

Massachusetts State Hazard Mitigation and Climate Adaptation Plan



September 2018

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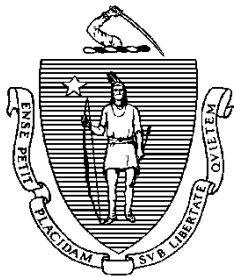
Appendices

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Annexes

Annex 1: Massachusetts Hazard Mitigation Grant Program Administrative Plan
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OFFICE OF THE GOVERNOR
COMMONWEALTH OF MASSACHUSETTS

STATE HOUSE • BOSTON, MA 02133

(617) 725-4000

CHARLES D. BAKER
GOVERNOR

KARYN E. POLITO
LIEUTENANT GOVERNOR

September 17, 2018

I am pleased to present and formally adopt the 2018 Massachusetts State Hazard Mitigation and Climate Adaptation Plan. This plan is for the entire Commonwealth and was driven by Executive Order No. 569, which calls for the establishment of an "Integrated Climate Change Strategy for the Commonwealth" and development of a statewide climate adaptation plan. It also complies with current federal requirements for state hazard mitigation plans and maintains the Commonwealth's eligibility for federal disaster recovery and hazard mitigation funding under the Stafford Act.

The Commonwealth is exposed to numerous natural hazards, and these hazards are being exacerbated by rising temperatures, changes in precipitation, extreme weather, and sea level rise. This plan provides a framework that links pre- and post-disaster mitigation with long-term climate adaptation, resiliency planning, and implementation. It includes an assessment of the Commonwealth's natural hazard and climate change vulnerabilities, an analysis of our existing capabilities and adaptive capacity, and an actionable strategy for risk reduction. It also serves as a first-of-its-kind fully integrated statewide hazard mitigation and climate adaptation plan and builds upon Massachusetts' commitment to clean energy and climate resiliency demonstrated most recently through the selection of the largest offshore wind project in our nation's history as well as over \$2.4 billion in climate change and environmental investments.

This plan is a living document that will reside on the Massachusetts Climate Change Clearinghouse (resilientma.org). The Commonwealth's Executive Offices and state agencies will begin immediately to advance and track their assigned actions. The plan is also intended to be dynamic—changing and improving as needed through routine maintenance procedures that help to ensure the plan is reviewed, updated, and enhanced as conditions change and we learn from experience. The plan will be improved and updated to reflect the most up-to-date climate change science and natural hazard data, and new actions will be identified and incorporated into the plan as part of the plan maintenance process.

This initial plan is a product of a robust outreach and engagement process, and we heard from hundreds of diverse stakeholders from across the Commonwealth over the course of its development. The thoughtful input and ideas we received helped shape the plan and were critical to the project's success. Thank you to those who were involved for your contributions, and I look forward to your continued involvement in future versions of this plan as we all work together toward a more resilient Massachusetts.

Sincerely,

A handwritten signature in blue ink that reads "Charles Baker".

Charles D. Baker
Governor

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Acknowledgments

The 2018 Massachusetts State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) was developed through an intensive and collaborative planning process that involved numerous state agencies, a large cross-section of stakeholders, members of the public, working groups, and a consulting team. Special thanks go to the following individuals and teams who contributed to the plan.

State Leadership

Governor

Charlie Baker

Lt. Governor

Karyn Polito

Executive Office of Energy and Environmental Affairs

Secretary Matthew Beaton

Executive Office of Public Safety and Security

Secretary Daniel Bennett

SHMCAP Project Management Team

Jeremy Caron Division of Capital Asset Management and Maintenance	Sally Miller Division of Capital Asset Management and Maintenance
Brian Domoretsky Executive Office of Public Safety and Security	Steve Miller Massachusetts Department of Transportation
Beth Dubrawski Massachusetts Emergency Management Agency	Shelly O'Toole Massachusetts Emergency Management Agency
Joy Duperault Department of Conservation and Recreation (Flood Hazard Management)	Kristen Patneaude Department of Energy Resources
Kurt Gaertner Executive Office of Energy and Environmental Affairs	Marybeth Riley-Gilbert Massachusetts Bay Transportation Authority
Marybeth Groff Massachusetts Emergency Management Agency	Margaret Round Department of Public Health
Julia Knisel Office of Coastal Zone Management	Shannon Sullivan Executive Office of Public Safety and Security
Will Lauwers Department of Energy Resources	Katie Theoharides (Co-Chair) Executive Office of Energy and Environmental Affairs
Thad Leugemors Massachusetts Emergency Management Agency	Sarah White (Co-Chair) Massachusetts Emergency Management Agency
Margot Mansfield Office of Coastal Zone Management	

Secretariat Climate Change Coordinators

Jennifer Sullivan Executive Office of Administration and Finance	William McKinney Executive Office of Labor and Workforce Development
B. Kim Executive Office of Education	Brian Domoretsky and Shannon Sullivan Executive Office of Public Safety and Security
Katie Theoharides Executive Office of Energy and Environmental Affairs	Katherine Fichter Massachusetts Department of Transportation
Michael Kelleher and Robert Jones Executive Office of Health and Human Services	Laurie Pessah Executive Office of Technology Services and Security
Genevieve McLaughlin Executive Office of Housing and Economic Development	

