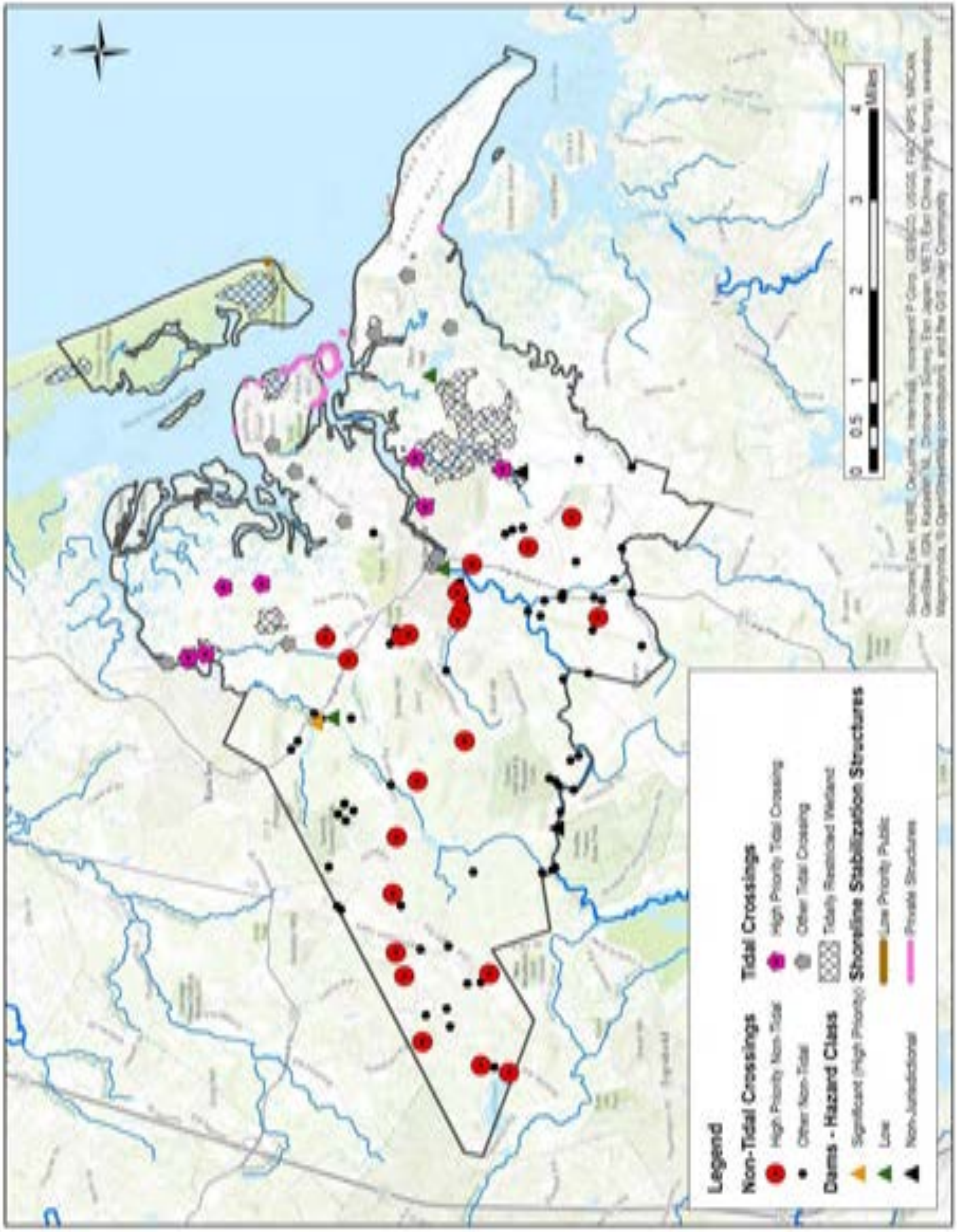

Figure B-5. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Ipswich, MA.

Table B-6. Summary results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Essex, MA.

Data Set		Structure Count	Structures by Category		
Non-Tidal Stream Crossings		38*	Priority	Storm Return Interval	Initial Hydraulic Screen Fail
			Low	Pass all	7
				100 year (1%)	0
				50 year (2%)	0
			High	25 year (4%)	3
				10 year (10%)	2
				2 Year (50%)	3
Tidal Stream Crossings		12	Priority	Count	
			Low	7	
			High	5	
Dams		0	Priority	Hazard Class	Count
			Low	Non-Jurisdictional	
				Significant Hazard	
			High	Non-Jurisdictional	
Shoreline Stabilization Structures	Public	0	Priority	Condition	Count
			Low	A - Excellent	
				B - Good	
				C - Fair	
			High	D - Poor	
				F - Critical	
	Private	0	Not Prioritized		

*There are a total of 38 non-tidal stream crossings in the Essex data set including a number of sites that were inaccessible for reasons including safety and private property. The Initial Hydraulic Screen Fail column indicates the number of sites that failed to pass for the first time at the associated return interval storm. That is, those sites passed the HC model screen at all higher percentage (more frequent) storms.

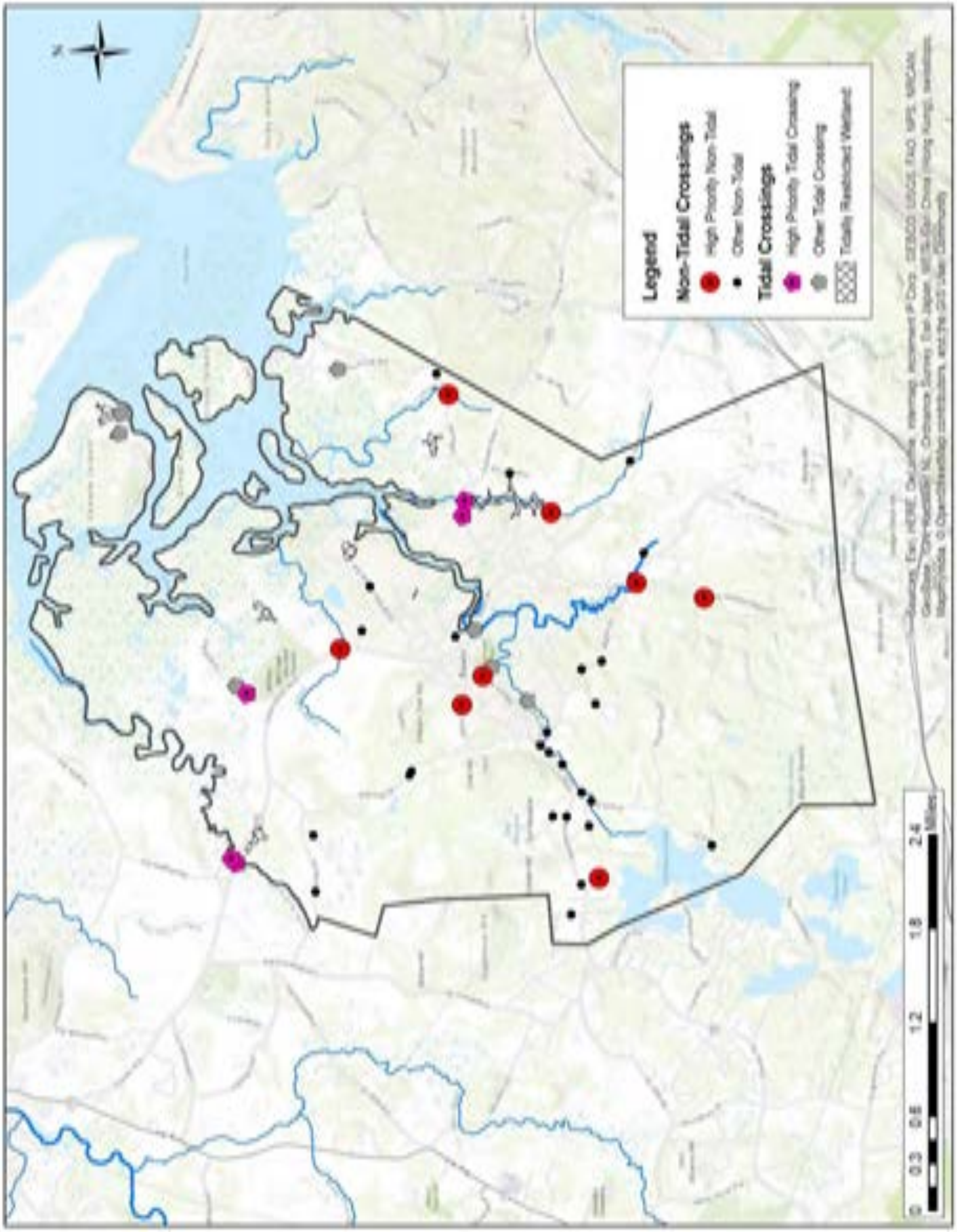

Figure B-6. Map and summary of results from the Regional Assessment and Prioritization of Barriers to Flow in the Great Marsh Watershed for the Town of Essex, MA.

APPENDIX C:
Vulnerable Areas of Special Concern

During the planning process, the following assets were identified as areas of special concern due to their current and future vulnerability and the consequences if the area/asset is impacted by flooding or erosion. The Municipal and Regional Resiliency Task Forces contributed extensive local knowledge to inform the identification of these areas. A geospatial analysis also helped identify areas vulnerable to future inundation.

Table C-1. Identified vulnerable areas of special concern by town; (*) = identified by the Resiliency Task Force as an area of primary concern; (◊) = Located in a state designated Area of Critical Environmental Concern (ACEC)

Town	Area of Concern	Location	Hazard Type
Essex	Main Street Causeway & Woodman's Landing*	74 to 166 Main Street	Flooding
Essex	Eastern Avenue at Ebben Creek*◊	81 Eastern Ave to 97 Eastern Ave	Flooding
Essex	Conomo Point Road*◊	All of Conomo Point Road	Flooding
Essex	Crane Beach (tip of point)* ◊	290 Argilla Rd, Ipswich	Erosion
Essex	Eastern Ave and Grove St	Intersection of Eastern Ave and Grove Street	Flooding
Essex	Richdale's Gas Station	156 Main Street	Flooding
Essex	Ball fields behind town hall and playground	30 Martin Street	Flooding
Essex	Landing Road culvert	9 Landing Road	Flooding
Essex	Apple Street culvert near Andrews Street	Essex River culvert at Apple Street	Flooding
Ipswich	Downtown Ipswich (including Choate Bridge and South Main Street)*	Downtown along the Ipswich River, Route 133/1A	Flooding
Ipswich	Sewage Pumping Station	Town Wharf at 68 East St.	Flooding
Ipswich	Jeffrey's Neck Road*◊	Beachview Lane northeast to 144 Jeffrey's Neck Rd	Flooding
Ipswich	Crane Beach (including parking lots/beach facility)*◊	290 Argilla Rd, Ipswich	Erosion, coastal flooding
Ipswich	Pavilion Beach◊	Beach connecting Great and Little Neck	Erosion
Ipswich	Massachusetts Bay Transportation Authority (MBTA) Newburyport Train Line◊	Ipswich portion of train tracks	Storm surge and sea level rise; tracks act as a barrier to natural coastal flowage patterns
Ipswich	Brown's well (Ipswich drinking water supply)	Route 1A at Muddy Run /188 High St	Flooding, salt water infiltration due to sea level rise

Town	Area of Concern	Location	Hazard Type
Ipswich	Clark Beach◊	Beach bordering Clark Pond	Erosion
Ipswich	Clark Pond◊	Great Neck	Coastal flooding
Newbury	Plum Island Turnpike/Plum Island Airport/Plumbush Downs*◊	MA Audubon's Joppa Flats Education Center East to Sunset Dr.	Tidal and storm flooding
Newbury	Sewage Pumping Station on Plum Island*	Webbers Ct. & Olga Way, in Basin Harbor neighborhood	Near area subject to overtopping, projected coastal inundation
Newbury	Low-lying houses along bayside of Plum Island	Basin Harbor neighborhood located between Old Point Road and Northern Boulevard, north of Plum Island turnpike.	Projected coastal inundation
Newbury	Newbury Elementary School (Little River @ Hanover St)*◊	63 Hanover St.	Emergency shelter – access point from west side floods
Newbury	Newburyport Turnpike/Rt. 1*◊	Rt.1 at Parker River bridge	Tidal and storm flooding
Newbury	Low-lying houses along bayside of Plum Island	Basin Harbor neighborhood located between Old Point Road and Northern Boulevard, north of Plum Island turnpike.	Projected coastal inundation
Newbury	Route 1A at Rowley border, including Old Rowley Road	Route 1A at Rowley border	Flooding of roads & residences
Newbury	Lord Timothy Dexter Industrial Green ("Business Park")	Parker St, Scotland Rd)	Flooding caused by small culverts
Newbury	Triton Middle & High School	112 Elm St	Possible future flooding of ball fields
Newbury	Newburyport MBTA Train Station	Route 1 rotary near Little River & back end of Parker St	Flooding
Newbury	Pine Island Road	All of Pine Island Road that is along the marsh	Flooding, ice cakes, high winds, zero visibility
Newbury	Refuge Road	From the Plum Island Turnpike south into Parker River NWR	Flooding
Newbury	Governor's Academy	Campus and waste water treatment plant located between Mill River, Elm St, Route 1, and Parker River	Tidal and storm flooding from Parker River and floodplain
Newbury	Cottage Road, off of 1A near Parker River	Boat ramp at the end of Cottage Road	Flooding from Parker River
Newbury	Central St. dam	70 Central St	Flooding, possible dam failure

