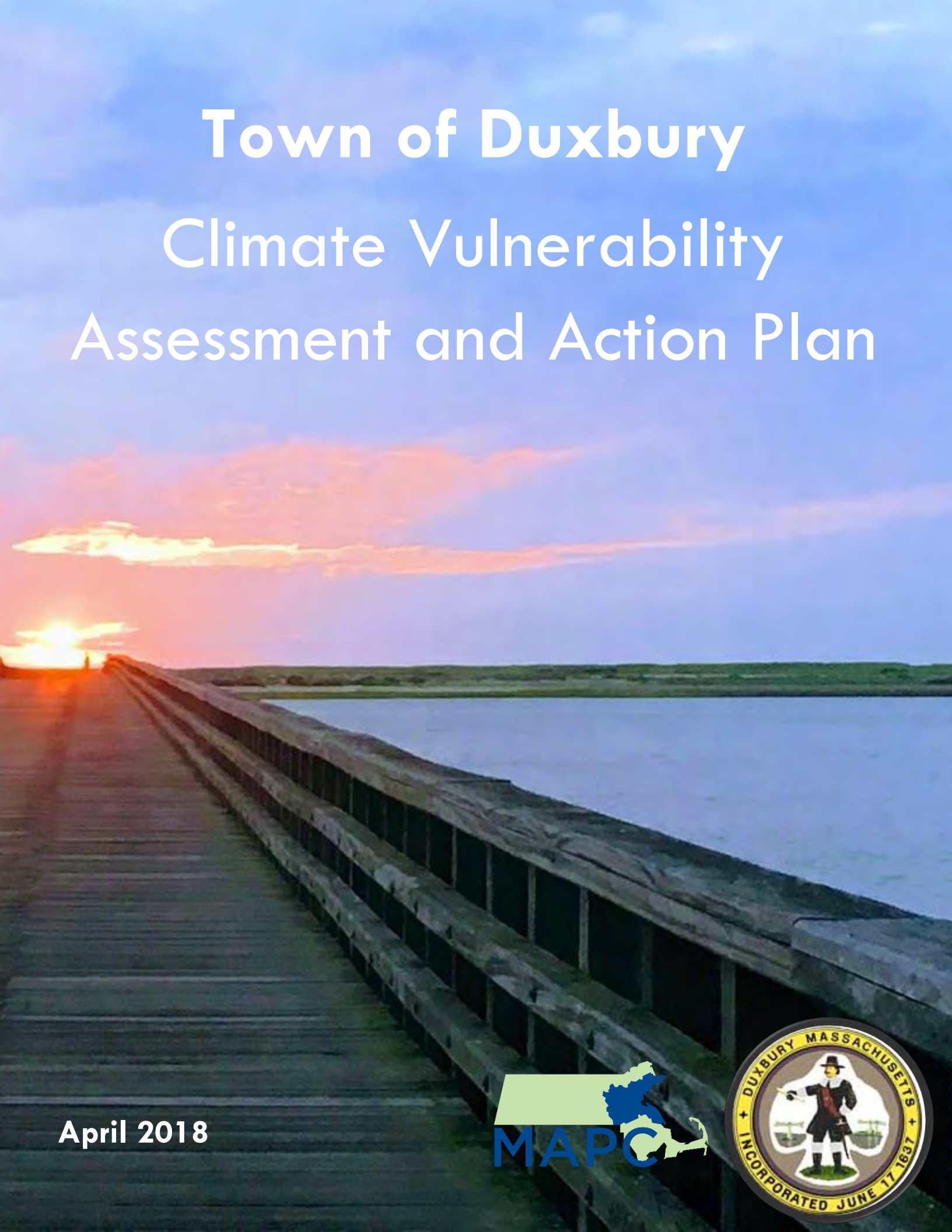
Town of Duxbury

Climate Vulnerability Assessment and Action Plan



April 2018

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EXECUTIVE SUMMARY

Flooding during Winter Storm Riley, March 2018.

Climate change is the most compelling environmental, economic, and social issue of our time. Duxbury contains a rich fabric of cultural and natural assets the community through time has had the foresight to protect. Duxbury Beach is a critically important resource affording shoreline protection to the Town and neighboring communities, supporting threatened and endangered species habitat, enabling diverse recreation opportunities, and supporting economic vitality. However, Duxbury routinely experiences coastal flooding and inundation with even just a lunar high tide. Projected sea level rise and changes in intensity of storm and precipitation events compel the need to assess the vulnerability of Duxbury's people and places as well as plan for protecting its future. This report summarizes the latest climate risks, evaluates the vulnerability of Duxbury's critical infrastructure and resources, and creates an action for incremental steps toward greater resilience and community vibrancy in an uncertain future.

Climate Change: Our Uncertain Future

2017 was the second warmest year on record and the period from 2006-2015 was the warmest decade since temperature has been measured. This has translated into an increase in the growing season by 10 days since 1980[1]and model temperature projections anticipate more frequent heat waves.[2]

Duxbury could experience five to 23 days over 90° by 2050 and nine to 58 days over 90°by 2100.[2]

Depending on various greenhouse gas emission scenarios, warming temperatures will cause ocean expansion and melting glaciers resulting in sea level rise. Sea level has risen by 11 inches over the last century and scientists anticipate this rate to accelerate.

Duxbury could experience an additional eight inches sea level rise by 2030 and six and a half feet by the end of the century.[1,3]

In the last 50 years, precipitation in the Northeast US increased 71% in the amount of rain that falls in the top 1% of storm events. Projections suggest an increase in total precipitation, changes in precipitation patterns, and increased frequency of extreme storms such as hurricanes and nor'easters.[3]

Duxbury could experience an increase of five inches of precipitation annually by 2050 and six inches by 2100 with the greatest increase during the winter.[1]

Duxbury's Strength and Vulnerability

[1] U.S. Environmental Protection Agency. 2016. Climate Change Indicators in the United States, 2016. Fourth meditation. EPA 430-R-16-004. www.epa/gov/climate-indicators Northeast Climate Science Center.

[2] Northeast Climate Science Center. UMass Amherst. Massachusetts Climate Change Projections. December 2017

[3] *Sea Level Rise Study. The Towns of Marshfield, Duxbury, Scituate, MA". 2013. Kleinfelder.*

Projected climate impacts are an intensification, increased frequency, or geographic expansion of existing challenges. Duxbury already has significant planning, experience and strengths to bring to these challenges.

Duxbury's seniors comprise 16% of the population and are the residents at greatest risk to climate change. Many seniors are vulnerable to extreme heat and coastal flooding. But the Town is well prepared with programs that connect seniors to programs, cooling centers, and resources for their well-being and safety.

Duxbury is at risk to increased occurrences of vector-borne diseases with warmer winters, standing flood waters, and extended growing seasons. But it has significant strengths in preventing heat-related illness with 50% tree canopy cooling the town, mitigating air pollutants, capturing stormwater, and sequestering carbon. There is a nominal risk to toxic exposure from flooding of hazardous materials storage sites.

Duxbury has over 1,200 acres of salt marsh meadows providing critical shoreline protection. The majority are healthy, intact ecosystems with the exception of the Bay Farm marsh showing signs of degradation and erosion. However, since 1995, Duxbury has experienced 1,000-acre loss of eelgrass meadow, an important natural shoreline protection system. Duxbury also contains 14,474 acres of State-designated BioMap2 Aquatic Core habitat demonstrating viable wetland systems able to withstand the impacts of climate change.

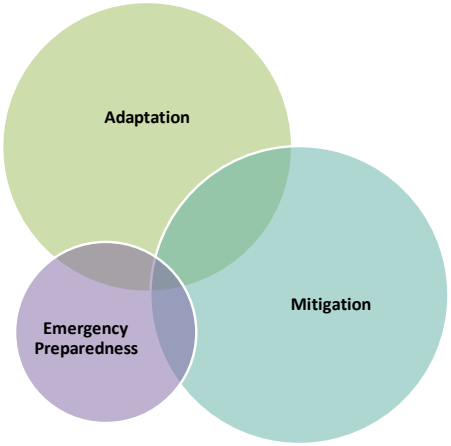
Duxbury's water comes from wells and the Town of Marshfield. It is vulnerable to scarcity during periods of drought, aquifer salinization from sea level rise, and well infrastructure damage/salinization from coastal flooding and sea level rise. Three of its shared waste water system leaching fields are located within a 1% Annual Chance Flood Zone and the flood risk increases greatly with sea level rise in 2038 and 2088.

Duxbury has suffered 423 flood insurance claims totaling nearly $5.5 million. There are two dams vulnerable to hurricane storm surge and sea level rise in 2038. No critical facilities are located in SLR 2038 or 2088 except the Powder Point Bridge and 22 dams are located in a 1% Annual Chance Flood. Businesses vulnerable to sea level rise are valued today at over $12 million.

There 68 historic structures at risk to flooding in a 1% Annual Flood Chance Flood and approximately 54 historic structures vulnerable to sea level rise in 2088 with a category 1 hurricane.

Duxbury's Climate Action Plan

This climate action plan builds upon previous completed plans for hazard mitigation, coastal flooding, emergency management and open space protection. It takes an adaptive management approach that combines emergency preparedness, mitigation, and adaptation. The Town's Climate Vulnerability Steering Committee created the prioritization of suggested climate actions agreed upon four guiding principles:



1. Balance growth, preservation, and resilience to enhance our vibrant community and ensure its livability into the next century.

2. Invest in infrastructure that promotes multiple benefits that address climate risks as well as safety, beautification, economic growth, natural resource protection, and public health.

3. Leverage the resources of multiple disciplines and sectors within municipal departments and across sectors to generate layers of resilience.

4. Approach Duxbury's climate resilience as an ongoing effort to ensure the Town's vibrancy and livability which considers changing climatic conditions.

Duxbury is committed to Resilience

The top climate action priorities were those receiving the most significant concern and sense of urgency for Duxbury's future livability and were recommended to be implemented as soon as possible. A subset of the climate action priorities are as follows:

- Incorporate climate resilience into all local and regional plans as well as capital improvement plans.
- Update Climate Action Plan every five years.
- Hire a consultant to fully assess the risk of salinization to Duxbury's Drinking Water.
- Prepare a list of key utility facilities that require critical power restoration and include the physical locations of the facilities to the power company during an outage to expedite electricity restoration.
- Identify location of and create a plan for vulnerable populations with limited mobility (seniors, handicap, and individuals without vehicles) or limited English proficiency during emergency response that may need transportation.
- Collaborate with and provide financial support to the Duxbury Beach Reservation, Inc. for ongoing beach nourishment, sacrificial dunes, sand fences, road improvements, and other coastal infrastructure investments to ensure Duxbury remains protected from high energy storm surge into the future while protecting an important recreational and economic amenity.
- Collaborate with the residents and businesses in the near- and long-term most vulnerable areas to examine potential zoning, regulatory, incentive, mitigation or cooperative-based approaches to dealing with the issues that sea level rise presents for existing structures and infrastructure, exploring funding opportunities to examine feasibilities of alternatives and to implement best practices.

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I. CLIMATE CHANGE: OUR CHANGING FUTURE

Introduction

Climate change is the most compelling environmental, economic, and social issue of our generation and the northeastern United States is one of the most vulnerable to our changing climate, particularly with projected sea level rise (SLR). Duxbury, 35 miles from Boston, is a commuter town and coastal community known for its shipbuilding and fishing history and its current oyster industry, the largest in the state, according to the Massachusetts Division of Marine Fisheries.

Howlands Landing. Photo credit Darci Schofield

Duxbury contains a rich fabric of cultural and natural assets and the community through time has had the foresight to protect these assets to uphold its cultural character and healthy, livable community. Duxbury Beach, a barrier beach, is a critically important resource affording shoreline protection to the Town and neighboring communities, supporting threatened and endangered species habitat, enabling diverse recreation opportunities, and supporting environmental and economic vitality. Its protection started originally by a group of concerned citizens which since has evolved to become organized as the Duxbury Beach Reservation, Inc. (1975),[4] is demonstrative of the value of the rich natural and cultural community that defines Duxbury. The Town also contains several beaches, extensive marshes, rich estuaries, healthy rivers, agricultural land, and large tracts of forest, and the Town in 1963 began an aggressive campaign to acquire land to protect its drinking water supply. Further, in 2002, Duxbury was an early adopter of the Community Preservation Act, enabling a dedicated source of funding for open space, historic preservation, and affordable housing, to preserve the Town's community character. Since that time, they have completed 78 community preservation projects and protecting over 800 acres of land, creating a total of over 3,500 acres of conservation land. This is demonstrated with its nearly 8,307 acres of tree canopy over 21,630 tons of carbon sequestered annually. These natural assets already have and will continue to create a strong fabric of resilience for the community while mitigating greenhouse gas emissions through our changing climate.

However, with sea level rise (SLR) and already significant changes in intensity of coastal storm and precipitation events with climate change, the need to evaluate its strengths and assess the vulnerability of its infrastructure, economy, and community as well as plan for protecting its future is critical for Duxbury. In just early 2018 alone, two coastal storms caused a state of emergency,

[4] Lease revenues generated by the Reservation, under municipal law, must only support beach preservation activities.

mandatory evacuations, and significant damage to seawalls. This Climate Vulnerability Assessment and Action Plan builds upon the *South Shore Coastal Hazards Adaptation Study* performed by MAPC in 2011 and *the SLR Study for the Towns of Marshfield, Scituate, and Duxbury, MA* performed by Kleinfelder in 2013. The goal of this plan is to identify Duxbury's most significant climate vulnerabilities from SLR, inland and coastal flooding, and increased temperature on its social, natural, economic, and physical infrastructure and to create near-term adaptation strategies to ensure Duxbury remains a resilient and vibrant town in the face of a changing climate.

This plan was guided by a designated Climate Steering Committee and residents and stakeholders at the following meetings and public forums:

1. Envision Duxbury Public Forum — November 15, 2017
2. Public Forum, Duxbury Open Minds Speaker Series — March 16, 2018
3. Climate Stakeholder Committee Meeting — March 27, 2018
4. Public meeting of Duxbury Board of Selectmen — April 23, 2018

Climate Processes

Our climate has always been regulated by gases, including carbon dioxide, methane, and nitrous oxide, that blanket the earth. These gases trap heat that would otherwise be reflected out to space; without them our planet would be too cold to support life. We refer to these gases as "greenhouse gases" (GHGs) for their heat trapping capacity. Changes in GHG concentrations occur naturally, due to such events as volcanic eruptions, and variations in solar energy entering the atmosphere.

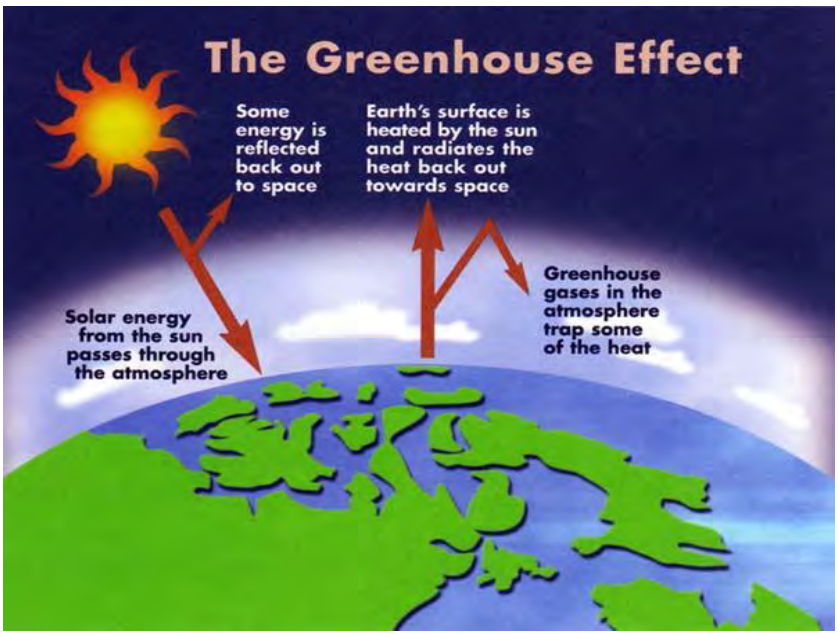
In the past century, human activity associated with industrialization has contributed to a growing concentration of GHGs in our atmosphere. The combustion of fossil fuels, our primary energy source in the age of industrialization, releases GHGs into the atmosphere. As shown in Figure 1, there is a correlation between increases in carbon dioxide concentrations and global temperature. There is by now widespread consensus among scientists regarding the warming of our climate and its causes.[5,6,7]

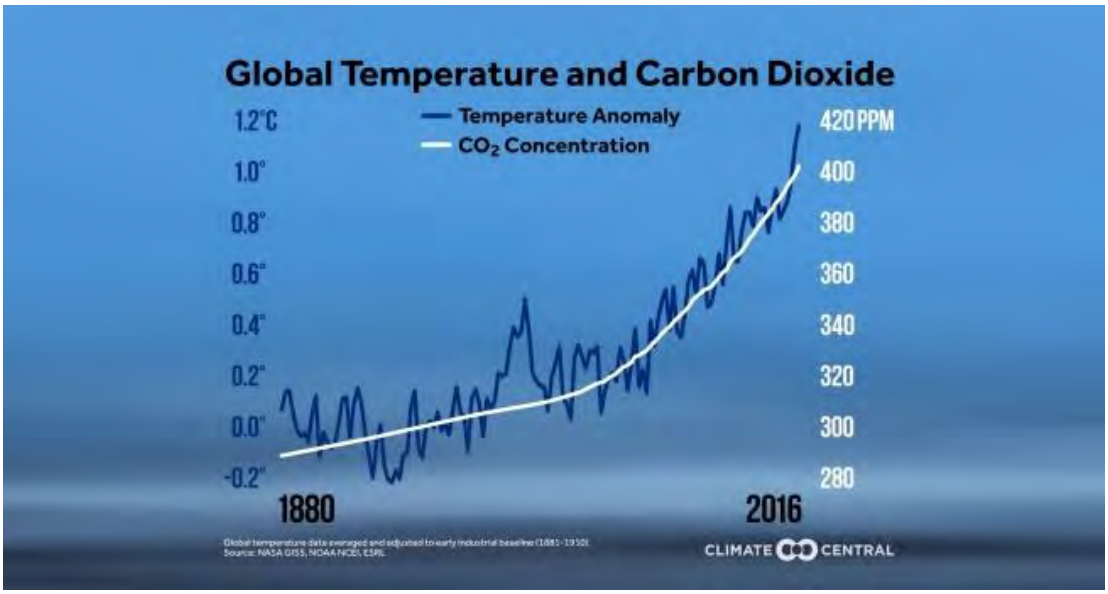
The following sections will review climate changes that have been observed to date and projections of future changes based upon the best available data. The focus of this report is on impacts relevant to Duxbury. We utilize data for the northeast United States, Massachusetts and the Boston region including (i) the UMass Amherst Northeast Climate Science Center's evaluation of the Commonwealth's temperature, precipitation, and sea level rise changes; (ii) Climate Ready Boston "The Boston Research Advisory Group: Climate Change and Sea Level Rise Projections for Boston; (iii) the City of Cambridge, Climate Change Vulnerability Assessment of 2015; and (iv)

[5] Third United States Climate Report (2014) (Chapter 2, page 12)
[6] Statement on Climate Change from 18 Scientific Organizations (https://www.aaas.org/sites/default/files/migrate/uploads/1021climate_letter1.pdf)
[7] Intergovernmental Panel on Climate Change. *Climate Change 2014 Synthesis Report Summary for Policymakers.*

the US Environmental Protection Agency Climate Change Indicators in the United States, Fourth Edition.

Figure 1 The greenhouse effect, global temperature and CO^2 trends.





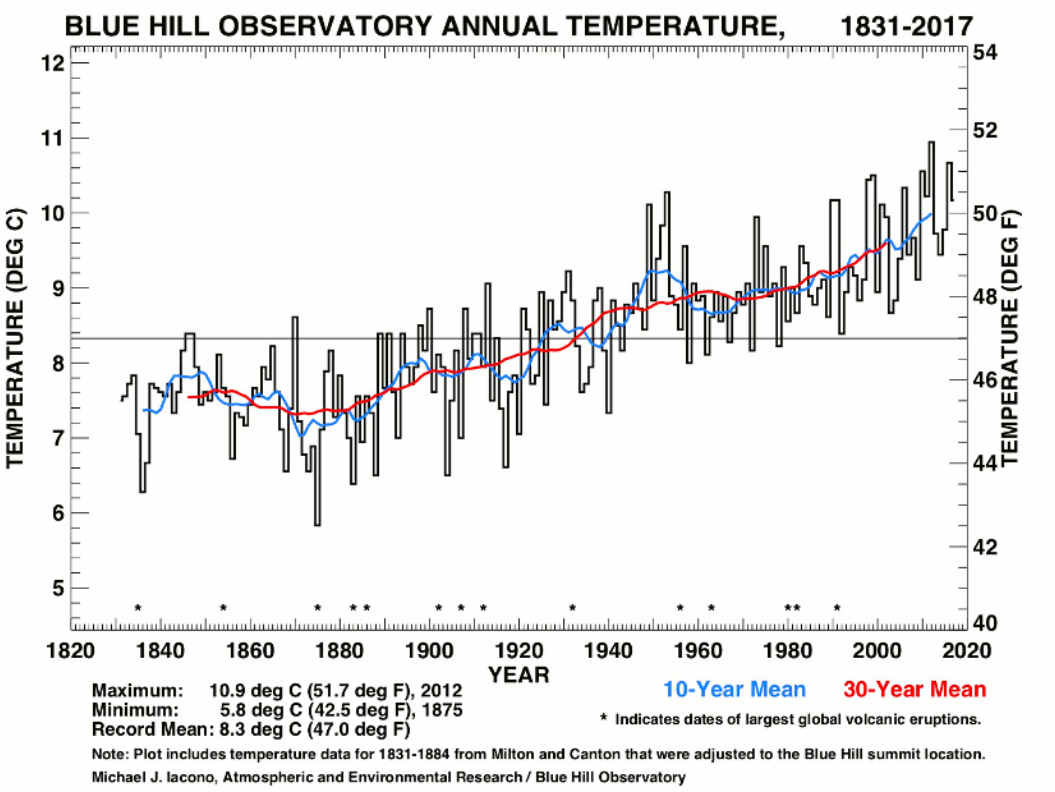
Climate change observations come from a variety of data sources that have measured and recorded changes in recent decades and centuries. Climate change projections, however, predict future climate impacts and cannot be observed or measured. As a result, climate projections are generally expressed as a range of possible impacts influenced by the uncertainty of future global

GHG emissions and/or land use, natural localized variability in climate, and variations in climate projection models.[8]

Temperature

According to the National Ocean and Atmospheric Administration and NASA, 2017 was the second warmest year on record[9] and according to the EPA's US Climate Change Indicators report, the period from 2006-2015 was the warmest decade since temperature has been measured.[10] Data from the Blue Hill Observatory in Milton (Figure 2) located 30 miles from Duxbury, reflects

Figure 2 Observed Temperature Change



this trend. Future temperature projections for the Northeast indicate an increasing likelihood of heat waves, measured by the likely number of days over 90 and 100. The South Coastal Basin, where Duxbury lies, may be cooler than other inland or dense urban areas in the Commonwealth due to the presence of offshore winds and this is demonstrated by differences in temperature projections. The South Coastal Basin could experience 8-13 days over 90° by 2030 and 9-57

[8] Daser, C., Philips, A., Bourette, V. et al. Climate Dynamics (2012) 38:527 https://doi.org/10.1007/s00382-010-0977-x

[9] https://www.washingtonpost.com/news/energy-environment/wp/2018/01/18/2017-was-among-the-planets-hottest-years-on-record-government-scientists-report/?utm_term=.77bff825293d

[10] U.S. Environmental Protection Agency. 2016. Climate Change Indicators in the United States, 2016. Fourth meditation. EPA 430-R-16-004. www.epa/gov/climate-indicators.

days over 90˚by the end of the century. Metro Boston may experience 20-40 days over 90˚ by 2030 and 90 days over 90˚ by the end of the century.[11,12,13] In addition to warming summer

Table 1 South Coastal Basin area (SC) projected increases in average temperature in degrees Fahrenheit.

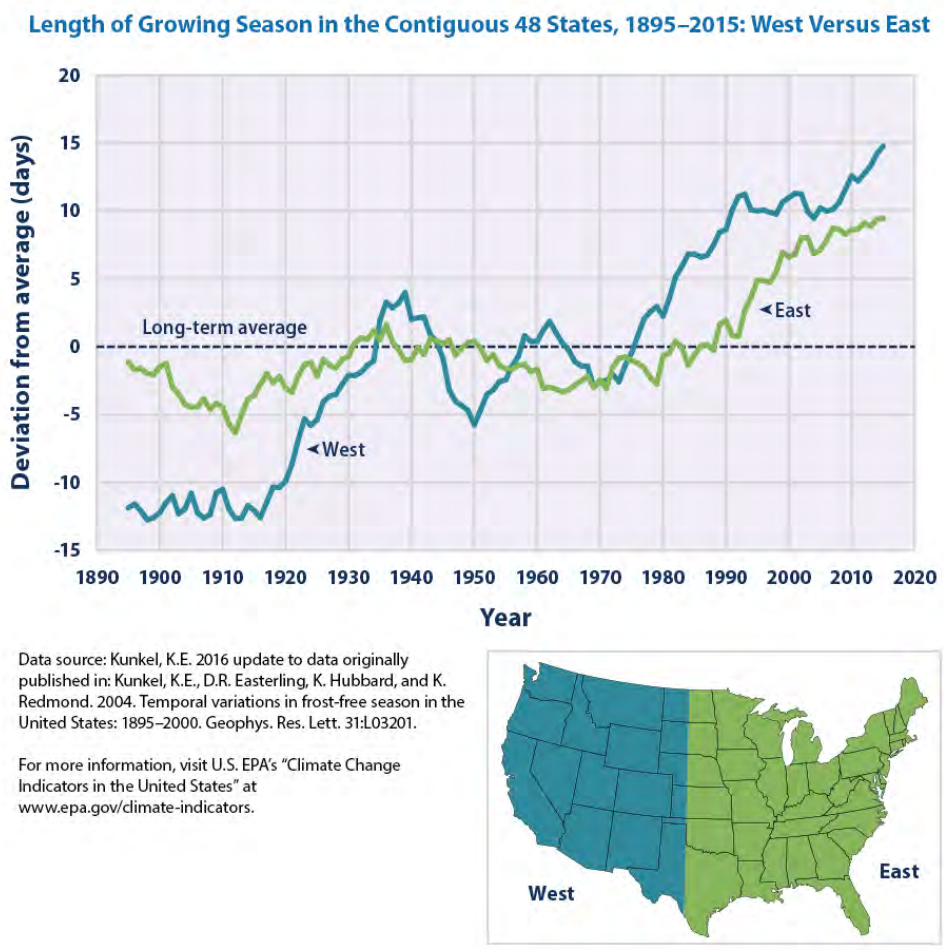
	Baseline 1961–2010	2030	2050-2070	2090-2100
SC Annual Average	50˚	52˚-58˚	52˚-58˚	53˚-60˚
SC Winter Average	31˚	33˚-35˚	33˚-39˚	34˚-40˚
SC Summer Average	69˚	71˚-73˚	71˚-78˚	72˚-81˚

Source: Northeast Climate Science Center. UMass Amherst. Massachusetts Climate Change Projections. December 2017

temperatures, winters are already warming and scientists project that to continue by an increase of 2˚- 6˚ in 2030 and an increase of 4˚-12˚by the end of the century.[6,7,8] Even small changes in temperatures can have a dramatic effect, such as changing precipitation patterns and extending the growing season.[14] The implications of warmer winters and summers are a shift in the growing season and freeze/thaw cycle for the northeast. The Northeast has already seen a significant deviation from the long-term average growing season beginning in the late 1980s with nearly 10 days longer growing season (Figure 3). Future projected warming translates into a climate similar to North Carolina and Virginia in the[15] or to Alabama in the 2070s.[16] These shifts in temperature will have an important effect on food production, natural systems, species and vector borne disease migration, and public health. In addition, they will affect energy use for heating and cooling.

[11] Climate Ready Boston, "The Boston Research Advisory Group Report: Climate Change and Sea Level Rise Projections for Boston," June 2016
[12] Under RCP 4.5 conditions. City of Cambridge, *Climate Change Vulnerability Assessment*, (City of Cambridge, 2015), http://www.cambridgema.gov/CDD/Projects/Climate/climatechangeresilianceandadaptation.aspx cited in BRAG.
[13]Northeast Climate Science Center. UMass Amherst. Massachusetts Climate Change Projections. December 2017
[14] Northeast Climate Science Center. UMass Amherst. Massachusetts Climate Change Projections. December 2017
[15] Northeast Climate Science Center. UMass Amherst. Massachusetts Climate Change Projections. December 2017
[16] Climate Ready Boston, "The Boston Research Advisory Group Report: Climate Change and Sea Level Rise Projections for Boston," June 2016

Figure 3 Increased length of days in growing season across the U.S.



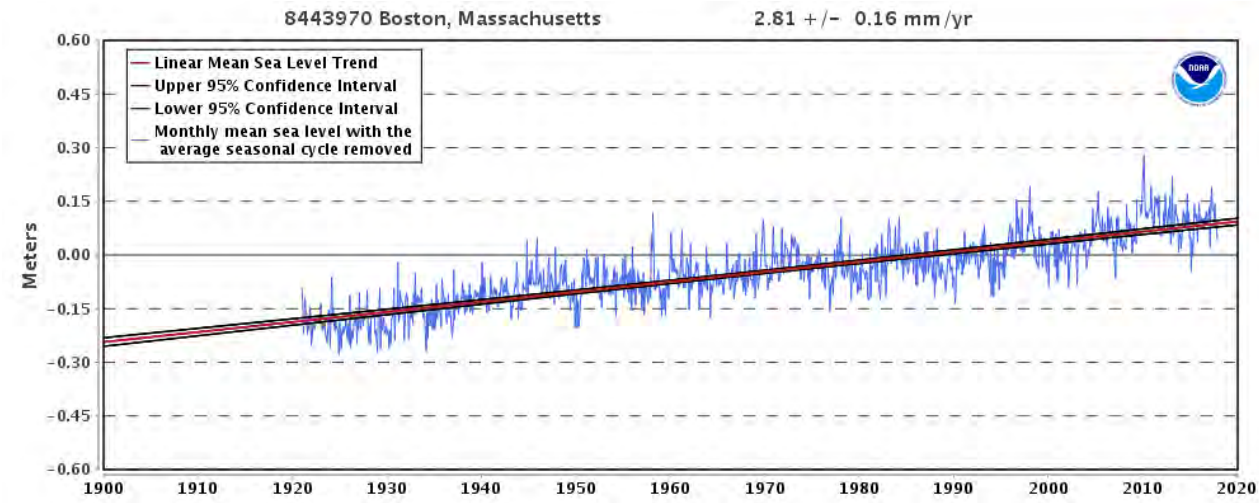
Sea Level Rise

Over the last century, sea level rise has increased by 11 inches (Figure 4) and the Boston Research Advisory Group (BRAG) anticipates that the rate of increase will accelerate, anticipating an additional eight inches by 2030.[17,18] Warming temperatures contribute to sea level rise in two ways. First, warm water expands to take up more space. Second, rising

[17] U.S. Environmental Protection Agency. 2016. Climate Change Indicators in the United States, 2016. Fourth meditation. EPA 430-R-16-004. www.epa/gov/climate-indicators.
[18] Climate Ready Boston, "The Boston Research Advisory Group Report: Climate Change and Sea Level Rise Projections for Boston," June 2016

temperatures are melting land-based ice which enters the oceans as meltwater. Also, another minor contributor to sea level rise in New England is a small amount of land subsidence (drop in elevation in response to the last glacial period, when pressure from the heavy ice compressed the land causing land areas around the glacier to curl upward in that time period. With glacial retreat, the land is very slowly reshaping its elevation (returning to an isostatic balance) causing some portions of the east coast to rebound (rise), and some areas to subside (sink).[19]

Figure 4 Observed Sea Level Rise.



Boston Tide Station from 1921-2016 which indicates over 11 inches of sea level rise in the last century.

There are several models and projections for sea level rise available. The majority derive results that are relatively similar based upon some key assumptions, such as emission scenarios.
In 2013, Kleinfelder performed sea level rise and storm surge modeling for the towns of Scituate, Marshfield, and Duxbury, projecting scenarios in 25, 50, and 75 years. Sea level rise was estimated using NOAA Technical Report *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (December 2012) and storm surge was modeled using the hydrodynamic Sea, Lake, and Overland Surge from Hurricanes Model (SLOSH) developed by the National Weather Service.