Draft Plan Reviewers and Stakeholder Workshop Facilitators

Kathy Baskin
Weston & Sampson

John Bolduc
City of Cambridge

Kirk Bosma
Woods Hole Group

Jonathan Brooks
Massachusetts Division of Fisheries and Wildlife

Sara Burns
The Nature Conservancy

Bill Clement
University of Massachusetts

Stephanie Covino
Mass Audubon

Melissa Cryan
Executive Office of Energy and Environmental Affairs

Hunt Durey
Massachusetts Division of Ecological Restoration

John Ebel
Boston College

Ed Fratto
Northeast States Emergency Consortium

Cynthia Greene
U.S. Environmental Protection Agency

Rebecca Haney
Office of Coastal Zone Management

Anne Herbst
Metropolitan Area Planning Council

Scott Jackson
University of Massachusetts, Amherst

Cristina Kennedy
Office of Coastal Zone Management

Beth Lambert
Massachusetts Division of Ecological Restoration

Rich LaTour
Massachusetts Emergency Management Agency

Steven Long
The Nature Conservancy

Steve Mabee
University of Massachusetts

Mia Mansfield
City of Boston

Deanna Moran
Conservation Law Foundation

Paul Morey
Federal Emergency Management Agency

Melissa Ocana
University of Massachusetts, Amherst

Adrienne Pappal
Office of Coastal Zone Management

Gabby Queenan
Massachusetts Rivers Alliance

Rebecca Quinones
Massachusetts Division of Fisheries and Wildlife

Vandana Rao
Executive Office of Energy and Environmental Affairs

Julie Richburg
The Trustees of Reservations

Tracy Rogers
Franklin County Regional Council of Governments

Mehrdad Sasani
Northeastern University

Axum Teferra
Metropolitan Area Planning Council

Julie Wood
Charles River Watershed Association

Dave Woodbury
Massachusetts Emergency Management Agency

Viki Zoltay
Massachusetts Department of Conservation and Recreation

AECOM Consulting Team

AECOM
Durand & Anastas
Ellen Douglas

Kleinfelder
Jamie Caplan Consulting
Punchard Consulting

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Acronyms and Abbreviations

§	Section	DART	Deep-ocean Assessment and Reporting of Tsunami
°F	Degrees Fahrenheit	DCAMM	Division of Capital Asset Management and Maintenance
A&F	Executive Office of Administration and Finance	DCR	Department of Conservation and Recreation
ACEC	Areas of Critical Environmental Concern	DEP	Department of Environmental Protection
ASCE	American Society of Civil Engineers	DER	Division of Ecological Restoration
BBRS	Board of Building Regulations and Standards	DFIRMS	Digital Flood Insurance Rate Maps
BFE	Base Flood Elevation	DHCD	Department of Housing and
BIA	U.S. Bureau of Indian Affairs	DLS	Department of Labor Standards
BMPs	Best Management Practices	DMA 2000	Disaster Mitigation Act of 2000
CDBG	Community Development Block Grant	DMA	Disaster Mitigation Act
CDBG-DR	Community Development Block Grant Disaster Recovery	DMP	Drought Management Plan
CDC	Centers for Disease Control and Prevention	DMTF	Drought Management Task Force
CEC	Coastal Erosion Commission	DOER	Department of Energy Resources
CEMP	Comprehensive Emergency Management Plan	DPA	Designated Port Areas
CERT	Community Emergency Response Teams	DPH	Department of Public Health
CFR	U.S. Code of Federal Regulations	DPU	Department of Public Utilities
CIP	Capital Improvement Program	EAP	Emergency Action Plan
CMR	Code of Massachusetts Regulations	EECC	Early Environmental Coordination Checklist
CO ₂	Carbon Dioxide	EJ	Environmental Justice
COSTEP MA	Coordinated Statewide Emergency Preparedness in Massachusetts	EMAP	Emergency Management Accreditation Program
CPG	Comprehensive Preparedness Guide	EMPG	Emergency Management Performance Grant
CRB	Community Resilience Building	EOEEA	Executive Office of Energy and Environmental Affairs
CRS	Community Rating System	EOPSS	Executive Office of Public Safety and Security
CY	Calendar Year	EOTSS	Executive Office of Technology Services and Security
CZM	Office of Coastal Zone Management	EPA	U.S. Environmental Protection Agency
DAR	Department of Agricultural Resources	FBFM	Flood Boundary and Floodway Maps

Acronyms and Abbreviations

FEMA	Federal Emergency Management Agency	MAESF	Massachusetts Emergency Support Function
FHMP	Flood Hazard Management Program	MAGIC	Minuteman Advisory Group on Interlocal Coordination
FHWA	Federal Highway Administration	MAPC	Metropolitan Area Planning Council
FIRM	Flood Insurance Rate Map	MassDEP	Department of Environmental
FIRMs	Flood Insurance Rate Maps	MassDOT	Massachusetts Department of Transportation
FIS	Flood Insurance Studies	MassWildlife	Division of Fisheries and Wildlife
FMA	Flood Mitigation Assistance	MBTA	Massachusetts Bay Transportation Authority
FMAG	Fire Mitigation Assistance Grants	MEMA	Massachusetts Emergency Management Agency
FOA	First Order Approximation	MGL	Massachusetts General Laws
FRCOG	Franklin Regional Council of Governments	MHHW	Mean Higher High Water
FY	Fiscal Year	MIPAG	Massachusetts Invasive Plant Advisory Group
GCRP	Global Change Research Program	MLLW	Mean Lower Low Water
GHG	Greenhouse Gas	MM/YR	Millimeters per Year
GIS	Geographic Information System	MORIS	Massachusetts Ocean Resource Information System
GWSA	Global Warming Solutions Act of 2008	MOTT	Massachusetts Office of Travel and Tourism
HIRA	Hazard Identification and Risk Assessment	MPH	Miles per Hour
HMA	Hazard Mitigation Assistance	MPRO	Massachusetts Permit Regulatory Office
HMGP	Hazard Mitigation Grant Program	MSBC	Massachusetts State Building Code
HRD	Human Resources Division	MVP	Municipal Vulnerability Preparedness
IBHS	Institute for Business and Home Safety	MWRA	Massachusetts Water Resources Authority
ICC	International Code Council	NAVD88	North American Vertical Datum of 1988
I-Codes	International Codes	NBI	National Bridge Inventory
IHP	Individuals and Households Program	NBS	Nature-Based Solutions
IRC	International Residential Code	NCDC	National Climate Data Center
ISO	Insurance Services Office	NCEI	National Centers for Environmental Information
LAMP	Levee Analysis and Mapping Procedures	NE CASC	Northeast Climate Adaptation Science Center
LHAs	Local Housing Authorities		
LiDAR	Light Detection and Ranging		
LiMWA	Limit of Moderate Wave Action		
LSCSF	Land Subject to Coastal Storm Flowage		

NEHRP	National Earthquake Hazards Reduction Program	SHMCAP	State Hazard Mitigation and Climate Adaptation Plan
NERC	North American Electric Reliability Corporation	SHMP	State Hazard Mitigation Plan
NESEC	Northeast States Emergency Consortium	SHMT	State Hazard Mitigation Team
NESIS	Northeast Snowfall Impact Scale	SLOSH	Sea, Lake, and Overland Surges from Hurricanes
NFIP	National Flood Insurance Program	SMART	Solar Massachusetts Renewable Target
NGDC	National Geophysical Data Center	SPI	Standardized Precipitation Index
NGO	Nongovernmental Organization	SRL	Severe Repetitive Loss
NOAA	National Oceanic and Atmospheric Administration	SRMP	Statewide Resilience Master Plan
NRCS	Natural Resources Conservation Service	Stafford Act	Robert T. Stafford Disaster Relief and Emergency Assistance Act
NWS	National Weather Service	STIP	State Transportation Improvement Plan
OPSI	Office of Public Safety and Inspection	TDI	Transformative Development Initiative
PA	Public Assistance	THIRA	Threat and Hazard Identification and Risk Assessment
PDM	Pre-Disaster Mitigation	U.S. EPA	U.S. Environmental Protection Agency
Percent G	Percent of Acceleration Force of Gravity	U.S.	United States
PGA	Peak Ground Acceleration	USACE	U.S. Army Corps of Engineers
PMT	Project Management Team	USGS	U.S. Geological Survey
PV	Photovoltaic	V Zone	Velocity Flood Zone
PVPC	Pioneer Valley Planning Commission	WPA	Wetlands Protection Act
PWS	Public Water Suppliers	WURP	Water Utility Resilience Program
RCP	Representative Concentration Pathways		
RGGI	Regional Greenhouse Gas Initiative		
Risk MAP	Risk Mapping, Assessment, and Planning		
RL	Repetitive Loss		
RMAAT	Resilient MA Action Team		
RPA	Regional Planning Agencies		
RSI	Regional Snowfall Index		
RTA(s)	Regional Transit Authority (Authorities)		
S waves	Shear Waves		
SFHA	Special Flood Hazard Area		

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Massachusetts State Hazard Mitigation and Climate Adaptation Plan

September 2018



EXECUTIVE SUMMARY



The Commonwealth's 2018 State Hazard Mitigation and Climate Adaptation Plan is an innovative, first-of-its-kind statewide plan that fully integrates a traditional hazard mitigation plan with a climate change adaptation plan.

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First-of-its-Kind Integrated State Plan

In the face of climate change, it is critical to build long-term resilience throughout Massachusetts by leveraging historical risk data and integrating that data with projected future climate conditions. The *2018 State Hazard Mitigation and Climate Adaptation Plan* (SHMCAP) expands upon the previous planning efforts of the Commonwealth's 2013 State Hazard Mitigation Plan and the 2011 Massachusetts Climate Change Adaptation

Report. It accounts for projected changes in precipitation, temperature, sea level rise, and extreme weather events to position the Commonwealth to effectively reduce the risks associated with natural hazards and the effects of climate change.

The SHMCAP fulfills two important requirements: It updates the 2013 Massachusetts State Hazard Mitigation Plan and fulfills the requirements for the Executive Order 569 climate adaptation plan.



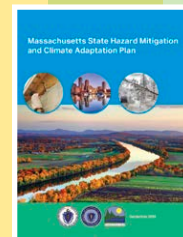
Eligibility for Federal Disaster Mitigation Funding

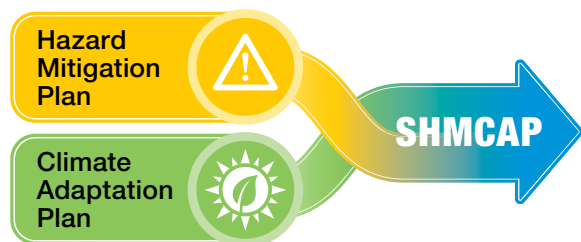
As a condition of receiving non-emergency Stafford Act assistance and Federal Emergency Management Agency (FEMA) disaster mitigation grants, states are required to have an approved State Mitigation Plan following the criteria established in 44 CFR §201.4, including requirements to address the projected effects of climate change on hazard risks.