Town	Area of Concern	Location	Hazard Type
Newbury	River St./Forest St. dam	Just north of intersection between West St and Main St	Flooding, possible dam failure
Newbury	Plum Island Beach and groins/jetties	East from the end of Plum Island Turnpike and south on beach next to Southern Boulevard	Flooding, erosion, jetties deteriorate over time
Newburyport	Plum Island Beach and groins/jetties	East from the end of Plum Island Turnpike and south on beach next to Southern Boulevard	Flooding, erosion, jetties deteriorate over time
Newburyport	Merrimack River Jetty System*	Mouth of the Merrimack River	Deteriorates over time; potentially increases erosion, jetty design is a concern
Newburyport	North End of Plum Island*	Reservation Terrace Old Point Neighborhood	Projected coastal inundation
Newburyport	Plum Island Turnpike (including Plum Island Airport)*◊	Joppa Flats Nature Center East to Sunset Dr.	Tidal and storm flooding
Newburyport	Waste Water Treatment Facility*	157 Water Street	Flooding from storm surge and sea level rise
Newburyport	Central Waterfront (historic downtown)	East of Merrimac/Water Street, between Green Street and the Harbor Master Shack	Flooding
Newburyport	Water Street (including Salvation Army & Coast Guard Station)	Plum Island Turnpike to Merrimac Street	Flooding
Newburyport	Cashman Park	West of Route 1 bridge, between Merrimac River and Merrimac Street	Flooding
Newburyport	Lower Artichoke Reservoir*	Between Storey Ave (Rt 113) & Middle Rd., West Newbury	Salt-water intrusion
Newburyport	Bartlett Spring Pond*	742 Spring Ln	Salt-water intrusion
Newburyport	Lord Timothy Dexter Industrial Green (Business Park)	104 Parker Street/Scotland Road	Flooding at Little River
Rowley	Route 133 at Bachelder Brook*	Northeast of 312 Haverhill St	Flooding
Rowley	Jewel Mill Dam*	west of the intersection between Mill St and Glen St	Dam failure/flooding

Town	Area of Concern	Location	Hazard Type
Rowley	Rowley Town Well # 3*	Along Mill River off of Boxford Road	Flooding, inundation of well pump station
Rowley	13 acres of beach on Parker River National Wildlife Refuge*◊	Plum Island	Erosion, coastal flooding
Rowley	Hillside St culvert at tributary to Mill River*	Great Swamp Brook at Hillside Street	Flooding
Rowley	Stackyard Road + Route 1A◊	Stackyard Road and Route 1A from Stackyard Road north to town line (plus Newbury section of Route 1A to Parker River)	Flooding
Rowley	Marina & town boat launch◊	Railroad Avenue/Warehouse Lane, off of Rt 1A	Flooding
Rowley	Massachusetts Bay Transporta-tion Authority (MBTA) Newburyport Train Line◊	Rowley portion of train tracks	Storm surge and sea level rise; tracks act as a barrier to natural coastal flowage patterns
Salisbury	Route 1A (Beach Road)*	North End Blvd intersection west .5 miles	Flooding
Salisbury	Salisbury Beach at Broadway*	East of the Broadway Mall, stretching 200ft north and south	Erosion, flooding
Salisbury	Salisbury Barrier Beach	3.8 mile long beach from NH Border to Merrimack River, including jetty and dunes.	Erosion, flooding
Salisbury	Route 1 and Associated Infrastructure	From downtown to the Merrimack bridge, particularly low-lying areas near 54 and 93 Bridge Road and at the Merrimack River Bridge.	Projected coastal inundation
Salisbury	Low-lying houses along the bayside of Salisbury Beach	- Neighborhood east of road to Salisbury reservation - Low-lying residential area north of Beach Center, west of 1A that surround the Blackwater river	Projected coastal inundation
Salisbury	North End Boulevard	from Old Town Way to 18th street	Flooding
Salisbury	Sewage Pumping Station	228 Beach Rd	Flooding
Salisbury	Town Pier	32 1st Street	Erosion, coastal flooding

Town	Area of Concern	Location	Hazard Type
Salisbury	Beach Rose RV Park	147 Beach Road	Projected coastal inundation
Salisbury	Rings Island neighborhood & marina	1st St neighborhood between Route 1 and Merrimack River	Projected coastal inundation
Salisbury	Access Road to Salisbury Beach State Park	State Beach Road, State Reservation Road	Projected coastal inundation
Salisbury	Hayes Street neighborhood	Off of Beach Road near 163 Beach Rd	Projected coastal inundation
Salisbury	Salisbury Police Station	175 Beach Road	Projected coastal inundation

APPENDIX D:
Town-specific Inundation Maps

The following maps illustrate current (2013) and future (2070) probability of coastal inundation in the six shore-front communities (listed north to south). Coastal inundation data was produced by the Woods Hole Group[14] using a hydrodynamic model developed for the Massachusetts Department of Transportation[15] (Figure D-1). It's important to note that this model does not take into account inland freshwater flooding. Present day (considered 2013) results incorporate existing sea level conditions. 2070 results incorporate 3.4 feet of sea level rise, which is also approximately the "Intermediate-High" scenario for 2090.

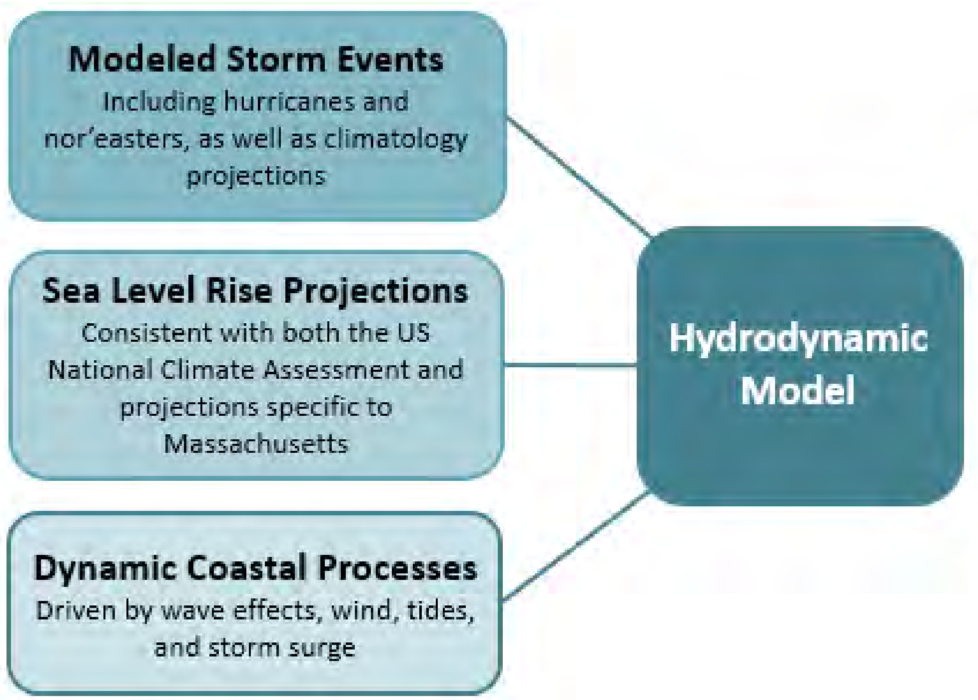

Figure D-1. Schematic summary of inputs built into the hydrodynamic model, as developed for the Massachusetts Department of Transportation (Bosma et al. 2016).

[14] Famely, J., K. Bosma and B. Hoffnagle, *Sea Level Rise and Storm Surge Inundation Mapping – Great Marsh Communities (Essex County, MA)*, Prepared for National Wildlife Federation and U.S. Geological Survey (East Falmouth, MA: Woods Hole Group, 2016).

[15] Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson, *MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery* (East Falmouth, MA: Woods Hole Group, 2016), https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_Report_MassDOT_FHWA.pdf