In 2018, we anticipate completion of a more comprehensive SLR and storm surge analysis for Duxbury through the *Massachusetts Department of Transportation Coastal Transportation Vulnerability Assessment*. Comprised of the widely-accepted Advanced Circulation (ADCIRC) probabilistic model, this analysis is a high-resolution, hydrodynamic, probabilistic model that calculates probable future water flows as a result of tides, elevations, waves, winds, rivers, and various storms, accounting for inland storm runoff interaction with the coastal water activity at their interface in the model, with respect to state roads. It was used in Boston Harbor, called the Boston Harbor Flood Risk Model (BH-FRM) and is one of the most detailed projections for coastal

[19] Upton, J. Sinking Atlantic Coastline Meets Rapidly Rising Seas. Scientific American. April 2016.

flooding available.[20] Finally, the Northeast Climate Science Center at UMass Amherst completed a SLR analysis for the Commonwealth in December 2017. This analysis is based upon the one used for Boston Harbor in *Climate Ready Boston* and a method recently used in Southern California.[21] This is a probabilistic model that projects changes in sea level based upon existing tide gauges. For Duxbury, the closest analysis is the Boston tide gauge.

Table 2 Total Relative Sea Level Rise projections in Boston and South Shore for the "Highest" emission scenarios.

	2030	2050	2070	2100
Boston BH_FRM [22]	8.00 in.	1.50 ft.	3.10 ft.	7.40 ft.
South Shore [23]	8.04 in.	1.85 ft.	3.39 ft.	6.52 ft.
Boston Tide Gauge[24]	0.4-0.9 ft.	0.8-1.5 ft.	1.3-2.4 ft.	2.0-4.0 ft.

The Kleinfelder model was calculated using the "highest" emission scenario as directed through consensus with the municipalities and other local and statewide experts. The other models report both medium and high emission scenarios, but the highest emission scenarios are reported for total relative sea level rise in Table 2. The projections completed by the Northeast Climate Science Center vary from the BH_FRM and the Kleinfelder models and further research is likely required to ascertain the differences. For this report, we utilize the Kleinfelder model to analyze vulnerability in response to sea level rise and storm surge.

[20] Bosma, K., Douglas, E., Kirshen, P., McArthur, K., and Miller, S. MassDOT-FHWA Pilot Project Report. Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. June 2015.
[21] Northeast Climate Science Center. UMass Amherst. Massachusetts Climate Change Projections. December2017.
[22] Douglas, E.M., Kirshen, P.H., Bosma, K., et al. 2017. Simulating the Impacts and Assessing the Vulnerability of the Central Artery/Tunnel System to Sea level Rise and Increased Coastal Flooding. J Extreme Events 3 (4): 1650013 (28 pages).
[23] *"Sea Level Rise Study. The Towns of Marshfield, Duxbury, Scituate, MA". 2013. Kleinfelder.*
[24] Northeast Climate Science Center. UMass Amherst. "Massachusetts Climate Change Projections". December 2017

Precipitation

In the last 50 years, precipitation in the Northeast US increased 71% in the amount of rain that falls in the top 1% of storm events.[25] Projections for future Northeastern US precipitation suggest an increase in total precipitation, changes in precipitation patterns, and increased frequency of extreme storms such as hurricanes and nor'easters. Local precipitation projection models indicate that the frequency of these events and the amount of precipitation occurring during these events is likely to increase. For example, a 100-year storm is defined as a storm that would have a 1% chance of occurring in any given year. Historically this could create 8.9 inches of rain, but models project that amount could increase to10 inches of rain by 2044 and 11.7 inches of rain by 2084 (Figure 5).[26]

What is a "100-year" flood?

The term "100-year flood" is shorthand for a flood that has a 1% chance of happening in a given year. In reality, a 100-year flood could occur two years in a row, or not at all for 100 years. But each year, there is a 1% chance it will occur.

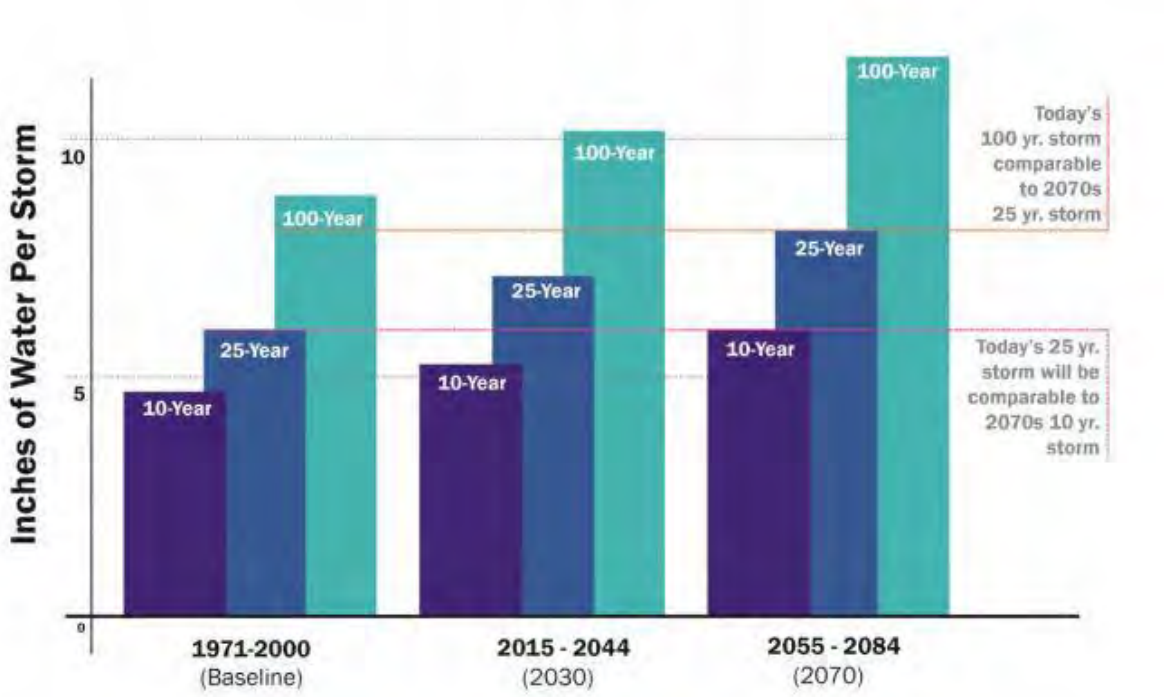
The 0.2% chance flood = 500-year flood
The 1% chance flood = 100-year flood
The 2% chance flood = 50-year flood
The 10% chance flood = 10-year flood

The 100-year flood zone is the location where there is a 1% chance of flooding each year. In the 500-year flood zone there is a 0.2% chance of flooding each year.

Figure 5 Precipitation Projections.

[25] Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, A. Whelchel, D. Wolfe, and F. Lipschultz, 2014: Ch. 16: Northeast. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn.

[26] City of Cambridge, *Climate Change Vulnerability Assessment*, (City of Cambridge, 2015), Temperature and Precipitation Projections (http://www.cambridgema.gov/CDD/Projects/Climate/~/media/A9D382B8C49F4944BF64776F88B68D7A.ashx)



Precipitation projections. Modeling from Kleinfelder and ATMOS indicates more rain in any given storm event above the baseline into the end of the century. Source: Cambridge Climate Vulnerability Assessment 2015. Kleinfelder based on ATMOS projections November 2015

The actual amount of increased precipitation or number of extreme weather events per year is difficult to project into the future.[27,28] However, the Northeast Climate Science Center does report an anticipated increase in rainfall for Massachusetts in the spring and winter months and their climate projection models suggest that the frequency of high-intensity rainfall events will also increase.[29] Consequently, warming temperatures can cause greater evaporation in the summer and fall, as well as earlier snowmelt,[23] leading to periods of either drought or extreme snowfall. The Northeast Climate Science Center projects a small decrease in average summer precipitation into the century; this combined with projected higher temperatures could increase the frequency of episodic droughts.[23] Finally, scientists anticipate the Boston region will continue to experience significant snow events through 2100,[20] though at this time, winter precipitation will be more rain than snow due projected warmer winters.[23]

[27] Climate Ready Boston, "The Boston Research Advisory Group Report: Climate Change and Sea Level Rise Projections for Boston," June 2016

[28] Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, A. Whelchel, D. Wolfe, and F. Lipschultz, 2014: Ch. 16: Northeast. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn

[29] Northeast Climate Center UMass Amherst. Massachusetts Climate Change Projections. December 2017.

II. DUXBURY VULNERABILITY ASSESSMENT

This climate vulnerability assessment is an effort to determine which Duxbury community assets –people, places, infrastructure, and economy – may be susceptible to harm from climate change. Climate vulnerability assessments generally consider:

- Exposure – whether climate changes will have a negative effect on various assets in the community.
- Sensitivity – if affected by climate change, how much damage, or loss of function will occur.
- Adaptive Capacity – sensitivity will be lessened, or heightened, by the degree to which there may be ways for the community to cope, compensate, or be modified, to adjust to climate changes.

Flooding from Winter Storm Riley March 2018 of Powder Point Ave. Source: Twitter @SymmondsLeanne

Once vulnerabilities are identified, Duxbury can prioritize climate actions (Part III) and capital investments according to the perceived risk they present. Generally, this involves considering the probability of damage to an asset and the consequences of damage. As an example, flooding to a sewer pump station and a public park might be equally likely, but the pump station would presumably have higher priority as the consequence of failure is more severe.

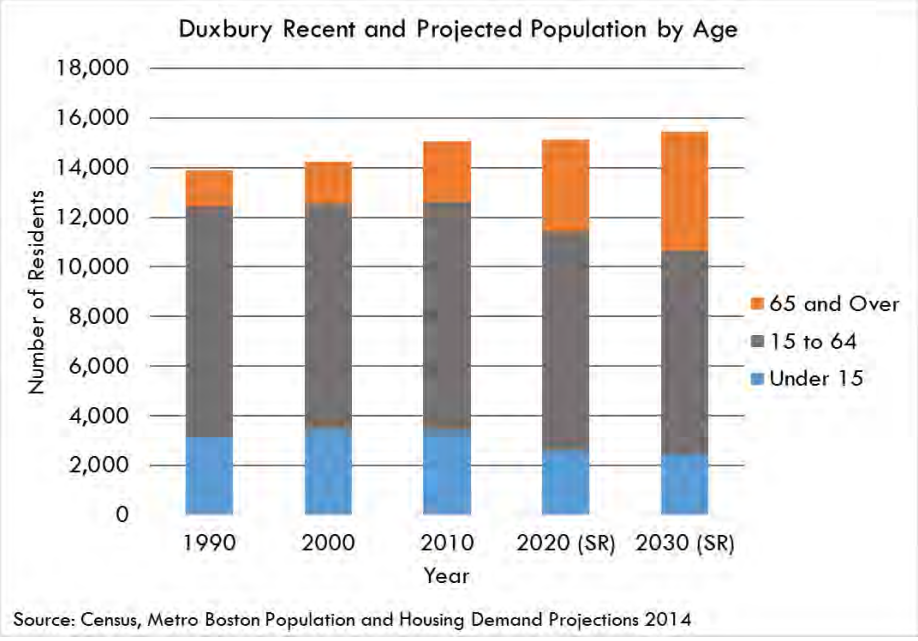
Overall, projected climate impacts do not create new concerns, rather they are an intensification, increased frequency, or geographic expansion of existing challenges. Duxbury already has significant planning, experience and expertise to bring to these challenges. Further, many initiatives to address climate impacts provide benefits to the Town (tree planting, open space preservation), can help address obligations (EPA MS4 permit compliance), or combat already identified problems (coastal flooding).

Although disruptive storms may occur at any time, most of the predicted climate changes are happening relatively slowly over time. Identifying future vulnerabilities now gives the Town of Duxbury time to plan and enact projects and policy changes that will make ensures a resilient community now and in the future.

Social Vulnerability

Demographic information helps identify residents that may be most vulnerable to climate change. It can also provide opportunities to build stronger community cohesion in order to enhance resilience. Social vulnerability refers to characteristics such as income, age, health, race/ethnicity and proximity to environmental hazards, which influence vulnerability to climate change. Just as some geographic areas in Duxbury will be more vulnerable to climate impacts than others, it is also the case that climate change will not affect all residents of Duxbury equally. In the context of climate change, vulnerable populations include those who may be more susceptible to climate impacts, and those who will have more difficulty adapting to, preparing for, and recovering from extreme weather events.

Figure 6 Current Population and Projections

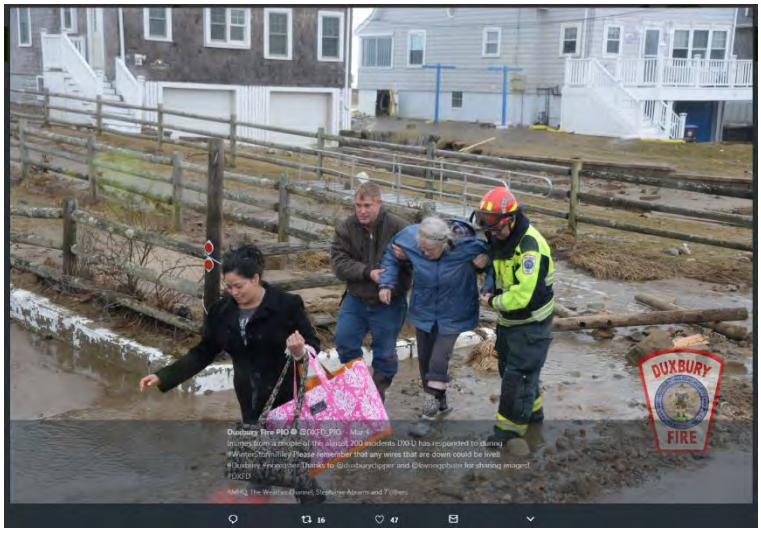


Duxbury's population is 15,297 which has grown and is expected to continue to grow into 2030 (Figure 6). According to the American Community Survey (2010), 16.3% of residents were 65 years or older and 11.8% of the total households in Duxbury are seniors living alone. Four percent are female only households with children living at home and 4.7% of all residents were under 5 years old.

Ninety-seven percent of Duxbury residents identify as white with Black, Hispanic or Latino, Asian, other or one or more races also being represented. Similarly, 98% of residents speak English only and two percent speak a language other than English at home. We found no data suggesting Duxbury has "limited English speaking" or "linguistically isolated" households.[30]

[30] 2010 Census. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF

Duxbury's residents have a higher annual income in comparison to the Commonwealth with a median household income of $119,428 (±6,963)[31] with no significant differences in geography and income across the Town. However, in 2016, 12.4% (±6.9%) of families were living with an annual income of $49,999 or less residents were living in poverty.[27]



Rescue during Winter Storm Riley March 2018. Source: Twitter @DuxburyFirePIO

Based upon these demographics, we suggest seniors (over age 65) are the most vulnerable residents for Duxbury. Specifically, one-third of all households have a person 65 or older. Population projections demonstrate this age group will grow. Seniors are likely at the greatest risk due to older age and declining health or chronic health conditions, fixed-income, and changes in social factors such as isolation. With potentially a fixed income, residents may have limited access to healthcare services or are under-insured, though as of 2013, 98.44% of residents had health insurance. After extreme weather events, they may be more susceptible to financial shocks, having long-lasting impacts on financial security, securing safe shelter and meeting medical needs. Furthermore, they may have limited access to transportation, impairing their ability to relocate to emergency shelters or away from areas susceptible to climate impacts. Seniors may also have physical mobility constraints and may require special assistance with emergency response.

One of many of Duxbury's strengths is the Duxbury Senior Center, accredited by the National Association of Senior Centers. In 2015, over 34,000 individuals participated in programs from Pilates, walking club and yoga to rug hooking, genealogy, cribbage, conversational French and much more. In addition to the robust social programming the Senior Center is a critical asset to serving those in need. They deliver meals to homebound individuals, utilize their network for outreach and visitation, and importantly, provide rides to seniors for social and independent activities as well as medical appointments. IN 2015, the Senior Center provided rides to over 7,800 individuals for shopping, library, meals, and medical appointments. Seniors engaged in the Center have also contributed over 20,000 hours of volunteer service in 2015 and provided respite to Alzheimer's disease or dementia caregivers.[32] The Senior Center also serves as a warming and cooling center during

[31] American Community Survey 2016 Estimates
[32] http://www.duxburyseniorcenter.org/about-us/#HISTORY

extreme weather events. The Duxbury Senior Center is a model for social vulnerability resilience – connecting and protecting its residents in climate change, extreme weather events, and every day.

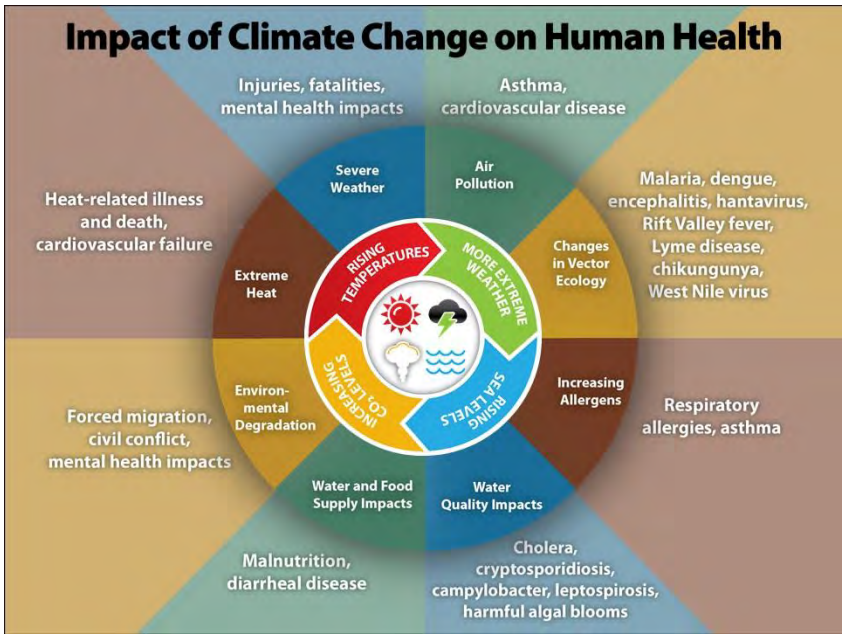
Public Health Vulnerability

Climate change already and will increase risk to public health. The Center for Disease Control Prevention illustrates in Figure 7 the intersection of climate change, impacts to human health and health outcomes as a result of exposure. In this section, we identify some of Duxbury's important public health vulnerabilities as a result to existing and future climate change.

Extreme Heat

The projected increase in extreme heat and heat waves is the source of one of the key health concerns related to climate change. According to the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Association (NOAA), heat was the leading cause of weather fatalities in the United States from 1987-2016 and the second leading cause of weather fatalities in the last decade.[33] As noted earlier, scientists project 30 to 60 days over 90°F, and 3 to 28 days over 100°F annually, by the end of this century.

Figure 7 Climate Change and Health Roadmap.



Source: Centers for Disease Control and Prevention (https://www.cdc.gov/climateandhealth/effects/default.htm)

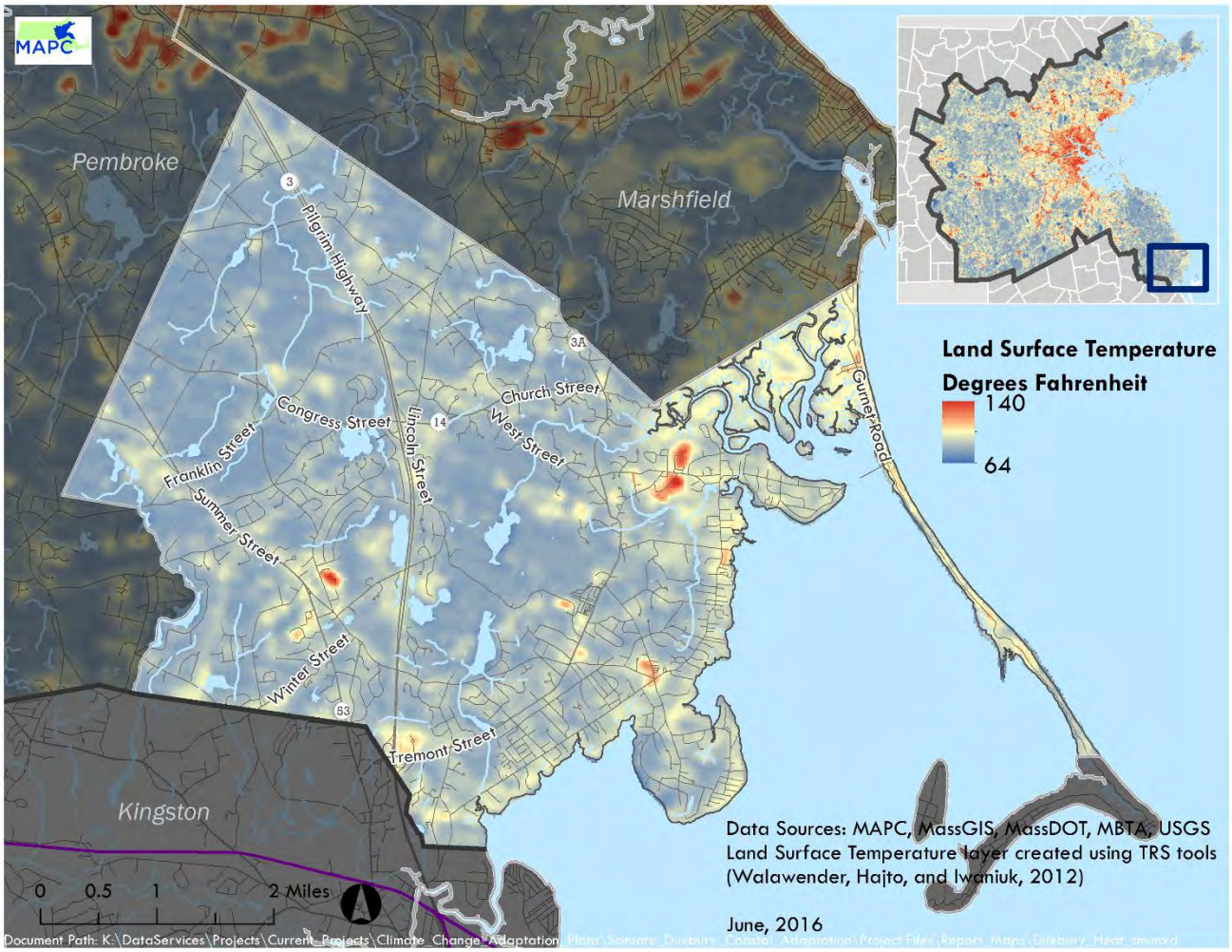
Duxbury contains significant tree cover, open space, and natural features that mitigate "heat islands", areas that are significantly warmer than the surrounding areas due to human activity. MAPC identifies heat islands as areas with elevated daytime land surface temperature above the mean daily temperature during late June/early July. Figure 8 illustrates the areas in Duxbury most vulnerable to extreme heat; these include the Duxbury Middle School/High School, Duxbury

[33] National Oceanic and Atmospheric Association, National Weather Service. Office of Climate, Water and Weather Services http://www.nws.noaa.gov/om/hazstats.shtml

Athletic Complex on St. George Street, Chandler Elementary School, and Halls Corner and the adjacent shopping center. It is important to note that Duxbury School Complex contains solar panels on its roofs providing an important climate mitigation function with clean energy use, but these panels would not implicate the heat island at this location. However, the Middle School and High School were recently constructed on this site and the many newly planted trees are not yet large enough to provide a notable cooling effect.

Other areas that indicate vulnerability to higher temperatures include the Snug Harbor business district and public access ramp (higher percentage of paved area and building coverage), Duxbury Beach (which by definition is not heavily vegetated as it is a barrier beach), and the Route 3 interchange on Tremont Street (reflecting recently developed higher-density residential complexes and the associated parking). Though there are many factors contributing to heat islands, the amount of impervious surfaces and nominal tree cover at these locations are likely important factors.

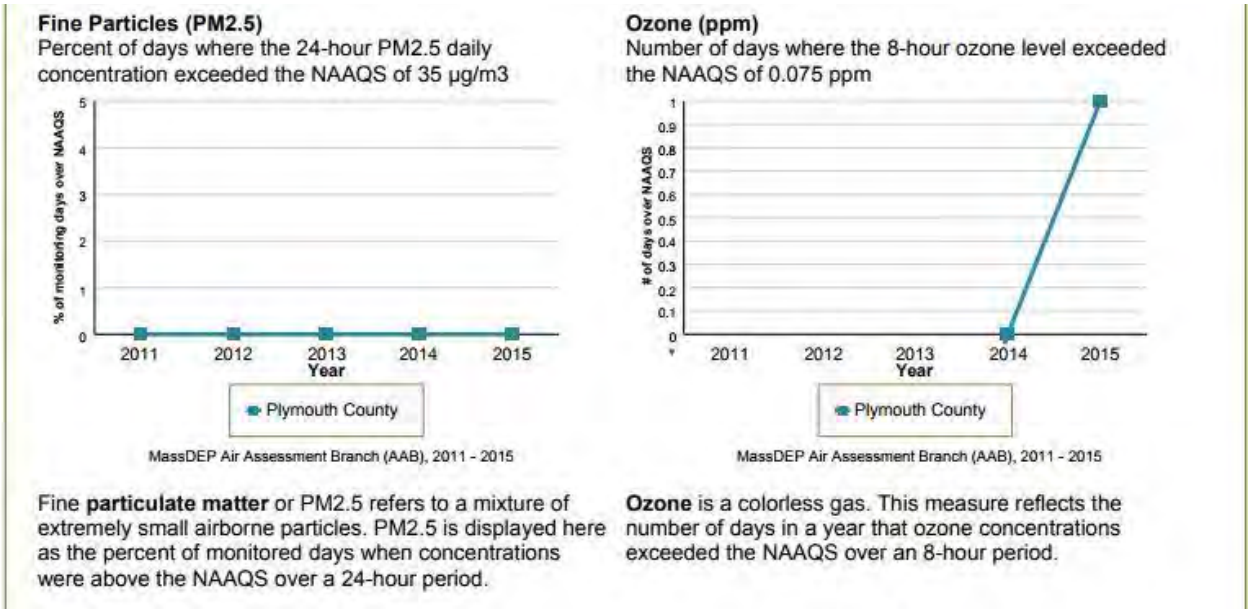
Figure 8 Heat Islands in Duxbury.



MAPC identifies heat islands in areas using LANDSAT satellite data with elevated daytime land surface temperature (LST) during late June/early July. This date provides a 30m downscaled average of land surface temperature every 16 days.

Prolonged exposure to high temperatures can cause heat-related illnesses, such as heat cramps, heat exhaustion, heat stroke, and in severe cases, death. Heat exhaustion is the most common heat-related illness and if untreated, it may progress to heat stroke. Prolonged heat exposure can also exacerbate pre-existing conditions, including respiratory illnesses, cardiovascular disease, and mental illnesses. Senior adults are at particularly high risk to heat for several reasons. They may not adjust to sudden changes in temperature as quickly as younger people, they are more likely to have a chronic medical condition whose symptoms may be exacerbated by heat, and they are more likely to be taking prescription medications that affect their ability to control body temperature.[34,35] Power failures can occur during heat waves, where intense heat spikes electricity demand and aging infrastructure. This occurred in June 2017 in the Town of Belmont, MA where intense heat cause a spike in electricity demand. With its aging infrastructure, the combination of these factors led to equipment failure.[36] Loss of electricity not only impair a resident's ability to cool, but can cause significant medical emergency for those who require electronic medical equipment or from food-borne illnesses from contaminated food, ingested after loss of refrigeration.

Figure 9 Air Quality in Duxbury 2011-2015



[34] Gamble, J. L., Hurley, B. J., Schultz, P. A., Jaglom, W. S., Krishnan, N., & Harris, M. (2013). Climate Change and Older Americans: State of the Science. Environmental Health Perspectives, 121(1), 15–22. http://doi.org/10.1289/ehp.1205223

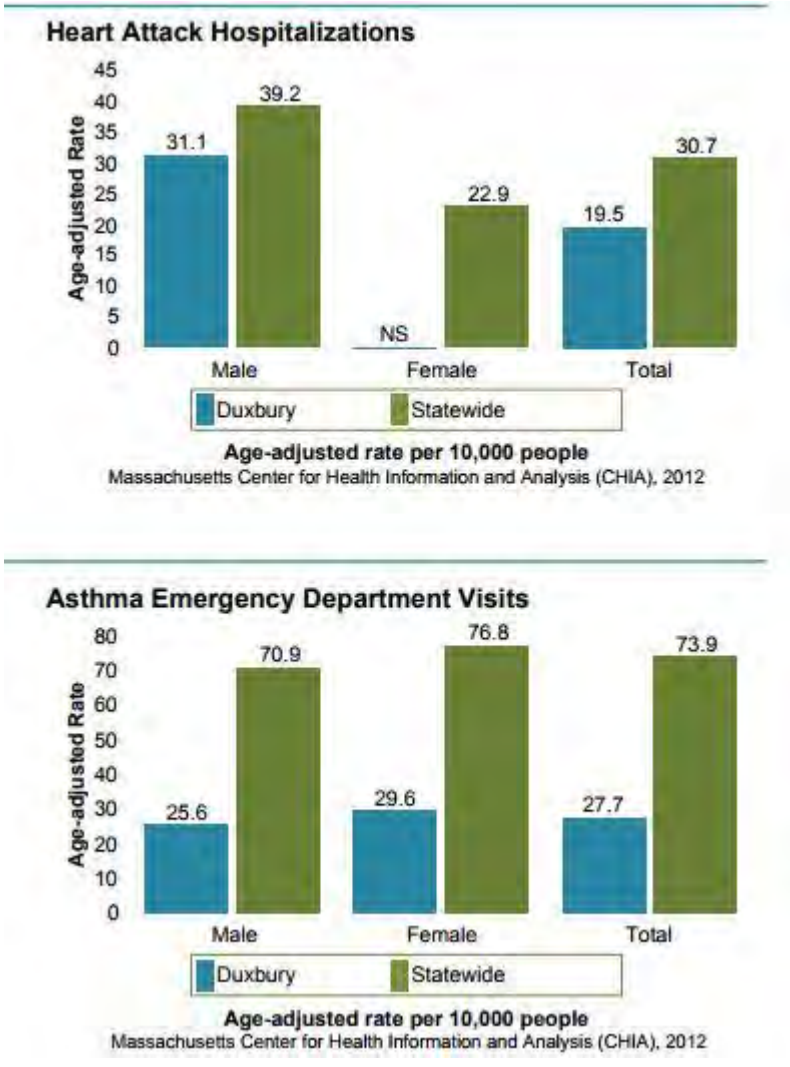
[35] Center for Disease Control and Prevention. Natural Disasters and Severe Weather. https://www.cdc.gov/disasters/extremeheat/older-adults-heat.html

[36] Wicked Local Belmont "Power Outage in Belmont Affects 2,000 Customers" June 14, 2017. http://belmont.wickedlocal.com/news/20170612/power-outage-in-belmont-affects-2000-customers.

Source: MA Department of Public Health-Bureau of Environmental Health https://matracking.ehs.state.ma.us/

Extreme heat can affect the general population even outside of heat islands. People who perform manual labor, particularly those who work outdoors, are at increased risk for heat-related illnesses. Extreme heat contributes to greater levels of ground level air pollution and allergens, and anyone who does outdoor physical activity during hot days with poor air quality is at increased risk for respiratory illness. For example, in 2015, Duxbury experienced one day where the 8-hour ozone level exceeded the National Ambient Air Quality Standards (NAAQS), from zero days in 2014 but zero days from 2011-2015 where fine particles daily concentrations exceeded the NAAQS (Figure 9).

Figure 10 Cardiovascular and Respiratory Health in Duxbury.



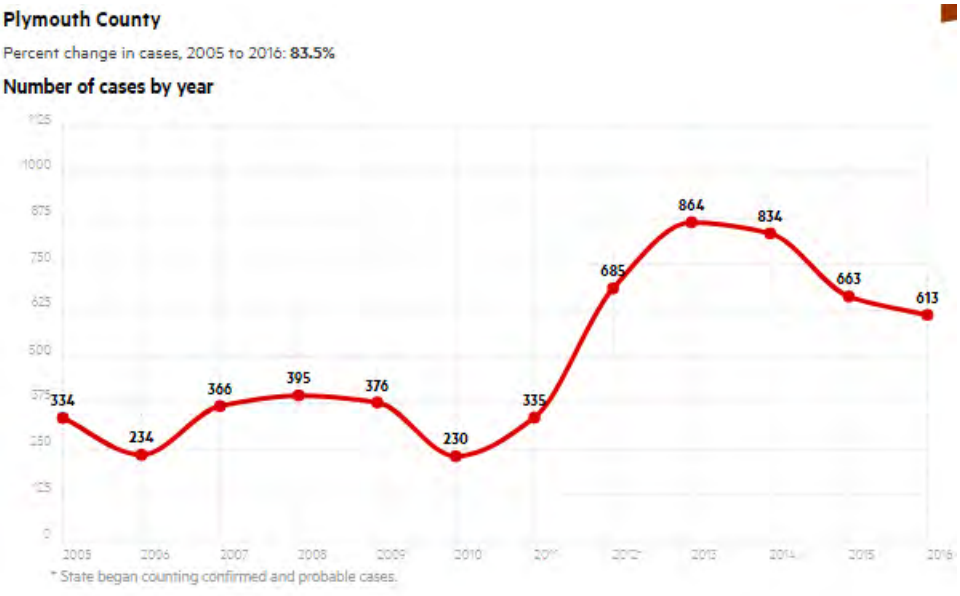
Source: MA Department of Public Health-Bureau of Environmental Health https://matracking.ehs.state.ma.us/

The poor air quality and high humidity that often accompany heat waves can aggravate asthma and other pre-existing cardiovascular conditions, particularly for those individuals on heart medications which can exaggerate the body's response to heat. One way to ascertain residents' vulnerability to heat and these medical conditions is to review local hospitalizations measured by count of hospital discharges and Figure 10 illustrates Duxbury's hospitalizations for heart attacks and asthma as well as pediatric asthma prevalence. Overall, Duxbury residents are generally at lower risk than that of the State from the combined health risks of heat and poor air quality.