Compliance with Governor Baker's Executive Order 569

Executive Order 569 directs the Executive Office of Energy and Environmental Affairs (EOEEA) and the Executive Office of Public Safety and Security (EOPSS) to coordinate efforts across the Commonwealth to strengthen the resilience of communities, prepare for the impacts of climate change, and proactively plan for and mitigate damage from extreme weather events, including publishing a climate adaptation plan that outlines a statewide strategy to address these impacts through adaptation and resiliency measures and policies.





This innovative plan encompasses the results of a multi-step planning process with a robust outreach and engagement program to incorporate diverse stakeholders across the Commonwealth in all phases of plan development, including identification of risks and vulnerabilities as well as goal setting and action development. The planning process was managed through a close partnership among the Executive Office of Energy and Environmental Affairs (EOEEA), the Executive Office of Public Safety and Security (EOPSS), and the Massachusetts Emergency Management Agency (MEMA), and involved a Project Management Team composed of technical specialists from several key state agencies.

GLOSSARY

Hazard mitigation

The effort to reduce loss of life and property by lessening the impact of disasters.

Climate change

A change in the state of the climate that can be identified by statistical changes of its properties that persist for an extended period.

Climate adaptation

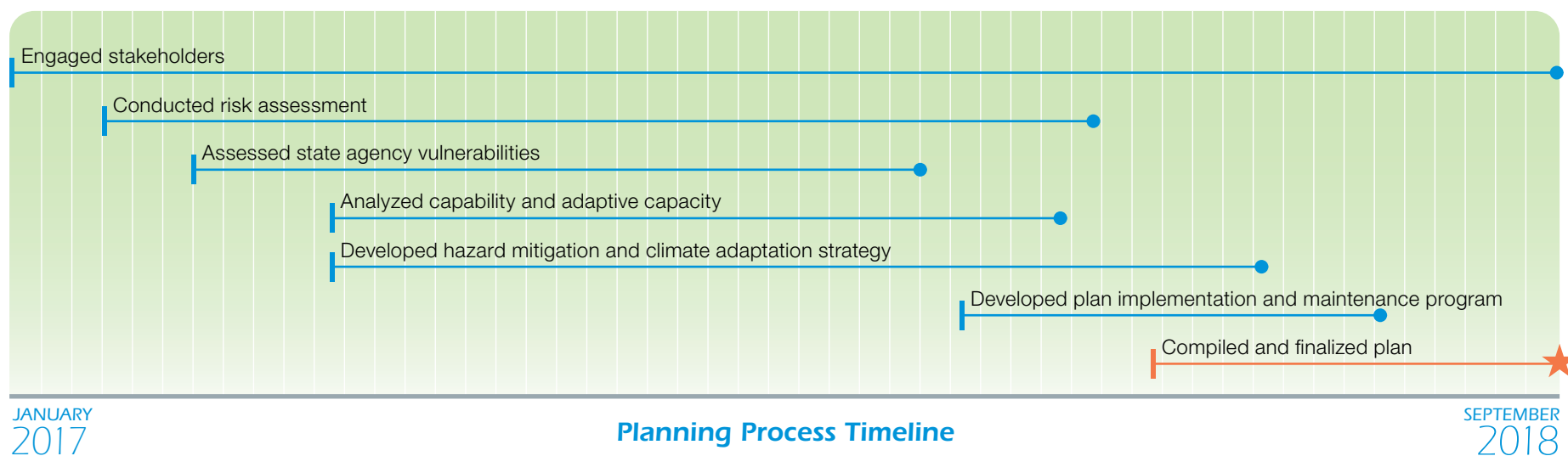
Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Resilience

The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner.

Natural hazards

Natural events that threaten lives, property, and other assets. Often, natural hazards can be predicted. They tend to occur repeatedly in the same geographical locations because they are related to weather patterns or physical characteristics of an area.





Climate change is already exacerbating natural hazards and extreme weather events, as well as leading to new impacts that will affect the Commonwealth.

Climate Change is Intensifying Natural Hazards

The SHMCAP integrates information and planning elements for 14 natural hazards that could affect the Commonwealth of Massachusetts with the following four climate changes: changes in precipitation, sea level rise, rising temperatures, and extreme weather. Projected climate changes will alter these natural hazards, in most cases increasing their severity, duration, or frequency.

The table on the following page shows the relationships between the natural hazards and projected climate changes. Natural hazards can be affected by more than one climate change, but a primary climate change has been identified for each hazard for the purpose of this plan.

How Precipitation Increases Affect Inland Flooding

Example of Climate Change / Natural Hazard Interaction





The Fourth National Climate Assessment published by the U.S. Global Change Research Program shows that heavy precipitation events have increased in both intensity and frequency over the past century across much of the country, with the largest increases occurring in the Northeast. Annual precipitation in Massachusetts is projected to increase by as much as 7.3 inches by the end of this century.

Because this additional precipitation will likely take the form of more intense periods of precipitation coupled with more frequent episodic drought, it is likely to result in more stormwater runoff and higher surface water levels. As storms occur more often and produce more precipitation, areas that lie in FEMA-designated floodplains (which are mapped using historical records) will flood more frequently, and land that is not typically affected by flooding may become inundated.

Also, projected increases in extreme precipitation events will increase the risk of flash flooding and damage to drainage systems not designed to accommodate the higher flows.

Storm-watching, Cape Cod

Climate Change Projections for Massachusetts

CLIMATE CHANGES	RELATED NATURAL HAZARDS	PROJECTIONS BY THE END OF THIS CENTURY
Changes in precipitation 	<ul style="list-style-type: none"> – Inland flooding – Drought – Landslide 	<ul style="list-style-type: none"> – Annual precipitation: Increase up to 16% (+7.3 inches) – Days with rainfall accumulation 1+ inch: Increase up to 57% (+4 days) – Consecutive dry days: Increase 18% (+3 days) – Summer precipitation: Decrease
Sea level rise 	<ul style="list-style-type: none"> – Coastal flooding – Coastal erosion – Tsunami 	<ul style="list-style-type: none"> – Sea level: Increase 4.0 to 10.5 feet along the Massachusetts coast
Rising temperatures 	<ul style="list-style-type: none"> – Average/extreme temperatures – Wildfires – Invasive species 	<ul style="list-style-type: none"> – Average annual temperature: Increase up to 23% (+10.8 degrees Fahrenheit) – Days/year with daily minimum temperatures below freezing: Decrease up to 42% (-62 days) – Winter temperatures: Increase at a greater rate than spring, summer, or fall – Long-term average minimum winter temperature: Increase up to 66% (+11.4 degrees Fahrenheit) – Days/year with daily maximum temperatures over 90 degrees Fahrenheit: Increase by up to 1,280% (+64 days) – Growing degree days: Increase by 23% to 52%
Extreme weather 	<ul style="list-style-type: none"> – Hurricanes/tropical storms – Severe winter storms/nor'easters – Tornadoes – Other severe weather 	<ul style="list-style-type: none"> – Frequency and magnitude: Increase

Note: This plan also assesses earthquakes, but there is no established correlation between climate change and earthquakes.

Source of Climate Change Projections: Northeast Climate Adaptation Science Center at the University of Massachusetts, Amherst.



Climate change and the anticipated exacerbation of natural hazards will affect residents, government, local communities, infrastructure, natural resources, and the private sector. The degree of exposure and consequences of these changes will vary across the Commonwealth.

Risks and Vulnerabilities the Commonwealth Faces

A risk assessment is used to identify potential hazards and analyze the consequences if a hazard occurs. The risk assessment conducted for this plan covers five key sectors—populations, government, built environment, natural resources and environment, and economy—and incorporates the best scientific data available to more accurately and comprehensively assess risks and vulnerabilities associated with natural hazards in a changing climate.



Foggy morning, New Bedford

The risk assessment includes information from almost 80 state agency climate change vulnerability assessments undertaken during development of this plan as a key requirement of Executive Order 569. Vulnerability to climate change is a function of exposure, sensitivity, and adaptive capacity.