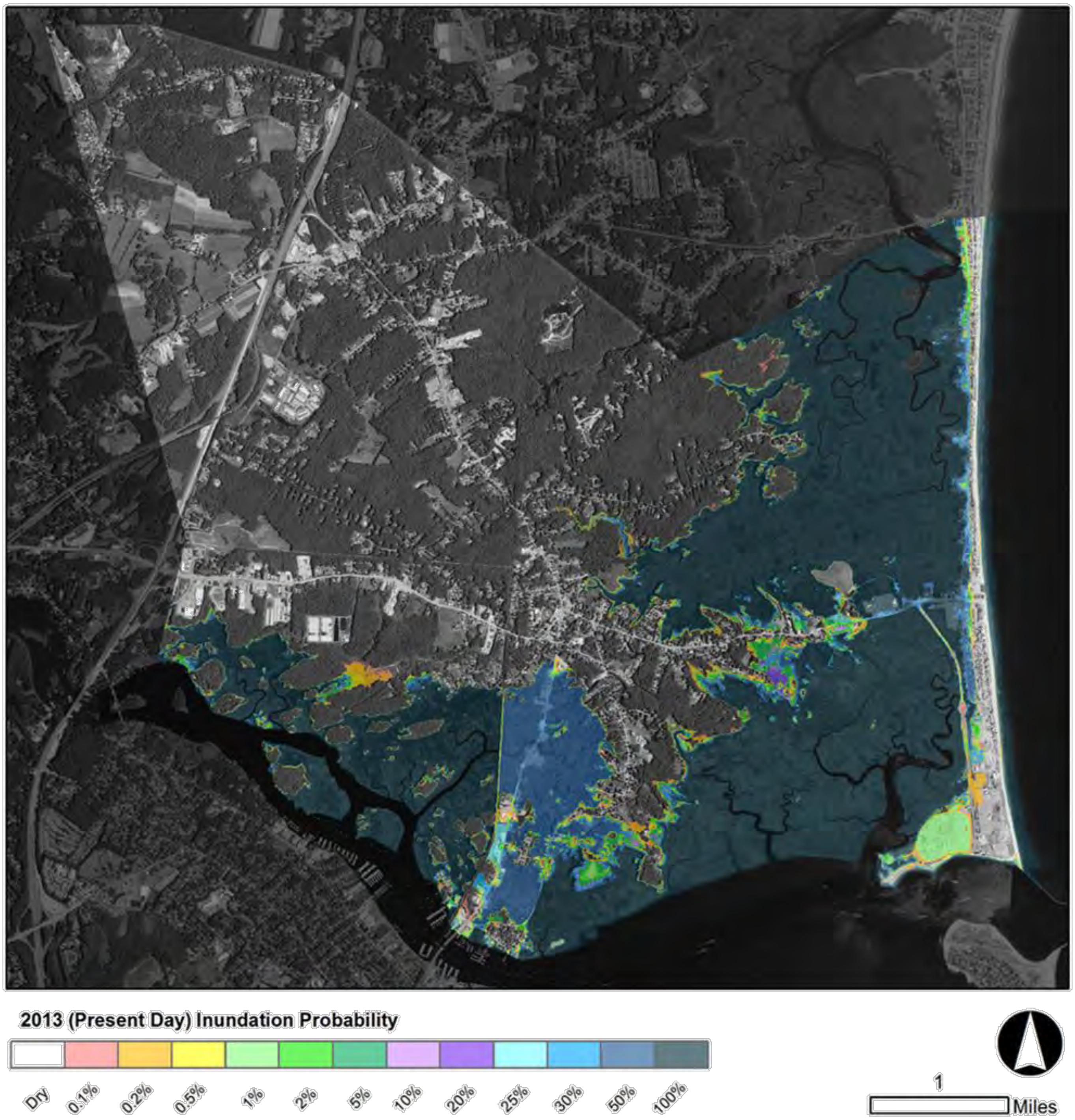

Figure D-1. Town of Salisbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

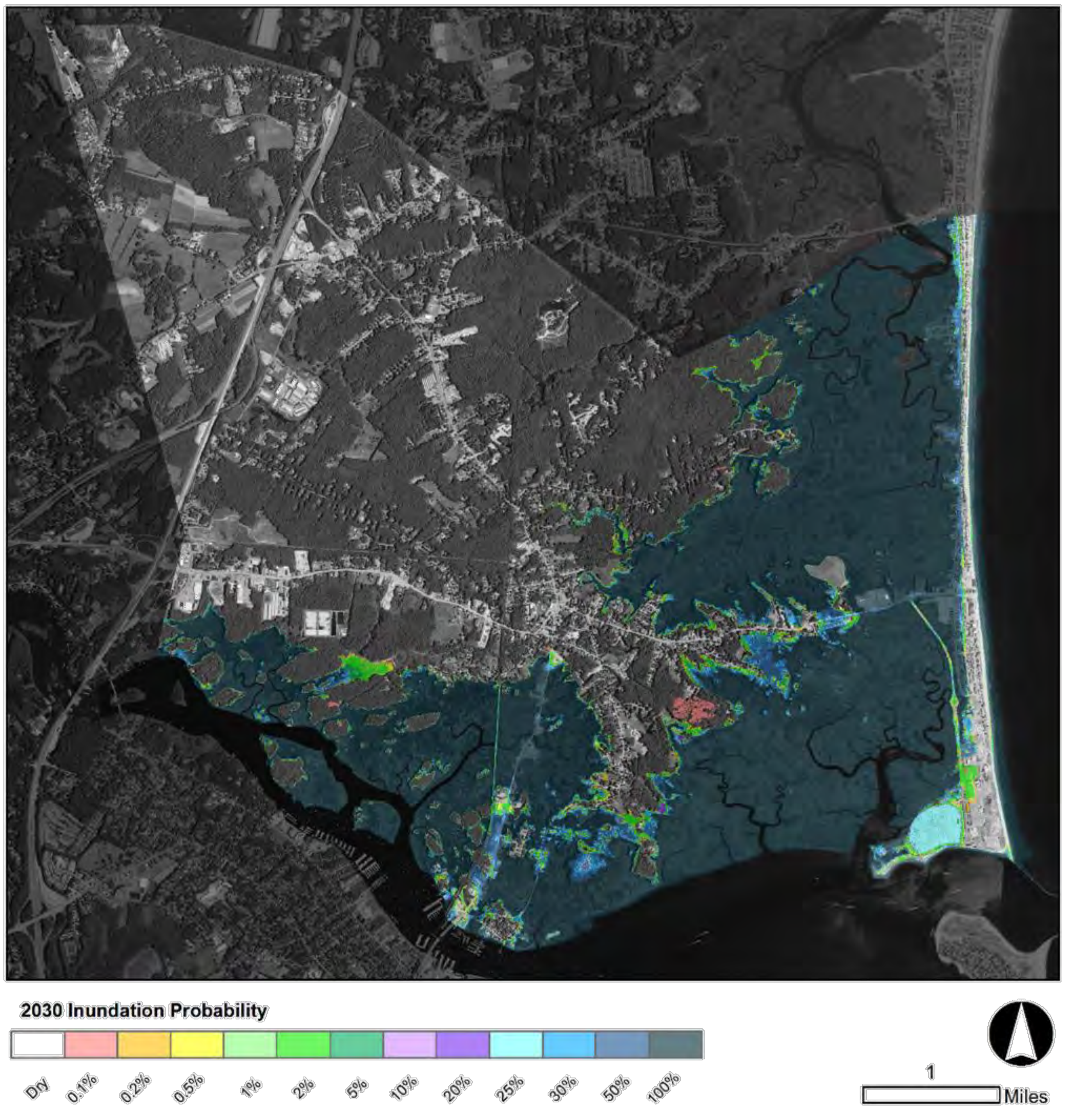

Figure D-2. Town of Salisbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

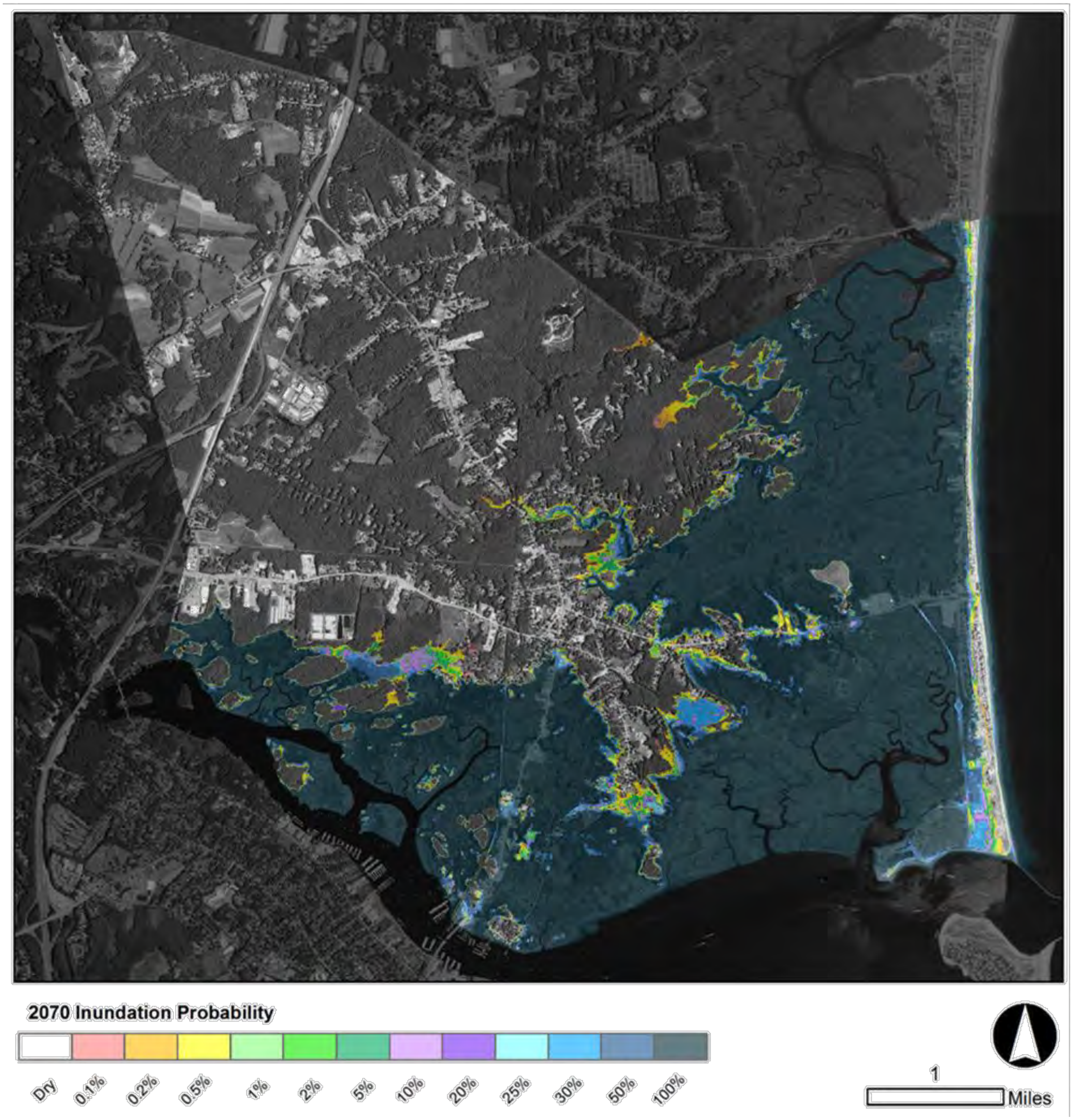

Figure D-3. Town of Salisbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

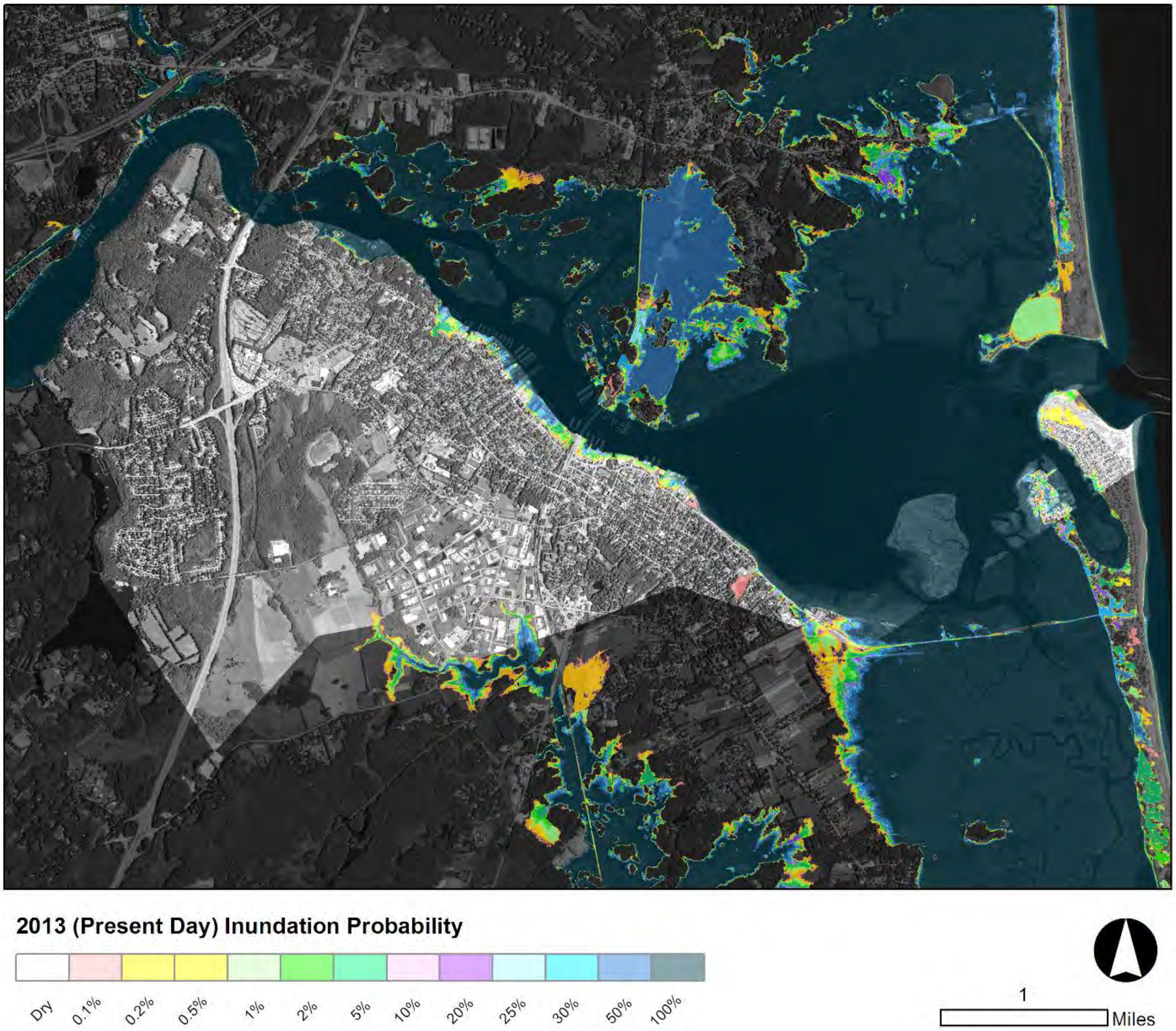

Figure D-4. City of Newburyport, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