Changes in Vector Ecology

Vector-borne illnesses are those that stem from contact with moving, living, biological sources such as mosquitos and ticks. The spread of vector-borne illnesses is influenced by vector type, weather conditions, built environment conditions, and human behavioral factors. The two most common mosquito-borne illnesses in Massachusetts are eastern equine encephalitis (EEE) and West Nile virus (WNV). Thirty-three human cases of WNV and seven cases of EEE have occurred since 2012 in Plymouth County. As of September and October 2017, the MA Executive Office of Health and Human Services determined that Duxbury has a low risk of exposure to both WNV and EEE, though the neighboring towns of Kingston and Pembroke have a moderate risk of exposure to WNV.[37][20] As climate change is expected to bring heavy precipitation events (which increase areas of standing water) and warmer temperatures, it is expected that mosquito populations will grow and that the transmission season will extend beyond its traditional late spring through early fall. Warmer temperatures also accelerate a mosquito's lifecycle and increase their biting rates.

Figure 11 Change in Lyme disease infections 2005-2012 in MA.



Source: WBUR "Map: Where Lyme Disease is Worsening in MA."
http://www.wbur.org/commonhealth/2017/07/18/massachusetts-map-lyme-disease

[37] MA Executive Office of Health and Human Services. Massachusetts Arbovirus Daily Update. http://www.mosquitoresults.com/

Tick-borne illnesses, particularly Lyme disease, babesiosis, and anaplasmosis have been on the rise in Massachusetts. From 1991-2014, there has been an average increase of 59 cases of Lyme disease per 100,000 people and from 2005-2012 there was an 83% increase in infections in Plymouth County (Figure 11). Winter frost plays an important role in limiting tick populations; warmer winter may lead to more nymphs surviving into the spring months. As with mosquitos, warmer temperatures can lead to longer transmission seasons as ticks begin to seek hosts earlier in the season. Tick populations thrive with increased precipitation and humidity, and may be more susceptible to annual fluctuations in precipitation than mosquitos.

Forecasting the spread of vector-borne illnesses and estimating risk due to climate change is very challenging, due to multiple factors at play. For example, research suggests that heavy precipitation in urbanized areas could actually reduce mosquito populations by flushing underground breeding habitat. Further, vector populations' size and range is dependent on the size and range of their host species (i.e., migratory birds, mice, and deer), which may shift as the climate changes. As the climate gets warmer, tropical vector species may expand their ranges north, which could bring with them vector-borne illnesses not typically found in the Northeast (i.e., dengue fever or chikungunya). As vector-borne disease outbreaks occur globally, residents may import vector-borne illnesses acquired during trips to other countries.

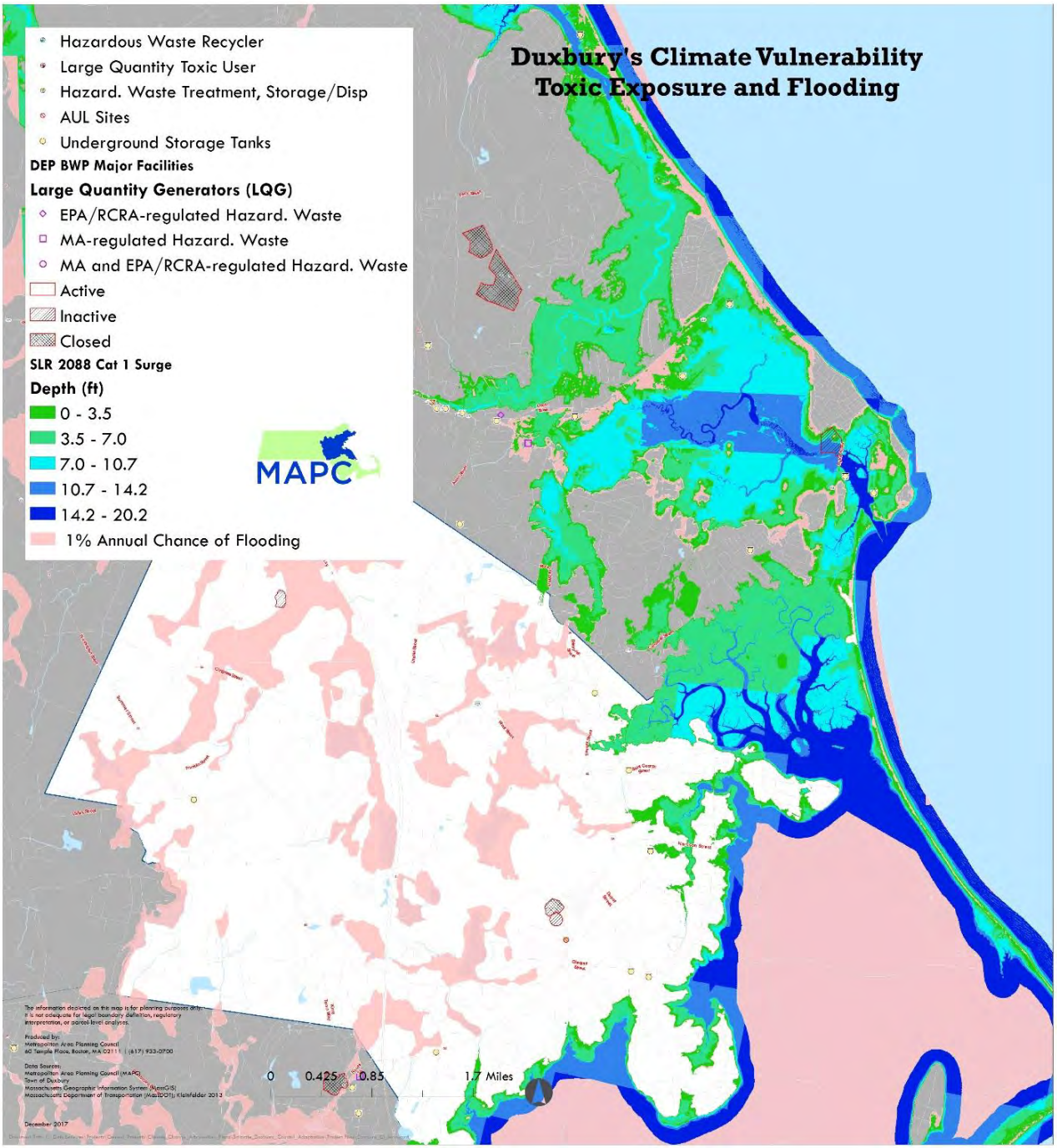
People who spend a lot of time outdoors, or live close to vector habitats, are at greatest risk of exposure to vector-borne illnesses. The ability to protect oneself from mosquito-borne illnesses has been associated with socioeconomic status via housing conditions. Households that can afford air-conditioning and maintenance of windows/screens are less likely to come into contact with mosquitos in their home. Those most likely to experience severe vector-borne illnesses are children, people over the age of 50, and people with compromised immune systems.

Toxic Exposure

A significant public health risk in the face of extreme precipitation or storm events with subsequent flooding is exposure to environmental hazards and toxins, for both the immediate and long-term. Duxbury has nominal to no risk of exposure due to flooding from a 1% Annual Chance Flood or from SLR in 2088 (Figure 12). This analysis includes MA Department of Environmental Protection and/or the US Environmental Protection Agency hazardous waste regulated sites, landfills, and underground storage tanks (UST). Areas proximate to flood zones that are cautionary include the UST at Duxbury Yacht Club for SLR 2088, the UST and S&M Gas Station on Tremont Street (1% Annual Chance Flood), and the Duxbury stump landfill on Keene Street (though this site's purpose is for wood waste only). There are also two additional noteworthy sites. The former Battelle Laboratory site, no longer in operation, was a hazardous waste regulated area by the EPA and the DEP as a large quantity hazardous waste producer. Its storage location is within approximately three feet of flooding with SLR in 2088. The second is the closed Marshfield Brant Rock Dump. Located on Marshall Avenue/Route 139, this site contains municipal solid waste, and according to the DEP is unlined. It is located within a 1% Annual Chance Flood and submerged over three feet of water with SLR in 2088. The greatest exposure risk for this location is to the residents of North Duxbury.

These sites could potentially release toxic or hazardous substances if structures and containments were damaged as a result of inland flooding, storm surge, or coastal flooding. In an extreme flooding event, potential exposer to these health-threatening substances like waste water can

Figure 12 Flooding and Toxic Exposure Potential.



cause water contamination, including bacteria, viruses, and chemicals that cause gastrointestinal diseases, dermatological conditions, toxicity/poisoning, and other illnesses. Often people come into contact with contaminated water when it floods onto their property, but contact with contaminated water through recreation can be dangerous, too. Climate change is expected to increase the risk of residents coming in contact with contaminated water in their parks, homes, schools, and places of work.

Long term risk with more frequent precipitation and/or with localized flooding is water damage to buildings – and the formation of mold. Chronic mold can be an already existing problem particularly in public housing, senior housing, and in buildings built before the 1980s. Mold triggers allergies and respiratory illnesses, such as asthma. Some strains of mold release airborne toxins, called mycotoxins, which can cause mold toxicity. Mold toxicity can influence the function of internal organs, the nervous system, and the immune system.

Natural Resources Vulnerability

Marshall Street marsh by Eagles Nest Bay. Photo credit: Darci Schofield

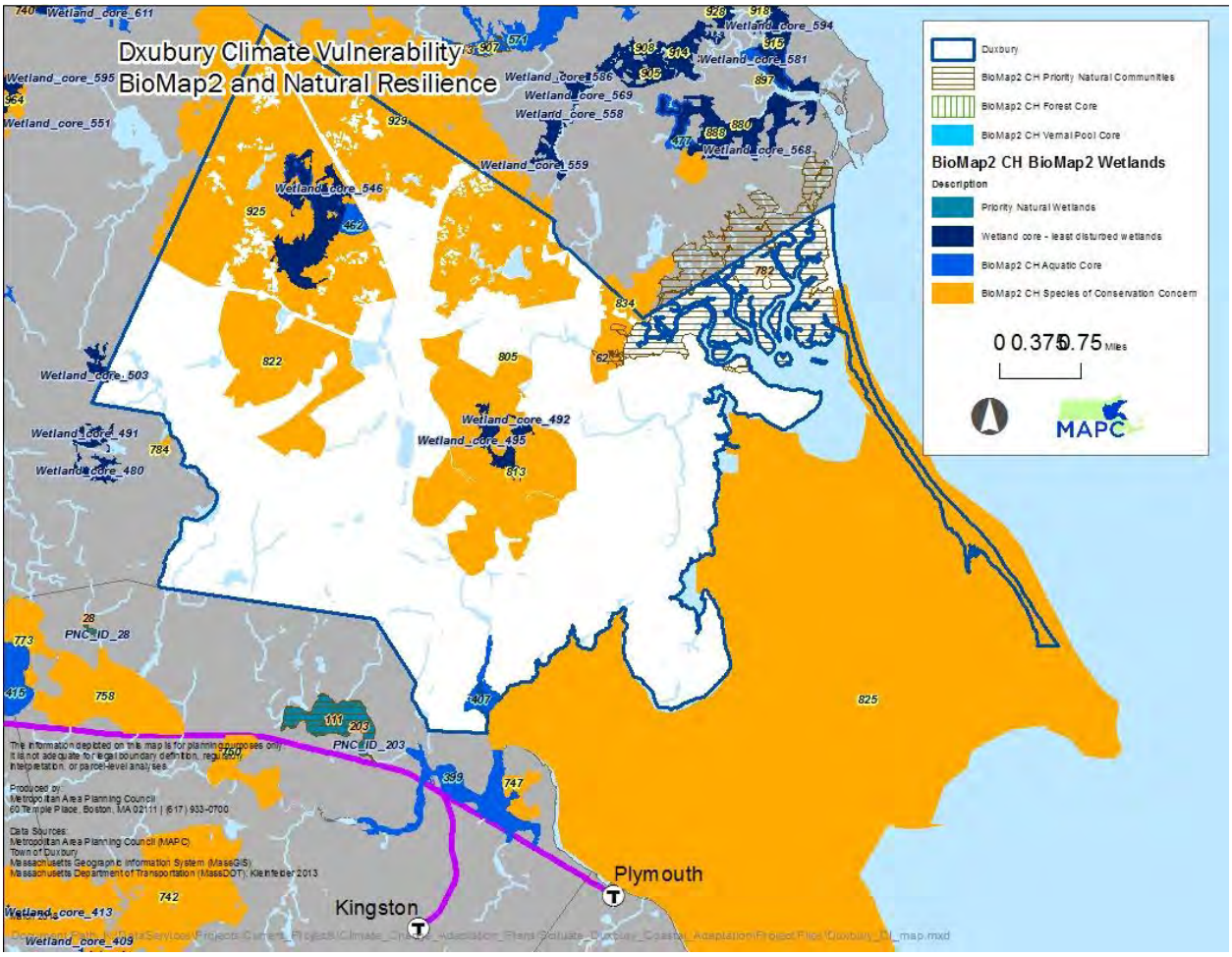
Duxbury is a coastal community shaped by its extensive natural assets that define the values and cultural richness of the Town. With 37 miles of tidal shoreline, 1,200 acres of salt marshes, over 3,500 acres of protected open space, and prime forest land, Duxbury is well-served by the ecological services and resilience these natural features provide. Intact natural systems support clean drinking water, clean air, important agricultural and recreation amenities, flood control, beautification, economic benefits and carbon sequestration. Since 1963, Duxbury has been aggressive in acquiring and protecting land for its drinking water[38] and this effort has restored many endangered and sensitive wildlife habitats.

Indeed, the Town contains 10,356 acres of BioMap2 Core Habitat and Critical Natural Landscape and nearly 70% of that total area is protected.[39] BioMap2 is a program created by the MA Department of Fish and Game Natural Heritage and Endangered Species Program (NHESP) and The Nature Conservancy to map important natural resource areas that will protect biodiversity and the nature of Massachusetts in the face of climate change. These areas also support 17 rare, endangered or threatened wildlife species or natural communities. The large expanse of intact natural lands, ensures strong ecosystem function to protect the community from the impacts of climate change. Core Habitats are areas required to sustain rare wildlife and their exemplary natural ecosystems and habitat. Critical Natural Landscape are areas to support these exemplary ecosystems or habitats to endure stressors from climate change or development. (Figure 13).

Healthy, intact ecosystems in Duxbury provide a multitude of benefits from public health to floodwater storage to beautification, but they also provide a fabric of climate resilience to the community. But these natural resources are also vulnerable to our changing climate. Erratic and extreme precipitation patterns, SLR, ocean acidification from carbon sequestration, and impacts related to warmer climate such as changes in growing season, species migration, invasives, and the freeze/thaw cycle will all cause increased stress to ecosystem function. This section highlights Duxbury's natural assets and ecosystem risks from climate change impacts.

[38] Duxbury Conservation Commission. 2017. *Duxbury Open Space and Recreation Plan.*
[39] Natural Heritage and Endangered Species Program. Conserving the Biodiversity of Massachusetts in a Changing World- Duxbury. 2012. http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Duxbury.pdf

Figure 13 BioMap2 Core and Wetland Habitat



Coastal Environment

In 2011, MAPC completed the *South Shore Hazards Adaptation Study* and in 2013, Kleinfelder completed *SLR Study for Duxbury, Marshfield, and Scituate*. These studies provide an important analysis on SLR, storm surge, and coastal adaption and the infrastructure at risk. Both studies provide recommendations for long-term resilience and/or adaptation strategies and further study and the 2017 DRAFT Open Space and Recreation Plan for Duxbury summarizes these risks and recommendations as well. This section will identify risks to the coastal environment coastal resilience that are nominally or not addressed in the aforementioned reports.

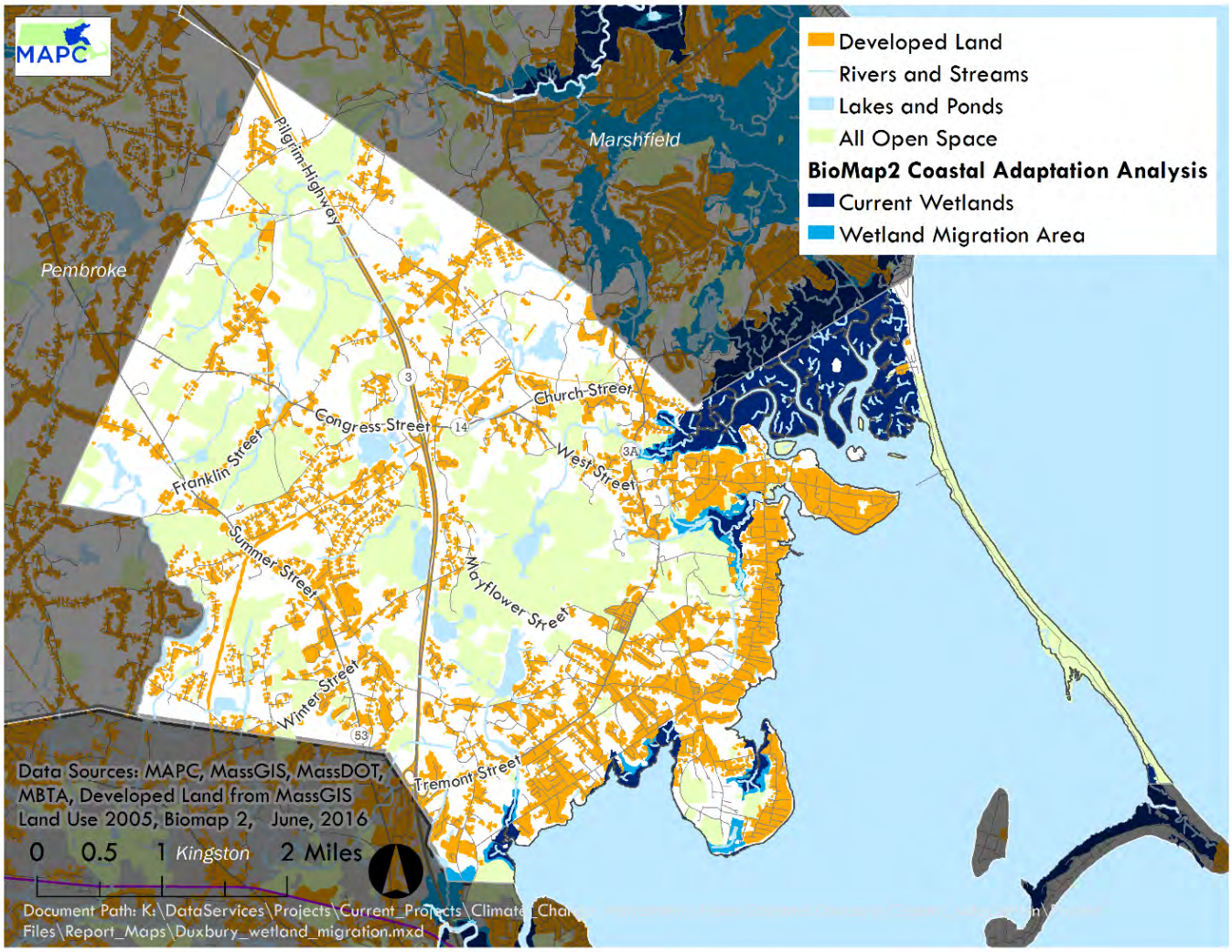
Salt Marshes

Duxbury has approximately 1,200 acres of salt marshes and estuaries. The Duxbury Marsh is one of the largest salt marshes in Massachusetts extending over 1,000 acres[34,40,41] but other important marshes include at the marsh at Hicks Point, the marsh along Bay Road along the shore to Howlands Landing, the marsh at Hardin Hill, and the marsh at the Bluefish River extending along

[40] Duxbury Bay Management Commission. 2011. *Duxbury Bay Management Report.*
[41] Duxbury Conservation Commission. *DRAFT Duxbury Open Space and Recreation Plan.* 2017

Powder Point Avenue. These salt marshes are already protecting coastal residences and business from storm surge and SLR.

Figure 14 Wetland migration for inland and coastal wetland climate resilience.



Salt marshes and estuaries are complex and highly productive ecosystems generally resilient to wide variations in temperature, salinity, and tidal inundation.[42] Ecological benefits of salt marshes include floodwater storage, storm surge protection, carbon sequestration, nutrient removal and water quality improvements. Healthy marshes also support important commercial fish and shellfish habitat.[43] The sustainability of the system is a delicate balance of complex coastal processes. Salt marshes are typically found in low energy coastal areas; they require consistent inundation but cannot survive if submerged. Salt marshes today are already threatened by several factors: nutrient loading/non-point pollution from stormwater runoff, extreme precipitation events, loss of

[42] Executive Office of Energy and Environmental Affairs and Adaptation Advisory Committee. 2011. *Massachusetts Climate Adaptation Report.*

[43] Linda A. Deegan, David Samuel Johnson, R. Scott Warren, Bruce J. Peterson, John W. Fleeger, Sergio Fagherazzi & Wilfred M. Wollheim. Coastal eutrophication as a result of salt marsh loss. 2012. Nature 490: 388-392

tidal flow due to insufficient culverts, invasive species and persistent salt water inundation. Salt marshes are protected by the Wetlands Protection Act with a 100-foot buffer and no disturbance regulation. However, historic development has created hardened shorelines that affect the horizontal migration and vertical migration of the salt marsh.

With climate change, the deteriorated conditions of many of Massachusetts' salt marshes will be exacerbated with sea level rise, lack of migration area from hardened shores, and extreme precipitation events flushing the salt marsh and creating an environment conducive to invasive species. Figure 14 illustrates the location and adaptation areas needed for migration to alleviate or reduce these stressors and enhance endurance to ecosystem function through a changing climate. Monitoring and management of ecosystem health will be an important long-term adaptation strategy.

Figure 15 Eroding Salt Marsh at Kingston Bay.

Evidence of degraded salt marsh at the shore of Bay Farm in Duxbury along Kingston Bay.

The greatest risk to Duxbury in the face of climate change is the impacts of SLR and storm surge, today and into the future as scientists anticipate an acceleration of SLR with global warming. This will affect not only the infrastructure along the immediate shoreline but also many of the natural systems currently supporting the Town's shellfish economy, water-based tourism and recreation, and coastal resilience.[44]

Mass Bays is an EPA National Estuary Program that facilitates research and partnerships to create more resilient and sustainable estuarine ecosystems. According to the Mass Bays Ecologist,

[44] https://www.nature.com/articles/s41598-017-09269-z

most of Duxbury's salt marshes appear healthy with no signs of shifting plant species of tall and short *Spartina* (salt marsh cord grass), an indicator of marsh migration, salt marsh, and ecosystem health.[45] However, the salt marsh in Kingston Bay at Bay Farm is showing signs of deterioration and erosion (Figure 15).

Bays

Snug Harbor. Photo credit Darci Schofield

Kingston and Duxbury Bays are robust seasonal amenities with boating, swimming, sailing, windsurfing, paddle boarding, windsurfing etc.[46] The bays also host important tidal flats that sustain a productive shellfish growing areas, eel grass, anadromous fish, and many resident and migratory birds,[47] some of which are threatened and endangered. The Duxbury Bay Management Plan completed in 2011 used available data and indicators to ascertain the health of the bay ecosystem, which indicated that coastal water pollution was affecting the water quality of the bay but it was generally supporting healthy ecological, fishing, and recreational systems. According to the MA Department of Environmental Protection, both bays are in the 2014 "Final Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314 and 303(d) of the Clean Water Act," as Category Five, requiring TMDLs[48]. Kingston Bay at the mouth of the Jones River has use-restrictions such as limitations on shellfish harvesting from the presence of fecal coliform (Table 3). As of 2016, of the potential acreage for shellfish harvesting, approximately 25% is approved, 57% is conditionally approved, and approximately 18% is prohibited. Kingston has invested over $1 million in stormwater remediation work for bacteria since 2011-2012 resulting in some water quality improvements and allowances in commercial shellfish harvesting licenses.[49] Duxbury Bay is an approved shellfish growing area by the Division of Marine Fisheries.

With climate change, another important risk to Kingston and Duxbury Bay are ocean acidification and warmer temperatures. Oceans capture excess carbon dioxide (CO^2) released into the atmosphere through the burning of fossil fuels, which when dissolved forms carbonic acid

[45] Personal Communication. Sara Grady, South Shore Regional Coordinator, Mass Bays, September 2017.
[46] Duxbury Conservation Commission. 2008. *Duxbury Open Space and Recreation Plan.*
[47] Duxbury Bay Management Commission. 2011. *Duxbury Bay Management Report.*
[48] Total Maximum Daily Loads of specific nutrients allowed to impact coastal embayments or other water bodies as established through EPA regulations under the Clean Water Act – which establish the cap at which the water body or embayment can still satisfy water quality standards while absorbing these nutrients.
[49] Town of Kingston FY16 Coastal Pollutant Remediation Grant. Summary Report Kingston Bay Shellfish Harvest Area Status.

ultimately affecting the typically basic pH levels in the ocean. The *2017 Climate Science Special Report: Fourth National Climate Assessment* states that under high emission scenarios, ocean pH could decline from the current average of 8.1 to 7.8 by the end of the century. Because colder waters retain more CO^2, colder waters could heighten under-saturation of carbonate.[50]

Table 3 Water Quality Impairments

Waterbody	Category	Impairment
Duxbury Bay	5	Fecal coliform, discharges from municipal separate storm sewer systems (MS4)
Kingston Bay	5	Fecal coliform, discharges from municipal separate storm sewer systems (MS4)
Bluefish River	5	Fecal coliform, source unknown
Jones River (Kingston)	4a	Fecal coliform, discharges from municipal separate storm sewer systems (MS4)

Future ocean acidification may cause shellfish larvae to create smaller shells or not develop them at all[51] or reduce shellfish reproduction and growth rates. This phenomena is being studied by the University of New Hampshire in partnership with Mook Farm, an oyster farm in Maine and the National Oceanic and Atmospheric Administration (NOAA). In 2017, they have been collecting carbonate chemistry data during fisheries surveys along the eastern seaboard to develop models of how ocean acidification may affect the shellfish industry and the people whose livelihoods rely upon the industry.[52] Currently, Massachusetts Bays is seeking to install an ocean acidification monitor at the Mattakeesett Public Boat Launch in Duxbury and to work with the fishermen using the launching area to assist in the monitoring.[53]

Increasing ocean temperatures locally can detrimentally affect ecosystem function, causing species migration, potentially introduction of new pathogens, and harmful algal blooms.[46] In the last three decades, sea surface temperatures have been higher on average than over the last century or ever since being recorded.[54] During this time, sea surface temperatures have exceeded the last century's average every year. The MA Department of Public Health, in partnership with the Department of Fish and Game and Division of Marine Fisheries (DMF), monitors pathogenic marine micro-organisms related to foodborne illness. There is a reported increase in some naturally-occurring bacteria found in warm, brackish waters on the Eastern seaboard,[55] and state agencies,

[50] USGCRP, 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume 1[Wuebbles, D.J., D.W. Fahey, K.A Hibbard, D.J. Dokken, B.C. Stewart. And T.K. Maycock (eds.)] U.S. Global Change Research Program, Washington, DC, USA 470 pp doi 10.7930/J0J964J6
[51] Waldbusser, George G. et al. 2015. Saturation-state sensitivity of marine bivalve larvae to ocean acidification. Nature Climate Change *5*, 273-280
[52] National Oceanic and Atmospheric Administration. Climate Change Indicators in the United States. 2016 http://www.globalchange.gov/browse/indicators/indicator-sea-surface-temperatures
[53] Personal Communication. Sara Grady, South Shore Regional Coordinator, Mass Bays, September 2017.
[54] National Oceanic and Atmospheric Administration. Climate Change Indicators in the United States. 2016 http://www.globalchange.gov/browse/indicators/indicator-sea-surface-temperatures
[55] Vezzulli et al. 2016. Climate influence on *Vibrio* and associated human disease during the past half-century in the coastal North Atlantic. PNAS August 23, 2016. 113(34)

local health officials and the shellfish industry carefully monitor for the presence of such organisms.

This prevents occurrences of illness which can result when contaminated shellfish are consumed raw.[56] Duxbury, Kingston and Plymouth Bays at times are temporarily closed to swimming and shellfishing after storm events to prevent harvests of shellfish or exposure to waters [57] with elevated levels of storm-related contaminants. These bays are home to some of the most successful oyster harvesting businesses in the United States, and the careful coordination and cooperation of the industry, as well as the ongoing work to reduce land-based nutrient loads by these communities, has significantly improved water quality during this same time period.

Seagrass meadows such as eelgrass provide important ecological and climate resilience benefits. They capture sediment and take up nutrients ultimately providing better water clarity provide important habitat for fish. Importantly, seagrass meadows will dissipate wave energy and wave height thereby reducing shoreline erosion.[58] Seagrass decline can be attributed to many factors such as pathogens, sea grass is highly vulnerable to environmental stressors as nitrogen loading from stormwater, sewer systems, and fertilizers and warming ocean temperatures.[59]

Duxbury has experienced a loss of nearly1,000 acres of eelgrass between 2012 and 2014,[50] whose meadows are routinely monitored by DMF (Figure 16). Noting the decline, DMF Habitat Research Team conducted an analysis in 2016 using sonar and video to capture eelgrass beds not covered by other annual seafloor mapping studies. Their research suggests that as much as 3,440 acres of eelgrass were present in 1951. Further, they suggest that eelgrass could be entirely lost at the earliest in the immediate present, or the latest 2051, with a median rate of loss of 27 acres per year. DMF is now utilizing ocean temperature data to monitor its effect on eelgrass loss, particularly for Duxbury Bay.[53] Some suggested causes for this decline including warming ocean temperatures, limited light penetration from turbidity, and water quality impairments from nutrient loading and stormwater. Duxbury and Kingston Bays are slightly and moderately impaired and according to MA DMF.[60] SLR, warming ocean temperatures and increased runoff from extreme precipitation could exacerbate this already stressed system and create dysfunction in the overall marine ecosystem critical for water quality, shoreline protection, and commercial fish industry.

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[56] Executive Office of Health and Human Services. Public Health Implications of Climate Change. http://www.mass.gov/eohhs/gov/departments/dph/programs/environmental-health/exposure-topics/public-health-implications-of-climate-change.html

[57] MA Division of Marine Fisheries. 2016 Annual Report. http://www.mass.gov/eea/docs/dfg/dmf/publications/2016-dmf-annual-report.pdf

[58] Bradley, Kevin and Houser, Chris. 2009. Relative velocity of seagrass blades: Implications for wave attenuation in low-energy environments. Journal of Geophysical Research, Vol 114 F01004

[59] Short, Fred; Klein, Anita; Burdick, David; and Moore, Gregg. 2012. The Eelgrass Resource of Southern New England New York: Science in Support of Management and Restoration Success. NOAA Restoration Center

[60] MA Division of Marine Fisheries. 2016. Eelgrass loss over time in Duxbury, Kingston, and Plymouth Bays, Massachusetts. Final Report. https://www.mass.gov/files/2017-08/2015%20DuxburyKingstonPlymouth%20Eelgrass.pdf

Figure 16 Duxbury eelgrass meadows from 2010 to 2012.

BioMap2 is a program created by the MA Department of Fish and Game Natural Heritage and Endangered Species Program (NHESP) and The Nature Conservancy to map important natural resource areas that will protect biodiversity and the nature of Massachusetts in the face of climate

change.[61] Aquatic Cores are intact river corridors whose ecological processes are critical to supporting fish species and other aquatic Species of Conservation Concern as well are providing a myriad of important wetland ecosystem functions. The Bays and brackish tidal marshes are part of a 12,815-acre Core Habitat designated by the MA Natural Heritage and Endangered Species Program, including11rare and uncommon species, particularly for federally Endangered Roseate and other Terns for nesting and pre-migration staging area.[62] These combined factors make Duxbury Bay a critically important ecosystem that serves to provide multiple benefits and a more resilient coastal ecosystem.