Key Vulnerability Assessment Findings for State Agencies

- Vulnerability assessment completed by approximately 80 state agencies
- Nearly 1,000 critical items were assessed:
386 physical/non-physical assets | 340 functions | 231 population groups
- Vast majority of agencies identified multiple concerns regarding impacts from climate change and natural hazards
- Top five hazards based on number of assets with a “High Risk” rating:
Extreme Precipitation | Hurricanes/Tropical Storms | Nor’easter | Ice Storms | Severe Winter Storm
- Ability to withstand natural hazards and climate impacts:
Excellent: 6% | Good: 38% | Satisfactory: 42% | Fair: 14% | Poor: 0%
- Length for agency to return to essential functionality following an extreme weather event that results in significant damage to critical assets and/or functions:
Months: 7% | Weeks: 32% | Days: 43% | Hours: 19%
- Remote operation capability:
Yes: 82% | No: 18%
- Status of incorporating natural hazard mitigation and climate change adaptation into programs:
Currently incorporating: 28% | Planning to incorporate: 32% | Not incorporating: 29% | Don’t know: 10%
- Plans, policies, or procedures in need of revision to better consider climate change:
Yes: 24% | No: 37% | Don’t know: 39%
- Application of factors derived from state agency adaptive capacity responses to risk scores significantly reduced the number of “High Risk” critical items – overall 80% reduction
- Top hazards with “High Vulnerability” scores based on number of critical items:
Physical/Non-Physical Assets: Severe Winter Storm/Ice Storm | Functions: Coastal Flooding | Population Groups: Coastal Flooding

Assessing Climate Change Vulnerability



Key Risk Assessment Findings by Hazard Type



Inland flooding

- Areas that are highly developed or within the floodplain are most vulnerable
- Caused an average of over \$9.1 million in damages/year between 2007 and 2014
- Essex County experienced the most FEMA flood disaster declarations from 1954–2017
- More intense and frequent downpours will result in more frequent flooding and greater area exposed



Drought

- Entire commonwealth is vulnerable and impacts on all sectors are widespread
- Chance of a Watch level drought occurring in any given month: 8%
- Frequency and intensity projected to increase during the summer and fall



Landslide

- Areas with unstable slopes, such as around Mount Greylock and the US Highway 20 corridor near Chester, are most vulnerable
- Secondary impacts such as road closures can have a significant impact on communities
- More frequent and intense storms will result in more frequent soil saturation conditions that are conducive to landslides



Coastal Flooding

- An average of six events/year have occurred in the last decade
- Highest concentration of events has occurred in Eastern Plymouth County
- Sea level rise will increase the frequency and severity of both routine tidal flooding and storm-related coastal flooding



Coastal Erosion

- Exacerbated by storm surge and development
- Highest erosion rates occur in Eastham, Orleans, and Yarmouth
- Rising waves, tides, and currents will contribute to increased levels of future coastal erosion



Tsunami

- Likelihood of occurring is low (one every 39 years on the east coast), but impact could be extensive
- Sea level rise may increase the area potentially impacted



Average and Extreme Temperatures

- An average of two extreme heat and 1.5 extreme cold weather events/year have occurred over the last two decades
- Young and elderly populations and people with preexisting health conditions are especially vulnerable to heat and cold
- By the end of the century there could be 13–56 extreme heat days during summer



Wildfire

- Massachusetts is likely to experience at least one event/year with noteworthy damages
- Barnstable and Plymouth Counties are most vulnerable due to their vegetation, sandy soils, and wind conditions
- There are over 1,200 state-owned buildings in identified wildfire hazard areas
- Projected increase in seasonal drought and warmer temperatures will increase the risk for wildfire



Invasive species

- Risk to native or minimally managed ecosystems has increased as dispersion of exotic species has increased
- Changes in temperature and precipitation may increase chances of a successful invasion of non-native species



Hurricanes/Tropical Storms

- Average occurrence of one event every two years
- Coastal areas are more susceptible to damage due to high winds and tidal surge, but all locations are vulnerable
- Vulnerable populations include those who may have difficulty evacuating
- Warmer oceans will likely result in increased intensity of storms



Severe Winter Storm/Nor'easter

- Currently the most frequently occurring natural hazard in the state
- High snowfall and ice storms are greater in high elevations of Western and Central Massachusetts, while coastal areas are more vulnerable to nor'easters
- Over 1,000 state-owned facilities are in coastal locations that are vulnerable to nor'easters
- Increases in the intensity and frequency of extreme weather events as the climate changes may include more nor'easters and higher precipitation amounts during winter storms



Tornadoes

- Massachusetts experiences an average of 1.7 tornadoes/year
- The most tornado-prone areas of the state are the central counties
- Over 200 critical facilities and 1,500 government facilities are in identified tornado hazard zones
- Increase in frequency and intensity of severe thunderstorms may increase risk of tornadoes



Other Severe Weather

- The coastal zone is most frequently impacted by high-wind events
- Massachusetts experiences 20–30 thunderstorm days/year, high winds occur more frequently
- Road closures and power outages are common impacts
- Expected increase in the intensity and frequency of severe weather events

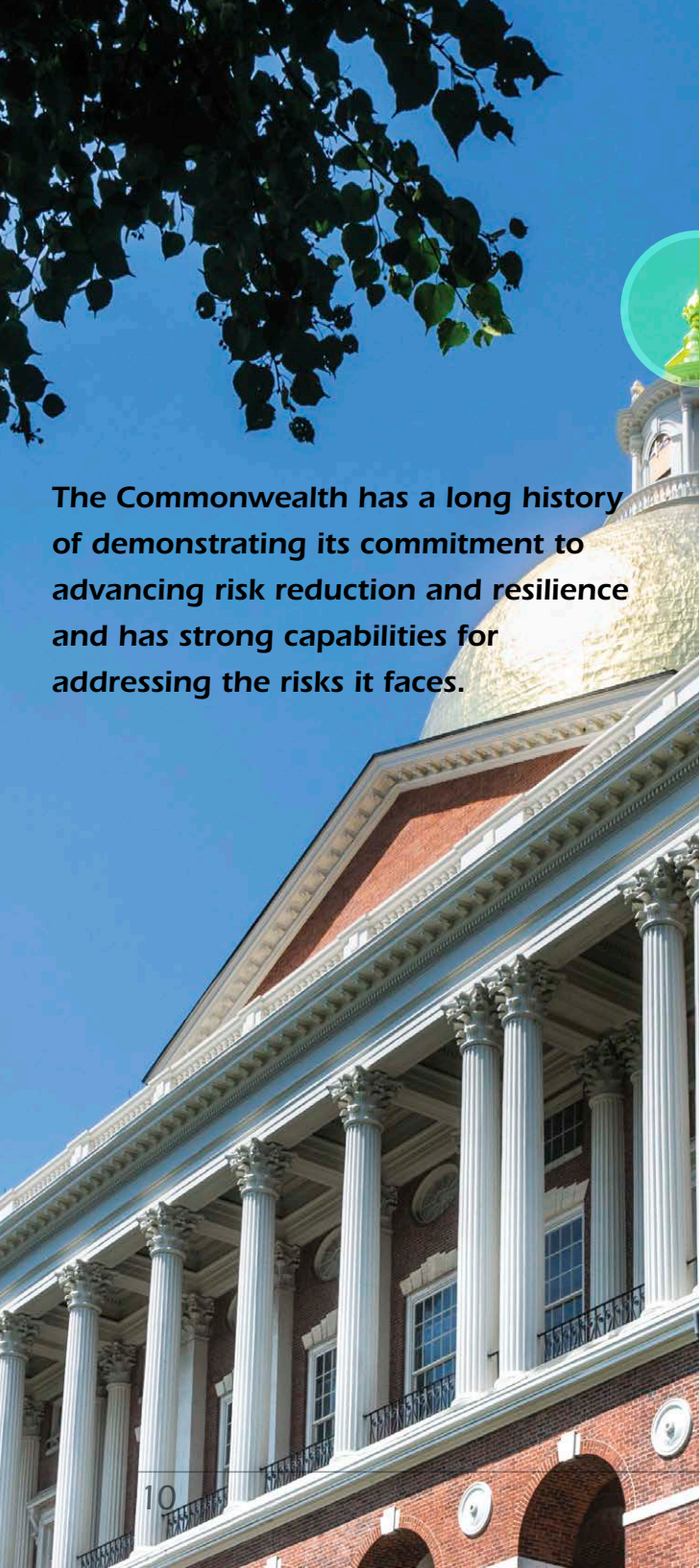


Earthquakes

- Cannot be predicted
- Probability of a magnitude 5.0 or greater earthquake centered in New England is about 10–15% in a 10-year period
- Tall buildings, high population, and soil characteristics contribute to vulnerability



Atlantic storm, Lynn



The Commonwealth has a long history of demonstrating its commitment to advancing risk reduction and resilience and has strong capabilities for addressing the risks it faces.