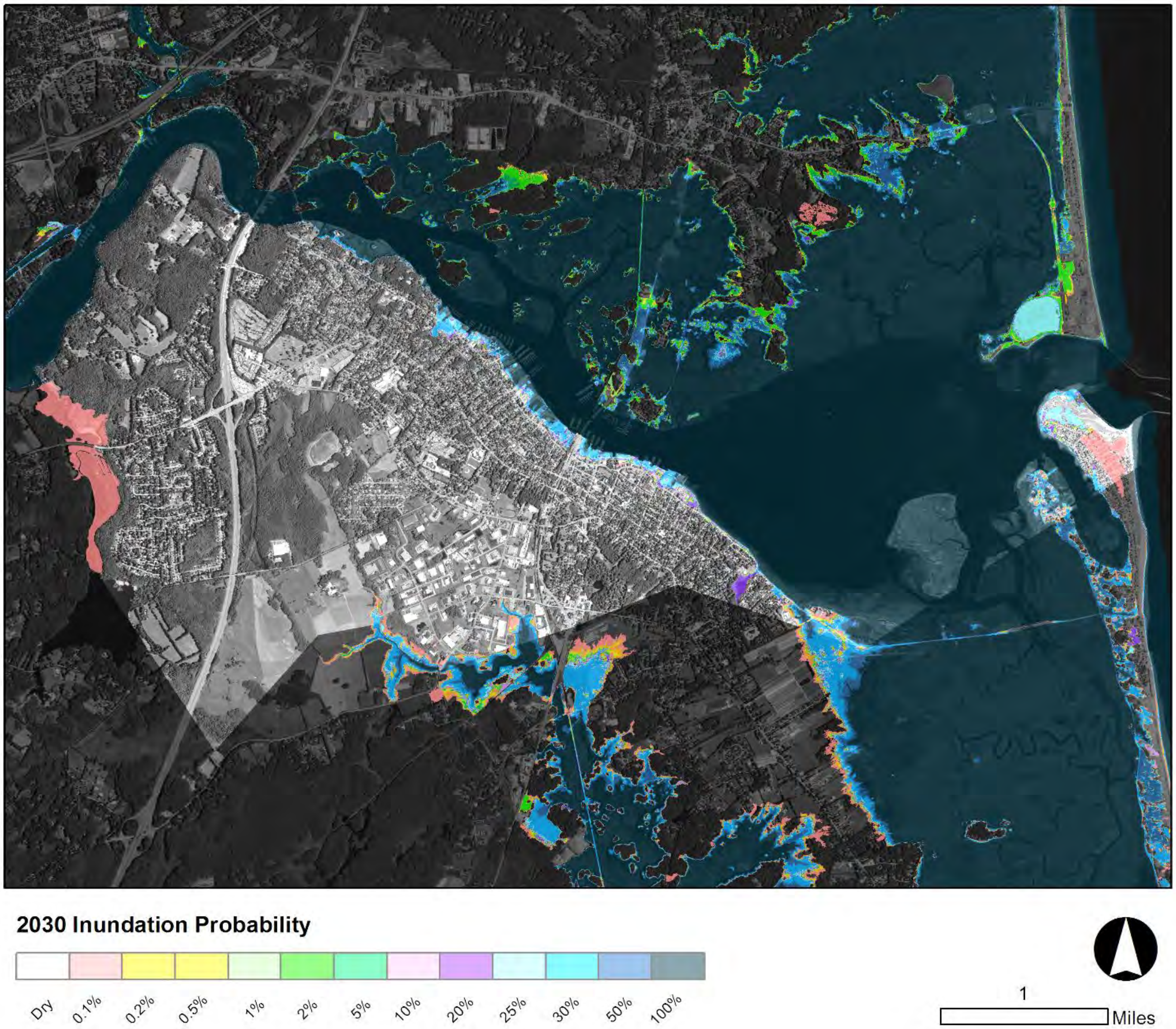

Figure D-5. City of Newburyport, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

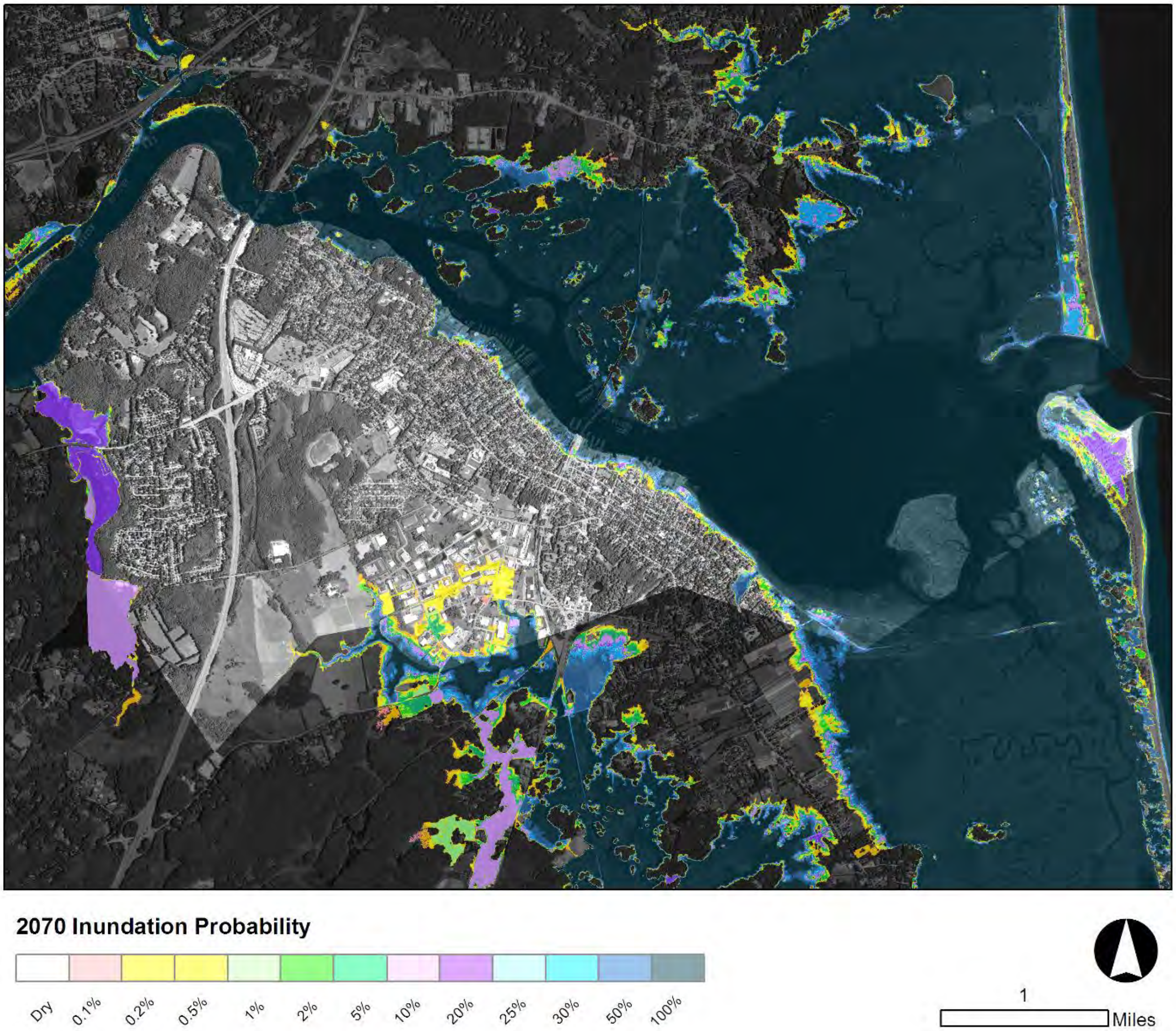

Figure D-6. City of Newburyport, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