Barrier Island and Beaches

Duxbury contains several public beaches including Duxbury Beach, the beach at Landing Road, Shipyard Lane Beach, and the beach at Powder Point Bridge. Duxbury Beach is a critically important natural system, storm barrier, and recreation amenity not only to the Town of Duxbury but also its neighboring towns. Owned by the Duxbury Beach Reservation, Inc. and leased by the Town of Duxbury, thousands enjoy the beautiful beach all year round. Indeed, in a 2015 survey completed by residents, Duxbury Beach was the most important factor for nearly 80% of respondents in choosing to live in Duxbury.[63]

Not only is it one of the most beautiful and accessible beaches in the South Shore, Duxbury Beach is an indispensable asset to the Towns of Kingston, Duxbury, and Plymouth for the wave attenuation, energy dissipation, storm surge and SLR shoreline protection it already affords to the Towns; its protection, restoration, and stewardship is critical to protecting the waterfront homes, businesses, and commercial entities from significant damage during coastal storm surge. Duxbury Beach is already prone to deterioration from SLR and storm as demonstrated by repeated flooding, over wash in multiple areas by the third crossover, and loss of sacrificial dunes (Figure 17).

The Duxbury Beach Reservation, Inc.'s mission is to restore and protect the beaches in their natural state, to provide public access, and protect Duxbury and Kingston as a barrier. Since 1975, Duxbury Beach Reservation has undertaken over twenty-seven studies and projects to enable this mission. These include (i) vulnerability and risk assessments from coastal flooding and invasive species, (ii) road redesigns for stormwater management and beach migration, (iii) natural storm damage protection projects such as installing cobble berm, sacrificial dunes, and beach nourishment (iv) installation of innovating fencing systems to mitigate erosion, and (v) ecological restoration projects for predator evaluation, artificial habitats for plover, and symbolic fencing for birds. They are currently in the design phase for a dune restoration project between the 1st and 2nd crossovers to raise the dune crest and to widen the dune to a minimum width of 45 feet

[61] Natural Heritage and Endangered Species Program. Conserving the Biodiversity of Massachusetts in a Changing World

[62] Natural Heritage and Endangered Species Program. Conserving the Biodiversity of Massachusetts in a Changing World-https://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Duxbury.pdf

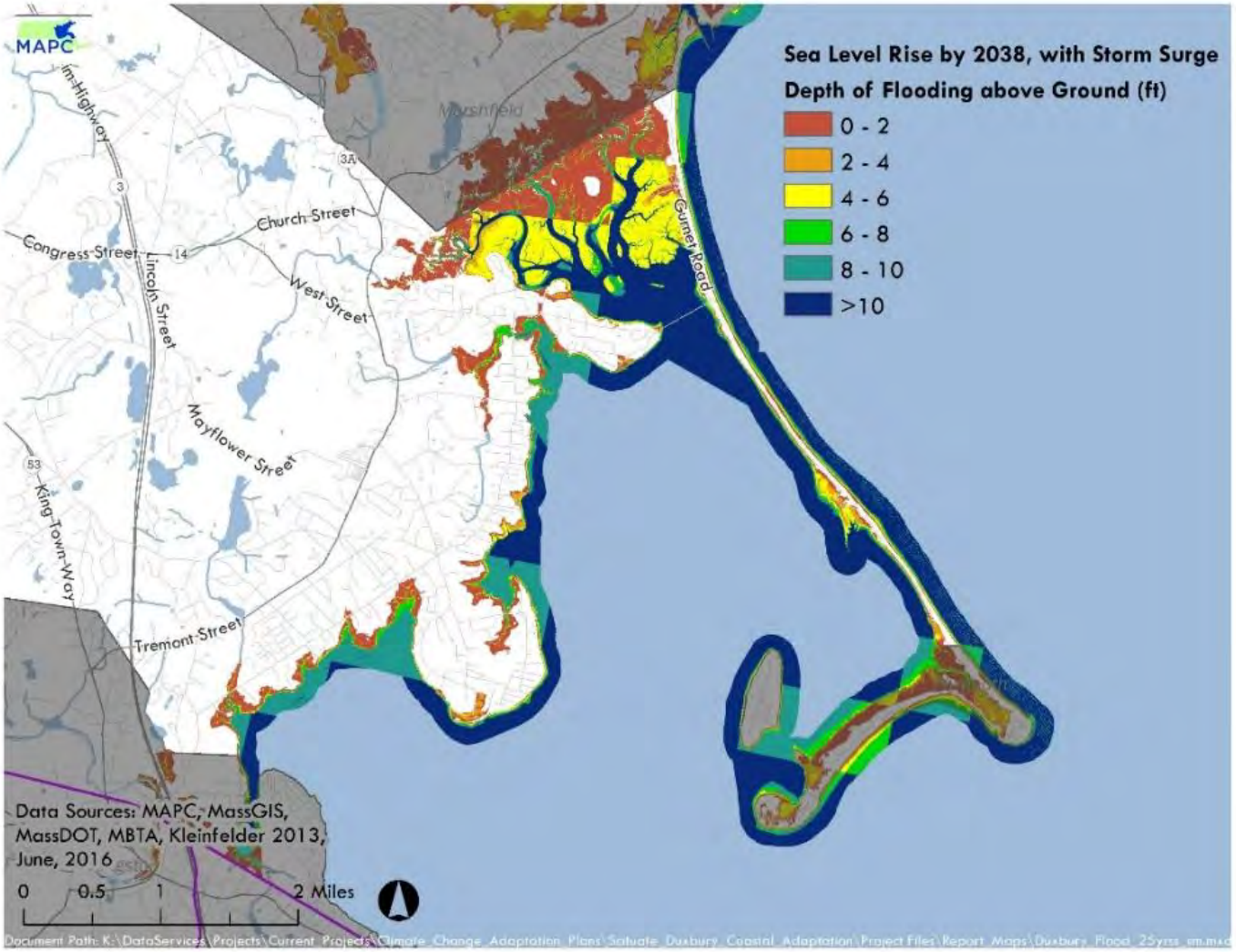
[63] Duxbury Conservation Department.
ttps://www.town.duxbury.ma.us/sites/duxburyma/files/uploads/2015_open_space_survey_executive_summary.pdf

Figure 17 Coastal storm damage at Duxbury Beach

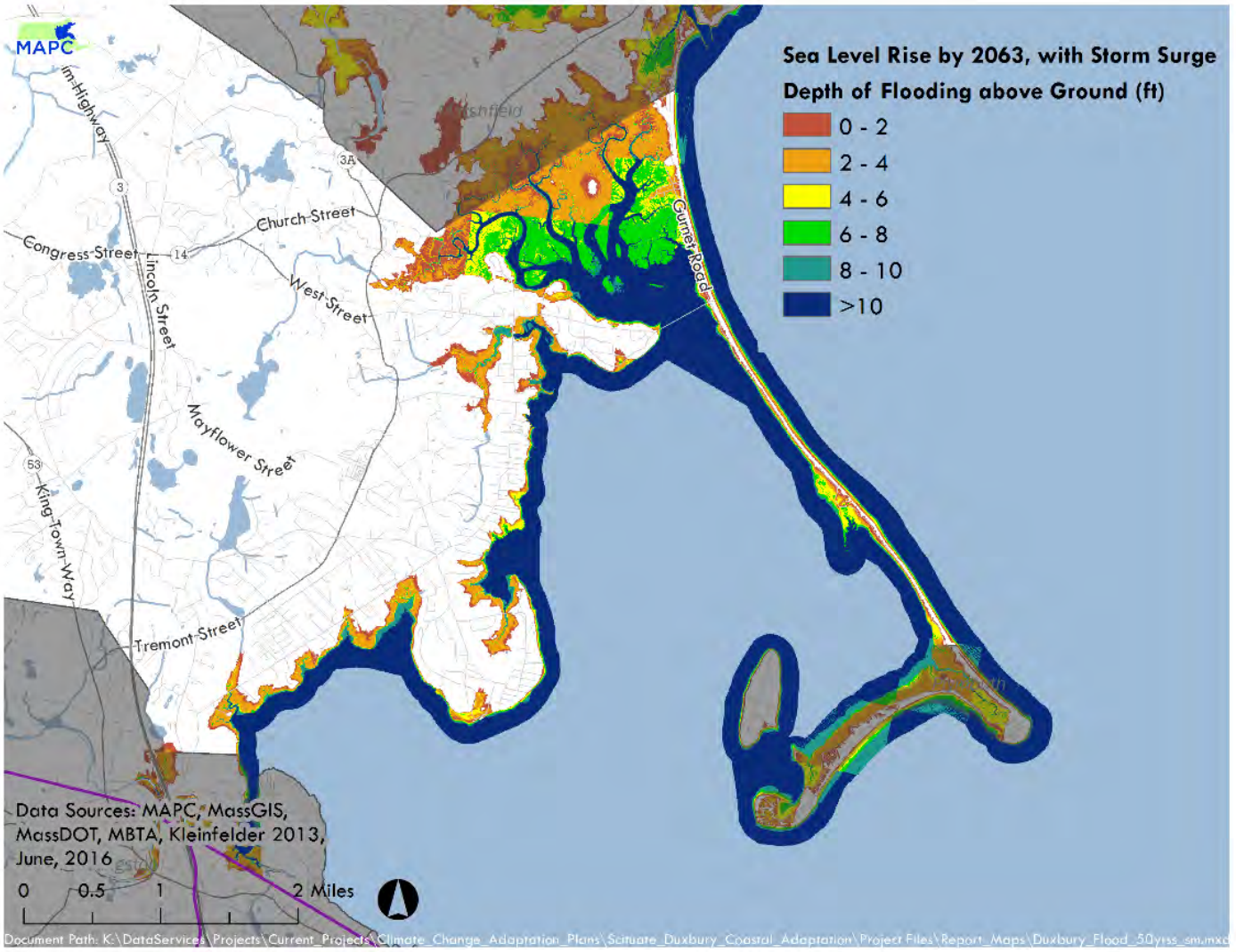
Significant coastal storm damage at Duxbury Beach after a blizzard in February 2014 (top 2 photos) and Winter Storm Riley, March 2018. Photo: Duxbury Beach Reservation, Inc. Facebook

(as opposed to 35 feet).[42] The *Duxbury Beach Management and Habitat Conservation Plan* provides greater detail on the evaluation, assessment restoration, and management of the beach.[64] As SLRs, Duxbury Beach dunes will become more submerged and be increasingly exposed to severe storms (Figure 18), and increasingly important not only for recreation and habitat preservation but also the three towns infrastructure and economy is the maintenance, extension, and preservation of the coastal dunes along the Duxbury Beach barrier. In 2007, FEMA declared Duxbury Beach ineligible for funding related to restoration after coastal storms because it was deemed a "recreational resource" rather than a shoreline protection resource.[65,66] Funding and municipal collaboration for the three towns is critical to ensure long-term maintenance and coastal adaptation of the beach and dunes at a rate consistent with SLR and resilient to severe and frequent coastal storms in the future.

Figure 18 SLR in 2038 and 2088.



[64] Duxbury Beach Reservation, Inc. Duxbury Beach management and habitat Conservation Plan. May 2016
[65] Personal communication, Cris Luttazi Duxbury Beach Reservation, Inc. September 27, 2017.
[66] Duxbury Beach Reservation, Inc. Duxbury Beach Management and Habitat Conservation Plan. May 2016


MAPC
Sea Level Rise by 2063, with Storm Surge
Depth of Flooding above Ground (ft)
0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
>10
Church Street
Congress Street
Lincoln Street
West Street
Mayflower Street
Tremont Street
King Town Way
Gurney Road
Data Sources: MAPC, MassGIS,
MassDOT, MBTA, Kleinfelder 2013,
June, 2016
0 0.5 1 2 Miles
Document Path: K:\DataServices\Projects\Current_Projects\Climate_Change_Adaptation_Plans\Scituate_Duxbury_Coastal_Adaptation\Project Files\Report_Maps\Duxbury_Flood_50yrss_sm.mxd

Fresh Water Resources

Rivers and Inland Wetlands

North Hill Pond. Photo credit Darci Schofield

Containing over 1,400 acres of freshwater resources and through its extensive open space and conservation land, Duxbury contains important freshwater ecological assets critical to supporting clean drinking water, flood control, and overall ecosystem health for climate resilience. Important rivers include the Bluefish River, Island Creek, West Brook/Duck Hill River and portions of the South River. Though not in Duxbury, the Jones River is important because it flows into Kingston Bay and several of Duxbury's streams flow into it. The Bluefish River, Jones River, Island Creek, Island Creek Pond, and ponds within the Duxbury Yacht Club contain anadromous fish habitats and/or runs.[67] Anadromous fish are ecologically important to an overall river system because they provide nutrient transfer from marine to fresh waters and a food source for predatory fish and birds. Impairments on two of these rivers (Table 4) could diminish the health of these natural systems, important for overall ecosystem function and ecosystem services.

Table 4 BioMap2 Core Habitat for Aquatic and Wetland Core.

BioMap2 Core Habitat	Location	Acres	Species
1011	Duxbury Bay	12,815	Aquatic Core
947	North Hill Marsh/Town Forest	1,185	Wetland
1083	Camp Wing Conservation Area/ South River	374	Wetland/Aquatic Core
407	Island Creek	53	Aquatic Core

Connecting these rivers are extensive wetlands and ponds, some of which are notably healthy containing 1,612 acres of Wetland Core Habitat (Table 4). According to NHESP, Wetland Cores represent healthy, intact wetland systems sustaining critical ecosystem functions and biodiversity, and are most likely to maintain those functions into the future. Aquatic Cores are intact river systems and corridors supporting important ecosystem function and services for wildlife and water management.[68] Finally, characteristic of the South Shore and defining for Duxbury is the several hundred acres cranberry bogs, owned by the Conservation Commission, the Water Department,

[67] Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services

[68] Natural Heritage and Endangered Species Program. Conserving the Biodiversity of Massachusetts in a Changing World- Duxbury. 2012. http://maps.massgis.state.ma.us/dfg/biomap/pdf/town_core/Duxbury.pdf

and privately owned. These are enjoyed by residents locally and regionally for their fruit, beauty and recreation opportunity, particularly around the Duxbury Bogs Conservation Area.[69]

Climate Risks to Freshwater Resources

Overall, the integrity of Duxbury's wetland resources are at risk to climate change do to several factors: (i) SLR and storm surge, (ii) drought, (iii) increasing temperatures and (iv) extreme precipitation events. SLR/storm surge will impact the Bluefish River, the Jones River, and Island Creek the most significantly causing flooding (Figure 15) into many residential areas and some commercial areas, potentially overflowing culverts and causing significant road and bridge

Cranberry bogs at Duxbury Town Forest. Photo: Darci Schofield

damage. Existing and capped landfills could be vulnerable to impairing historic and existing wetlands, groundwater resources, or adjacent water bodies. With anticipated increase in extreme and more frequent rain events with climate change, excessive rain could result structural damage to the mitigating structures on capped sites and increase infiltration of toxic leachate into adjacent wetlands or waterbodies.[70] Heat waves, hotter summers, and drought, combined with earlier spring run-off due to warmer temperatures and a shift from snow to rain, can lead to warmer waters and seasonal low-flow or no-flow events in rivers and streams or early flooding with winter rains rather than snow.

[69] Duxbury Conservation Commission. Open Space and Recreation Plan. 2008

[70] Executive Office of Energy and Environmental Affairs and Adaptation Advisory Committee. 2011. *Massachusetts Climate Adaptation Report.*

Shallower waters and warmer temperatures also lead to low levels of dissolved oxygen, with resulting negative effects on fish species. If dry conditions persist, wetlands could shrink in area or lose some of their absorptive capacity and be more prone to runoff and erosion. Heavy precipitation accompanied by flooding can scour stream and river vegetation eroding banks and degrading ecosystem function. It also has a negative effect on water quality, because it flushes ground pollutants – everything from dog waste, to oils on the road, to sand – into rivers, streams, and ponds. The cranberry bogs are at risk to climate change from potential salt water intrusion, strains in drainage, and changes in growing patterns with warming temperatures, shifting to a mild climate management practice, such as those that are currently practiced in New Jersey.[48]

The combined effects of washing nutrients into lakes and ponds and warmer summer temperatures may lead to an increase in the growth of aquatic vegetation. For example, warmer winter temperatures and lack of ice cover extend the growing season enabling greater aquatic growth in ponds. Excessive aquatic vegetation can deplete dissolved oxygen and lead to die-offs of aquatic animals. Additionally, algae blooms can also lead to growth in toxic bacteria that makes water bodies unsafe for use by humans and pets. The health of these wetlands are critical to Duxbury's climate resilience. Contiguous and connected tracks of open space and conservation land combined with stormwater management practices that brings water back into the ground can help mitigate these climate risks. Monitoring and management of ecosystem health will be an important long-term adaptation strategy.

Forests and Trees

Duxbury has a long history of acquiring and protecting land and has demonstrated and consistent support from its residents for conservation land and protecting its natural integrity. Indeed, Duxbury has historically used open space as a framework for planning, beginning with its General Plan in 1959 and an aggressive land acquisition campaign to protect drinking water resources in the 1960s.[71] This history is evident where over 50% of the land use is forest, an additional 16.2% of land use is open space and recreation lands, and only 25% of the land use is considered urban or developed.[72] Nearly 8,307 acres of Duxbury is covered by tree canopy (Figure 19) and is lauded as a Tree City USA for its 24th year. Three thousands of these acres are under the care and control of the Duxbury Conservation Commission. The most notable large, contiguous tracts of open space is the Camp Wing Conservation Area, North Hill Marsh and adjacent Duxbury Bogs Conservation Areas, and the Lansing Bennet Forest.[73]

A stand of white pines in Duxbury Town Forest. Photo: Darci Schofield

Duxbury's natural lands, though susceptible to a changing climate, creates a weave of resilience against climate risks and hazards. These areas mitigate flooding, alleviate stress on stormwater systems, serve to recharge and clean the Towns aquifer, mitigate air pollutants, and overall cool the town with evapotranspiration and shade. According to the EPA, suburban areas with mature trees are four to six degrees Fahrenheit cooler than new suburbs without trees. Shaded surfaces can be 25-40 degrees cooler than the peak temperatures of unshaded surfaces. Trees also absorb remarkable quantities of precipitation; in addition to water uptake by roots, tree leaves intercept rainfall and it is stored or evaporated back into the atmosphere reducing the amount of stormwater runoff and flooding.

The peer-reviewed USDA Forest Service i-Tree software creates models of ecological services from forests and tree canopy. Based on their model with Duxbury's 50% forest cover, Duxbury's

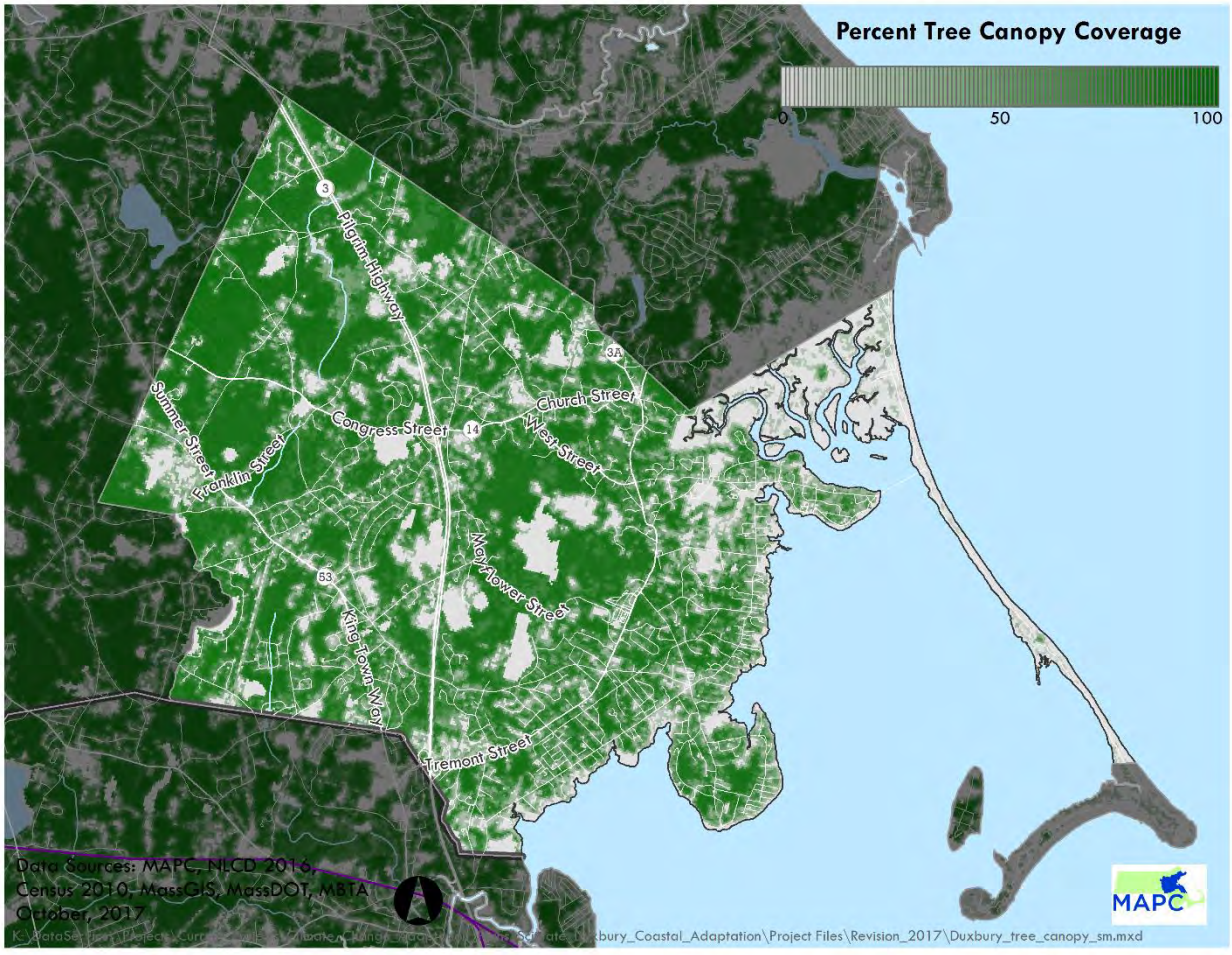
[71] Executive Office of Energy and Environmental Affairs and Adaptation Advisory Committee. 2011. *Massachusetts Climate Adaptation Report.*

[72] Duxbury Conservation Commission. DRAFT *Open Space and Recreation Plan.* 2017

[73] Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services

trees intercept 794 million gallons per year with a value of the reduced runoff at $769,585 per year. Estimates of pollution reduction from Duxbury's canopy include 5, 834 lbs./yr. of carbon monoxide, 60,594 lbs./yr. of nitrogen dioxide, and 442,806 lbs./yr. of ozone. The estimated value of Duxbury's tree canopy for carbon storage is over $48 million while the value of annual carbon sequestration (tree growth minus loss due to decomposition and mortality) is over $845,000 per year, equivalent to 21,630 tons of carbon dioxide sequestration per year.[74]

Figure 19 Duxbury Tree Canopy Cover (2011).



Duxbury's land use contains over 50% forest and 16.2% open space and recreation land.

Intact forest ecosystems are critical for maintaining long-term climate resilience. Though longer growing seasons and increased carbon in the atmosphere overall may benefit forest productivity, forests will undergo stressors related to our changing climate such as periods of intense precipitation and/or drought, and warmer winters. As mentioned, the growing season in the last

[74] United States Forest Service. Itree. https://www.itreetools.org/resources/content/Landscape_factsheet.pdf

Table 5 Tree species adaptive capacity to climate change.

Southern New England Forest		
Tree Species	Low Emissions Scenario	High Emissions Scenario
Balsam Fir	--	--
Black Spruce	--	--
Eastern White Pine	--	--
Northern White Cedar	--	--
Paper Birch	--	--
Quaking Aspen	--	--
Red Spruce	--	--
White Spruce	--	--
Tamarack	--	•
American Beech	•	--
Red Maple	•	--
Northern Red Oak	•	--
Bear/Scrub Oak	•	•
Black Cherry	•	•
Sugar Maple	•	•
Bigtooth Aspen	+	•
Pitch Pine	+	•
American Basswood	•	+
Bitternut Hickory	+	+
Black Oak	+	+
Chestnut Oak	+	+
Shagbark Hickory	+	+
White Oak	+	+
Threatened by Current Forest Health Issues		
Black Ash	--	--
Eastern Hemlock	•	•
White Ash	•	•

The values indicate whether a species will decrease in habitat (–), stay the same (•), or increase in habitat (+). Source: Catanzaro, P., A. D'Amato, E. Silver Huff 2016. Increasing Forest Resiliency for an Uncertain Future. UMass Extension Landowner Outreach Pamphlet. 28 pages.

60 years has increase a week to 10 days;[75] warmer winters may increase the incidence of ice storms, and extreme precipitation regimes could cause severe rainfall in a single event causing

[75] Massachusetts Climate Adaptation Partnership. 2015. Massachusetts Wildlife Climate Action Tool. Accessed in October 2017

flooding or drought conditions with inconsistent precipitation patterns. These factors work in conjunction to cause several vulnerabilities to the forest: (i) favoring invasives and exotics establishments with gaps in the canopy due to wind and ice storms, (ii) migration of species to more northern climates and immigration of new species and/or pests; (iii) weakened trees with drought causing greater susceptibility to insects and diseases.[76] The overall impact is an anticipated shift in forest type in Southern New England from a Maple/Birch/Beech forest to forests chart eristic of southern New York, New Jersey and Pennsylvania, and Oak/Hickory forests.[77] Table 5 lists species that will be more or less competitive with a changing climate. Managing forests and trees for climate adaptation will be an important strategy to retaining Duxbury's forest health, clean air and water, and overall climate resilience.

[76] Catanzaro, P., A. D'Amato, E. Silver Huff 2016. Increasing Forest Resiliency for an Uncertain Future. UMass Extension Landowner Outreach Pamphlet. 28 pages

[77] U.S. Forest Service, *Changing Climate, Changing Forests*. The Impacts of Climate Change on the Northeast United States and Eastern Canada. 2011

Critical Infrastructure Vulnerability

The Town of Duxbury is currently underway on its Natural Hazard Mitigation Plan, prepared by MAPC. The purpose of a Hazard Mitigation Plan is to evaluate the Town's vulnerability to natural disasters and create mitigating strategies to minimize exposure and loss to those hazards and disasters. Hazards include coastal and inland flooding, extreme heat, severe storms like hurricanes and Nor'easters, etc. The vulnerability of the Town's Critical Infrastructure for current and existing natural hazards is evaluated in this plan. This Critical Infrastructure Vulnerability section will evaluate future risks of Duxbury's infrastructure as it relates to climate change projections in SLR, inland flooding, and extreme heat.

Drinking Water

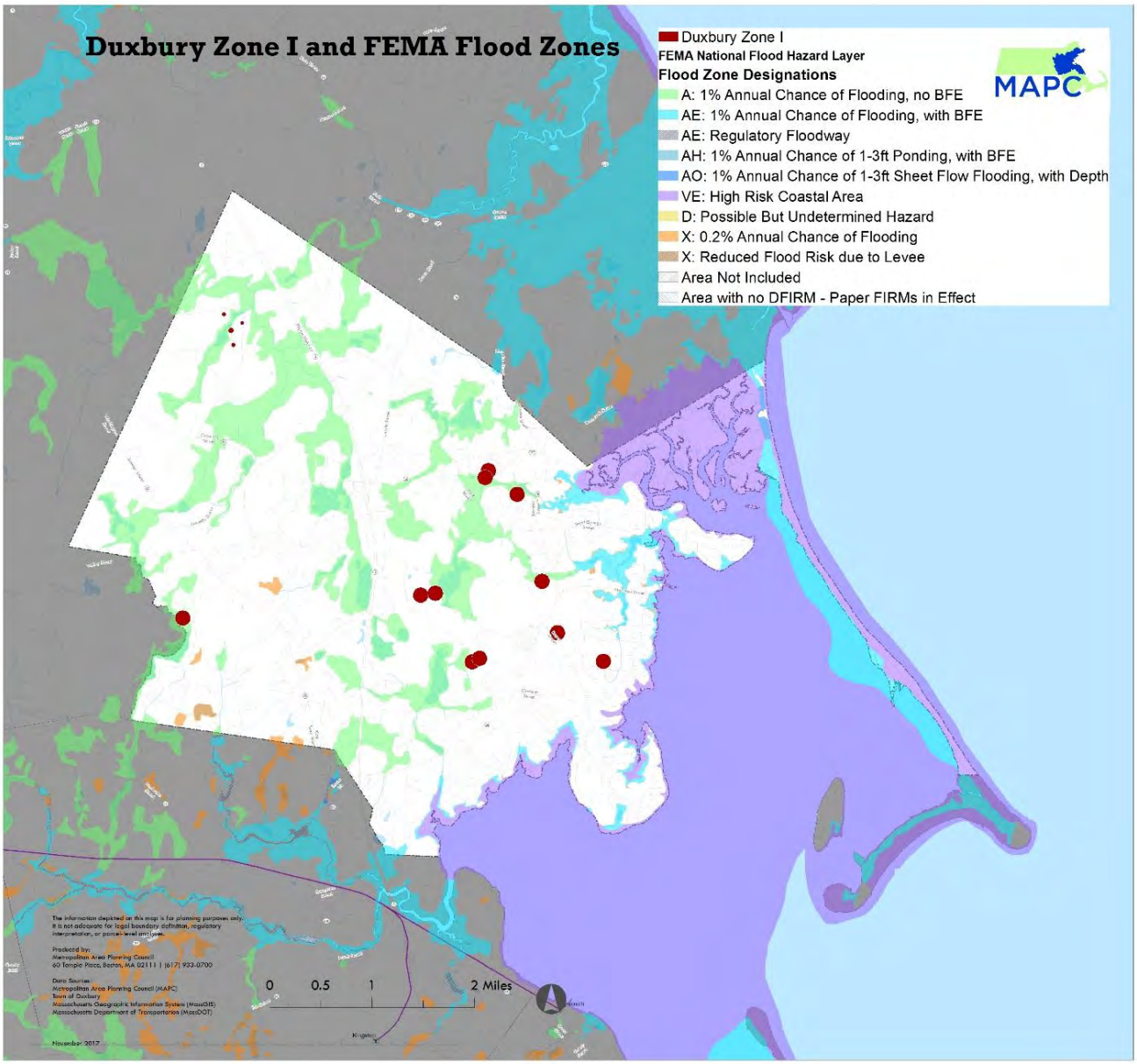
With anticipated SLR, increased frequency and intensity of precipitation events and/or drought, extreme heat and shifting freeze/thaw cycles, climate change is expected to strain drinking water resources, both in quality and quantity. It is important to understand the extent of water supply and demand today, plan for the water demand for new residential, commercial, industrial, and agricultural growth into the future, and evaluate the system's vulnerabilities to meeting the Town's demands today and into future. Overall, vulnerabilities for Duxbury's drinking water include potentially a stressed water supply, contamination, and potential salt water intrusion of groundwater aquifers along the coast.