Current Capabilities and Adaptability

To maintain its commitment, the Commonwealth will continue to work across state government to build institutional capacity, maintain best available science and data, and develop operations and policies to adapt to changing natural hazards and the effects of climate change. The SHMCAP evaluates the Commonwealth's existing capabilities to implement hazard mitigation and climate adaptation activities on a statewide level, and presents agency-specific analyses of the State's capacity to adapt to changing hazards and climate conditions over time. These results were used to create a comprehensive and effective strategy to integrate future hazard mitigation and climate change adaptation.

The Commonwealth has bolstered its long history of advancing risk reduction and resilience across the state through recent State-led initiatives to increase state and local government capacity to deal with the challenge of climate change and natural hazards. Examples include:

- Significant investment in statewide, downscaled climate change projections at the county and watershed scale

GLOSSARY

State capabilities

The authorities, laws, policies, programs, staff, funding, and other resources available to support hazard mitigation and climate adaptation efforts.

Adaptive capacity

The ability of state agencies to adjust or modify their operations, policies, or other functions to adapt to changing natural hazards and climate change impacts.

- Coordination of regional and community-based hazard mitigation plans
- Fiscal Year 2019 Capital Investment Plan
- Environmental Bond Bill signed into law August 2018
- Coastal Resilience Grant Program expansions
- Municipal Vulnerability Preparedness program growth (see map on the following page)

Massachusetts Statehouse, Boston

Fiscal Year 2019 Capital Investment Plan

The Fiscal Year 2019 Capital Investment Plan incorporates the goals of Executive Order 569 and has an increased emphasis on climate change mitigation (emissions reduction) and adaptation. Each investment was evaluated for potential climate change implications, and the plan provides more than \$60 million in FY19 to directly address issues related to climate change.

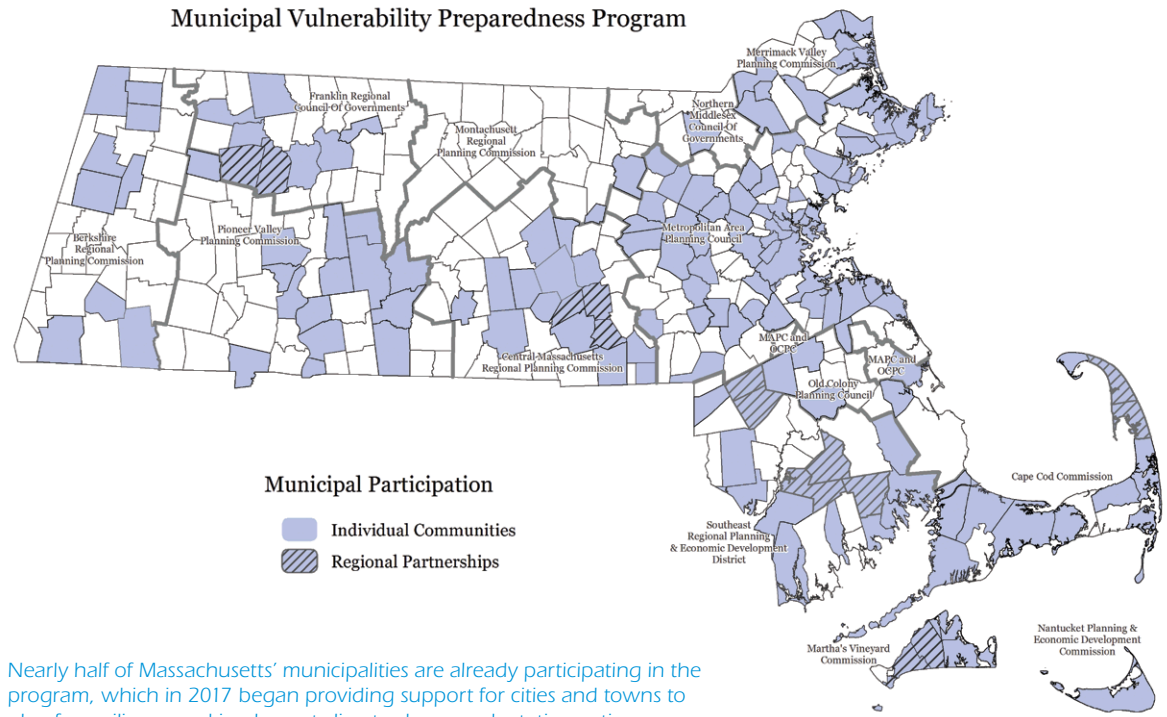
Environmental Bond Bill

The \$2.4 billion Environmental Bond Bill recently signed into law promotes climate change adaptation and the preservation and improvement of the environmental and energy assets of the Commonwealth and puts into law key components of Executive Order 569. It dedicates over \$500 million to climate change resiliency efforts and stipulates that investments made by EOEEA and its agencies must be consistent with the SHMCAP.

The Commonwealth also maintains a strong capacity at the state government level to adapt to changing future conditions. Results of a self-assessment survey completed by state agencies indicate that many agencies are well-positioned to protect their key assets, accomplish their missions, and deliver critical constituent services in the face of potentially increasing threats from natural hazards and climate change. For some state agencies, threats from natural hazards and climate change are significant, but for others they are minimal.

Despite these findings, there are obstacles and challenges to overcome as the Commonwealth works to further increase state and local capacity to address climate change and natural hazards. The plan's strategy outlines initial actions for state agencies to lead by example and to begin to tackle these challenges in a coordinated and forward-looking way. At the same time, additional capabilities and opportunities to increase natural hazard and climate resilience are rapidly emerging, including increased legislative support for spending and bond financing for resiliency investments, and incorporation of climate change considerations into existing budgets.

Municipal Vulnerability Preparedness Program



Nearly half of Massachusetts' municipalities are already participating in the program, which in 2017 began providing support for cities and towns to plan for resiliency and implement climate change adaptation actions.

State agencies identified over 100 initial priority actions to increase resilience and overcome the Commonwealth's risks and vulnerabilities related to natural hazards and projected climate changes.

Our Strategy

The SHMCAP's strategy to address risks and vulnerabilities from natural hazards and climate change impacts, is guided by a mission statement and five goals, and includes a series of specific hazard mitigation and climate adaptation actions.

The process to develop these actions included extensive stakeholder engagement, reference to strategies and actions identified in local hazard mitigation plans, and development of initial actions by the Commonwealth's state agencies and Climate Change Coordinators across all Secretariats.



Hazard mitigation or climate adaptation action

A specific action, project, activity, or process taken to reduce or eliminate long-term risk to people, property, and natural systems from climate change and/or natural hazards and their impacts.

- GOAL 1 Integrate programs and build institutional capacity
68 recommended actions
- GOAL 2 Develop forward-looking policies, plans, and regulations
69 recommended actions
- GOAL 3 Develop risk-reduction strategies for current and future conditions
82 recommended actions
- GOAL 4 Invest in performance-based solutions
56 recommended actions
- GOAL 5 Increase education, awareness, and incentives to act
39 recommended actions

Total number of recommended actions

108

SHMCAP action development workshop

SHMCAP Mission Statement: Reduce the statewide loss of life, and protect natural resources, property, infrastructure, public health, and the economy from natural hazards and climate change impacts through the development of a comprehensive and integrated hazard mitigation and climate adaptation program.