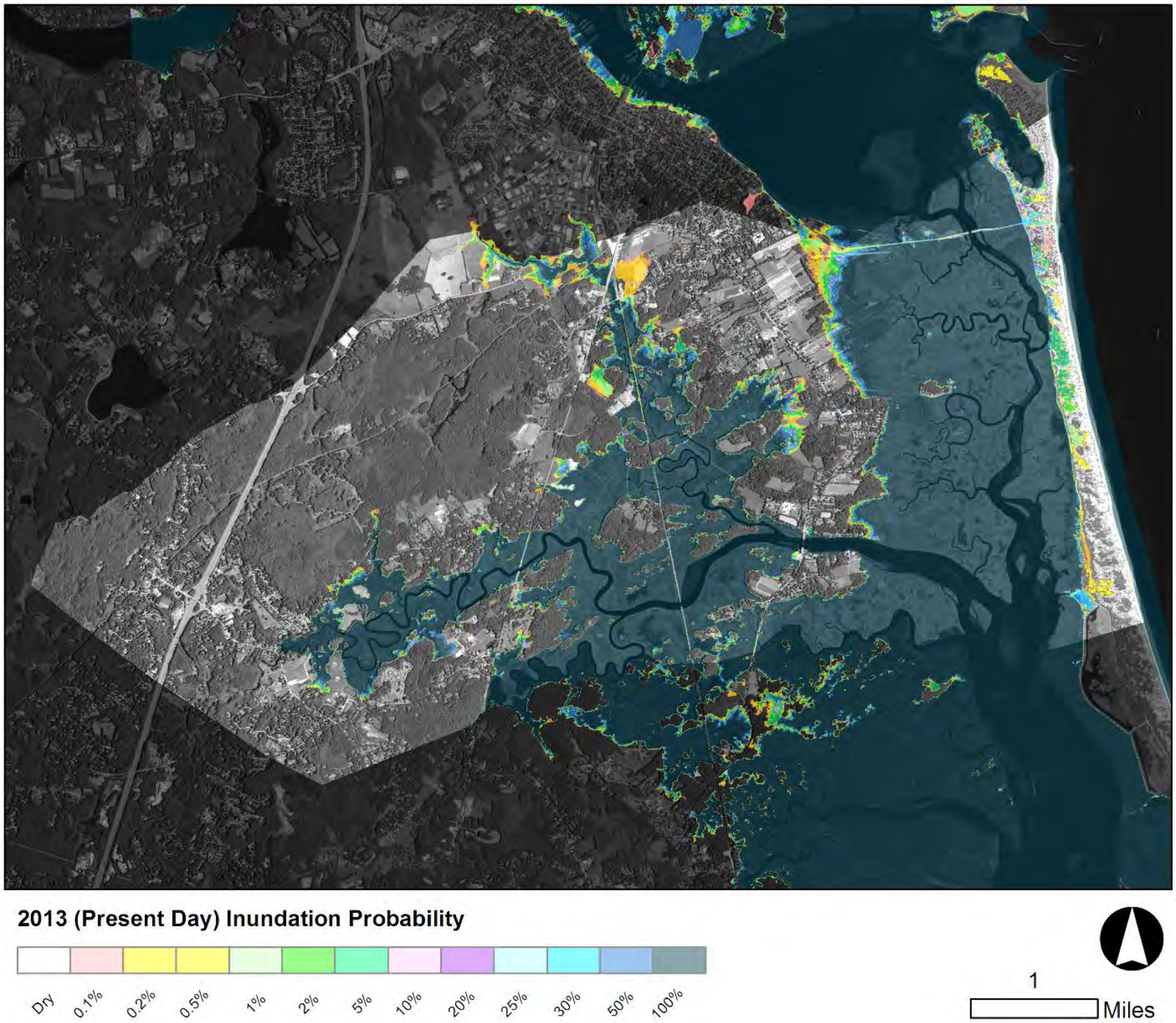

Figure D-7. Town of Newbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

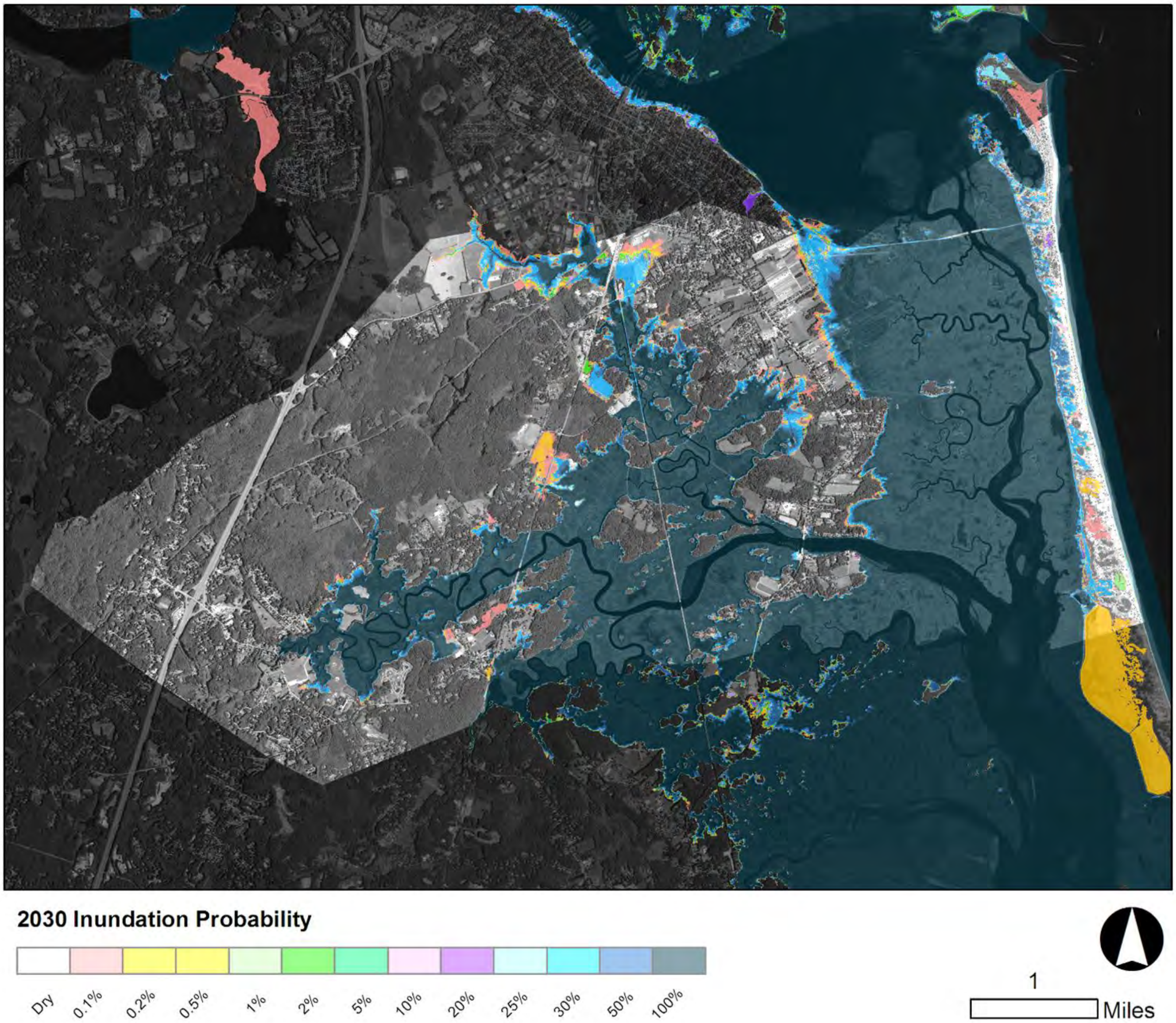

Figure D-8. Town of Newbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

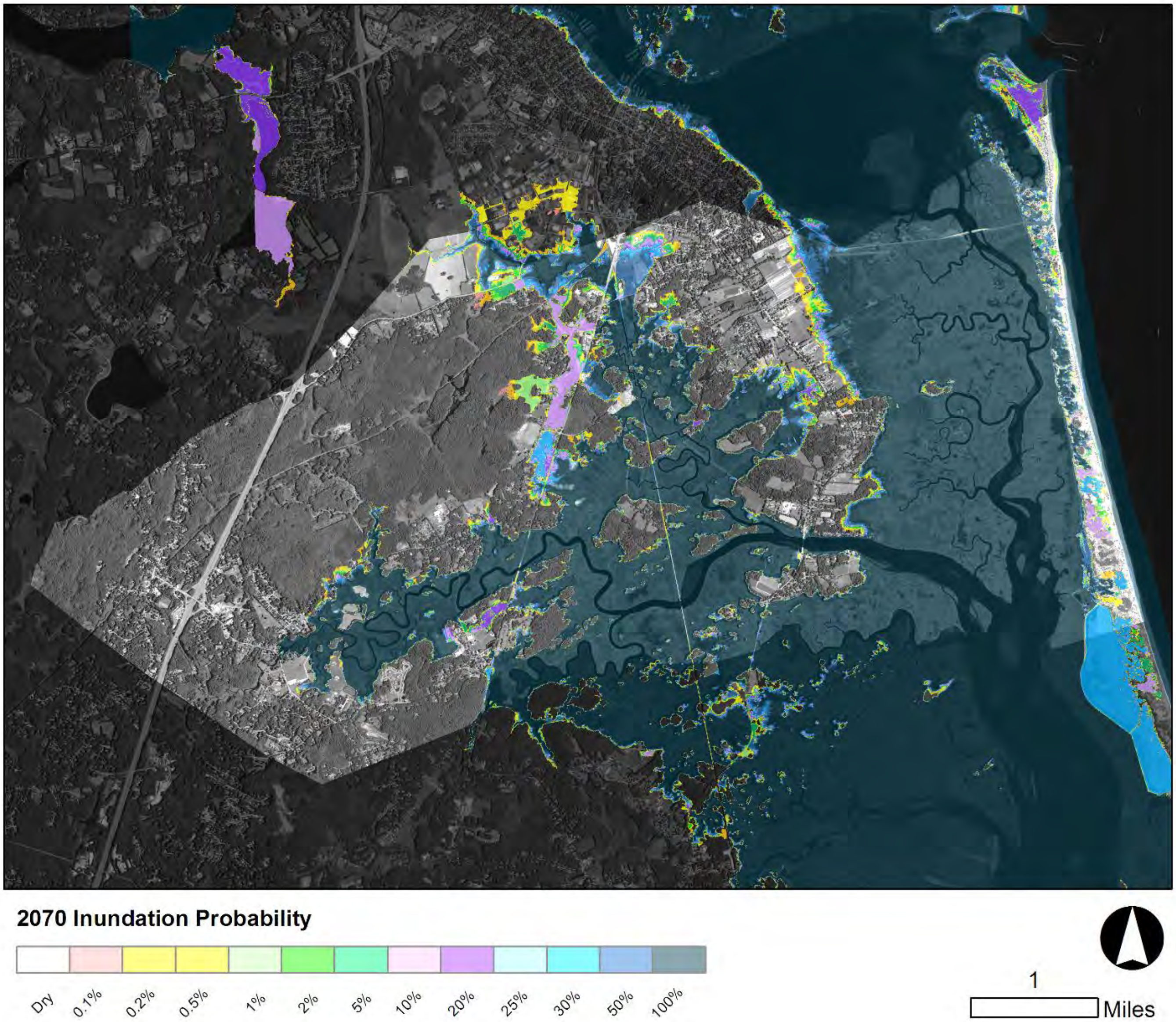

Figure D-9. Town of Newbury, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

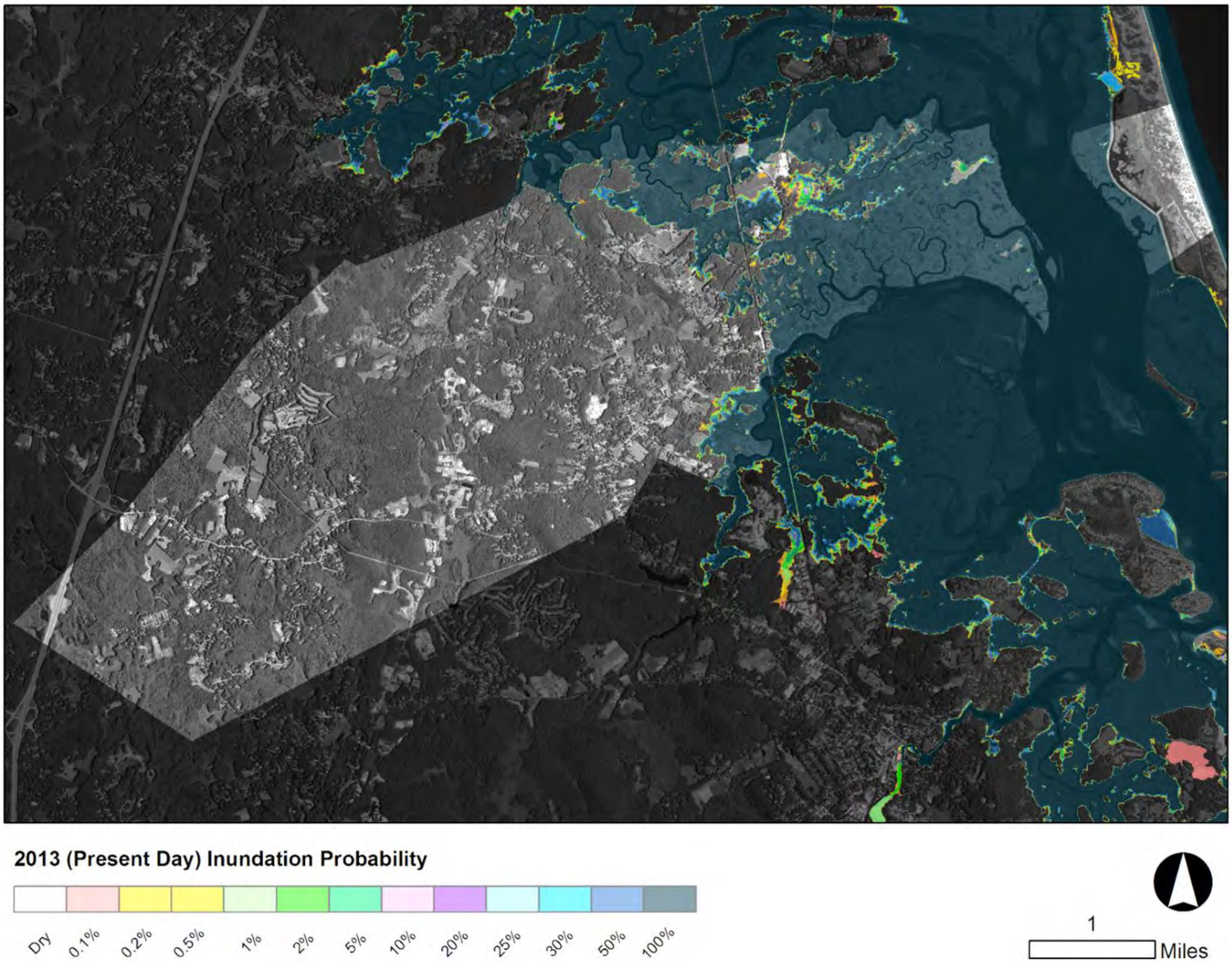

Figure D-10. Town of Rowley, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

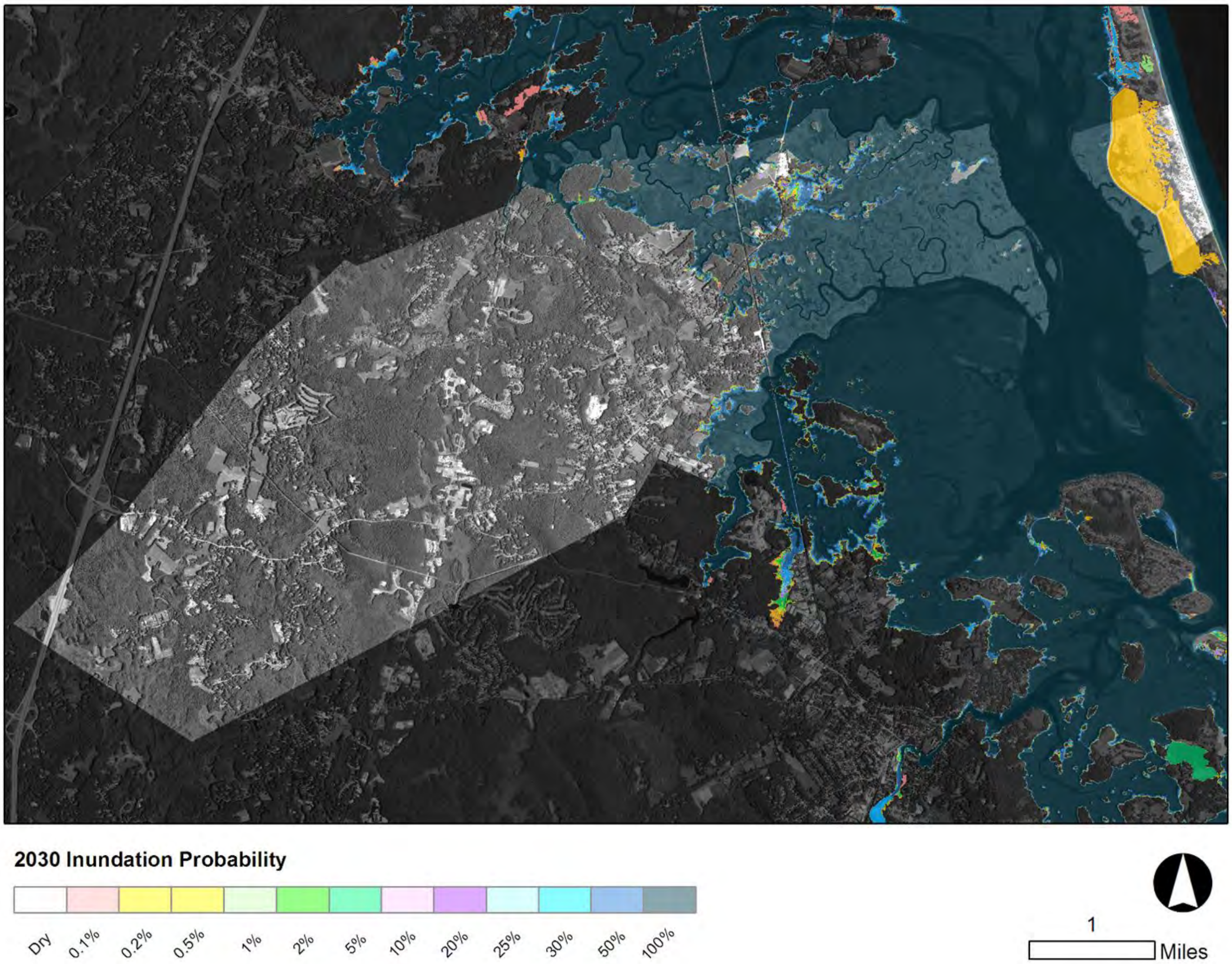

Figure D-11. Town of Rowley, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