Duxbury receives its drinking water from two sources, the Town of Marshfield (for residents of the Bay Avenue and Gurnet Road region at the north end of the coastal beach) and 12 municipal wells drawing from its significant aquifer for the remaining residents. These wells are gravel-packed containing their own pump stations and chemical feed equipment.[78] Each of these wells are located within a designated Zone I protective radius of 400 feet and Zone II Groundwater Recharge area. The land around these wells is regulated as Zone II groundwater recharge areas bounded by the extent of pump extraction for 180 days without precipitation recharge and physical/geomorphological features such as bedrock or till. There are three Zone II areas in Duxbury, one that extends in Pembroke, totaling 5,208 acres[79] of mostly forested and residential land and some smaller portions of commercial and transportation land use.[80] Overall, the MA Department of Environmental Protection has had concerns of well contamination because of the highly-drained soils in and around Duxbury's aquifer, from septic systems household hazardous materials, heating oil storage, and stormwater.[73]

Water supply in the future will greatly depend on precipitation, both quantity and timing, and capturing rain and stormwater into the ground before it reaches streams, rivers, and the ocean-effectively keeping Duxbury's water within its own aquifer and watershed system. MAPC performed a study in 2001 to ascertain drinking water supply challenges for municipalities in the

[78] Duxbury Water Department. Consumer Confidence Report. 2016. http://www.town.duxbury.ma.us/sites/duxburyma/files/uploads/consumer_confidence_report_2016.pdf
[79] Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services
[80] MA DEP. Source Water Assessment and Protection Report. 2003. http://www.mass.gov/eea/docs/dep/water/drinking/swap/sero/4082000.pdf

Figure 20 Duxbury's drinking water infrastructure and flooding.



region and Duxbury was identified as a town facing water supply issues by 2025 based upon projected growth and the 2001 allowable water withdrawals. These arise from increased demand with new development and increased discharge of water outside of the watershed recharge area.[81] However, water supply is already a concern for the Town of Duxbury where the Town Selectmen voted to enact a mandatory water ban to reduce outdoor watering for the entire year of 2017.[82] Further, Duxbury consumes more gallons per person per day than allowed according to the Massachusetts Water management Act of 1985 where in 2016, the average

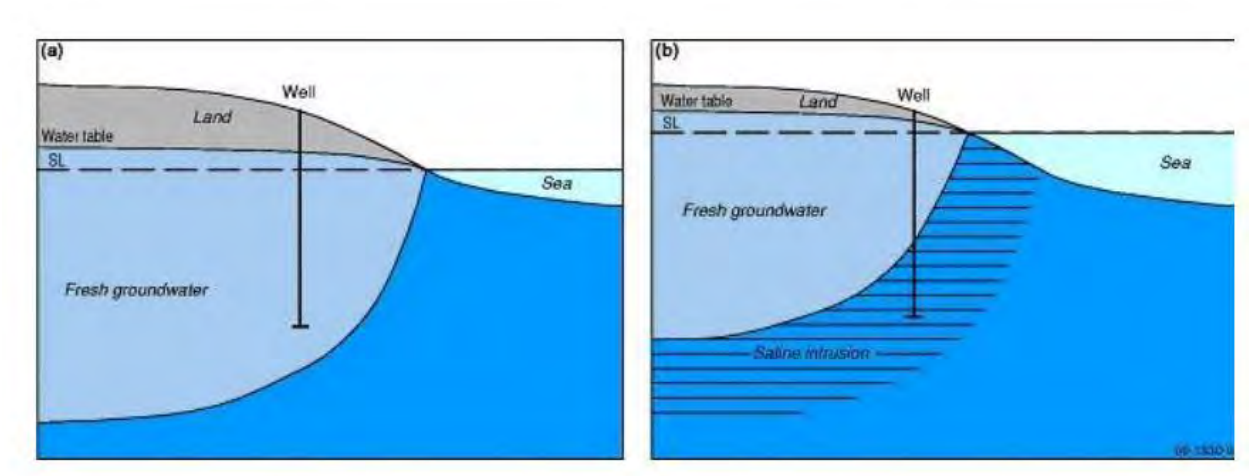
[81] Metropolitan Area Planning Council. *South Coastal Basin Watershed Pilot Project*, Final Report. 2001
[82] http://959watd.com/blog/2017/04/duxbury-selectmen-to-vote-on-mandatory-water-ban-for-2017/

resident of Duxbury consumed 80 gallons per day[83]. Patterns of water use and demand indicate that outdoor watering of lawns and gardens is the cause.[76]

There are significant concerns regarding water contamination and infrastructure damage related to flooding. With extensive flooding area and direction of ground water flow, wells can become contaminated with bacteria and other contaminants from chemicals or septic systems. In addition, flooding can carry debris that may cause damage to the well and water pump station infrastructure, distort casting, or in older wells, cause collapse. Finally, electrical systems can be damaged by flood water and sediment.[84] Flooding could potentially disrupt drinking water supply for some period time while systems, construction, and water quality are evaluated and repaired. None of Duxbury's wells or water pump stations are located within a zone of SLR for both 2038 and 2088, including SLR with a Category 1 Hurricane Storm Surge nor are they located within a 0.2% Annual Chance (500-year) Flood. However, six of Duxbury's wells are located within a current FEMA 1% Annual Chance (100-year) Flood. These include the Evergreen Street Well 1, Mayflower Well 2, Tremont Well 1, Millbrook Pond Well, and Damon Well 1 (Figure 20). There is also evidence of salt water intrusion in irrigation wells in coastal locations today in Duxbury.[85]

A critical concern for coastal aquifers is salt water intrusion and/or salinization with SLR. Scientists anticipate that SLR will raise the ground water table closer to the surface reducing the barrier between the fresh groundwater and the ocean salt water. Salt water intrusion can also occur if the well head and/or pump station is submerged by the underlying salt water with SLR effectively pushing salt water onshore (Figure 21). None of Duxbury's wells drinking water wells are proximate to the coast (Figure 20).

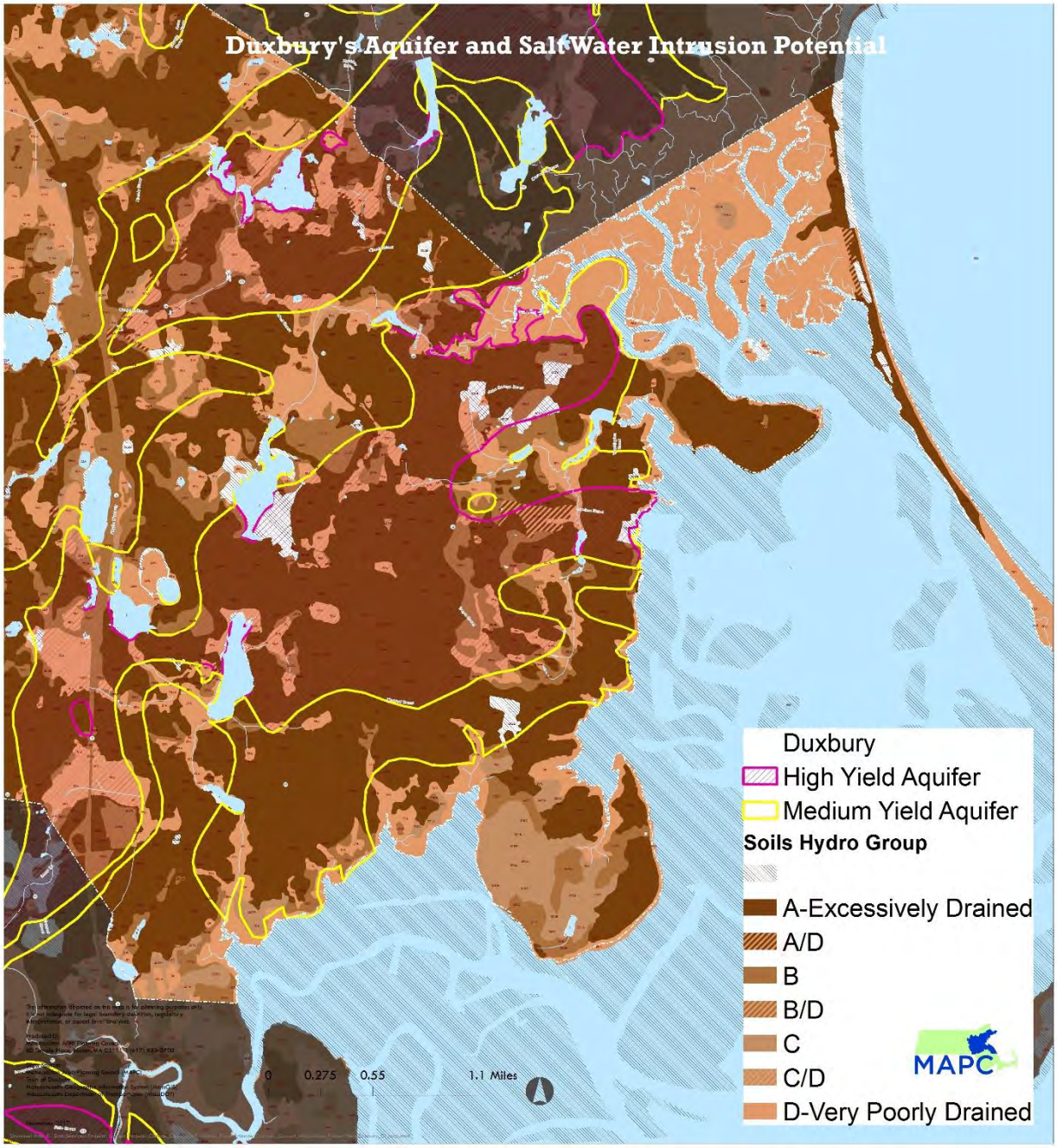
Figure 21 The potential for SLR to intrude through well infrastructure. .



Source: https://www.epa.gov/sites/production/files/2015-07/documents/soil-based_onsite_wastewater_treatment_and_the_challenges_of_climate_change.pdf

[83] Duxbury Water Department. Consumer Confidence Report. 2016
[84] https://www.epa.gov/sites/production/files/2015-05/documents/epa816f05021.pdf
[85] Personal Communication. Valerie Massard, Planning Director, March 2018

Figure 22 Duxbury's Aquifer and soil permeability.



Duxbury's potential for salt water intrusion of the aquifer along the coastline by soil hydrogroup.

However, Duxbury may be at a higher risk to salinization of its aquifer. Aquifers near the coastline are susceptible to salt water intrusion when the soil barrier between the salt water table and the aquifer is permeable or containing well-drained soils such as sand, gravel, and till, characteristic of Duxbury's coastal soil structure and aquifer locations. There are several areas along the coast that may be vulnerable to SLR exposure. The most important is where the aquifer reaches Snug Harbor to the mouth of the Bluefish River which is part of the high yield aquifer

surrounded by Type A, excessively drained soils, specifically Plymouth loamy course sand and Carver loamy course sand (Figure 22). The Natural Resources Conservation Service classify Type A soils as sands or loams that are well to excessively drained sands, gravels, and loams with high infiltration rates and greater water transmission potential.[86] Other potential areas of concern with the medium yield aquifer and intrusion include Shipyard Lane Beach and Bay Road, from Hicks Point to nearly The Nook. The latter location contains more impermeable soils, Ipswich-Pawcatuck-Matunuck complex, along the coast (Type A/D) though the soils quickly shirt to excessively drained Plymouth and Carver loamy coarse sand inland.[87] Further hydrologic study is required to affirm and determine the potential for salt water intrusion at the aquifer and wells.

Wastewater Infrastructure

Duxbury's municipal sewer system is managed by the Department of Public Works and is under the direction of the Duxbury Water and Sewer Commission and Board of Selectmen. The Town has three shared treatment plants. Two shared sewage disposal systems were completed in 1996 on Washington Street, one at the Snug Harbor commercial area and the second at the Bluefish River. In the Snug Harbor business district, eleven buildings, including the Duxbury Yacht Club, Duxbury Bay Maritime School and Bayside Marine, are connected to a shared system with a leaching facility located under the Duxbury Yacht Club's golf course on Harrison Street, away from the harbor area. Three buildings on the edge of the Bluefish River and the municipal buildings at the school complex are similarly connected to a shared sewage disposal system with the leaching facility located at the Ellison Center for the Arts on St. George Street, which has the capacity for approximately 100,000 gallons per day (permitted for 50,000 gallons per day) and which also supports the Percy Walker Pool. In both of these cases, the leaching sites were provided by private non-profit organizations. The systems are being paid for by betterments to the owners while the engineering water quality studies and project oversights were provided by the town using a combination of state grant monies and town meeting appropriations. The town acted as a facilitator for both projects. A third shared sewage disposal system was constructed in 2002 to serve 30 residents on Bay Road. The leaching field is located under the Wadsworth Field at the corner of Tremont Street and Wadsworth Lane. The shared systems were all necessary to improve the water quality of Duxbury and Kingston Bays. Gurnet Road in Duxbury, located at the north end of Duxbury Beach adjoining the town of Marshfield, is connected by municipal sewer to the town of Marshfield Sewerage Treatment Plant. Sewage from the Duxbury Town Pier boat pump out station is transported to Marshfield for treatment for which Duxbury pays Marshfield a user fee. Lastly, there is a shared system for the residences and businesses of the Island Creek Village complex near Exit 10. The remainder (and the majority) of the town is serviced by On Site Wastewater Treatment (OSWT). [88]

Sea level rise, extreme precipitation, and flooding are the most important factors in understanding Duxbury's Sewer and OSWT systems vulnerability. The impact of inundation by

[86] https://www.epa.gov/sites/production/files/2015-05/documents/epa816f05021.pdf
[87] Natural Resources Conservation Service. USDA. Urban Hydrology for Small Watersheds. Technical Release 55. 1988
[88] Duxbury Conservation Commission. 2017. Town of Duxbury Open Space and Recreation Plan.

Mother's Day Storm—Infrastructure Overwhelmed!

The 2006 Mother's Day storm began Friday, May 12 and, for the next 100 hours, dumped up to 15 inches of rain on many North Shore communities in Massachusetts. A U. S. Geological Survey flood gauge at Lowell showed that the flood level in the Merrimack River reached 59 feet, making it a 40-year occurrence event. On May 13, two days before flood levels in the Merrimack River peaked, a force main to the Haverhill Wastewater Treatment Plant gave way, spilling 35 million gallons per day of untreated sewage into the Merrimack River. The break occurred when the rapidly moving river in a tributary washed out a culvert that ran beneath a section of a power easement roadway and the force main. As the storm continued, waters flowed over bridges and into the streets and basements throughout the region. It took almost a week to repair the break.

The Department of Environmental Protection estimates that, had the water level in the Merrimack risen another two to three feet, wastewater treatment plants in the Greater Lawrence Sewer District would have lost their pumping stations and power to their treatment plants, resulting in major additional discharge of untreated sewage to the Merrimack River. It is also likely the drinking water treatment facilities in Tewksbury, Lowell, and Lawrence would have also become incapacitated.

Source: Executive Office of Energy and Environmental Affairs. Massachusetts Climate Adaptation Plan. September 2011. http://www.mass.gov/eea/docs/eea/energy/cca/eea-climate-adaptation-report.pdf

SLR and/or storm surge is significant, potentially causing an overload to the system and/or electricity failures resulting in the release of raw sewage and hazards to drinking water systems. For example, during Hurricane Sandy, many water utilities lost electricity and did not have back-up generators. Counties in New York and New Jersey had drinking water advisories and boil water notices, and Passaic Valley was forced to release billions of gallons of raw and partially treated sewage into New York Bay.[89] Today, municipal staff report that the outfalls at Snug Harbor are vulnerable to flooding with just tidal waters.[90]

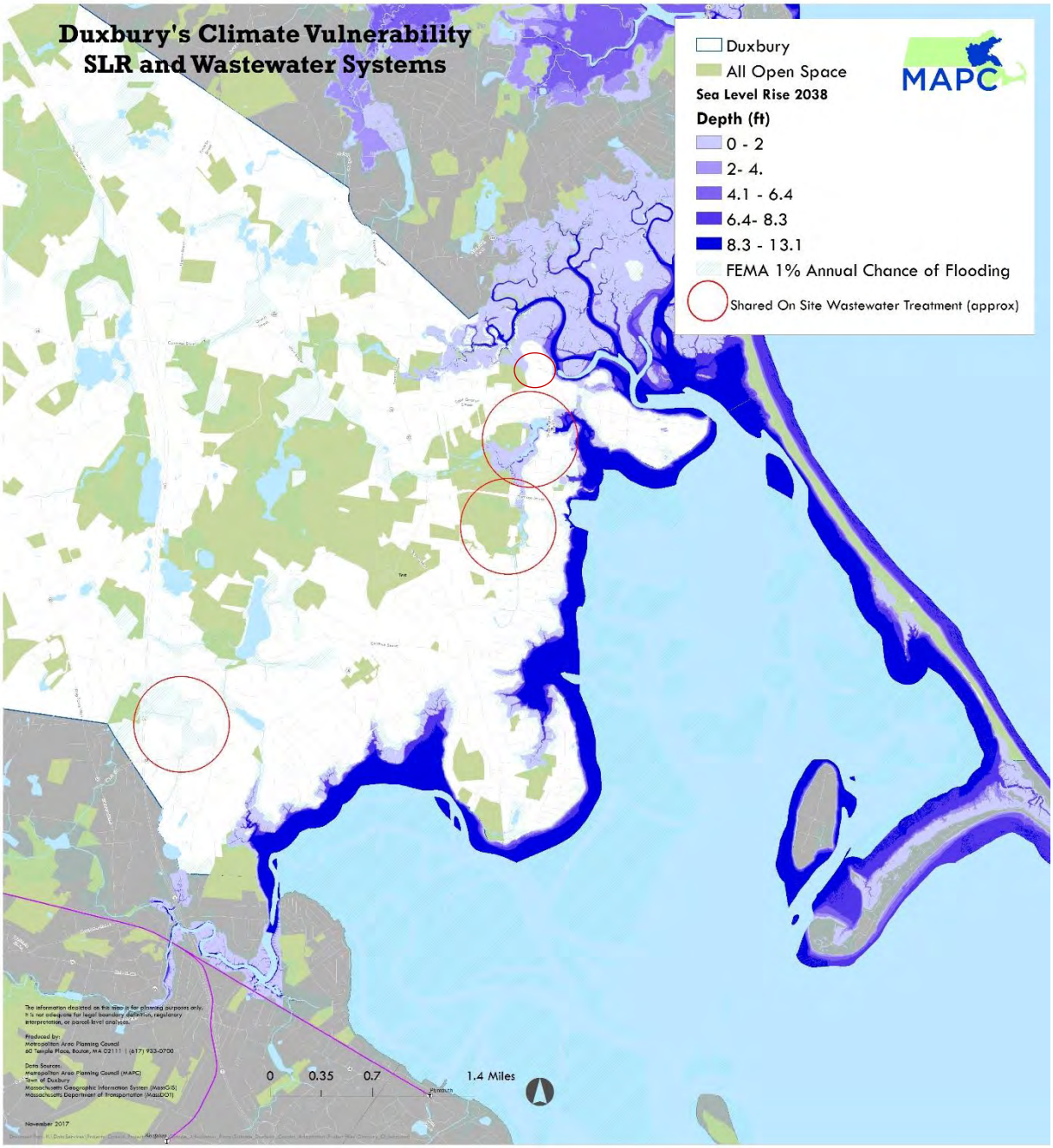
Figure 23 Exposed septic system after coastal storm in Westport, CT.

Source: https://www.epa.gov/sites/production/files/2015-07/documents/soil-based_onsite_wastewater_treatment_and_the_challenges_of_climate_change.pdf

89 65 http://www.mwra.com/monthly/wac/presentations/2014/030714-climatechange.pdf
90 Duxbury Hazard Mitigation Plan meeting 1. September 20, 2016
67

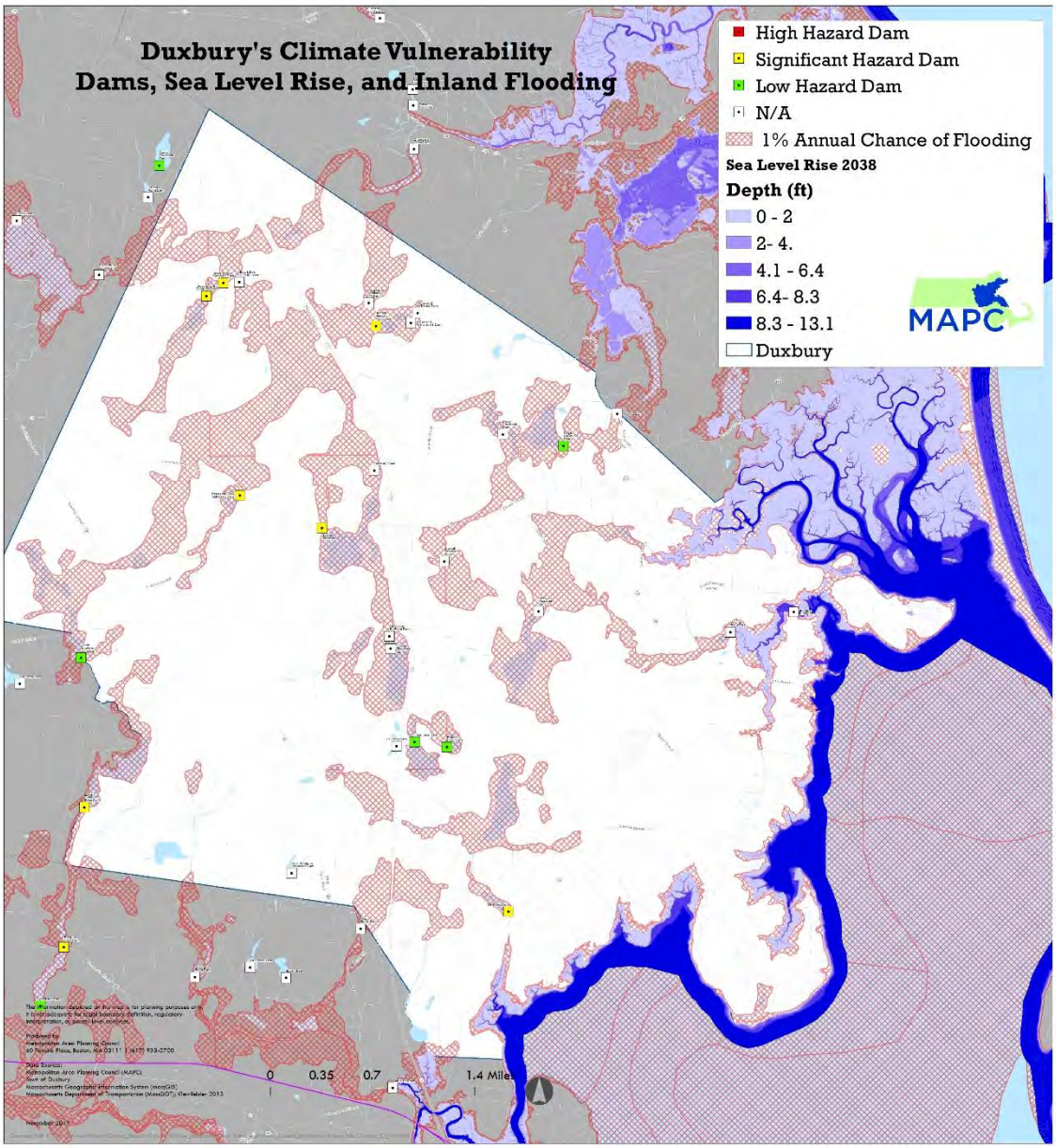
Third, OSWT and shared systems will be susceptible to groundwater infiltration of leach fields, particularly during severe precipitation events and during times of inland and/or coastal flooding. This poses a significant health risk for the community of Duxbury. Finally, groundwater and/or salt water intrusion of pipes with SLR, storm surge and inland flooding can cause deterioration of the municipal sewer system itself.

Figure 24 Shared OSWT and Coastal Flooding.



The shared waste water systems/leach fields along the Bluefish River and Duxbury Yacht Club golf course servicing Snug Harbor are potentially vulnerable. The leach fields are located in areas subject to two to four feet of flooding with SLR 2038 and 2088 from the Bluefish River (Figure 24). In addition, the systems infrastructure itself may be at risk to SLR 2038 and 2088. The shared system at Island Creek Villages is not subject to SLR in 2038 or 2088 but is subject to flooding in a FEMA 1% Annual Chance Flood. Category 1 hurricane storm surge does not increase exposure.

Figure 25 Duxbury dams' hazard status and flooding exposure.



Dams

The Department of Conservation and Recreation (DCR) Office of Dam Safety monitors the condition of the state's dams and DCR requires that dams with low hazard ratings be evaluated every decade. The dams which are rated significant and high hazard are inspected every five years.[91] DCR potential hazard ratings are high, significant, and low; conditions are rated good, satisfactory, fair, poor, or unsafe. The State Hazard Mitigation Plan uses the term "High Hazard Potential" for dams located where failure will likely cause loss of life and serious damage to homes, industrial or commercial facilities, important public utilities, main highways, or railroads. A "Significant Hazard Potential" dam is one located where failure may cause loss of life and damage homes, industrial or commercial facilities, secondary highways, or railroads; or cause interruption of use or service of relatively important facilities. "Low Hazard Potential" dams are located where failure may cause minimal property damage to others, and loss of life is not expected. The Town of Duxbury has 24 dams in total, 14 of those dams are privately owned and the remaining are owned by the Town of Duxbury. Seventeen of the dams have a no hazard code (N/A) indicating the dam regulatory entity is non-jurisdictional.

Cranberry bogs adjacent to North Hill Pond, adjacent to the Merry Memorial Dam. Photo credit Darci Schofield

Figure 25 illustrates dam hazards and risk/exposure to 1% Annual Chance Flood and SLR 2038 with Category 1 storm surge. Most of the dams are located in a current 1% Annual Chance Flood except four: Golden, Pitch Pond, Keith & Adams, and Crowell Reservoir dams. None of the dams are located in a 0.2% Annual Chance Flood. There are two dams that are at risk today and will become increasingly exposed to future SLR and flooding, the Bluefish River Dam and the Wrights Pond Dam (Figure 25). The Massachusetts Climate Adaptation Report notes that increased intensity of precipitation is the primary concern regarding dams as they were most likely designed based on historic weather patterns. A potential effect of increased significant rain events is the failure and/or overtopping of existing dams. In 2038, the Bluefish Dam could experience greater than 6-8 feet of flooding or as much as 13 feet increased water depth where overtopping may occur. The Wrights Pond Dam will experience an increase 0-2 feet putting

[91] Executive Office of Energy and Environmental Affairs. Department of Conservation. Dam Safety http://www.mass.gov/eea/agencies/dcr/conservation/dam-safety/

additional stress on the infrastructure. Neither of these dams have a hazard status. Appendix A lists all the dams, hazard status, and location in a flood or hurricane storm surge zone.

Built Environment

Loss of electricity and lack of back-up energy source is a vulnerability due to extreme heat and high energy demand. The most significant threat to municipal and critical infrastructure (such as medical services) is flooding from coastal storms and extreme precipitation events. Other vulnerabilities to the built environment is extreme heat impacting electric demand and supply as well as deterioration to infrastructure. In this section, we review future risks to the built environment where SLR may change flood locations and depths. To date, however, there are no inland flooding projection models, only FEMA 2017 flood maps which is based upon historical data. There are particular challenges to projecting future inland flooding and damages, including varying impacts when rain falls on dry, frozen, or saturated land; and varying impacts between long and short-duration rain events. Flooding associated with storm drainage infrastructure is also particularly difficult to project.

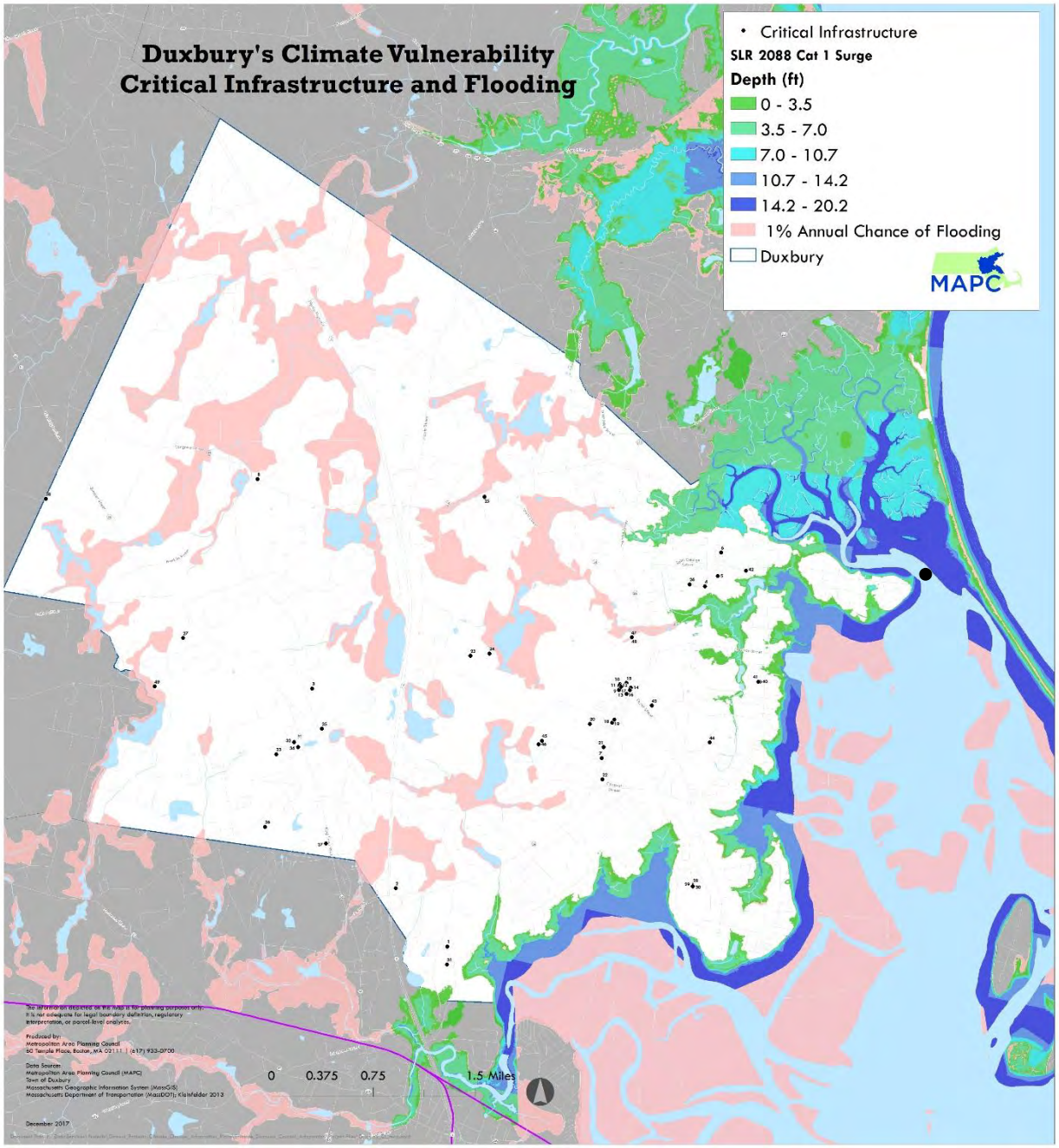
Yet there are ways to assess and consider future vulnerabilities that might result from increases in precipitation. Reviewing extreme events that may become more frequent is valuable for identifying where damage occurred and where it might have extended had rainfall amounts been greater (Figure 5). Since we anticipate that future precipitation regimes are expected to increase in frequency and intensity, we evaluate FEMA mapped 1% and 0.2% Annual Chance Flood to assess inland flooding vulnerability. As noted above, understanding the condition and location of culverts and storm drains is important, because of their potential for blockages and flooding. The only critical infrastructure, aside from the aforementioned dams, vulnerable to current or future flooding and SLR is Powder Point Bridge.

Figure 26 Twitter account of coastal flooding 2014.

Duxbury Beach provides significant protection from storm surge and minimizes the risk to coastal infrastructure. However, Duxbury has experienced significant flooding, mostly to its roads (discussed in Transportation Vulnerability section), and this is largely from coastal winter storms, Nor'easters, and/or blizzards. For example, in January 2014, a voluntary evacuation order was given to Duxbury, and there was mandatory evacuation as well as state of emergency declared in Duxbury during Winter Storm Riley in March 2018. Storm surge and coastal flooding had destroyed a sea wall in Marshfield causing significant flooding along Plymouth Avenue and

Gurnet Road in 2014 (Figure 26),[92] and in 2018, the wall was breached and destroyed in one location. Other examples include coastal flooding of Mattakeesett Court at high tide, flooding the Town Pier and parking lot (Figure 26).

Figure 27 Critical Infrastructure and coastal flooding.



[92] http://www.wcvb.com/article/scituate-duxbury-residents-urged-to-leave-as-flooding-looms/8193702

Since 1978, Duxbury has filed 397 National Flood Insurance Program (NFIP) claims, and 83% of those claims have been paid totaling $4,999,743.[93] Currently, there are 284 policies for NFIP in Duxbury, insuring a total of $81,634,400 with a total premium cost of $399,588.[94] As of 2010, Duxbury had 36 repetitive loss properties including 33 single family homes, one multi-family residence and two non-residential properties. Twenty-six of these properties are located in north Duxbury Beach in a 1% Annual Chance Flood and high velocity zone. A repetitive loss property is defined by the Community Rating System of NFIP as a property that NFIP has paid two or more flood claims of $1,000 or more since 1978. Since 1978 to February 28, 2018, Duxbury has had 423 National Flood Insurance losses, 347 of which are closed with a total payment of nearly $5.5 million.[94]

Duxbury does not participate in the Community Rating System (CRS) which can provide reduced insurance costs for property owner's flood insurance if the Town accomplishes certain mitigation actions to reduce its vulnerability to flooding. For example, Scituate is enrolled in CRS and in 2015, their Class 8 rating afforded $242,937 in annual premium savings. Though Duxbury has less enrollment in the NFIP, the benefits of the program also enable a robust public education programs on flooding such fact sheets, handbooks, and public workshops. However, the Town has adopted the latest Federal Emergency Management Agency (FEMA) flood maps and actively enforces the floodplain regulations.[95]

With a1% Annual Chance Flood, according to data collected from InfoGroup, the following would be at risk (Figure 26):

- approximately 630 residential properties (though not necessarily structures), assessed at $254 million,
- Six commercial and industrial properties worth $2,500,000, and
- Approximately 70 properties assessed at $78 million.

[93] Federal Emergency Management Agency. https://bsa.nfipstat.fema.gov/reports/1040.htm#25
[94] Federal Emergency Management Agency. https://bsa.nfipstat.fema.gov/reports/1011.htm#MAT
[95] Duxbury Hazard Mitigation Plan Team Meeting with MAPC. September 20, 2016.

Economic Vulnerability

Extreme weather events are important factors in determining economic vulnerability for Duxbury in climate change. These include extreme temperatures and flooding from coastal storms. Economic vulnerability arises from the loss of transportation to work, the inability to operate business due to lack of staff, loss of utilities, lack of accessibility and/or damage to business infrastructure itself, or loss of productivity from unexpected childcare with school closures. Extreme weather events have already caused loss of productivity in Duxbury. In 2018, Duxbury was hit by two "Bombogenesis" coastal storms in January and March that caused near record-breaking flooding. During these storms, Snug Harbor, a coastal commercial and retail district along the coast in the Shipbuilders Historic District, was completed flooded. This caused property damage, business closures, and disruption in operations.