Global/Cross-Cutting Hazard Mitigation and Climate Adaptation Actions

	ACTION TITLE	ACTION DESCRIPTION	EXECUTIVE OFFICE / LEAD AGENCY	COMPLETION TIME FRAME
Cross-cutting or global actions are intended to reduce risk across state government and the Commonwealth. In addition, actions are identified for all Executive Offices and over 20 state agencies. All actions address at least one of the primary climate change interactions and associated climate change impacts identified in the risk assessment. Each action includes specific details, such as completion time frame, lead agency, agency priority score, and possible funding sources.	Budgeting, coordinating administrative functions, and planning.	Incorporate climate change vulnerability, resiliency, and adaptation standards into budgeting, coordination, and capital planning.	A&F	3–5 years
	Incorporate hazard and climate change vulnerability into personnel and workplace policies, training, and guidance as appropriate.	Evaluate current policies and guidance to consider updates and other training opportunities related to personnel readiness, workplace climate change vulnerabilities, hazard mitigation, and climate adaptation techniques.	A&F / HRD	3–5 years
	Power system planning that incorporates climate change risk.	Assess how power system planning may incorporate existing climate models to evaluate risk and deploy cost-effective infrastructure to reduce outages, repair, and replacement. Identify key data gaps for system planning and provide to DPU / EOEEA to coordinate with ongoing research.	EOEEA / DPU	3–5 years
	Create and deploy a SHMCAP project database.	Deploy the SHMCAP Action Tracker, a customized tracking spreadsheet tool for reporting progress status updates on individual actions, to provide continuous updating and reporting in real-time. Actively maintain SHMCAP Action Tracker on a restricted, password-protected file sharing site as the primary mechanism for reporting status updates on each action and measuring effectiveness.	EOEEA	3–5 years



SHMCAP stakeholder engagement workshop

ACTION TITLE	ACTION DESCRIPTION	EXECUTIVE OFFICE / LEAD AGENCY	COMPLETION TIME FRAME
In consultation with DCAMM, MassDOT, and EOHED, develop climate change design standards.	EOEEA will work with Climate Change Coordinators and agency staff across Secretariats to review and update design standards using Massachusetts climate change projections that will support best management and construction practices for new and improved agency structures, roads, parkways, parking lots, housing, and other facilities.	EOEEA	3–5 years
Maintain and enhance climate change projections and specific climate change data sets to support different groups of end users.	Maintain, update, and enhance climate change projections for Massachusetts through additional studies, stakeholder engagement to determine key data needs, and ongoing incorporation of advancements in the field of climate change science. Updated climate change data will be maintained and made available to the public on the resilient MA website.	EOEEA	3–5 years
Review the state building code to assess feasibility of incorporating hazard mitigation and resilience.	Review the state building code to assess feasibility of incorporating hazard mitigation and resilience into standards.	EOHED / OPSI	3–5 years
Migrate critical systems that support multiple state agencies to the cloud.	Migrate critical operational systems that support multiple state agencies to the cloud, thereby removing the need to maintain and protect on premise servers for these systems.	EOTSS	3–5 years
Incorporate hazard and climate change vulnerability into capital planning, master planning, and facilities management functions.	<p>Incorporate climate change vulnerability, resilience, and adaptation standards into capital planning for new projects.</p> <p>Refer to agency climate change vulnerability assessments in master planning exercises.</p> <p>Integrate climate change vulnerability assessments into a facilities management system.</p>	A&F / DCAMM	Greater than 5 years

ACTION TITLE	ACTION DESCRIPTION	EXECUTIVE OFFICE / LEAD AGENCY	COMPLETION TIME FRAME
Review, evaluate, and implement revisions as needed to environmental and energy policies, regulations, and plans.	Conduct outreach with stakeholders to review, evaluate, and implement revisions needed to key state environmental and energy policies, regulations, and plans maintained by EOEEA and its agencies.	EOEEA	Greater than 5 years
Utilize available climate change projections and risk assessment data to assess vulnerabilities of all EOEEA properties. Support efforts across the administration to assess facilities held by other Executive Offices.	<p>Utilize climate projection information and information on site-specific vulnerabilities, agency adaptive capacity, populations served, and other information to assess climate change vulnerability at all of EOEEA's land holdings, facilities, parkways, fisheries, dams, and other properties.</p> <p>Use the resulting vulnerability scores and information for each asset, as well GIS layers depicting exposure and sensitivity to help EOEEA understand the risks at each site.</p>	EOEEA	Greater than 5 years
Incorporate climate change resilience into business continuity planning for state government.	Work with A&F and EOTSS to update business continuity planning and to incorporate climate change hazards into plans and procedures across state government.	EOPSS	Greater than 5 years
Update the SHMCAP and submit for FEMA review and approval.	<p>Update and submit the SHMCAP for FEMA review and approval every 5 years.</p> <p>Continue to incorporate climate adaptation into future updates.</p>	EOPSS / MEMA	Greater than 5 years
Expand and improve the Boston Harbor Flood Risk Model to create the Massachusetts Coastal Flood Risk Model.	Create improved sea level rise and storm surge scenarios for the present tidal epoch, 2030, 2050, 2070/2100; create northern and southern model grids; consider future shoreline changes; correct CZM/MassGIS shoreline mapping; assess the storm surge vulnerability of the coastal transportation network; and make data available to state agencies, coastal communities, and other interested stakeholders.	MassDOT / EOEEA	Greater than 5 years



Elevated houses in Scituate

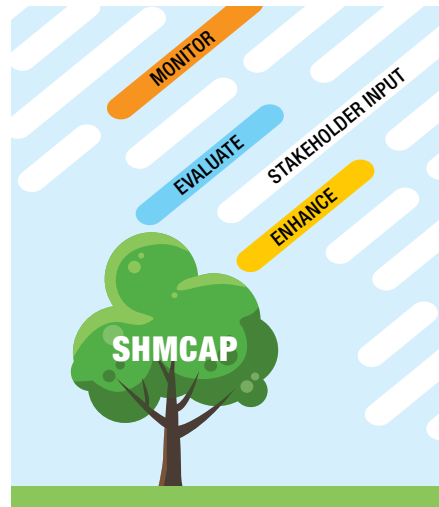
Acronyms:

A&F	Executive Office of Administration and Finance
DPU	Department of Public Utilities
DCAMM	Division of Capital Asset Management and Maintenance
EOEEA	Executive Office of Energy and Environmental Affairs
EOHED	Executive Office of Housing and Economic Development
EOPSS	Executive Office of Public Safety and Security
EOTSS	Executive Office of Technology Services and Security
HRD	Human Resources Division
MassDOT	Massachusetts Department of Transportation
MEMA	Massachusetts Emergency Management Agency
OPSI	Office of Public Safety and Inspection



A Living Plan

To maintain relevancy, evaluate progress, and improve long-term resiliency, the SHMCAP is a living document that will evolve as specific hazard mitigation and climate adaptation actions are implemented and in response to ongoing dialogue with stakeholders.



Over the next 5 years, the plan will be continually reviewed, revised, and updated as conditions and information change and with input from stakeholders. The Commonwealth's resilient MA Climate Change Clearinghouse (resilientma.org) will be the home for the online version of the 2018 SHMCAP as well as future updates and will enable communication with the general public, municipalities, state agencies, and other stakeholders.

To assist with the plan implementation and maintenance process, the Commonwealth is establishing a Resilient MA Action Team (RMAAT). The RMAAT will include representatives from each Secretariat as well as key state agencies and be tasked with specific responsibilities.

RMAAT Responsibilities:

Conduct quarterly meetings, annual plan reviews, post-disaster reviews, and 5-year plan review and updates.

Track and facilitate the completion of annual implementation updates for all hazard mitigation and climate adaptation actions included in the plan.

Ensure that the SHMCAP incorporates new data as they become available.

Provide outreach, technical assistance, stakeholder engagement, and other educational services that increase general awareness and understanding of the SHMCAP.

Coordinate the continuous enhancement of the SHMCAP through collaborative partnerships and the active engagement of key stakeholders.

Support incorporation of the SHMCAP into other state plans and programs as appropriate.

Beach house, Cape Cod

Plan Implementation

Effective plan implementation will be accomplished by designing implementation strategies and establishing timelines for priority actions and by continuing to monitor, evaluate, update, and develop actions as new data and experiences become available. Therefore, the responsibility for plan implementation falls on many state agencies.

Plan Maintenance

The key components for regular SHMCAP maintenance include an annual plan review, a post-disaster review, and a 5-year plan review and update. Effective plan maintenance will also require additional recurring activities that are not bound to specific methods or schedules, such as tracking and documenting new or best practices for hazard mitigation and climate adaptation, or new policies or procedures that may affect how the SHMCAP is implemented. The RMAAT is expected to perform many of these ongoing activities, which will be discussed during the regularly scheduled plan reviews.