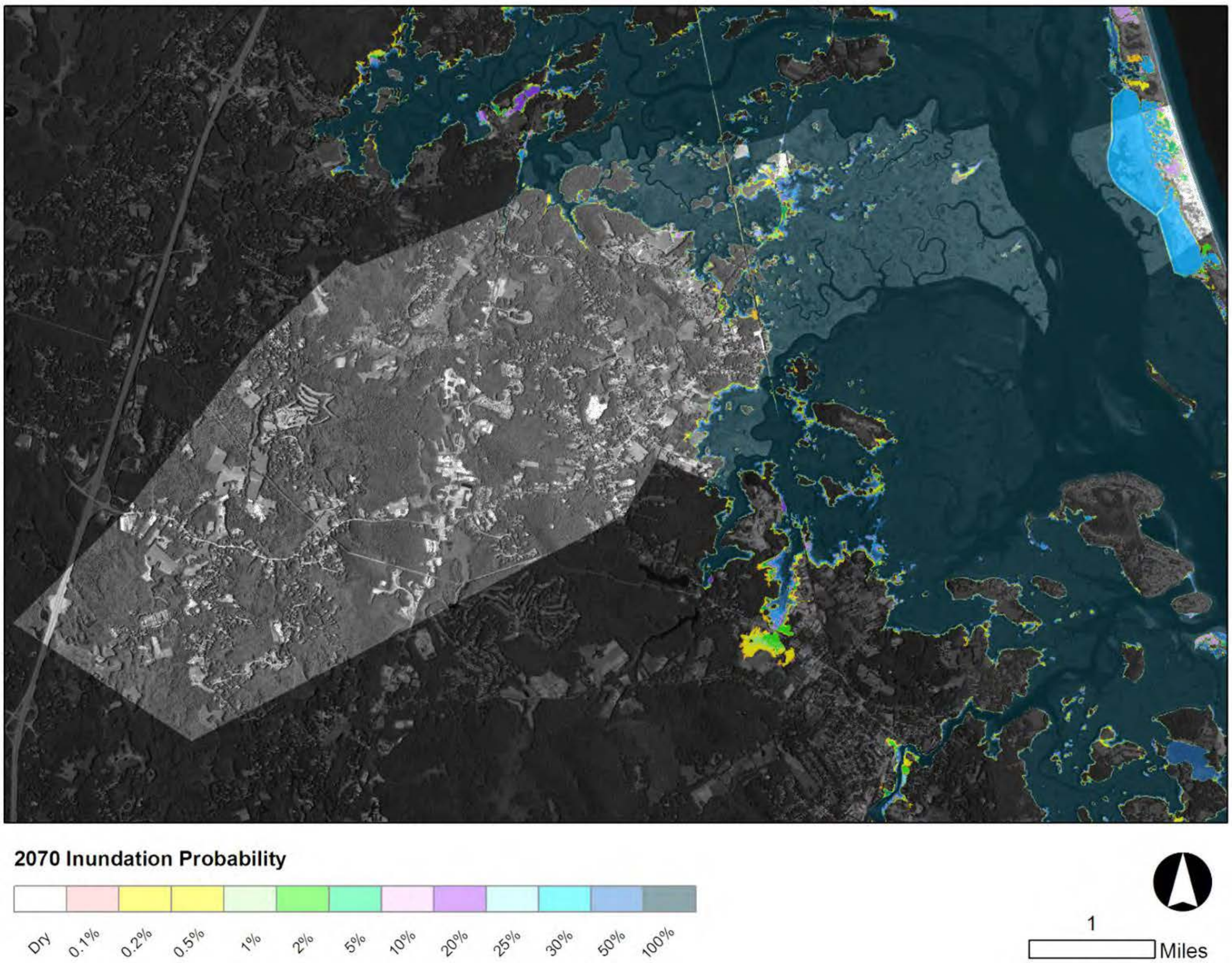

Figure D-12. Town of Rowley, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

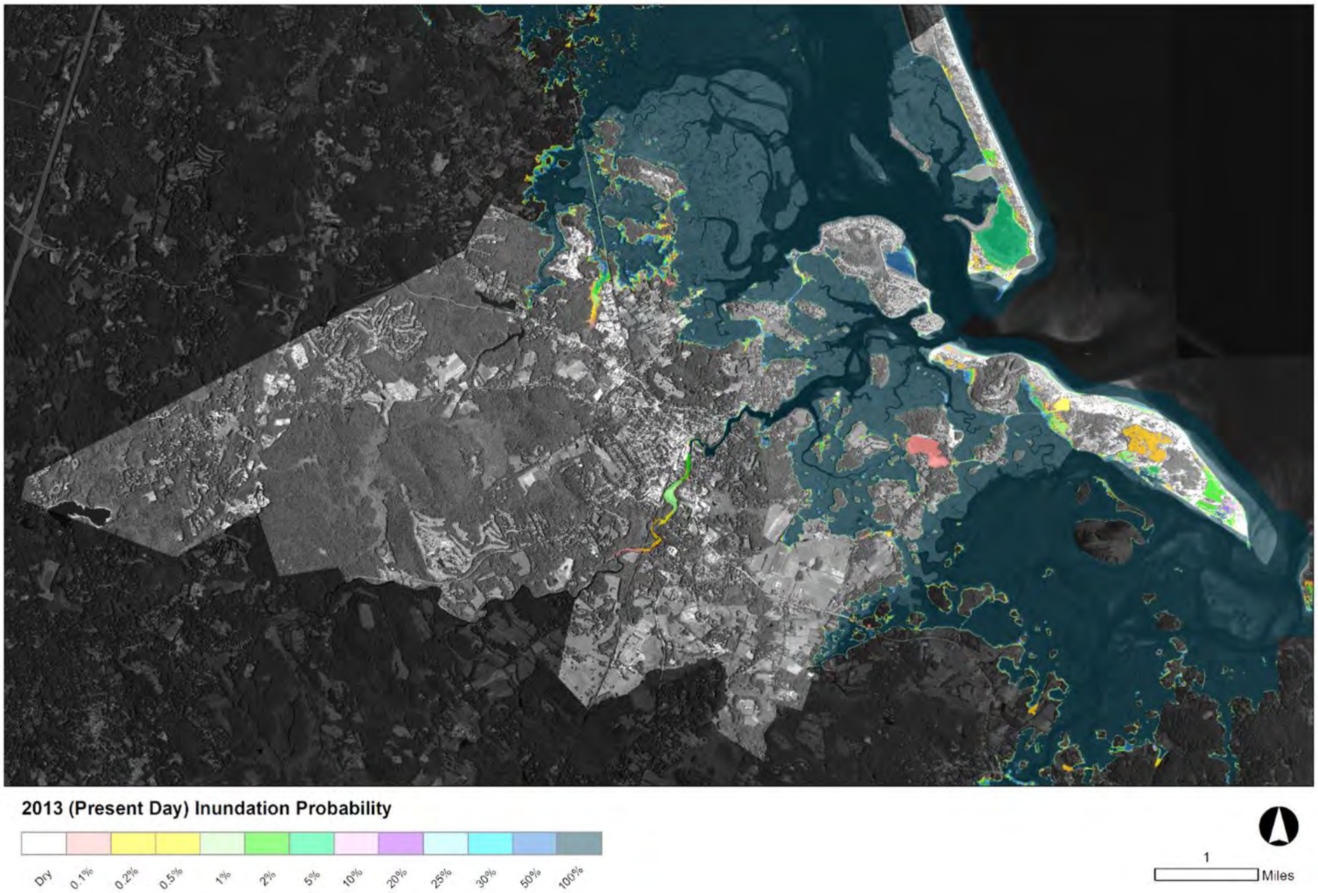

Figure D-13. Town of Ipswich, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

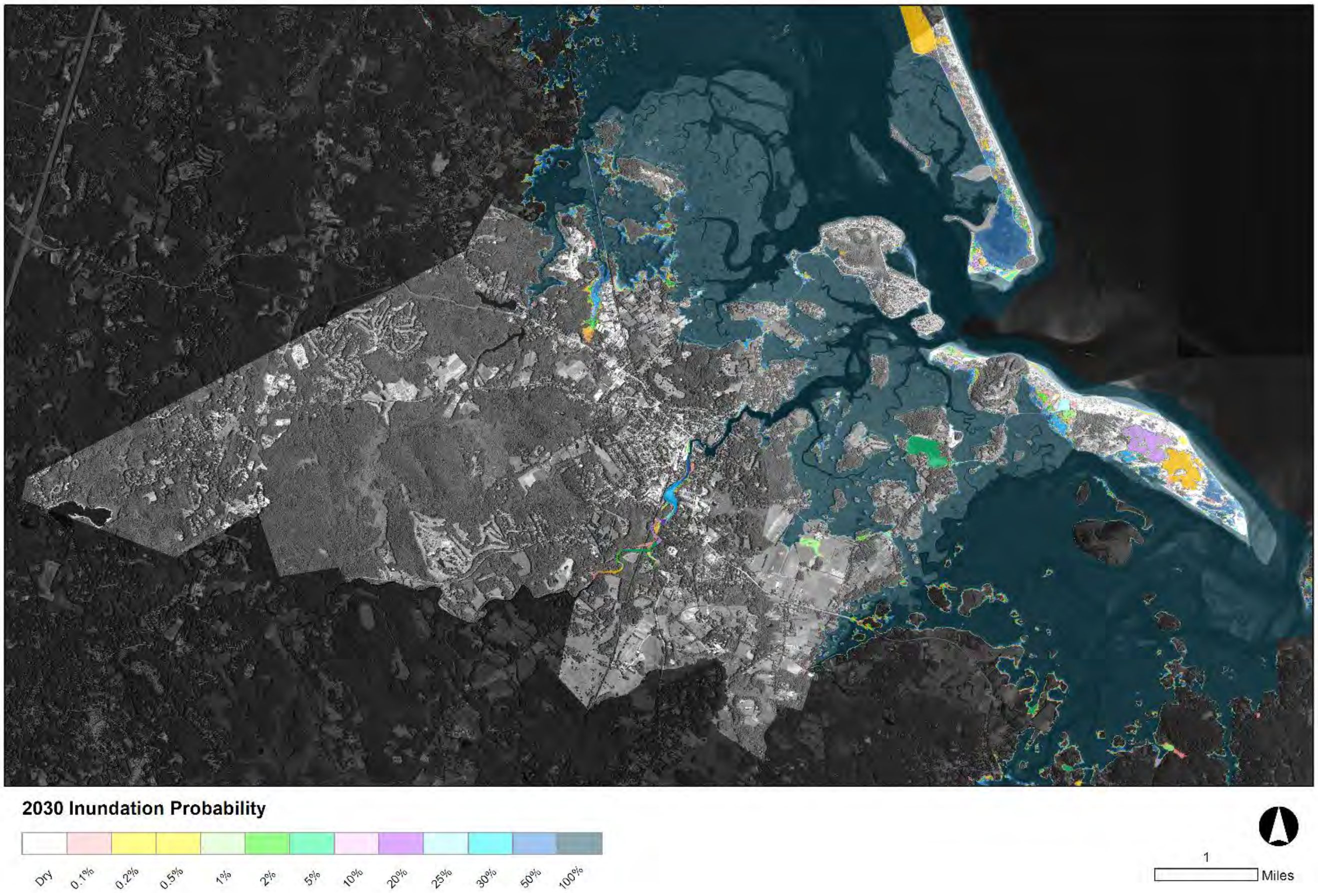

Figure D-14. Town of Ipswich, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