There has also been significant economic loss in the Boston region in recent years from extreme weather events. For example, in 2014, the Polar Vortex caused extreme cold temperatures that resulted in $5 billion in economic losses globally, a 2.1% drop in the GDP. These were largely due to loss of productivity from school and business closures from damaged infrastructure, such as frozen pipes and heating systems, and delayed or cancelled transportation, such as airlines.[96],[97]

The Town of Duxbury as of 2015, has 404 business establishments employing 2,861 individuals. Industries include 26.88% education, 20.24% health care/social assistance, 8.35% retail trade, ad 8.84% leisure and hospitality. With SLR in 2088 and Category 1 Storm Surge, there are six businesses employing approximately 17 people at risk to coastal flooding. The assessed value of commercial properties at risk is approximately $12 million.[98] As Kleinfelder reported in 2013, one of these businesses is Blakeman's Restaurant on Duxbury Beach. Though only open seasonally and a small employer, the restaurant has important cultural and economic function for the Town and its visitors who frequent Duxbury Beach.[99] Figure 28 illustrates the results of potential economic losses from coastal flooding and inundation in 2088.

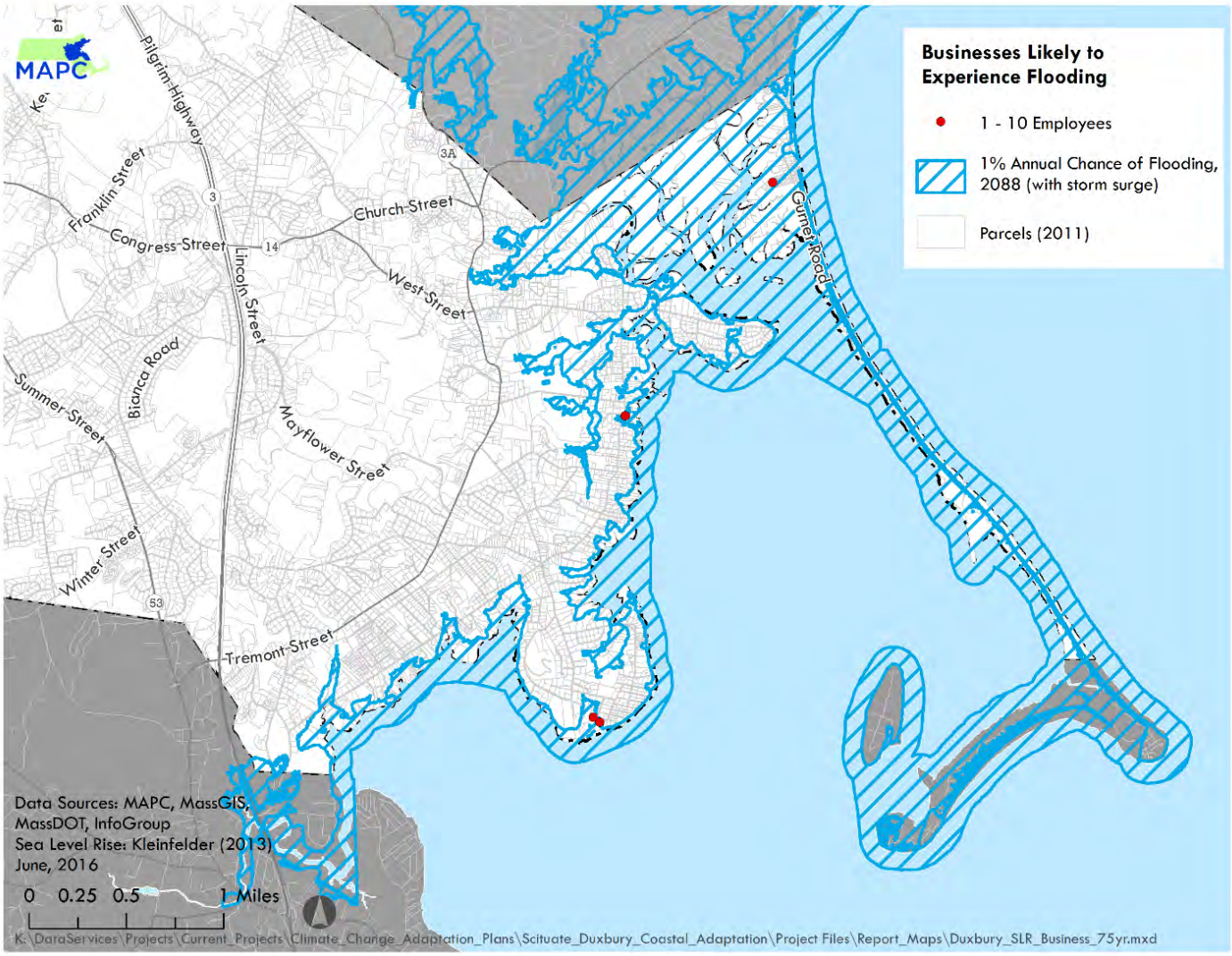
An important consideration for Duxbury is the potential economic losses with its vibrant shellfish industry, both from SLR and coastal storms. In 2016, Duxbury had 28 propagation permits and 77.5 acres under cultivation, primary Quahog, Oyster and Surf Clam. In 2016, there were 10,107,280 pieces of American Oyster harvested with a reported value of $5,708,971.[100] The 2013 SLR Study performed by Kleinfelder outlines how SLR and deeper waters can affect the shellfish industry such as

- Reduced time to access shellfish beds;
- Shifting aquaculture areas, where current acreage may become sub optimal;
- Alteration of patterns of predation and exposure;
- Rising water temperatures shifting shellfish growth patterns;

[96] http://money.cnn.com/2014/10/30/news/economy/us-gdp-3-and-half-percent-beats-expectations/?iid=EL
[97] https://www.cbsnews.com/news/economic-impact-of-polar-vortex-could-reach-5b/
[98] http://www.mass.gov/governor/docs/news/attachment-a-severe-winter-weather-pattern-impacts-supplemental-info.pdf
[99] Info Group 2011
[100] MA Division of Marine Fisheries Annual Report 2016.
http://www.mass.gov/eea/docs/dfg/dmf/publications/2016-dmf-annual-report.pdf

- Rising temperatures increasing potential for disease; and
- SLR and salt marsh deterioration impacting marine ecosystem and nutrient flow.[101]

Figure 28 Potential economic loss



However, an important consideration today and future climate risk is the disruption of business operations for the shellfish industry during coastal storms. For example, harvest days are lost in securing fishing infrastructure, before, during and after and Duxbury Bay provides no shelter to commercial fishing vessels and infrastructure during coastal storms. Oyster fishermen are required to move their infrastructure to the more-sheltered Bluefish River (Figure 29).

[101] Kleinfelder. SLR Study. Towns of Marshfield, Duxbury, Scituate, MA July 18, 2013.

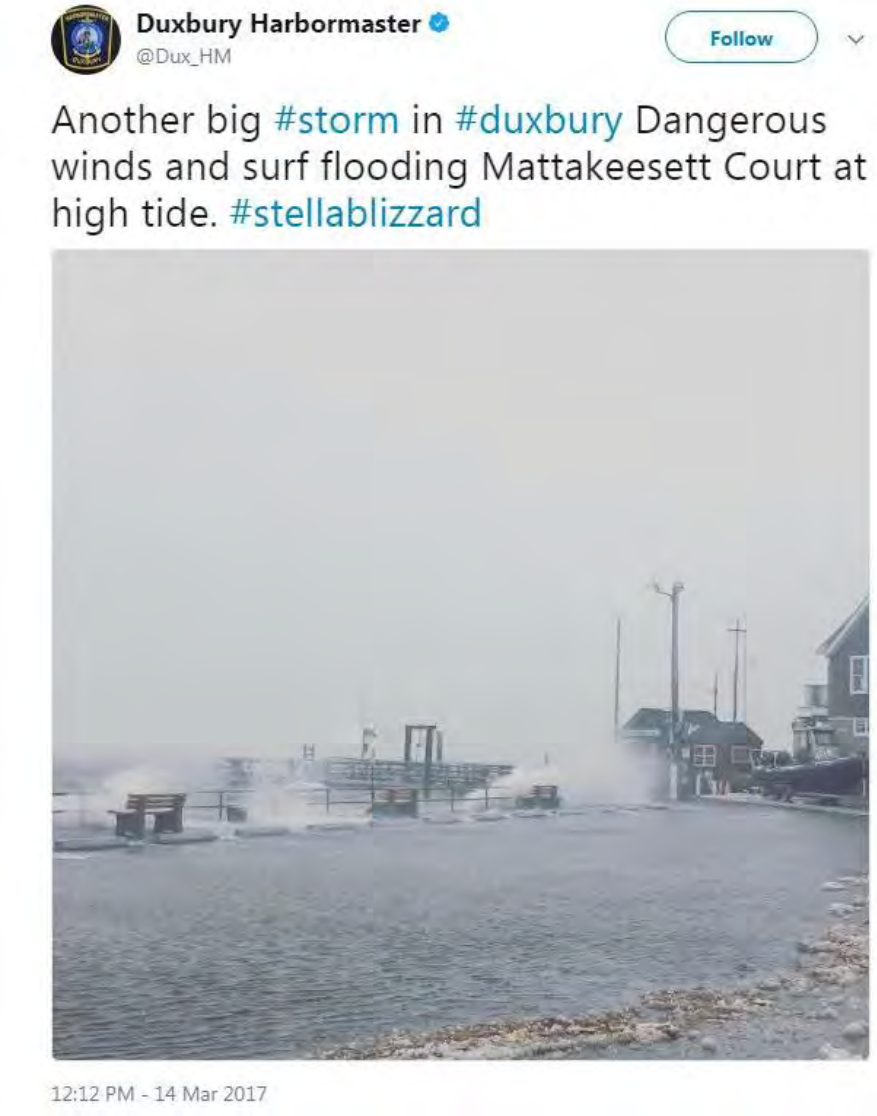
Figure 29 Commercial fishing structures sheltering during Hurricane Jose, September 2017.

Intense and more frequent coastal storms will have important implications on productivity of the shellfish industry with climate change, particularly loss of productivity before, during, and after storms. Photo: Darci Schofield

Finally, the Town and community may benefit from re-envisioning its waterfront access for both commercial and recreational users at Mattakeesett, particularly with SLR and storm surge implications. Many of the commercial fisherman use the Mattakeesett Court Town Pier to access the waterfront and harvest areas. As seen in Figure 30, this area is already experiencing flooding during severe coastal storms. In the 2018 bombogenesis coastal storms, Mattakeesett Court boat launch was completed flooded. Kleinfelder reports that raising the infrastructure will be critical to maintain its current function as it will be submerged by 2088.[102] Island Creek Oysters, a prominent oyster business founded and located in Duxbury recently acquired a 7-acre parcel recently owned by Battelle. This property provides additional waterfront access and amenities to the business while retaining the area's marine and historic character. However, there are other commercial fishermen and a robust recreational marine industry that relies on Mattakeesett.

[102] Kleinfelder. SLR Study. Towns of Marshfield, Duxbury, Scituate, MA July 18, 2013.

Figure 30 Mattakeesett Court Flooding March 2017 blizzard Stella.

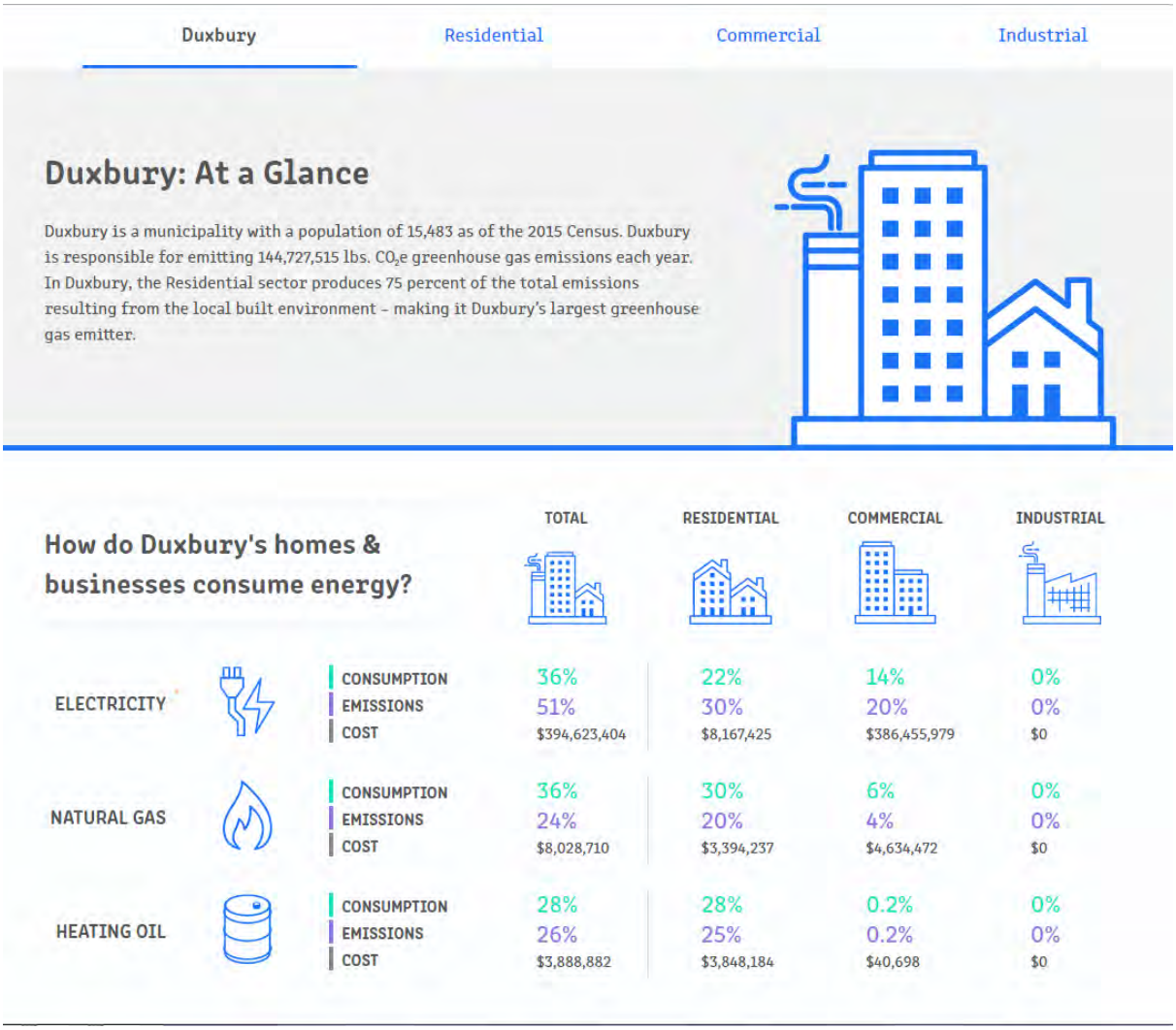


Mattakeesett Court is the location of a public boat launch and the Harbormaster, where most commercial fisherman access the ocean.

Utility Vulnerability

Figure 31 illustrates the breakdown of energy use by sector in Duxbury and its implications on carbon emissions, from the MAPC's Local Energy Action Dashboard (lead.mapc.org). This platform serves to explore and compare energy use, emissions, and cost estimates. It provides a high-level understanding the extent of potential loss during a storm but also as a baseline to assist communities in developing clean energy programs, important for reducing our carbon emissions and reducing SLR extent in the future. In 2012, Duxbury entered into an agreement with Pegasus

Figure 31 Energy and emission analysis, Duxbury.



An analysis of Duxbury's energy consumption, emissions, and cost from the Metropolitan Area Planning Council's Local Energy Action Dashboard (https://lead.mapc.org/cities/duxbury).

Renewable Energy Partners to buy solar energy generated by the Acushnet Gravel Pit solar array, to service its municipal and school buildings.[103] In 2009, with a donation from Sustainable

[103] https://www.solrenview.com/SolrenView/mainFr.php?siteId=1809

Duxbury, the Town installed 2.4 KW solar array at the Chandler School.[104] Other utilities include Columbia Gas Company for natural gas, and Eversource for electricity. In this section we evaluate the overall vulnerability of utilities to climate change and report on how companies are addressing climate resilience. Because energy infrastructure is not publicly available, we have limited data on the geographic locations of substations.

Electricity

Energy infrastructure is vulnerable to extreme weather, in particular winter storms, heat waves, and floods. Ice storms, freeze/thaw cycles, and flooding can cause severe damage. Winter storms and hurricanes can increase loads on transmission infrastructure, in particular power lines and utility poles, because of increased weight from precipitation and wind. Additionally, over 90% of power outages are caused by fallen trees and limbs during storms. Heat waves are also damaging to infrastructure, because of disruptions to cooling equipment within transformers, which are already overburdened during times of increased demand on the electric grid. Flooding can corrode critical systems and prevent electronic components from functioning.

Eversource provides electricity for Duxbury and is currently implementing initiatives to bolster the resiliency of their critical assets. These initiatives include emergency preparedness trainings for staff, flood-proofing vulnerable substations, and updating design standards for increased precipitation and flooding. Eversource has also partnered with the University of Connecticut for a variety of research and models to enhance emergency repair response, perform forest management, enable climate adaptation and mitigation activities in preparation for SLR and flooding, prioritize resilience projects with cost benefit analyses, and create a three dimensional model of local and utility infrastructure. Eversource is also utilizing and providing clean energy such as solar and wind to its customers.[105]

Natural Gas

Duxbury's natural gas infrastructure is serviced by Columbia Gas. Critical gas infrastructure includes pipelines, compressor stations, storage facilities, and control stations. This infrastructure is necessary to transport, store, and distribute natural gas. Flooding from heavy precipitation poses a threat to underground gas infrastructure. Gas pipes rely on internal pressure to keep natural gas flowing. Water intrusion can disturb this internal pressure and result in service disruption. Gas pipes within low pressure distribution systems are the most vulnerable to flooding, because they do not have the hydrostatic pressure necessary to keep water out. Aboveground infrastructure, such as compressor stations, metering stations, and control stations are also vulnerable to flooding. Freeze/thaw events can cause gas mains to break, and older cast iron pipes are the most vulnerable. Extreme heat does not pose significant threats to gas infrastructure.

Massachusetts has a gas leaks problem that adds complexity to addressing future climate impact. The natural gas system is one of the oldest in the country; cast iron pipes are susceptible to breaks from frost heaves, ground movement, and construction. Unprotected steel pipes are subject to corrosion. As of December 2016, Duxbury had 20 unrepaired gas leaks and 31 leaks repaired in

[104] http://www.sunviewer.net/portals/Chandler/details.html
[105] http://www.eversource.uconn.edu/wp-content/uploads/2016/11/brochure-eec-october-2016.pdf

2016(Figure 32) [106] and many of these are located within a FEMA 1% Annual Chance Storm or within SLR for 2038 and 2088. Gas leaks release methane, the most powerful greenhouse gas, into the soil and the air and can cause serious environmental and health risks, including suffocating the root systems of trees and forming ground-level ozone (an asthma trigger). In 2014, the Massachusetts legislature passed a law that requires gas companies to accelerate the replacement of leak prone pipes. Gas companies are required to submit annual Gas Safety Enhancement Plans. In 2015, Columbia Gas had over 800 miles of leak-prone pipes. In order to meet compliance, Columbia gas began working with municipalities to improve the process of

Figure 32 Natural gas leak in Duxbury.

Existing and repaired gas leaks as of December 2016.Source: https://www.heetma.org/squeaky-leak/natural-gas-leaks-maps/

construction for repairs including consensus on project start dates, identification of municipal special requests, and sequencing of gas main replacement with paving and/or water and sewer improvement projects. This collaborative approach enables cost-savings mechanism for municipalities and Columbia Gas in sharing expenses related to utility and road (paving) improvements.[107] In addition, Columbia Gas, National Grid, and Eversource are working with the Home Energy Efficient Team (HEET) to address natural gas leaks through a "Shared Action Plan." Specifically, they are targeting the Grade 3 large volume leaks that are of the greatest risks to health and the environment.[108]

[106] https://www.heetma.org/squeaky-leak/natural-gas-leaks-maps/

[107] http://fixourpipes.org/case-studies/

[108] https://www.columbiagasma.com/en/about-us/newsroom/news/2017/11/07/columbia-gas-of-massachusetts-plans-reliability-projects

Telecommunications

Telecommunications infrastructure is the technology that transmits information electronically. Telecommunications systems include phone and computer networks, and the internet. This infrastructure plays a critical role in emergency response and recovery. Telecommunications infrastructure is vulnerable to extreme heat, precipitation, and storms. Most heat-related service disruptions are caused by power outages resulting from increased demand on the electric grid. Extreme heat can also cause critical infrastructure to overheat or malfunction, leading to equipment failure and reduced lifespan. Corrosion and erosion that can be cause by flooding from heavy precipitation, SLR, and storm surges are primary concerns for underground infrastructure and critical facilities. Heavy ice formation and snow accumulation can increase the load on telecommunication lines and infrastructure, resulting in damage. Heavy precipitation and increased humidity can interfere with the signal transmission that wireless systems rely on.

Aboveground infrastructure is vulnerable to strong winds and lightning. Wired infrastructure and utility poles are particularly vulnerable to damage from falling trees and limbs. Many providers utilize shared fiber networks that reduce redundancy and increase vulnerability to systems disruption during extreme weather. Some service providers, such as Verizon, are taking steps to protect their infrastructure from the impact of climate change. They are creating backup power capability on critical sites, implementing emergency fuel plans for generators, hardening buildings and structures to withstand flooding and precipitation, deploying mobile communications units to heavily affected communities, and training staff to respond to emergencies. Specific data on the location of telecommunications infrastructure and networks is not publically available.

Transportation Vulnerability

MBTA

The MBTA provides important transportation services for communities and residents commuting to Boston. Duxbury is located closest to the Kingston/Plymouth line, and the Kingston MBTA Station is approximately 12 miles from Duxbury. Data from the MBTA Ridership and Services Statistics 2014 Report reports that the Kingston/Plymouth line services approximately 6,560 riders daily, with 500-1000 riders boarding at the Kingston station, but it is not one of the top 10 highest ridership lines. The MBTA makes 22 trips on the Kingston/Plymouth line daily.[109] While commuter rail ridership increases significantly at the Quincy Center station, the notable growth in ridership both locally, statewide, and nationally on public transportation presents this line as an amenity to the Town.[110]

Figure 33 Heat kink on the MBTA Orange Line.

Photo credit Universal Hub.

The Kingston MBTA station is not located within a current Flood Zone determined by FEMA but the Whitman and Hanson MBTA stations along the line are within a 1% Annual Chance Flood. Portions of the commuter line rail itself are also susceptible to1% Annual Chance Flood by the Jones River (though the line is elevated above the river), between the Hanson and Whitman Stations and before the Abington MBTA Station. At the border of Halifax and Hanson, the commuter rail line is adjacent to a 0.2% Chance Annual Flood. In addition, as the rail line approaches Quincy and Braintree into Boston, the line becomes more exposed to extreme heat with a lack of tree cover and dense urban environment. The overall impact is loss of service during severe storms due to flooding and potentially heat.

MBTA climate concerns include potential damage from flooding and extreme heat. Temperatures in excess of 85°F can cause rails to expand potentially causing kinks in the track (Figure 33) or prompt heat restrictions speeds when it has been excessively hot over a period of days. Heat can also cause overheating of equipment.[111,112] Warmer temperatures could lead to more damage

[109] American Public Transportation Association. Public Transportation Ridership Report. 2014. http://www.apta.com/resources/statistics/Documents/Ridership/2014-q4-ridership-APTA.pdf

[110] MBTA State of the Service Commuter Rail. 2015. http://old.mbta.com/uploadedfiles/About_the_T/Board_Meetings/StateofCommuterRailSystem.pdf

[111] https://www.metro.us/boston/how-the-mbta-keeps-it-cool-in-the-summer/zsJpgk---LSIrUluGhiplw

[112] http://www.keoliscs.com/heat-restrictions/

from ice storms if temperatures hover around freezing. Further, extreme weather events were the greatest cause of delays in service in 2015 with 4,743 incidents.

The MBTA is committed to creating a resilient transportation system and employing incremental steps to address climate resilience. New architectural and engineering plans must now address historic and future vulnerabilities by the 30% design stage; Capital plan requests need to indicate whether projects will improve resilience and are prioritized by climate resilience function. They have completed the Blue Line Vulnerability Assessment and Kenmore Square and Charlestown are underway to ascertain flood risk in stations with future SLR and storm surge projections and they are developing a request for proposal for a system-wide analysis.

Figure 34 Road closure at Bridge of Bluefish River, 2014.

High tides caused concerns for coastal flooding during a winter 2014 storm at the bridge at the mouth of the Bluefish River, as reported on Twitter.

Roadways

Transportation infrastructure would likely experience an acceleration in deterioration of its facilities, like asphalt, from the combination of extreme temperatures, increased precipitation and flooding. Extreme temperatures for long periods would cause thermal expansion of metal structures and stress bridge infrastructure. This would also affect roadway materials through

softening and expanding, which can lead to rutting and potholes.[113] While there may be decreased need to provide snow and ice removal, more rapid freezing and thawing cycles could cause more acute damage with damage sustained during the warmer months. Duxbury's most significant risk to its road infrastructure is coastal and inland flooding, and repeated flooding can cause accelerate deterioration of the road infrastructure.[114]

In September 2016, members of the Duxbury's Hazard Mitigation steering committee comprised of municipal staff across departments met to discuss existing natural hazards in the Town. The Committee reported roadways already subject to coastal flooding include Gurnet Road, Washington, King Caesar Road, St. George Street, Bay Road, and Congress Street. Plantation Drive, adjacent to the South River, has beaver activity causing inland flooding. King Caesar, Washington and St. George are low-lying streets with no flood mitigation measures. The greatest risk with coastal flooding with roads is the loss of access to emergency services during major storm events, and the probability of greater and more frequent exposure with lunar high tides and projected intense storms make these areas in the greatest need for future planning.[115]

Concerns today for flooding at bridges include the Bluefish River (Figure 34) and the Marshall Street Bridge; both have had improvements that have alleviated some flooding. Importantly, Kleinfelder's study of SLR in 2013 indicated that the Powder Point Bridge, Bluefish, and Marshall Street bridges are sufficiently high enough to NOT be impacted coastal flooding today or even with SLR in 2088 with Category 1 Storm Surge.[107] However, SLR in 2088 will greatly impact Washington Street in Snug Harbor, King Caesar and Powder Point Roads, Gurnet Road, Duxbury Beach Access Road, Marginal Road, Pine Point Road and Marginal Road.

[113] National Research Council. The Potential Impacts of Climate Change on U.S. Transportation, Transportation Research Board Special report 290. 2008.
[114] Kleinfelder. SLR Study. Towns of Marshfield, Scituate, and Duxbury. July 2013
[115] September 20, 2016. Duxbury Hazard Mitigation Plan Team Meeting #2.

Historic Assets Vulnerability

Nathaniel Winsor, Jr. House at Mattakeesett. Home of the Duxbury Rural and Historical Society. Photo by MAPC.

Although cultural heritage and historic resources are a critical component of our economy and livable communities, there is limited literature on planning for historic and cultural heritage preservation with climate change.[116] Most of the research is centered in Europe. However, a new focus has identified this gap in climate adaptation planning and researchers from North Carolina State are developing a new decision support tool that aligns budget, climate risk, historical significance, use potential and preservation costs to aid planners, municipalities, and preservationists in implementing long-term strategies to protect these resources.[117] These tools provide a forum for maneuvering the challenging area of balancing constrained budgets, increased threat, new preservation techniques for climate change, and the community-based value of the historic and cultural asset.[118]

Duxbury is rich with cultural assets contributing significant culture and beauty to the Town. Duxbury has 792 historic assets registered in the Massachusetts Historic Structures Inventory, the earliest dating to 1632, the Myles Standish (Chestnut Street) burial ground and many first period colonial homes such as the 1700 John Alden House. Other notable historic assets beloved by the community and visitors alike are Snug Harbor, Powder Point Bridge, the Girl Scout House, the King Caesar House, the Nathaniel Winsor, Jr. House and the Bradford House. Duxbury has the Duxbury Rural & Historical Society, a local non-profit located at the historic Nathaniel Winsor, Jr. house, which maintains four historic properties, archival library, museum collections, and 150 acres of conservation land. The society runs approximately 70 programs, events, and rentals a year and reported that 2017 was its most successful year to date.[119] The Town also has a Historic Commission, established in 1975, to "Identify, document, and protect, Duxbury's historic resources, to increase public awareness of Duxbury's heritage and the value of historic preservation." The Historic Commission also oversees the Demolition Delay Bylaw for any structure over 75 years old. [83] Since 2002, the Town of Duxbury has approved and implemented 23 historic preservation

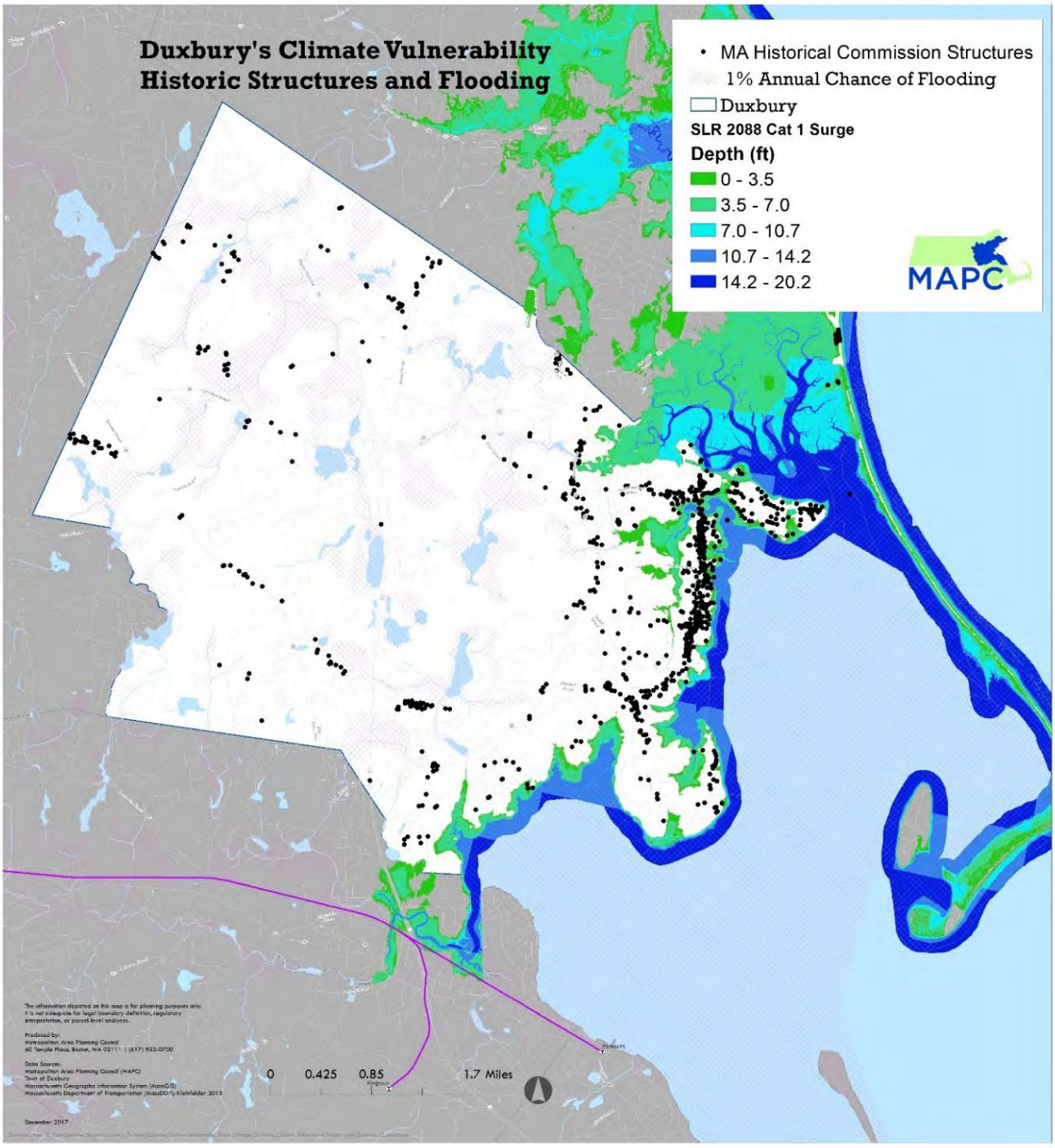
[116] Fatorić, S., and Seekamp, E. 2017. Assessing Historical Significance and Use Potential of Buildings within Historic Districts: An Overview of a Measurement Framework Developed for Climate Adaptation Planning. AG-832. Raleigh, NC: NC State Extension.

[117] Fatorić, S. & Seekamp, E. Climatic Change (2017) 142: 227. https://doi.org/10.1007/s10584-017-1929-9

[118] Fatorić, S. & Seekamp, E. Land Use Policy (2017) 68:254-263.Evaluating a decision analytic approach to climate change adaptation of cultural resources along the Atlantic Coast of the United States.