The RMAAT will be an expansion of the Project Management Team tasked with developing this original plan. It will continue to engage stakeholders as the plan is implemented.

The Commonwealth is proud to be a leader in establishing a forward-looking, integrated climate adaptation and natural hazard mitigation plan to advance statewide risk reduction and resilience.

Key Points

The SHMCAP builds upon previous Commonwealth planning actions to address changes in precipitation, temperature, sea level rise, and extreme weather events and effectively reduce the risks associated with natural hazards and a changing climate.

The SHMCAP:

- ✓ Acknowledges that climate change is already worsening natural hazards and extreme weather events and integrates information and planning elements for 14 natural hazards that affect the Commonwealth.
- ✓ Incorporates the best scientific data and projections available to assess risk and vulnerability associated with natural hazards and a changing climate for five key sectors—populations, government, built environment, natural resources and environment, and economy.
- ✓ Evaluates the Commonwealth's existing capabilities to implement agency-specific and statewide hazard mitigation and climate adaptation activities to reduce risk and increase resilience.
- ✓ Establishes a strategy for implementation and continued evolution of the plan to incorporate new information and data as they become available as well as engage relevant stakeholders.

Ice storm, Berkshire County road



Want to Learn More?

For more information, please visit the Commonwealth's resilient MA Climate Change Clearinghouse at resilientma.org and the State's climate action page at www.mass.gov/topics/climate-action. The resilient MA Climate Change Clearinghouse serves as a gateway to data and information relevant to climate change adaptation and natural hazard mitigation across the state. The Clearinghouse will be the home for the online version of the 2018 SHMCAP as well as future updates.







1. Introduction and Assurances

1.1 Purpose

This plan is a fully integrated, innovative, and actionable State Hazard Mitigation and Climate Adaptation Plan (SHMCAP). The purpose of this SHMCAP is to identify risks and vulnerabilities associated with natural disasters and climate change, and to develop long-term strategies for protecting people and property from future hazard events and climate change impacts. This is the first statewide integrated hazard mitigation and climate adaptation plan of its kind that empowers state agencies to tactically and effectively achieve multiple risk management objectives.

The plan is intended to help the Commonwealth of Massachusetts reduce the impact of hazards and climate change. It also helps the Commonwealth and its residents to better understand when, where, why, and how natural hazards occur; how natural hazards are expected to be affected by climate change; how to reduce the cost of recovery and rebuilding through making a more resilient Commonwealth; and how preparedness and adaptation planning can reduce health impacts. This plan outlines specific actions that should be taken by the State, local governments, and the general public to manage the risks of natural hazards and climate change, and reduce the future costs of rebuilding. To help the Commonwealth be better prepared for future events and

conditions, the plan incorporates lessons learned from recent disasters, as well as the most recently available downscaled climate projections.

The SHMCAP is an update of the 2013 Massachusetts State Hazard Mitigation Plan (SHMP), which was approved October 11, 2013. This plan was updated in compliance with the Disaster Mitigation Act of 2000 (Public Law 106-390) and the regulations of Parts 201 and 206 of 44 Code of Federal Regulations (CFR). As a condition for receiving non-emergency Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act) assistance and Federal Emergency Management Agency (FEMA) mitigation grants, states are required to prepare and submit to FEMA a Standard State Mitigation Plan following the criteria established in Section (§) 201.4. Mitigation plans are required for states to be eligible for the following:

- Public Assistance (PA) Categories C through G
- Fire Mitigation Assistance Grants (FMAG)
- Hazard Mitigation Grant Program (HMGP)
- Pre-Disaster Mitigation (PDM) Grant
- Flood Mitigation Assistance (FMA)

In addition to serving as the Commonwealth's hazard mitigation plan, this plan satisfies a key requirement of *Executive Order 569 Establishing an Integrated Climate Change Strategy for the Commonwealth*, which was signed in September 2016 by Governor Charlie Baker, and directs the Executive Office of Energy and Environmental Affairs (EOEEA) to publish a statewide climate adaptation plan. This plan summarizes the best available scientific information on climate change in Massachusetts; describes the interactions of climate change and natural hazards; and develops adaptation strategies to mitigate risk and increase resilience. This SHMCAP has been developed in response to this recognition of the need to address—and the benefits of addressing—climate change through an integrated strategy.

This plan also demonstrates the Commonwealth's commitment to emergency management. After receiving accreditation in 2006 through the Emergency Management Accreditation Program (EMAP), a national voluntary standards, assessment, and accreditation process for disaster preparedness programs, the Commonwealth has maintained its accreditation through a self-assessment, an on-site assessment, and a committee review in 2013. The

The purpose of the Disaster Mitigation Act is to establish a national disaster hazard mitigation program to (1) reduce the loss of life and property, human suffering, economic disruption, and disaster assistance costs resulting from natural disasters; and (2) to provide a source of pre-disaster hazard mitigation funding that will assist states and local governments (including Indian Tribes) in implementing effective hazard mitigation measures that are designed to ensure the continued functionality of critical services and facilities after a natural disaster.

Commonwealth is preparing for another EMAP accreditation assessment in 2019. This SHMCAP serves to support the Commonwealth's continued accreditation of its Emergency Management Program.

1.2 Authority and Scope

This plan was prepared pursuant to the:

- Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act), as amended by the Disaster Mitigation Act of 2000 (DMA) (P.L. 106-390);
- National Flood Insurance Act of 1968, as amended [42 United States Code 4001 et seq.];
- 44 CFR Part 201 Mitigation Planning;
- 44 CFR Part 206, Subpart N Hazard Mitigation Grant Program, Section 206.434 Eligibility; and
- Executive Order 569: Establishing an Integrated Climate Change Strategy for the Commonwealth.

DMA amended the Stafford Act to authorize a program for pre-disaster mitigation, to streamline the administration of disaster relief, to control the federal costs of disaster assistance, and for other purposes. DMA provides the legal basis for FEMA mitigation planning requirements for state, local, and Indian Tribal governments as a condition of mitigation grant assistance.

Section 104 of the DMA requires state, local, and Indian Tribal governments to develop a mitigation plan that outlines processes for identifying the natural hazards, risks, and vulnerability of the area under the jurisdiction of the government.

As identified in 44 CFR §201.3(c), the State is responsible for coordinating state and local activities related to hazard evaluation and mitigation, and is to:

- Prepare a Standard State Mitigation Plan following the criteria in §201.4 as a condition of receiving non-emergency Stafford Act assistance and FEMA mitigation grants. The plan may address severe repetitive loss properties in their plan (§201.4 (c)(3)(v)) to receive the reduced cost share for the FMA and severe repetitive loss programs.
- Review and update the Standard State Mitigation Plan every 5 years from the date of the approval of the previous plan to continue program eligibility.
- Make available the use of up to 7 percent of HMGP funding for planning in accordance with §206.434.

- Provide technical assistance and training to local governments to assist them in applying for HMGP planning grants and in developing local mitigation plans.

The plan must:

- Describe the current process used to update the plan, including how other state and federal agencies and other stakeholders were involved in the process in multiple sectors.
- Prepare a risk assessment that describes natural hazards and makes a connection between vulnerability and proposed hazard mitigation actions, focusing on areas most at risk by evaluating where populations, infrastructure, and critical facilities are vulnerable to hazards; and identifying to what extent injuries or damage may occur. The risk assessment should also consider the probability of future hazard events associated with climate change.
- Develop mitigation strategies to guide long-term reduction of the potential losses identified in the risk assessment, describe the process of evaluating and prioritizing actions, and identify funding sources.
- Describe existing State pre- and post-disaster hazard management policies, programs, and capabilities for mitigating hazards, and how the State supports developing local and Tribal mitigation plans.
- Identify criteria for prioritizing jurisdictions to receive planning and project grants under federal and non-federal programs.
- Describe the process to keep the plan current through monitoring, evaluating, and updating the plan, as well as the process to monitor implementation of the mitigation strategies.
- Document how the plan is formally adopted.
- Include assurances that the State will comply with all applicable Federal statutes and regulations.
- Develop a strategy to reduce the number of repetitive loss properties, including severe repetitive loss properties.