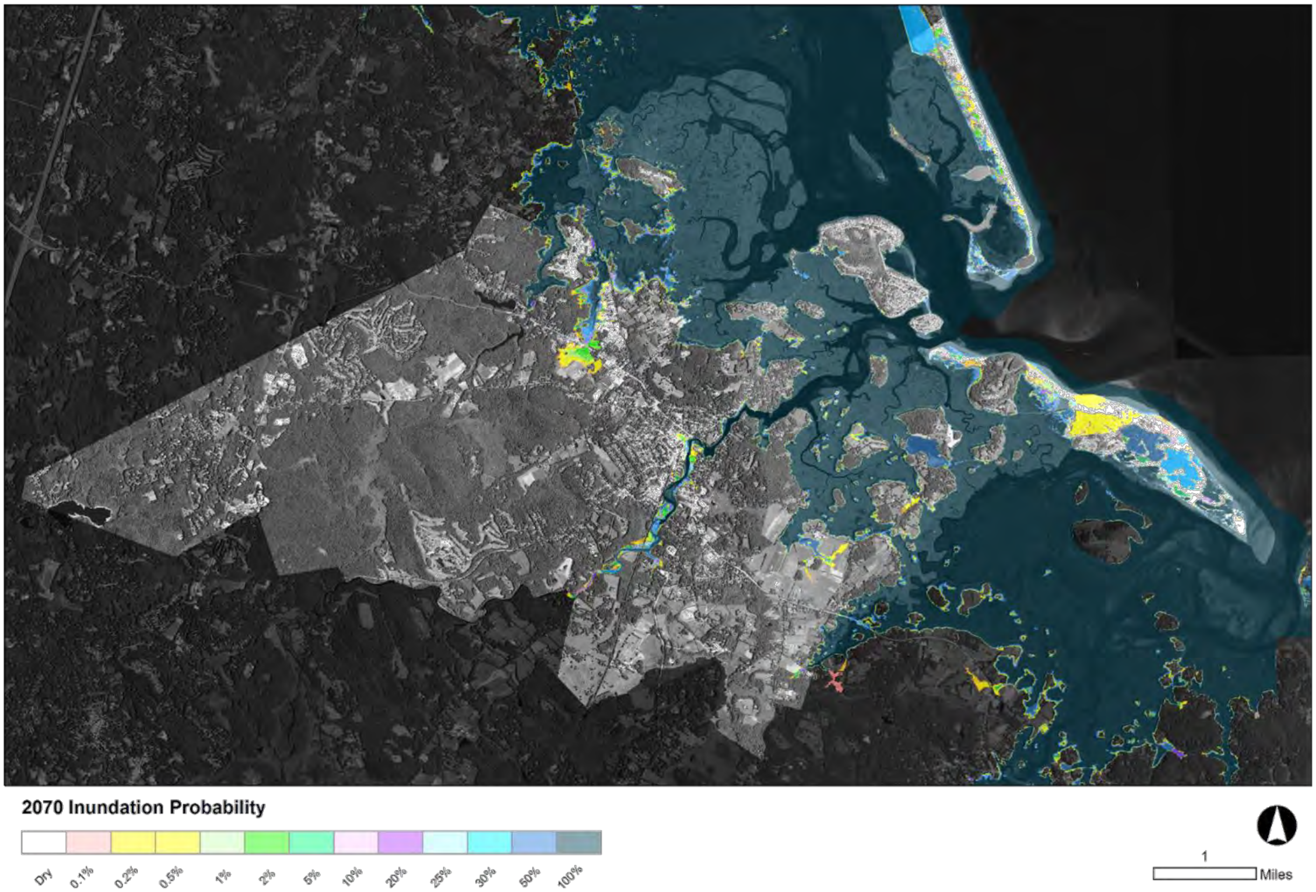

Figure D-15. Town of Ipswich, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

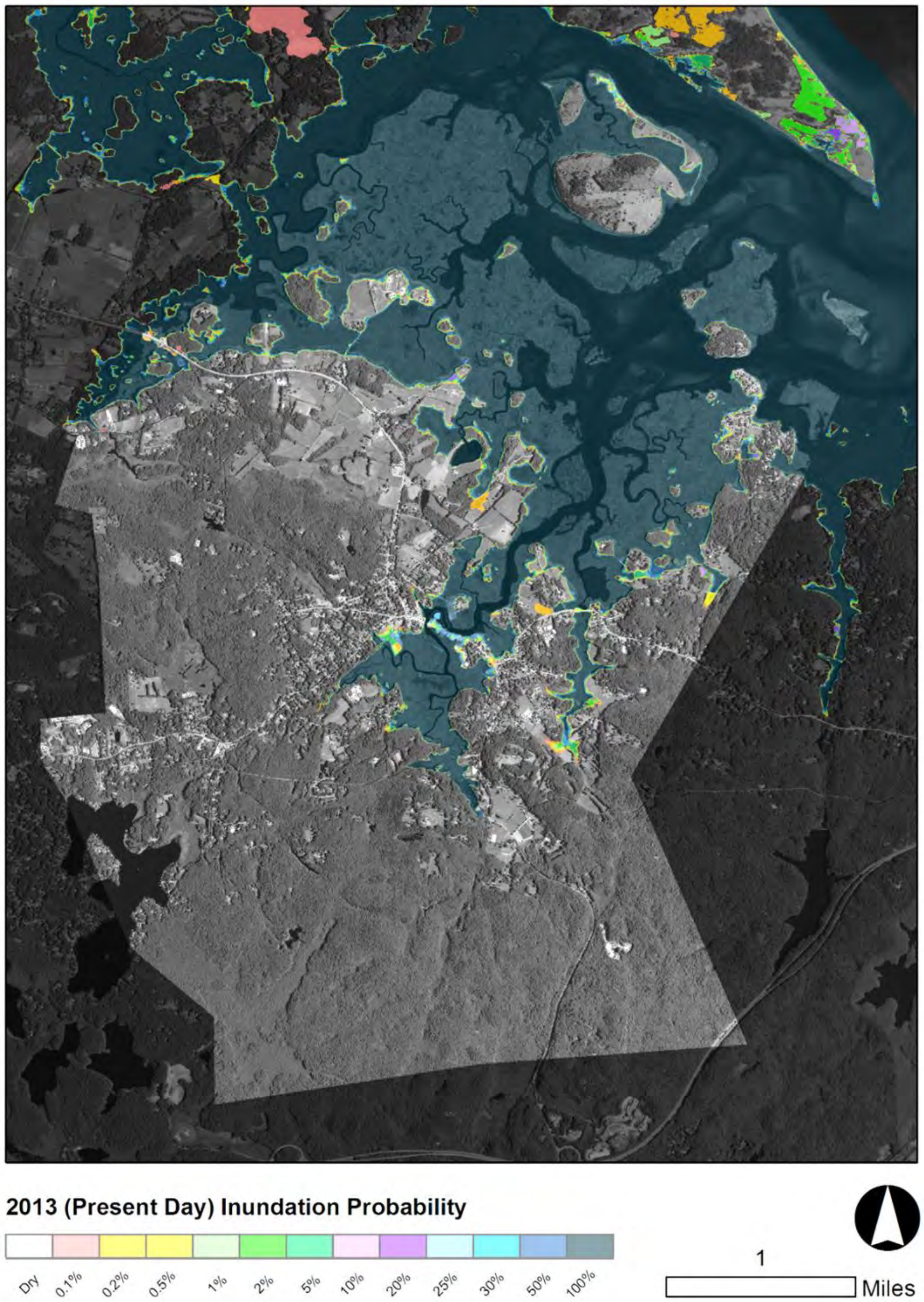

Figure D-16. Town of Essex, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2013 (Present Day). *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

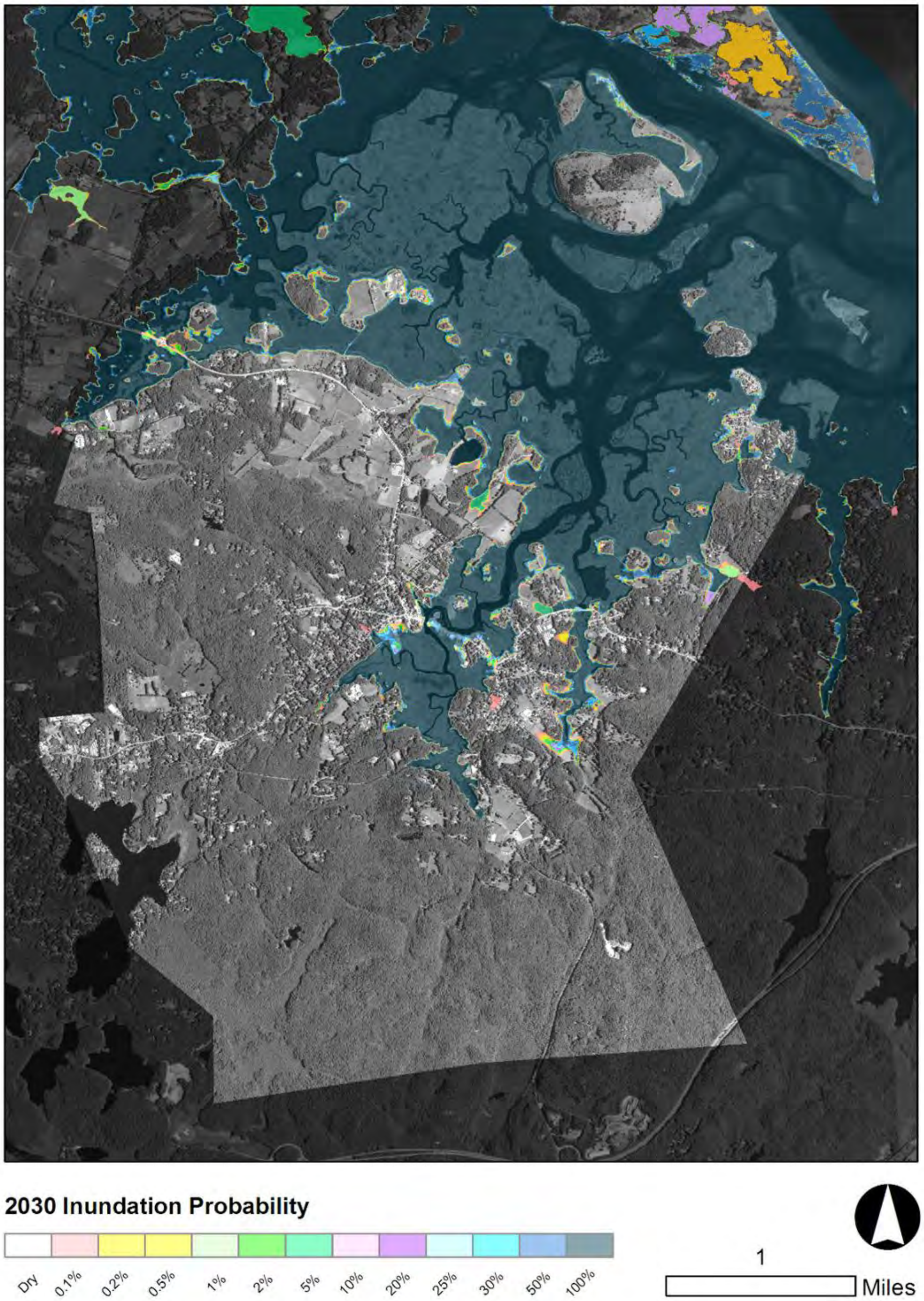

Figure D-17. Town of Essex, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2030. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

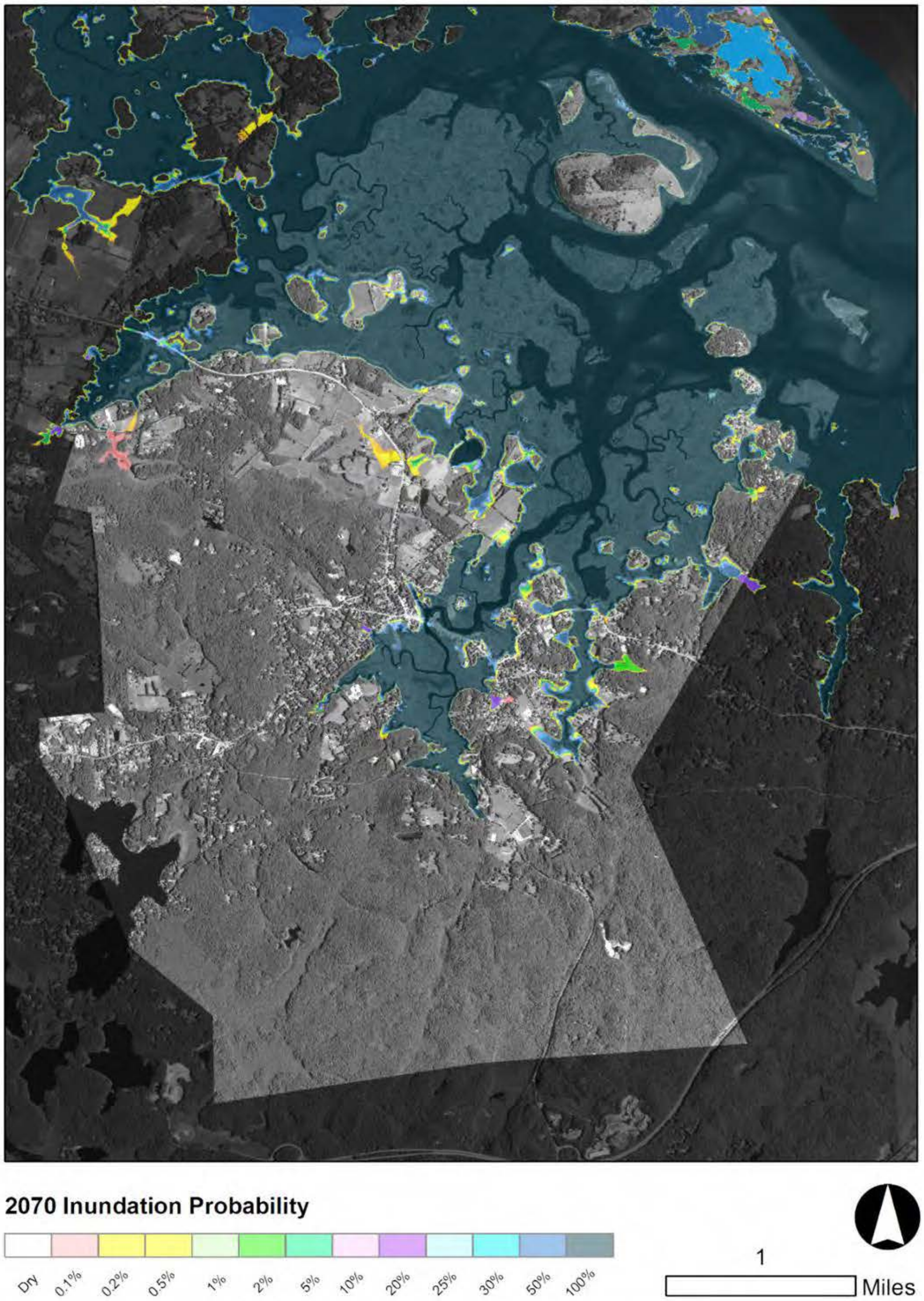

Figure D-18. Town of Essex, Massachusetts: Coastal inundation-probability map showing modeled hazard zones in 2070. *Data Source*: Bosma, K., E. Douglas, P. Kirshen, K. McArthur, S. Miller and C. Watson. 2016. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Photo Science, Inc. (2012). State of Massachusetts (Raster DEM): LIDAR for the North East – ARRA and LiDAR for the North East Part II. (USGS Contract: G10PC00026, ARRA LIDAR Task Order Numbers) USGS Contract: G10PC00026 Task Order Number: G10PD02143 Task Order Numbers: G10PD01027 (ARRA) and G10PD02143 (non-ARRA). Aerial Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001. Maps created by the National Wildlife Federation using: ArcGIS 10.3 for Desktop (v10.30.1332)