[119] http://duxburyhistory.org/about-us-2/

Figure 35 Historic structures vulnerable to flooding.



This analysis includes the FEMA 1% Annual Chance of Flood and SLR in 2088 with a category 1 storm surge.

projects using Community Preservation Act funds. There is demonstrated community value to Duxbury's historic and cultural assets and these are important to consider in future planning,

growth, and climate change resilience. With projected changes in temperatures, storms, and precipitation regimes, new preservation methodologies may need to be explored.

Historic assets in Duxbury are vulnerable to climate change. First, locations in flood zones, coastal areas, and heat islands will impact the integrity of the structure, but in addition, studies have indicated that our changing climate could accelerate the deterioration of stone and brick buildings. Mason building deterioration is caused by water infiltrating the stone, evaporation and/or freezing and thawing.[120] This process can typically occur over centuries but is likely to accelerate with increased temperatures and increased frequency of freeze/thaw cycles. Increased temperatures could also encourage fungal and plant growth and insect infestation which could further deteriorate building materials.[121]

Of Duxbury's 792 registered historic assets, 68 or 8.5% are located in a current 1% Annual Chance Flood, according to the 2017 FEMA flood insurance rates maps. Seven of these structures are inland, located in the Ashdod neighborhood around Union Street. Fifty-four or 6.8% of these are located in a flood zone for SLR in 2088 with a Category 1 storm surge. Table 6 shows the breakdown of historic structure vulnerability by Duxbury Neighborhood and Figure 35 is a map illustrating the structure's vulnerability to 1% Annual Chance Flood and SLR 2088 with Category 1 Storm Surge.

Table 6 Count of Historic Properties and Flooding.

Area	1% Annual Chance Flood	SLR 2088 Cat 1 Storm Surge
North Duxbury (Gurnet)	18	8
Soules Island/Powder Point	12	15
Bluefish River floodplain	10	10
Long Point Marine to Battelle (Washington St)	16	16
Battelle to Marshall Street Bridge (coast)	1	1
Goose Point	1	1
The Nook to Kingston Shore (coast)	3	3
Ashdod/Union Street (Philips Brook Flooding)	7	N/A

[120] http://www.town.duxbury.ma.us/historical-commission

[121] https://historicengland.org.uk/research/current/threats/heritage-climate-change-environment/what-effects/

III. Climate Action Plan

Duxbury will face new risks in the coming decades due to climate change such as changing oceans, waterfronts, rivers, and weather events whose related impacts may occur more frequently and more intensely than they have in the past.

Climate change resilience, including adaptation and mitigation, will serve as the response to these new conditions that will confront the town and the South Shore region. Mitigation strategies will seek minimize or eliminate the impacts of climate change in Duxbury and larger geographies. Adaptation strategies recognize that certain aspects of climate change are already set given past GHG emissions and that the future level of emission are uncertain, and seeks to strengthen the region's ability to adjust to the new conditions.

This action plan for climate resilience is informed by four assumptions and approaches: 1) Duxbury has existing strengths, 2) mitigation, adaptation and emergency preparedness are interconnected, 3) a 'no regrets' approach builds greater community cohesion, livability, and vitality, and 4) an "adaptive management" allows flexibility in timing and approach of capital investments for resilience. These are described in greater detail here:

Duxbury Existing Strengths

Duxbury has significant strengths that will minimize the impact of climate change. These strengths will inform a shared agenda for climate action by the Town and the South Shore Region.

1. **Duxbury is proactive**. Duxbury's propensity to act is demonstrated by its participation in multiple planning efforts around sea level rise and climate change, Hazard Mitigation Planning, and Envision Duxbury, its Master Plan. They are also Green Community. This foresight will create a foundation for incremental resilience programs and projects to ensure Duxbury remains a vibrant community into the next century and beyond.
2. **Duxbury is committed to conservation**. This is evident in town's robust history of acquiring land for drinking water, natural resources, recreation, and wildlife habitat protection in addition to implementing measures to ensure clean harbors and bays.
3. **Duxbury has a dynamic network** of non-profits, institutions, community groups, residents, and businesses that are highly engaged in the community and vested in its future.
4. **Duxbury supports collaboration.** In discussing and acting on current and future regional matters, there is a culture and practice of collaboration between elected officials, municipal staff, residents, community groups, and private sector representatives. The Town is also committed to collaborating with Duxbury Beach Reservation, Inc. to ensure its viability as a recreation and climate resilience resource.

Maintaining these strengths as guideposts for action will be essential in an uncertain future. They will serve as reminders of existing adaptive capacities and provide direction regarding new capabilities that are needed to respond to a changing climate.

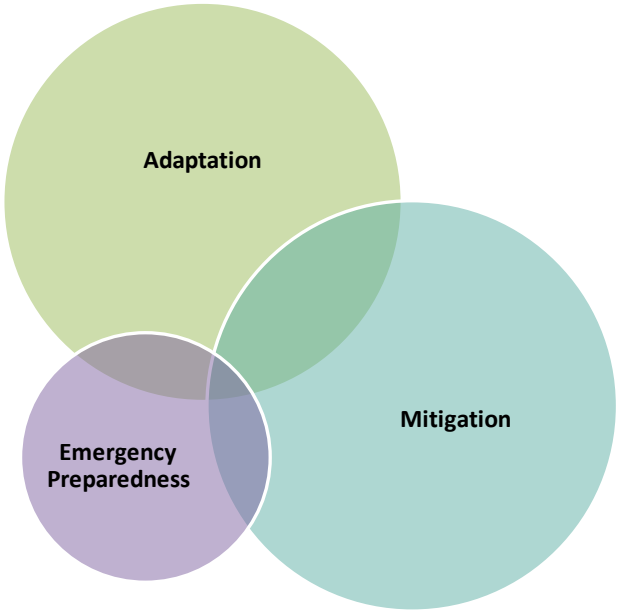
Mitigation, Adaptation, and Emergency Preparedness are Inter-connected.

Responses to climate change include mitigation and adaptation strategies as well as support for emergency preparedness (Figure 36).[98] Of the three, emergency preparedness planning is generally in place already in each municipality. However, emergency preparedness is a process

that requires continuous updating and the strategies used are likely to change as a result of climate change.

These three elements are also interconnected, as action in one dimension can help address the causes or outcomes that another is also trying to tackle. For example, mitigation activities address the causes of climate change (e.g., GHG emissions), and in reducing the magnitude of impacts, efforts may, in turn, affect what adaptation actions are needed or the extent that of emergency preparedness and planning activities are necessary. An instance of this would be clean energy investments that reduce GHG emissions through solar. If done under certain circumstances, the solar could be connected to a microgrid[122] that would enable a set of homes of a neighborhoods to maintain electricity during outages and reduce the demand on emergency responders and utility companies.

Figure 36 Conceptual Representation of the Interconnections of Mitigation, Adaptation, and Emergency Preparedness



Each dimension – adaptation, mitigation, and emergency preparedness - provide valuable perspectives and tools that are needed to holistically address the causes of and potential impacts.

The strategies embrace an approach that considers climate resilience a mechanism that creates more livable and vibrant communities regardless of shifting knowledge or patter of climate change, a "no regrets" approach. They include action items that should be considered even in the absence of climate change and that are anticipated to generate economic, environmental, and social benefits. They include evidence-based and best practices for environmental protection, public health and safety, sustainable economic growth, and a reduction in disparities. An example is the use of green infrastructure and low impact development (LID) techniques that reduce

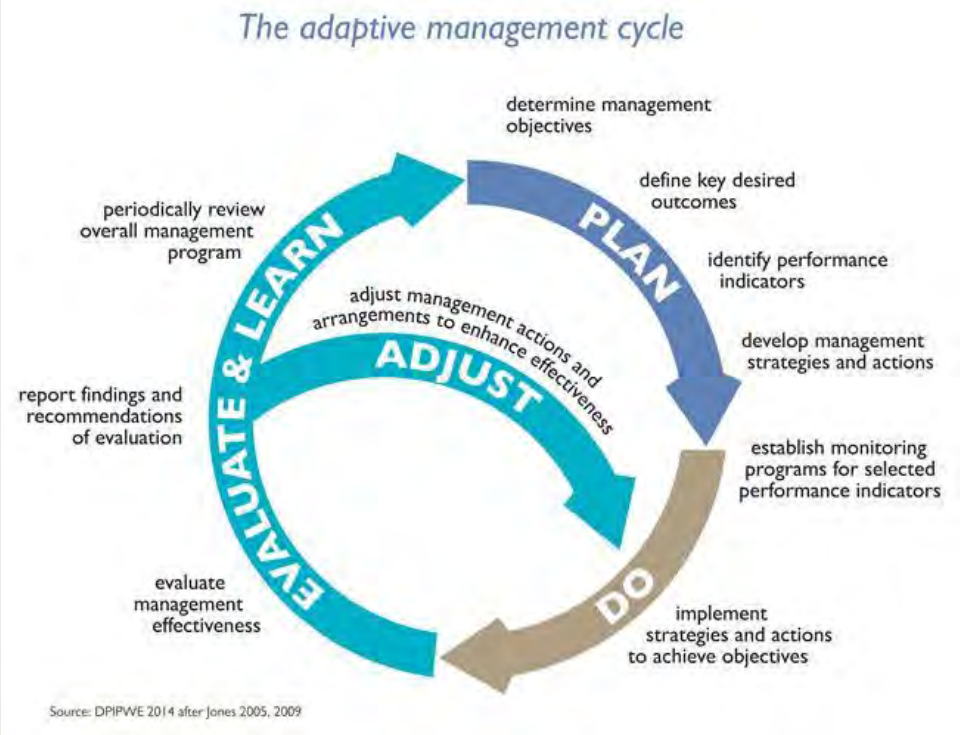
[122] Department of Energy, "How Microgrids Work", https://energy.gov/articles/how-microgrids-work, accessed April 5, 2017.

stormwater runoff, provide additional green space, reduce cooling cost due to less impervious ground cover, and recharge water in the local ecosystem. This change would provide benefits even if climate change was not occurring as it would expose more residents to green space, reduce demands on municipal stormwater drainage systems, and support the needs of local ecosystems.

Adaptive Management Framework

The strategies embrace the concept of Adaptive Management. This concept is used to address issues that involve uncertainty. It relies on iterative processes that use continuous monitoring and assessment to understand what actions are working, which are not, and how these actions could potentially come into conflict with one another. It operates best when new information (e.g., projections, estimates, etc.) can be integrated quickly so that new approaches can be better evaluated and modified in order to maximize impact under changing climate conditions.

Figure 37 Adaptive Management Framework



Source: Parks and Wildlife Service, Tasmania

An adaptive management operating approach is likely to face many challenges in a municipal framework. The concept requires decision-making to be agile and capable of working quickly in the face of evolving information. Massachusetts town governments and residents frequently do not like, or cannot operate, in such a manner. Therefore, a general proposal is to identify how adaptive management concepts can be tested and used to make enhancements in municipal decision-making in order to best address climate action.

Climate Resilience Actions

The climate action plan includes high priority items the Climate Steering Committee identified at a meeting on March 27, 2018 and Appendix C their prioritization. It also includes high priority action items identified in the DRAFT Duxbury Hazard Mitigation Plan and action items identified by the public through public forums (Appendix D). Duxbury's Climate Resilience Task Force should designate a lead entity to initiate these actions. The Climate Steering Committee does want to recognize that working across sectors is critically important for success and that staff capacity can present challenges, but the importance of this task must override the obstacles. Finally, potential public funding and technical assistance programs related to implementing these action items are categorized and listed in Appendix E.

Steering Committee Climate Actions

Overall Best Practices	Establish and maintain a Climate Resilience Task Force that works across departments and commissions for a comprehensive approach toward climate resilience across sectors.
	Incorporate climate resilience into all local and regional plans as well as capital improvement plans.
	Update climate action plan every five years.
Drinking Water	Hire a consultant to evaluate in greater detail Duxbury's susceptibility to salt water intrusion of its aquifer.
Waste Water/Sewer Resilience	Prepare a list of key utility facilities that require critical power restoration and include the physical locations of the facilities to the power company during an outage to expedite electricity restoration.
	Explore opportunities to create a municipal sewer system or other alternative wastewater system engineered for climate resilience to alleviate concerns and risk to drinking water contamination and OSWT failures with sea level rise and coastal flooding.
Transportation	Create a municipal working group to help inform design standards on raising roads in response to current and future coastal flooding. Consider also the implications for commercial, industrial, and residential building egress.
	Increase walkability and bike ability of Duxbury's Streets.
People	Community Based Adaptation approach to residents in Duxbury's Housing Authority to ensure needs of low-income, seniors, and other potentially vulnerable individuals are addressed and engaged in preparing for their own resilience.
People	Create a Heat Emergency Action Plan-Address those most vulnerable to heat, cooling centers, communications strategies, and back-up energy plans. Include importance of tree canopy for cooling buildings.

	Identify location of and create a plan for vulnerable populations with limited mobility (seniors, handicap, individuals without vehicles) or limited English proficiency during emergency response, which may need transportation.
Natural Resources	Engage in Community Adaptation Planning Process for three most vulnerable neighborhoods to leverage resident's leadership in visioning, instituting and prioritizing challenging resilience measures: Gurnet Road, Snug Harbor, and BlueFish River floodplain.
	Collaborate with and provide financial support to the Duxbury Beach Reservation, Inc. for ongoing beach nourishment, sacrificial dunes, sand fences, road improvements, and other coastal infrastructure investments to ensure Duxbury remains protected from high energy storm surge into the future while protecting an important recreational and economic amenity.
	Monitor health of submerged aquatic vegetation, such as eelgrass beds. Investigate opportunities to enroll in eelgrass bed restoration/planting programs with MA Division of Marine Fisheries, MassBays, and Boston University. If necessary, expand and/or restore eelgrass beds and perform measures to eradicate invasives such as green crabs.
Built Environment	Remove all unnecessary dams
	Hire a consultant to evaluate the status of all Duxbury sea walls and hard coastal protection infrastructure, including ownership, maintenance requirements, and endurance to sea level rise and storm surge.
	Explore zoning that prohibits building in high hazard areas.
	Collaborate with the residents and businesses in the near- and long-term most vulnerable areas to examine potential zoning, regulatory, incentive, mitigation or cooperative-based approaches to dealing with the issues that sea level rise presents for existing structures and infrastructure, exploring funding opportunities to examine feasibilities of alternatives and to implement best practices.

High and Mediums Priority Hazard Mitigation Actions

1. Maintain seawalls and the barrier beach off Powder Point to 16.5 NGVD to minimize flooding on King Caesar Road.
2. Study options for reducing flood impacts to Congress Street
3. Create a sacrificial dune between two existing sections of seawall where there is none on Plymouth Avenue off Gurnet Road to reduce flooding from Coastal Storms.
4. Continuation of Open Space Protection and Land Acquisition to ensure future development does not increase vulnerability to natural hazards, such as flooding. The town should continue its efforts for open space protection and purchases as prioritized in the 2017 Open Space and Recreation Plan.
5. Regulatory Revisions for Stormwater Management. The subdivision and site plan requirements could be updated to reflect more current trends to help prevent flooding from new development and redevelopment. In particular, the regulations could include:
    a. Requirements for aggressive and legally-binding operation and maintenance agreements, with enforcement mechanisms, for private drainage facilities.
    b. Regulatory controls to encourage Low-Impact Development (LID) practices.
6. Replace Powder Point Bridge
7. Raise Marshal Street Bridge which is routinely flooded.
8. Create Zoning restrictions for building in flood zone along Bay Road.

Climate Actions identified at Public Forums

1. Promote sidewalks, walkability and bike ability.
2. Protect community from Ticks and tick-borne diseases.
3. Maintain health of the ocean and bays.
4. Protect and enhance eelgrass beds.
5. Protect commercial fish industry.
6. Review zoning on mounded septic.
7. Review regulation and zoning to ensure climate resilience in all land use decisions.
8. Create a floodplain protection overlay district.

IV. Appendix

Appendix A

Vulnerability of Duxbury's dams by hazard status, current flood risk, current hurricane exposure and future SLR.

Dam	Owner	Hazard Severity with Failure	Current FEMA Flood Risk	Hurricane Surge Storm Zone	2038 SLR Depth (ft.)
Bluefish River Dam	Private	N/A	1%	Cat 1	>6-8
Lower Chandler Pond Dam	Duxbury	Significant	1%	____	____
Garside Reservoir	Duxbury	Significant	1%	____	____
Peterson's Saw Mill Pond Dam	Duxbury	Significant	1%	____	____
Boys & Girls Camp #3 Dam	Private	Significant	1%	____	____
Round Pond Dam	Private	Low	1%	____	____
Pine Lake Dam	Private	Low	1%	____	____
Mill Pond Dam	Duxbury	Significant	1%	____	____
Boys & Girls Camp #1 Dam	Private	Significant	1%	____	____
Temple Street Pond Dam	Duxbury	Significant	1%	____	____
Merry Memorial Dam	Private	N/A	1%	____	____
Wright Reservoir Dam	Private	Low	1%	____	____
Boys & Girls Club #2 Dam	Private	N/A	1%	____	____
Golden Reservoir Dam	Duxbury	N/A	___	____	____
Merry Reservoir Dam	Private	N/A	1%	____	____
Pit Pond Dam	Private	N/A	___	____	____
Mcissac & Williams #1 Dam	Private	N/A	1%	____	____
Mcissac & Williams #3 Dam	Private	N/A	1%	____	____
Pink #2 Dam	Private	N/A	1%	____	____
Mcissac & Williams Dam	Private	N/A	1%	____	____
Reed #2 Dam	Duxbury	N/A	1%	____	____
Keith & Adams Reservoir Dam	Private	N/A	____	____	____
Crowell Reservoir Dam	Private	N/A	____	____	____

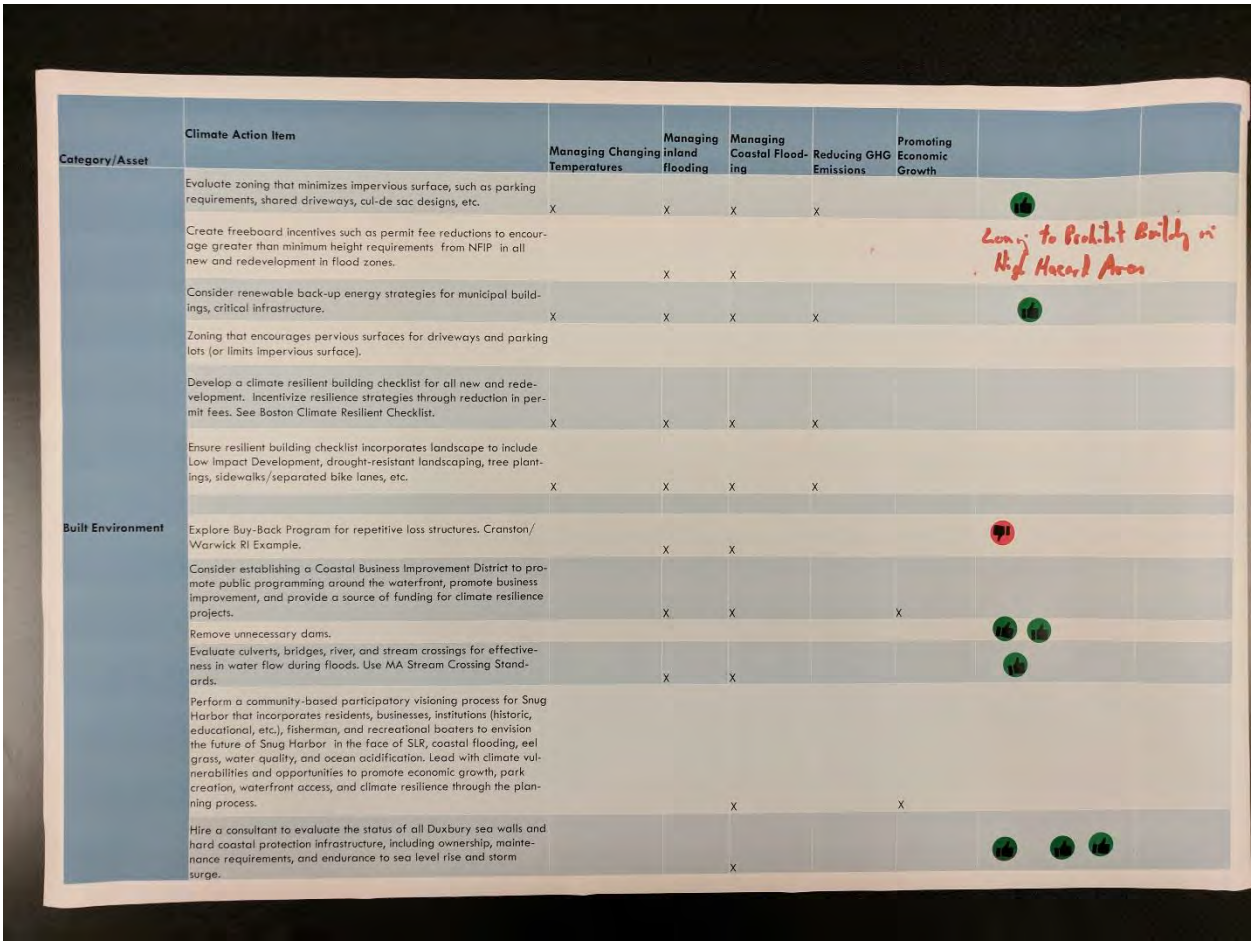
Wrights Pond Dike	Duxbury	N/A	1%	Cat 1	0-2
Mayflower St. Pond Dam	Duxbury	N/A	?	____	____
Upper Chandler Pond Dam	Private	Low	1%	____	____

Appendix B

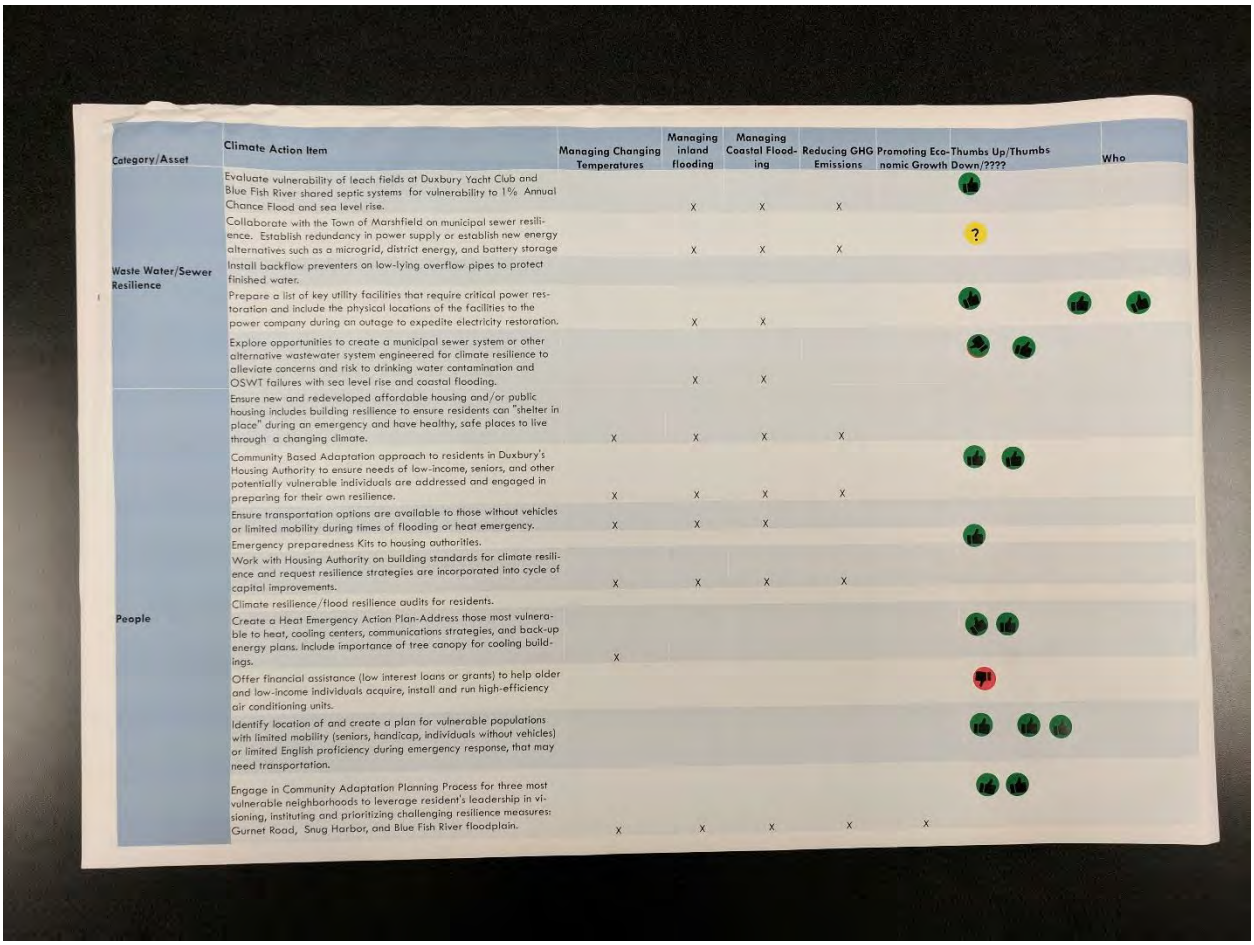
Critical Infrastructure ID	Name of Infrastructure	Address	Type
1	Bay Farm Montessori Academy	145 Loring Rd	School
2	Good Shepherd Christian Academy	2 Tremont Street	School
3	Chandler Elementary School	93 Chandler Street	School
4	Alden School	130 St. George St	School
5	Duxbury Middle School	130 St. George St	School
6	Duxbury High School	130 St. George St	School
7	Fire Department	668 Tremont St	Fire Station
8	Fire Department Station 2	794 Franklin St	Fire Station
9	Animal Shelter	878 R Tremont St	Municipal
10	Sand/Salt Shed	878 R Tremont St	Municipal
11	Salt Shed	878 R Tremont St	Municipal
12	Salt Shed	878 R Tremont St	Municipal
13	First Parish	842 Tremont St	Church
14	Town Hall	878 Tremont St	Municipal
15	DPW	878 R Tremont St	Municipal
16	Selectmen's Office	878 Tremont St	Municipal
17	DPW Barn	878 R Tremont St	Municipal
18	Mayflower Crematory	774 Tremont St	Crematory
19	Mayflower Cemetery	774 Tremont St	Cemetery
20	Transfer Station	Mayflower Street	Municipal
21	Council on Aging	10 Mayflower St	Senior Center
22	Holy Family Church	601 Tremont St	Church
23	Mayflower 1 Well	590 Mayflower St	Well
24	Mayflower 2 Well	590 Mayflower St	Well
25	Police Station	West Street	Police Station
26	Duxbury Free Public Library	71 Alden	Municipal
27	Birch Street Water Storage Tank	50 Birch Street	Water Storage Tank
28	Police Repeater	235 Crescent Street	Communication Tower
29	Captain Hill Stand pipe	235 Crescent Street	Water Stand Pipe
30	Scada Antenna	235 Crescent Street	Communication Tower
31	Society of Devine Word	121 Park Street	Church
32	Bay Path Nursing Home	308 Kingstown Way	Elder Housing
33	Village at Duxbury	290 Kingstown Way	Elder Housing
34	Duxbury House	298 Kingstown Way	Special Needs
35	Mass Highway DPW Barn District 5	113 Summer Street	Municipal
36	Berry Brook School	267 Winter Street	School
37	Pied Piper Pre-School	38 Kingstown Way	Child Care

38	High Street United Methodist Church	298 High Street	Church
39	Learn and Play Pre-School	298 High Street	Child Care
40	Pilgrim Child Care	404 Washington St	Child Care
41	Pilgrim Church	404 Washington St	Church
42	Ellison Center for the Arts Pre-School	64 Saint George St	Child Care
43	Depot Street Water Pump Station	261 Depot Street	Water Pump Station
44	Partridge Road Pump Station	106 Partridge Road	Water Pump Station
45	Evergreen 1 Water Pump Station	175 Evergreen St	Water Pump Station
46	Evergreen 2 Water Pump Station	165 Evergreen St	Water Pump Station
47	Tremont 2 Water Pump Station	19 Hound's Ditch Lane	Water Pump Station
48	Tremont 1 Water Pump Station	19 Hound's Ditch Lane	Water Pump Station
49	Lake Shore Drive Water Pump Station	360 Lake Shore Drive	Water Pump Station
50	Powder Point Bridge	Powder Point Road	Bridge

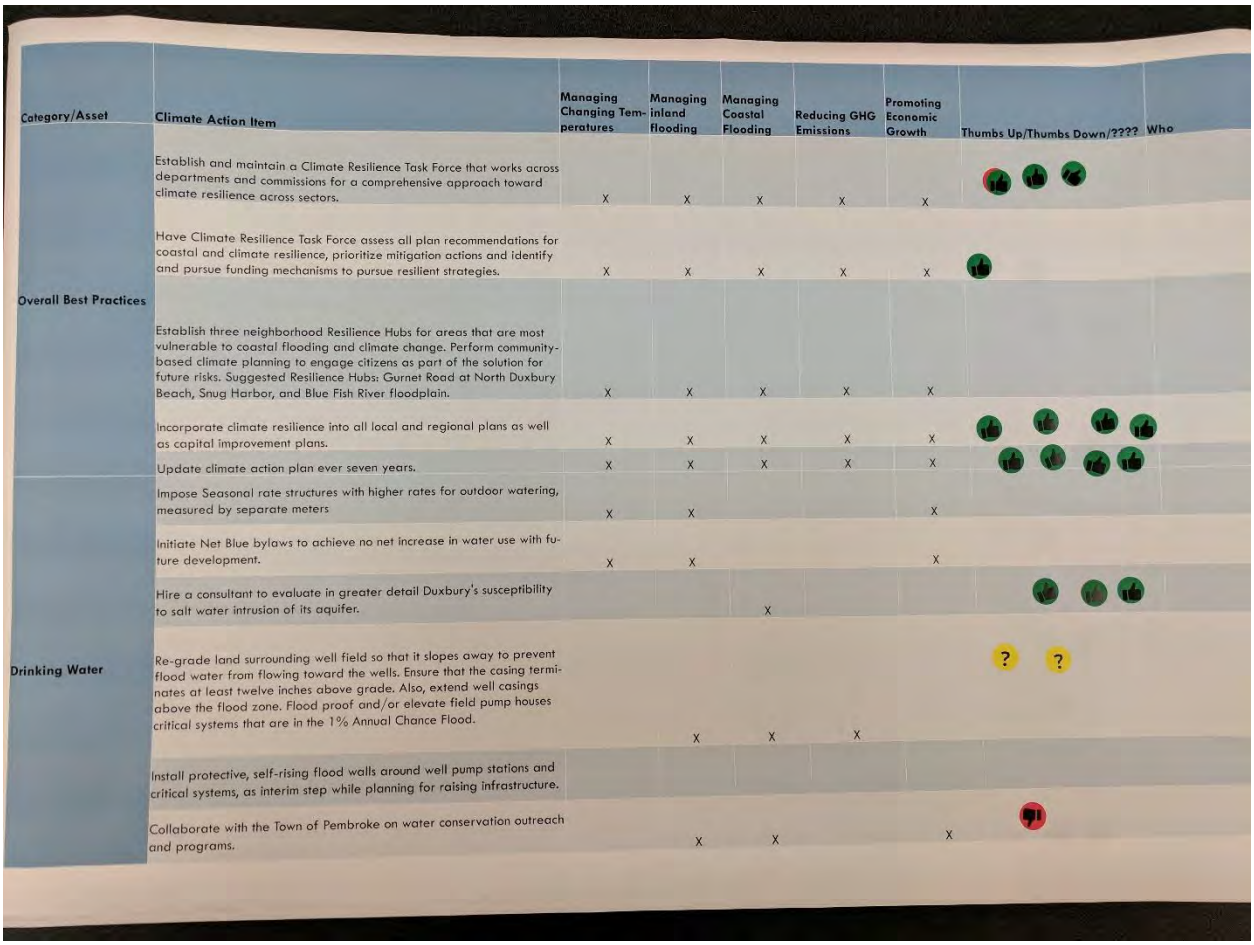
Appendix C



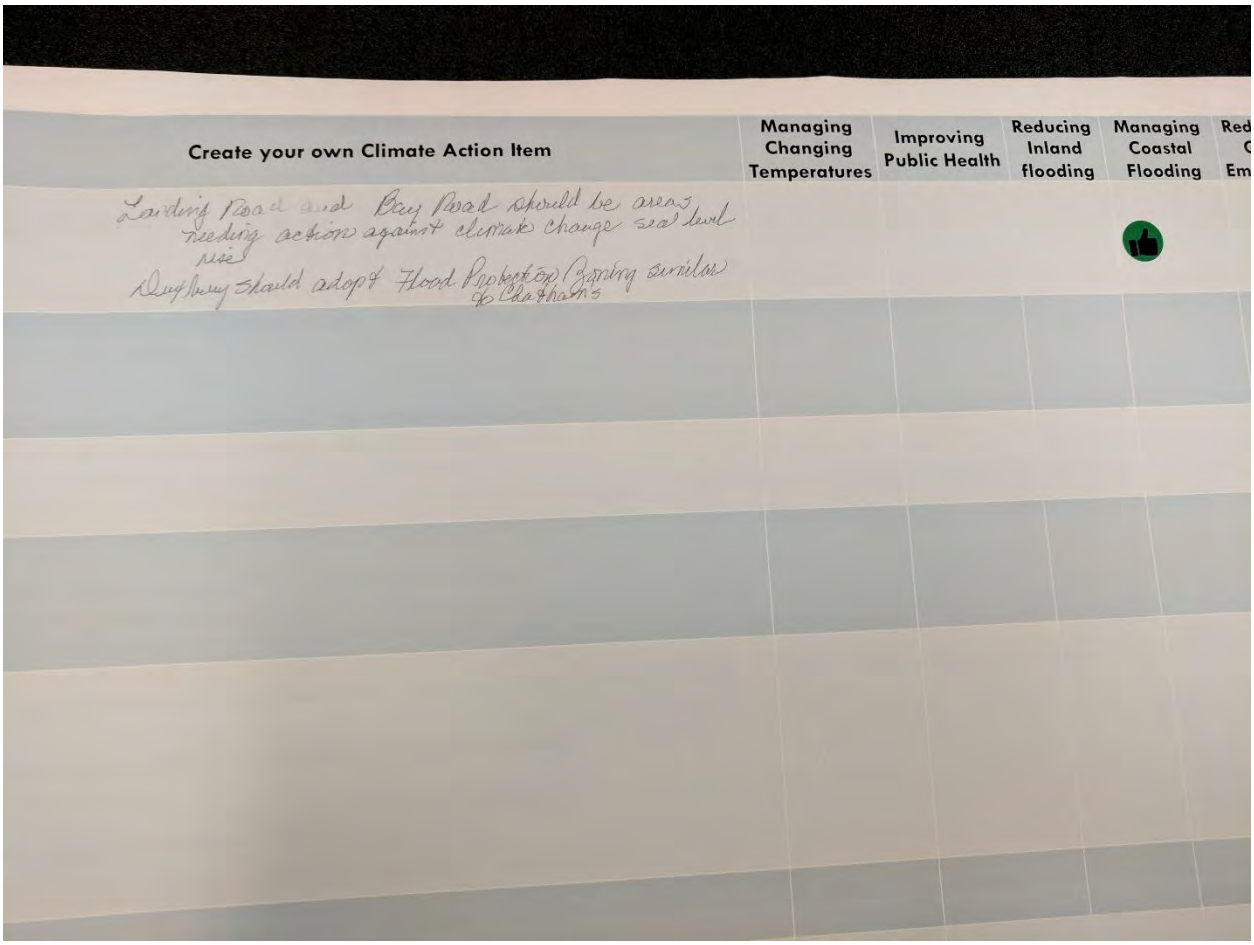
Category/Asset	Climate Action Item	Managing Changing Temperatures	Managing inland flooding	Managing Coastal Flooding	Reducing GHG Emissions	Promoting Economic Growth
	Evaluate zoning that minimizes impervious surface, such as parking requirements, shared driveways, cul-de sac designs, etc.	X	X	X	X	
	Create freeboard incentives such as permit fee reductions to encourage greater than minimum height requirements from NFIP in all new and redevelopment in flood zones.		X	X		
	Consider renewable back-up energy strategies for municipal buildings, critical infrastructure.	X	X	X	X	
	Zoning that encourages pervious surfaces for driveways and parking lots (or limits impervious surface).					
	Develop a climate resilient building checklist for all new and redevelopment. Incentivize resilience strategies through reduction in permit fees. See Boston Climate Resilient Checklist.	X	X	X	X	
	Ensure resilient building checklist incorporates landscape to include Low Impact Development, drought-resistant landscaping, tree plantings, sidewalks/separated bike lanes, etc.	X	X	X	X	
Built Environment	Explore Buy-Back Program for repetitive loss structures. Cranston/ Warwick RI Example.		X	X		
	Consider establishing a Coastal Business Improvement District to promote public programming around the waterfront, promote business improvement, and provide a source of funding for climate resilience projects.		X	X		X
	Remove unnecessary dams.					
	Evaluate culverts, bridges, river, and stream crossings for effectiveness in water flow during floods. Use MA Stream Crossing Standards.		X	X		
	Perform a community-based participatory visioning process for Snug Harbor that incorporates residents, businesses, institutions (historic, educational, etc.), fisherman, and recreational boaters to envision the future of Snug Harbor in the face of SLR, coastal flooding, eel grass, water quality, and ocean acidification. Lead with climate vulnerabilities and opportunities to promote economic growth, park creation, waterfront access, and climate resilience through the planning process.			X		X
	Hire a consultant to evaluate the status of all Duxbury sea walls and hard coastal protection infrastructure, including ownership, maintenance requirements, and endurance to sea level rise and storm surge.			X		



Category/Asset	Climate Action Item	Managing Changing Temperatures	Managing inland flooding	Managing Coastal Flooding	Reducing GHG Emissions	Promoting Economic Growth	Thumbs Up/Thumbs Down/????	Who
Waste Water/Sewer Resilience	Evaluate vulnerability of leach fields at Duxbury Yacht Club and Blue Fish River shared septic systems for vulnerability to 1% Annual Chance Flood and sea level rise.		X	X	X			
	Collaborate with the Town of Marshfield on municipal sewer resilience. Establish redundancy in power supply or establish new energy alternatives such as a microgrid, district energy, and battery storage		X	X	X		?	
	Install backflow preventers on low-lying overflow pipes to protect finished water.							
	Prepare a list of key utility facilities that require critical power restoration and include the physical locations of the facilities to the power company during an outage to expedite electricity restoration.		X	X				
	Explore opportunities to create a municipal sewer system or other alternative wastewater system engineered for climate resilience to alleviate concerns and risk to drinking water contamination and OSWT failures with sea level rise and coastal flooding.		X	X				
People	Ensure new and redeveloped affordable housing and/or public housing includes building resilience to ensure residents can "shelter in place" during an emergency and have healthy, safe places to live through a changing climate.	X	X	X	X			
	Community Based Adaptation approach to residents in Duxbury's Housing Authority to ensure needs of low-income, seniors, and other potentially vulnerable individuals are addressed and engaged in preparing for their own resilience.	X	X	X	X			
	Ensure transportation options are available to those without vehicles or limited mobility during times of flooding or heat emergency.	X	X	X				
	Emergency preparedness Kits to housing authorities.							
	Work with Housing Authority on building standards for climate resilience and request resilience strategies are incorporated into cycle of capital improvements.	X	X	X	X			
	Climate resilience/flood resilience audits for residents.							
	Create a Heat Emergency Action Plan-Address those most vulnerable to heat, cooling centers, communications strategies, and back-up energy plans. Include importance of tree canopy for cooling buildings.	X						
	Offer financial assistance (low interest loans or grants) to help older and low-income individuals acquire, install and run high-efficiency air conditioning units.							
	Identify location of and create a plan for vulnerable populations with limited mobility (seniors, handicap, individuals without vehicles) or limited English proficiency during emergency response, that may need transportation.							
	Engage in Community Adaptation Planning Process for three most vulnerable neighborhoods to leverage resident's leadership in visioning, instituting and prioritizing challenging resilience measures: Gurnet Road, Snug Harbor, and Blue Fish River floodplain.	X	X	X	X	X		

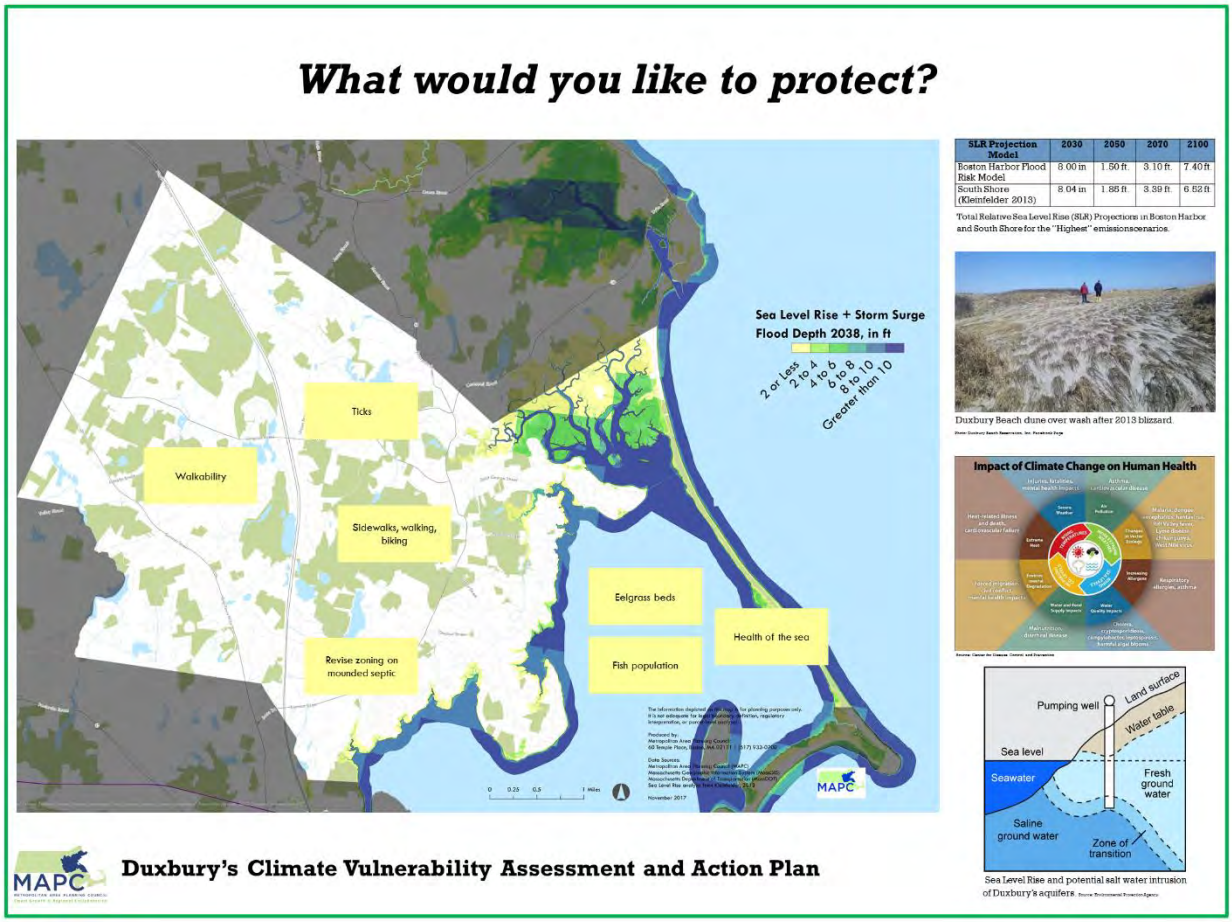


Category/Asset	Climate Action Item	Managing Changing Temperatures	Managing inland flooding	Managing Coastal Flooding	Reducing GHG Emissions	Promoting Economic Growth	Thumbs Up/Thumbs Down/????	Who
Overall Best Practices	Establish and maintain a Climate Resilience Task Force that works across departments and commissions for a comprehensive approach toward climate resilience across sectors.	X	X	X	X	X		
	Have Climate Resilience Task Force assess all plan recommendations for coastal and climate resilience, prioritize mitigation actions and identify and pursue funding mechanisms to pursue resilient strategies.	X	X	X	X	X		
	Establish three neighborhood Resilience Hubs for areas that are most vulnerable to coastal flooding and climate change. Perform community-based climate planning to engage citizens as part of the solution for future risks. Suggested Resilience Hubs: Gurnet Road at North Duxbury Beach, Snug Harbor, and Blue Fish River floodplain.	X	X	X	X	X		
	Incorporate climate resilience into all local and regional plans as well as capital improvement plans.	X	X	X	X	X		
	Update climate action plan ever seven years.	X	X	X	X	X		
Drinking Water	Impose Seasonal rate structures with higher rates for outdoor watering, measured by separate meters	X	X			X		
	Initiate Net Blue bylaws to achieve no net increase in water use with future development.	X	X			X		
	Hire a consultant to evaluate in greater detail Duxbury's susceptibility to salt water intrusion of its aquifer.			X				
	Re-grade land surrounding well field so that it slopes away to prevent flood water from flowing toward the wells. Ensure that the casing terminates at least twelve inches above grade. Also, extend well casings above the flood zone. Flood proof and/or elevate field pump houses critical systems that are in the 1% Annual Chance Flood.		X	X	X		? ?	
	Install protective, self-rising flood walls around well pump stations and critical systems, as interim step while planning for raising infrastructure.							
	Collaborate with the Town of Pembroke on water conservation outreach and programs.		X	X		X		



Create your own Climate Action Item	Managing Changing Temperatures	Improving Public Health	Reducing Inland flooding	Managing Coastal Flooding	Red C Em
Lawding Road and Bay Road should be areas needing action against climate change sea level rise Dennis may should adopt Flood Protection Zoning similar to Chatham's				👍	

Appendix D



Appendix E

Potential Funding Sources to Implement Climate Action Plan

Overall Best Practices Climate Action.

EEA Planning Grant. The Executive Office of Energy and Environmental Affairs provides funding to municipalities and Regional Planning Agencies to pursue Massachusetts Sustainable Development Principles that preserve natural resources, ensure sufficient and diverse housing, and prepare for climate change. Eligible requests include zoning for sustainable housing production, actions implementing the results of a climate vulnerability assessment or MVP program, or mitigation of climate change through zoning or other regulations that reduce energy use and greenhouse gas emissions. In 2017, EEA awarded $1,296,219 to 37 applicants. https://www.mass.gov/service-details/planning-assistance-grants

Municipal Vulnerability Preparedness Program. The Executive Office of Energy and Environmental Affairs provides financial assistance to municipalities to pay for technical assistance to complete assessments and planning using the Community Resilience Building workshop guide (CRB). Municipalities who complete this process and develop a final report will be designated as an MVP Community, which may lead to increased standing in future funding opportunities and signify

the commitment of this municipality to building resiliency and preparing for climate change. https://www.mass.gov/municipal-vulnerability-preparedness-program

Drinking Water Climate Action

The Clean Water State Revolving Fund program is a federal-state partnership that provides communities a permanent, independent source of low-cost financing for a variety of water quality infrastructure projects: wastewater treatment, stormwater management, nonpoint source pollution control, and watershed and estuary management, including retrofit projects and certain types of "green" projects. Most loans are for a 20-year period and some are zero interest. Loans in Massachusetts are implemented by MassDEP.
http://www.mass.gov/eea/agencies/massdep/water/grants/clean-water-state-revolving-fund.html

Massachusetts DEP Drinking Water Supply Protection Grant (DWSP). The DWSP grant program provides financial assistance to public water systems and municipal water departments for the purchase of land or interests in land for the following purposes: 1) protection of existing DEP-approved public drinking water supplies; 2) protection of planned future public drinking water supplies; or 3) groundwater recharge. The program is a reimbursement grant with a maximum award of $300,000 and 50% project cost reimbursement rate.

The National Drought Resilience Partnership (NDRP, or the Partnership) is a partnership made up of Federal departments and agencies that have roles or responsibilities in planning for and/or responding to drought. The purpose of the Partnership is to harness and coordinate distinct efforts by individual agencies already underway to assist in building resilience to drought on the ground. Two distinct roles are envisioned: one, as a policy coordinating body, and two, as an entity to align Federal agencies around their individual roles in drought planning and risk mitigation. This will help the Federal government to deliver expertise and resources to facilitate community preparedness and strengthen the Nation's resilience to drought.
https://www.drought.gov/drought/resources/national-drought-resilience-partnership

Mass DEP Water Utility Resilience Program. This new program provides technical assistance, partnership opportunities, adaptation planning, asset management, vulnerability assessments and training to enhance the resilience of water and waste water utilities from hazards weather events related to climate change. https://www.mass.gov/files/documents/2016/08/mo/circuit-rider-for-resiliency.pdf

Built Environment Climate Action

EEA Planning Grant. The Executive Office of Energy and Environmental Affairs provides funding to municipalities and Regional Planning Agencies to pursue Massachusetts Sustainable Development Principles that preserve natural resources, ensure sufficient and diverse housing, and prepare for climate change. Eligible requests include zoning for sustainable housing production, actions implementing the results of a climate vulnerability assessment or MVP program, or mitigation of climate change through zoning or other regulations that reduce energy use and greenhouse gas emissions. In 2017, EEA awarded $1,296,219 to 37 applicants. https://www.mass.gov/service-details/planning-assistance-grants

FEMA Hazard Mitigation Assistance. FEMA provides three different grant programs for mitigation planning and projects that are designed to minimize loss and protect life and infrastructure from natural hazards such as flooding and extreme heat. Grant programs include Hazard Mitigation Grant Program (long-term planning and projects after federal declared emergency), Pre-Disaster Mitigation Program (hazard mitigation planning grant) and Flood Mitigation Assistance (planning and projects to reduce or eliminate risk of flood damage insured by NFIP).

HUD Loan Guarantee Program. The US Department of Housing and Urban Development's Section 108 Loan Guarantee Program allows future Community Development Block Grant allocations to be used to guarantee loans for neighborhood revitalization projects, including construction and installation of public facilities and infrastructure. Section 108-guaranteed projects can incorporate green infrastructure into their design and construction.https://portal.hud.gov/hudportal/HUD?src=/states/massachusetts

HUD Sustainable Communities Regional Planning Grants.This HUD program supports metropolitan and multijurisdictional planning efforts to integrate housing, land use, economic and workforce development, transportation and infrastructure investments to empower communities and help them meet challenges of economic competitiveness and revitalization, social equity, inclusion and access to opportunity, energy use and climate change, and public health and environmental impact. https://portal.hud.gov/hudportal/documents/huddoc?id=greeninfrastructsci.pdf

Massachusetts Community Preservation Act. The Community Preservation Act (CPA) has been adopted by 172 cities and towns in Massachusetts representing 60 percent of the state's residents. CPA funds bring an annual match from the state CPA Trust Fund, and leverages investments from state, federal and private sources. Each year, CPA provides funding for affordable housing; historic resources, and outdoor recreation/open space, and is flexible to help fund all types of creative improvements. Funds for open space and recreation, for example, can be used to acquire and restore land and water resources and to acquire and improve parks, playgrounds, ball fields, parks, greenways, farms and gardens that use nature-based solutions to help cities and towns become more resilient to climate change impacts. http://communitypreservation.org/projectsdatabaseaccess

Massachusetts Office of Coastal Zone Management (CZM). CZM administers the Coastal Resilience Grant Program to provide financial and technical support to municipalities to reduce risks associated with coastal storms, flooding, erosion, and sea level rise. The grant is managed through CZM's StormSmart Coasts program. Eligible projects include Vulnerability and Risk Assessment; Public Education and Communication; Local Bylaws, Adaptation Plans, and other Management Measures; Redesigns and Retrofits; Natural Storm-Damage Protection Techniques. Recipients receive up to $500k and are required to provide at least 25% of the total project cost. The program is open to the 78 municipalities located within the MA coastal zone. Certified 501(c)(3) nonprofit organizations with vulnerable coastal property that is open and accessible to the public are also eligible for funding. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/grants/

Municipal Vulnerability Preparedness Program. The Executive Office of Energy and Environmental Affairs provides financial assistance to municipalities to pay for technical assistance to complete assessments and planning using the Community Resilience Building workshop guide (CRB). Municipalities who complete this process and develop a final report will be designated as an MVP Community, which may lead to increased standing in future funding opportunities and signify the commitment of this municipality to building resiliency and preparing for climate change.

Transportation Climate Action

Congestion Mitigation and Air Quality Program. The Congestion Mitigation and Air Quality program allocates federal funding for infrastructure projects that reduce congestion and improve air quality. Bicycle transportation and pedestrian walkways are eligible, and can be designed to include green infrastructure features, such as permeable surfaces for trails, and bioswales and bioretention for areas adjacent to trail surfaces.
http://www.massdot.state.ma.us/planning/Main/PlanningProcess/FundingConsiderations.aspx

Transportation Investment Generating Economic Recovery. Transportation Investment Generating Economic Recovery (TIGER) Discretionary Grant program provides funding for investments in road, rail, transit and port projects, and can include green stormwater management components. TIGER grants funding can be distributed to any public entity, including local governments.
https://www.transportation.gov/tiger

Transportation Alternatives Program. The Transportation Alternatives Program provides funding for transportation "alternatives" that improve transportation networks by efficiently and cost-effectively mitigating street and alley flooding. Projects can include green infrastructure components of trails and sidewalks for non-motorized transportation, such as permeable pavements.
http://www.massdot.state.ma.us/planning/Main/PlanningProcess/FundingConsiderations.aspx

Waste Water/Sewer Climate Action

Mass DEP Water Utility Resilience Program. This new program provides technical assistance, partnership opportunities, adaptation planning, asset management, vulnerability assessments and training to enhance the resilience of water and waste water utilities from hazards weather events related to climate change. https://www.mass.gov/files/documents/2016/08/mo/circuit-rider-for-resiliency.pdf

Municipal Vulnerability Preparedness Program. The Executive Office of Energy and Environmental Affairs provides financial assistance to municipalities to pay for technical assistance to complete assessments and planning using the Community Resilience Building workshop guide (CRB). Municipalities who complete this process and develop a final report will be designated as an MVP Community, which may lead to increased standing in future funding opportunities and signify the commitment of this municipality to building resiliency and preparing for climate change.

The Clean Water State Revolving Fund program is a federal-state partnership that provides communities a permanent, independent source of low-cost financing for a variety of water quality infrastructure projects: wastewater treatment, stormwater management, nonpoint source pollution control, and watershed and estuary management, including retrofit projects and certain types of "green" projects. Most loans are for a 20-year period and some are zero interest. Loans in Massachusetts are implemented by MassDEP.
http://www.mass.gov/eea/agencies/massdep/water/grants/clean-water-state-revolving-fund.html

EPA Water Infrastructure and Resiliency Finance Center. This program administered by the EPA provides technical assistance, toolkits, and resources to help decision makers building wastewater infrastructure projects that protect human and environmental health.
https://ofmpub.epa.gov/apex/wfc/f?p=165:1

People Climate Action

EPA Smart Growth and Technical Assistance Program. The EPA administers a variety of technical assistance and planning grant programs to help communities improve the quality of the built environment, protect public health, and protect the environment. https://www.epa.gov/smartgrowth/smart-growth-technical-assistance-programs

Municipal Vulnerability Preparedness (MVP) Program. The Executive Office of Energy and Environmental Affairs provides financial assistance to municipalities to pay for technical assistance to complete assessments and planning using the Community Resilience Building workshop guide (CRB). Municipalities who complete this process and develop a final report will be designated as an MVP Community, which may lead to increased standing in future funding opportunities and signify the commitment of this municipality to building resiliency and preparing for climate change.

EEA Planning Grant. The Executive Office of Energy and Environmental Affairs provides funding to municipalities and Regional Planning Agencies to pursue Massachusetts Sustainable Development Principles that preserve natural resources, ensure sufficient and diverse housing, and prepare for climate change. Eligible requests include zoning for sustainable housing production, actions implementing the results of a climate vulnerability assessment or MVP program, or mitigation of climate change through zoning or other regulations that reduce energy use and greenhouse gas emissions. In 2017, EEA awarded $1,296,219 to 37 applicants.

George Climate Center Federal Funding Compendium for Urban Heat Adaptation. This compendium provides a comprehensive analysis on diverse federal programs that can be applied to mitigate extreme heat. http://www.georgetownclimate.org/files/report/Federal%20Funding%20Compendium%20for%20Urban%20Heat%20Adaptation.pdf

Energy Climate Action

Weatherization and Intergovernmental Program-The US Department of Energy's Weatherization and Intergovernmental Program provides grants, technical assistance, and information tools to states, local governments and community action agencies for their energy programs. The funding can be used to encourage installation of green infrastructure, such as green roofs, as part of the weatherization process. https://energy.gov/eere/wipo/weatherization-and-intergovernmental-programs-office

Massachusetts Clean Energy Center's (MassCEC) Community Microgrids Program. This program helps municipalities harness the innovative microgrid technology that lowers customer energy costs, reduces greenhouse gas (GHG) emissions, and provides increased energy resilience. In February, In February 2018, MassCEC awarded over $1 million to 14 different projects across Massachusetts. http://www.masscec.com/community-microgrids-program

MA Clean Energy Center (CEC) Government and Non-Profit Clean Energy Programs. MassCEC manages the Massachusetts Renewable Energy Trust Fund for the state and has diverse programs that promote clean energy, energy efficiency, and wastewater treatment plant innovation. Grant programs include solar energy, clean heating and cooling, hydro projects, organics to energy projects and many more. http://www.masscec.com/get-clean-energy/government-and-non-profit

Natural Resources Climate Action

Coastal

The National Coastal Wetlands Conservation Grant Program. This program annually provides grants of up to $1 million to coastal and Great Lakes states, as well as U.S. territories to protect, restore and enhance coastal wetland ecosystems and associated uplands. The grants are funded through the Sport Fish Restoration and Boating Trust Fund, which is supported by excise taxes on fishing equipment and motorboat fuel. Typically states, local governments, private landowners, and conservation groups will provide additional funds for projects. All states with a coastline are eligible. https://www.fws.gov/coastal/CoastalGrants/

National Oceanic and Atmospheric Administration (NOAA). The NOAA Coastal Resilience Program is a federal funding offers two categories of funding activities: 1) Strengthening Coastal Communities and 2) Habitat Restoration. The Strengthening Coastal Communities provides funding for activities that improve capacity of multiple coastal jurisdictions (states, counties, municipalities, territories and tribes) to prepare and plan for, absorb impacts of, recover from, and/or adapt to extreme weather events and climate-related hazards. The Habitat Restoration grant provides funding for activities that restore habitat to strengthen the resilience of coastal ecosystems and decrease the vulnerability of coastal communities to extreme weather events and climate-related hazards. Typical awards range from $250,000 to $1million for projects lasting up to 35 months. The minimum request is $100,000 and the maximum request is $2million. Non-profits, private, institutions of higher education, regional organizations, and municipalities are eligible. https://coast.noaa.gov/funding/_pdf/NOAA-NOS-NRPO-2017-2005159-FFO.pdf

Massachusetts Office of Coastal Zone Management (CZM). CZM administers the Coastal Resilience Grant Program to provide financial and technical support for local efforts to increase awareness and understanding of climate impacts, identify vulnerabilities, conduct adaptation planning, redesign vulnerable public facilities and infrastructure, and implement non-structural approaches that enhance natural resources and provide storm damage protection. The grant is managed through CZM's StormSmart Coasts program. Eligible projects Vulnerability and Risk Assessment; Public Education and Communication; Local Bylaws, Adaptation Plans, and Other Management Measures; Redesigns and Retrofits; Natural Storm-Damage Protection Techniques. Recipients receive up to $500k and are required to provide at least 25% of the total project cost. The 25% local match could be cash or in-kind contributions or a combination of the two. The Coastal Resilience Grant Program is open to the 78 municipalities located within the MA coastal zone. Certified 501(c)(3) nonprofit organizations with vulnerable coastal property that is open and accessible to the public are also eligible for funding for natural storm-damage protection (or green infrastructure) projects. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/grants/

Stormwater/Water Quality Funding

Stormwater Utility/Enterprise Fund. Several cities and towns in Massachusetts and hundreds of communities across the country have adopted a stormwater utility to help fund the costs of stormwater programs, including the costs of capital improvements and repair or replacement of green infrastructure. Such fees create a dedicated and stable funding source to address

stormwater impacts. To help understand if a stormwater utility is practical to implement, MAPC and its partners developed a Stormwater Utility/Funding starter kit to help municipalities evaluate and pursue a stormwater utility for local water quality. https://www.mapc.org/resource-library/stormwater-bylaws-toolkit/

Clean Water Act Nonpoint Source Grants. Under Section 319 of the federal Clean Water Act, the US EPA provides states with funds to support a variety of activities to reduce nonpoint source pollution, including technical and financial assistance, education and training, technology transfer, demonstration projects and monitoring to assess the success of projects. EPA has stated specifically that such grants can be used to reduce pollution from stormwater runoff and other sources, recognizing the importance of green infrastructure in managing stormwater. Grant awards very widely in among and scope; a 40 percent non-federal funding match is required. Note 319 grants may not be used for stormwater activities that directly implement municipal separate storm sewer system (MS4) National Pollutant Discharge Elimination System (NPDES) permits.http://www.mass.gov/eea/agencies/massdep/water/grants/watersheds-water-quality.html#2

Massachusetts Environmental Trust (MET) Grant. The MET grant provides funding to support programs, research, and other activities that promote the responsible stewardship of the Commonwealth's water resources. MET's goal is to encourage development of new approaches and ideas and to spur innovation among grantees or partnering organizations. To achieve these outcomes, the Trust supports projects that: improve water quality or quantity, conserve aquatic habitat and species, reduce runoff pollution, mitigate the effects of climate change on water resources, promote human health as it relates to water resources, and/or other efforts consistent with the Trust's mission. There are three types of grants, one with a specific focus on the Mystic River. Awards range from $5,000 to $100,000. http://www.mass.gov/eea/grants-and-tech-assistance/grants-and-loans/mass-enviro-trust/met-grants.html

Division of Ecological Restoration (DER). DER initiates projects that restore our rivers, streams, wetlands, and watersheds. DER partners with nonprofits, towns, individuals, and groups to implement projects. These projects improve habitat for wildlife and provide many benefits such as reduced flooding, improved water quality, and public safety. Programs include culvert and dam removal as well as coastal wetland, inland wetland, and river restoration. DER provides technical assistance, helps secure funding, and coordinates project management until completion. https://www.mass.gov/orgs/division-of-ecological-restoration

Rivers, Trails, and Conservation Assistance Program. The National Park Service Rivers, Trails and Conservation Assistance Program (RTCA) assists community-led natural resource conservation and outdoor recreation initiatives. RTCA staff provides guidance to communities on: conserving waterways, preserving open space, and developing trails and greenways. https://www.nps.gov/orgs/rtca/apply.htm

Natural Resources-Land and Forest

National Urban and Community Forestry Program. Under the US Forest Service, this program's objectives are to establish sustainable community forests that improve the public's health, well-

being, and economic vitality, and create resilient ecosystems for present and future generations. When funds are available, cost-share grants support urban projects that have national and multistate application and impact. https://www.fs.fed.us/managing-land/urban-forests/ucf

Massachusetts Urban and Community Forestry. The Massachusetts Urban and Community Forestry Program assists communities and nonprofit groups in protecting, growing, and managing community trees and forest ecosystems, to improve the environment and enhance livability. The program includes grants, technical assistance, training and recognition awards, and provides guidance on urban forestry policy issues. http://www.mass.gov/eea/agencies/dcr/conservation/forestry-and-fire-control/urban-and-community-forestry.html

Parkland Acquisitions and Renovations for Communities (PARC). PARC assists cities and towns in acquiring and developing land for park and outdoor recreation purposes. Any city that has an authorized park or recreation commission is eligible to participate and use grant funds to acquire land, develop new parks or renovate existing outdoor public recreation facilities (which may include green infrastructure). Access by the general public is required. Municipalities must have a current open space and recreation plan to apply, and the land must be open to the general public. Awards range from $50,000 to $500,000. http://www.mass.gov/eea/grants-and-tech-assistance/grants-and-loans/dcs/grant-programs/massachusetts-parkland-acquisitions-and.html

Conservation Partnership. The Conservation Partnership Program within the Executive Office of Energy and Environmental Affairs (EEA) provides funding to nonprofit organizations to acquire land and interests in land (i.e., easements known as Conservation Restrictions) for conservation or recreation purposes, as part of a nature-based solution. The average grant size is $52,000. The maximum grant is $85,000. A 1:1 match is required. http://www.mass.gov/eea/grants-and-tech-assistance/grants-and-loans/dcs/grant-programs/conservation-partnership-grant.html

Local Acquisitions for Natural Diversity (LAND). LAND is a state grant program implemented by EEA provides grants for the acquisition of land for passive parks or conservation areas in cities and towns – which can include green infrastructure. Grants are up to $400,000 with reimbursement rates ranging from 52%-70% of the total project cost. Municipalities must have a current open space and recreation plan to apply, and the land must be open to the public. https://www.mass.gov/files/2017-06/LAND%20fy-18%20grant%20summary_1.pdf

Massachusetts Community Preservation Act. The Community Preservation Act (CPA) has been adopted by 172 cities and towns in Massachusetts representing 60 percent of the state's residents. CPA funds bring an annual match from the state CPA Trust Fund, and leverages investments from state, federal and private sources. Each year, CPA provides funding for affordable housing; historic resources, and outdoor recreation/open space, and is flexible to help fund all types of creative improvements. Funds for open space and recreation, for example, can be used to acquire and restore land and water resources, and to acquire and improve parks, playgrounds, ball fields, parks, greenways, farms and gardens that use nature-based solutions to help cities and towns become more resilient to climate change impacts. http://www.communitypreservation.org/