APPENDIX E:
Marsh Adaptation Strategy Tool (MAST)

GEI Consultants and the Project Team worked with 15 state and local land conservation professionals to apply the Marsh Adaptation Strategy Tool (MAST) to the Great Marsh region. MAST can help inform coastal land prioritization decisions in an era of marsh migration. Using the tool, the land conservation professionals ranked 11 high-priority coastal parcels (Figure E-1) in an auction process according to ecosystem services that they value. The software then gradually inundated each parcel according to identified sea level rise scenarios. Through topographic analysis in each year, in each of three sea level rise scenarios through 2100, and in reference to 13 benefit creation functions, the software then calculated cumulative ecosystem services that may be expected to emerge on each parcel over time.

Figure E-1. Map of 11 high-priority coastal parcels analyzed using the Marsh Adaptation Strategy Tool (MAST).

Key findings of the MAST analysis are highlighted below. For more detailed results, see the final MAST report published online.[16]

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

Table E-1. MAST survey results where experts subjectively ranked ecosystem services for each parcel.

	Services	Parcels 1	2	3	4	5	6	7	8	9	10	11	Totals
1	Prevention of flood damages	50	30	100	75	6	100	30	75	100	25	20	611
2	Increased land values	20	50	18	10	16	20	10	16	40	10	10	220
3	Water quality	10	10	100	30	10	20	20	30	100	10	20	360
4	Drinking water supply	10	10	10	10	10	10	20	10	30	10	15	145
5	Recreation	10	25	20	50	10	50	25	40	100	15	10	355
6	Aesthetics	10	10	30	50	10	25	20	40	50	10	10	265
7	Carbon storage	20	25	20	20	10	30	25	10	50	10	40	260
8	Habitat connectivity	50	25	90	50	15	50	30	50	200	10	20	590
9	Habitat for commercial sp.	50	10	20	75	10	75	10	50	70	10	10	390
10	Habitat for biodiversity	25	15	15	75	20	50	25	50	50	10	20	355
11	Nutrient export for commercial sp.	8	25	20	10	10	15	10	10	30	5	10	153
12	Nutrient export for biodiversity	5	6	30	20	20	30	25	10	50	6	20	222
13	Research value	9	5	20	10	5	10	5	8	30	5	8	115
	(acres)	*33*	*46*	*146*	*134*	*23*	*148*	*191*	*125*	*571*	*27*	*130*	
	Totals	277	246	493	485	152	485	255	399	900	136	213	

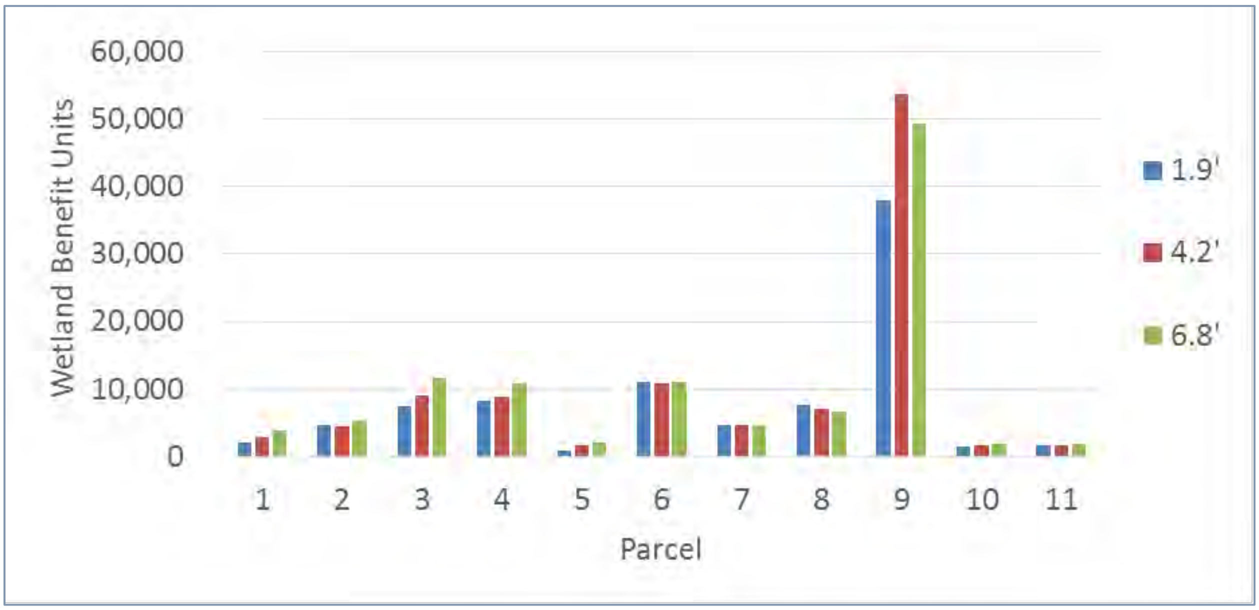

Figure E-2. Great Marsh MAST parcels and wetland benefits accrued in three sea level rise scenarios

APPENDIX F:
Coastal Adaptation to Sea Level Rise Tool (COAST)

GEI Consultants worked with NWF and Task Force members from the City of Newburyport to run the Coastal Adaptation to Sea Level Rise Tool (COAST). The Study area included parts of the downtown area of Newburyport along the Merrimack River (northwest and southeast of the U.S. Route 1 bridge), as well as parts of the industrial park adjacent to the Little River (Figure F-1). COAST analyzed potential damages to buildings from three sea level rise scenarios, both as single snapshots in time from a 100-year flood in 2030 and 2070; and as cumulative damages from all possible storms from 2015 to 2030 and from 2031 to 2070.

Key findings of the COAST analysis are highlighted below. **For more detailed results, see the final COAST report[17] published online.**

Figure F-1. Map of Newburyport COAST study area.

Table F-1. One-time damage estimates for a 100-year flood in 2030 and 2070 under low, medium, and high sea level rise scenarios. Damage estimates are to building structures only within the Newburyport, MA Study Area (does not include building contents).

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

[17] Merrill, S.B. and A. Gray, "COAST Modeling for the City of Newburyport, Massachusetts." In *Final Report to the National Wildlife Federation* (Portland, ME: GEI Consultants, Inc., 2015), http://www.pie-rivers.org/wp-content/uploads/2015/02/Great-Marsh-COAST-Final-Report_10072015.pdf

Table F-2. Cumulative storm surge and sea level rise damage estimates for buildings in Newburyport study area between 2015 and 2030, 2031 and 2070, and 2015 and 2070. Damage estimates are to building structure only (does not include contents).

Year	Sea Level Rise	Damage to Buildings	Buildings Lost to SLR
2015-2030	Low (0 ft - 0.31 ft)	$3,222,783	$270,600
2015-2030	Med (0 ft - 0.50 ft)	$3,385,577	$424,600
2015-2030	High (0 ft - 0.72 ft)	$3,606,155	$424,600
2031-2070	Low (0.33 ft - 1.09 ft)	$9,876,800	$414,400
2031-2070	Med (0.53 ft - 2.19 ft)	$15,438,355	$2,279,000
2031-2070	High (0.76 ft - 3.45 ft)	$25,072,509	$4,702,800
2015-2070	Low (0 ft - 1.09 ft)	$13,099,584	$685,000
2015-2070	Med (0 ft - 2.19 ft)	$18,823,932	$2,703,600
2015-2070	High (0 ft - 3.45 ft)	$28,678,663	$5,127,400

Table F-3. Parcels, land, buildings, and total parcel values in the Newburyport study area that are lost to sea level rise by 2030 and 2070.

Year	Sea Level Rise	Parcels Lost to SLR	Land Value	Building Value	Total Value
2030	Low (0.31 ft)	1	$415,400	$270,600	$686,000
2030	Med (0.50 ft)	2	$841,100	$424,600	$1,265,700
2030	High (0.72 ft)	2	$841,100	$424,600	$1,265,700
2070	Low (1.09 ft)	3	$1,222,000	$685,000	$1,907,000
2070	Med (2.19 ft)	11	$5,753,700	$2,703,600	$8,457,300
2070	High (3.45 ft)	27	$15,775,800	$5,127,400	$20,903,200

Figure F-2. Newburyport COAST Visual Results: 1% (100-year) flood in 2030 with 0.31 ft of sea level rise ("low" sea level rise scenario).

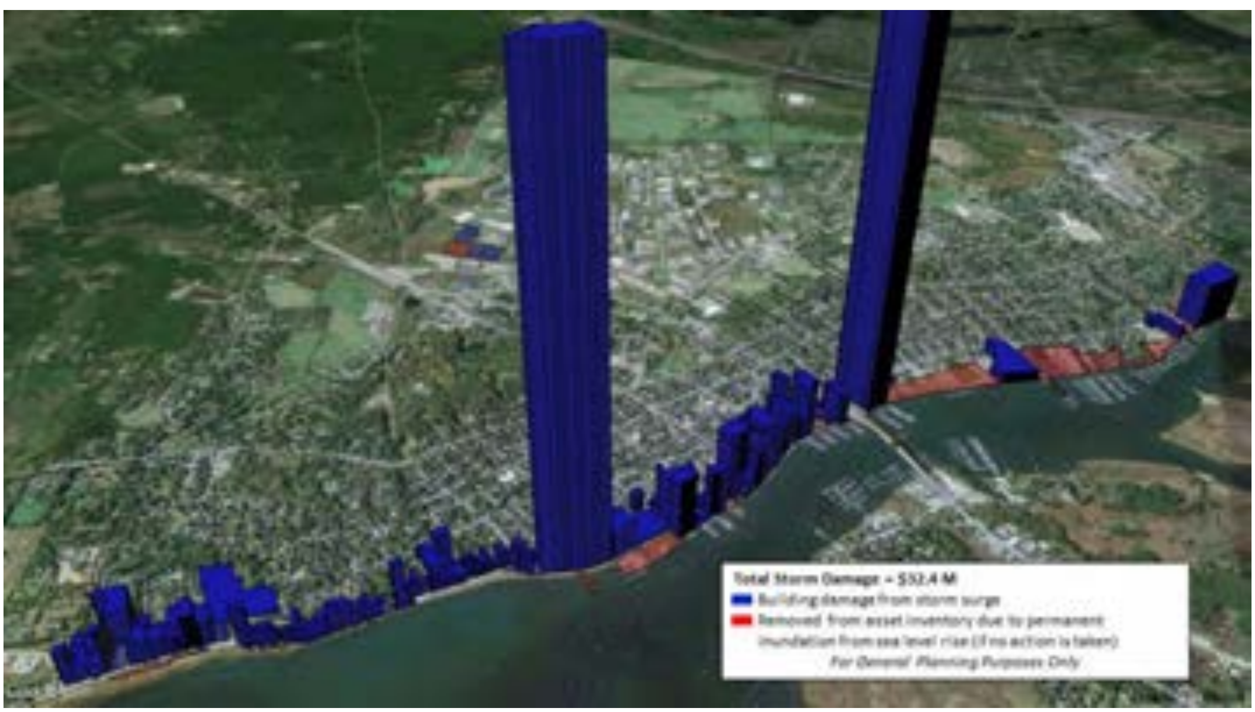

Figure F-3. Newburyport COAST Visual Results: 1% (100-year) flood in 2070 with 3.45 ft of sea level rise ("high" sea level rise scenario).