Massachusetts updated and received FEMA approval of its state plan following presidentially declared disasters in 1986, 1987, 1989, 1993, and 1998. In addition, Massachusetts' SHMP was reviewed and approved by FEMA Region I in 2000, 2004, 2007, 2010, and 2013.

The 2018 SHMCAP provides a framework that links pre- and post-disaster mitigation and resiliency planning and implementation. The plan recognizes that extreme weather events associated with climate change presents a serious threat to public safety, lives, and property; and it takes an integrated approach to addressing hazards associated with climate change. The intent is to prepare for the impacts of climate change by assessing vulnerability and adopting strategies

to increase the adaptive capacity and resiliency of infrastructure and other assets. This approach supports State administration of HMGP and non-disaster programs such as the PDM grant program and the FMA program. It also adheres to Executive Order 569. The SHMCAP represents the Commonwealth's commitment to mitigation and adaptation activities, comprehensive state mitigation planning, and improved state program management. It demonstrates the Commonwealth's leadership in planning and preparing for impending climate change, and enhancing the resilience of government investments.

1.3 Adoption by the State

This SHMCAP was adopted by Governor Charlie Baker on September 17, 2018, as required by 44 CFR Section §201.4(c)(6). A signed adoption letter from the Governor is included at the beginning of this plan.

This plan was reviewed by the Project Management Team (PMT) that was assembled for oversight of, and contribution to, the development of the SHMCAP. The PMT consists of staff across Secretariats and agencies, including representatives from the following entities:

- Coastal Zone Management
- Department of Conservation and Recreation
- Department of Energy Resources
- Department of Public Health
- Department of Transportation
- Division of Capital Asset Management and Maintenance
- Executive Office of Energy and Environmental Affairs
- Executive Office of Public Safety and Security
- Massachusetts Bay Transportation Authority
- Massachusetts Emergency Management Agency

Refer to *Chapter 9: Planning Process* for a complete list of individuals on the PMT.

1.4 Assurances

The Commonwealth of Massachusetts does comply, and assures it will continue to comply, with all applicable federal statutes and regulations in effect with respect to the periods for which it receives grant funding, in compliance with Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards 2 CFR 200 and 2 CFR 3002. This

includes managing and administering FEMA funding in accordance with applicable Federal statutes and regulations. The Commonwealth also assures it will amend the SHMCAP in accordance with 44 CFR 13.11(d). This includes amending the plan whenever necessary to reflect changes in State or Federal laws and statutes, as described in *Chapter 8: Plan Implementation and Maintenance*.

1.5 Plan Organization and Key Revisions

1.5.1 Organization

The 2018 SHMCAP is organized into 10 chapters, each of which has multiple sections and subsections. Table 1-1 provides a summary of the contents of each chapter in the plan.

Table 1-1: Organization of the 2018 SHMCAP

Chapter	Description
1. Introduction and Assurances	Provides an introduction of the integrated hazard mitigation and climate adaptation plan. Includes an overview of the purpose, authority, assurances, and organization of the plan.
2. Planning Context	Describes the organization of State government and provides an overview of Executive Order 569. This chapter summarizes demographic, housing, and development trends since the preparation of the 2013 SHMP, and summarizes climate change projections for Massachusetts.
3. Introduction to Risk Assessment	Identifies the natural hazards included in the 2018 SHMCAP plan and describes the four climate change interactions included in the plan: precipitation, sea level rise, rising temperatures, and extreme weather. This chapter reviews the sectors addressed in the plan and identifies vulnerable populations. Chapter 3 also describes methodologies, data, and key terms.
4. Risk Assessment	Examines the natural hazards that have the potential to impact the Commonwealth. Describes the hazards, identifies past occurrences and vulnerable locations, populations, State-owned facilities, infrastructure, and natural resources. Explores the interaction between climate change and each of 13 hazards. Non-climate-influenced hazards are also included.
5. Technological and Human-Caused Hazards	Introduces other State emergency management plans that assess technological and human-caused hazards to demonstrate that the Commonwealth's Emergency Management Program accounts for both natural and non-natural hazards.
6. State Capability and Adaptive Capacity Analysis	Includes an evaluation of existing Commonwealth capabilities for enabling hazard mitigation and climate adaptation, and an adaptive capacity analysis for specific state agencies. Describes local capabilities and coordination and concludes with a series of key findings and recommendations.
7. Hazard Mitigation and Climate Adaptation Strategy	Includes the 2018 SHMCAP mission statement, five goal statements, and a list of initial actions developed by stakeholders and state agencies to meet those goals.
8. Plan Implementation and Maintenance	Outlines procedures and strategies for effective plan implementation, as well as the process and schedule for monitoring, evaluating, and updating the plan on a routine basis.
9. Planning Process	Summarizes the process of updating the plan, including the PMT, stakeholder outreach and engagement, and the state agency vulnerability assessment survey.
10. Coordination of Local Hazard Mitigation and Climate Adaptation Planning	Describes funding and technical assistance provided by the State to local jurisdictions. Provides the status of local hazard mitigation and climate adaptation plans and discusses their integration with the SHMCAP.

1.5.2 Key Revisions

In addition to updating the plan to reflect changes in development, mitigation priorities, and recent hazards, revisions were made to the content, structure, and plan update process. A primary difference between the 2013 and 2018 plans is that this SHMCAP serves as both a hazard mitigation plan and a climate adaptation plan, whereas the previous plan was a traditional hazard mitigation plan. The integrated nature of this plan provides the opportunity to identify climate change impacts, describe the effect climate change is anticipated to have on natural hazards, and prepare an integrated strategy to understand and mitigate risks. In addition to integrating climate change, the structure of the plan was further revised and reorganized based on the integrated nature of the plan, scope of work, and the preferences of the State.

Significant focus was placed on the state capability and adaptive capacity analysis chapter for the 2018 update, and more attention was given to integrating the Commonwealth's capability and capacity to adapt to climate change and future hazard conditions. Some content from the previous plan, including information from other sections, has been incorporated and/or consolidated into *Chapter 6: State Capability and Adaptive Capacity Analysis* to make the plan a more concise and reader-friendly document. Specific and notable changes since the 2013 Plan include:

- The inclusion of a more detailed description of the Commonwealth's comprehensive statewide program for advancing natural hazard risk reduction and climate resilience across the state (Section 6.2.1).
- An extension of the state capability assessment summary to include climate adaptation capabilities (Section 6.2.2).
- The addition of a new section focused on the adaptive capacity of the Commonwealth and specific state agencies with respect to climate change and natural hazards (Section 6.2.3).
- A revised section on local capabilities and coordination, including an expanded summary of local capabilities, examples from local communities, and the identification of opportunities for the Commonwealth to help build or enhance local capabilities and coordination for implementing hazard mitigation and climate adaptation across the state (Section 6.3).
- A new concluding section on key findings and recommendations (Section 6.4), including a discussion on existing obstacles and challenges, as well as emerging capabilities and opportunities that relate to hazard mitigation and climate adaptation.

The planning context chapter, previously called the State Profile, was updated with current socioeconomic data. The focus of *Chapter 2: Planning Context* is to highlight key changes, trends, policies, and programs that shape development and influence vulnerability to hazards.

In addition to the incorporation of climate change, other changes were made to the risk assessment chapter. *Chapter 4: Risk Assessment* includes an additional hazard: invasive species. Chapter 4 also includes a discussion of dam overtopping as part of the inland flooding hazard profile. The risk assessment chapter has been restructured around four primary climate change interactions: changes in precipitation, sea level rise, rising temperatures, and extreme weather.

The process of preparing this SHMCAP differed from the previous plan in that it involved greater interagency coordination and program integration. This was a result of the increased focus on the state capability and adaptive capacity analysis and the state agency vulnerability assessment process. The process of developing goal statements and actions was also much more collaborative than was previously undertaken, and was driven by a robust stakeholder engagement program that is described in *Chapter 7: Hazard Mitigation and Climate Adaption Strategy* and *Chapter 9: Planning Process*.

Finally, the plan has been reformatted and enhanced through the inclusion of graphic summaries, icons, tables, figures, and callout boxes. These elements increase the user-friendliness and readability of the document.

Documentation of key changes since the 2013 SHMP as required by CFR Part 201 (i.e., changes in development, changes in risks/vulnerabilities, changes in priorities and goals, progress with mitigation efforts) is provided in the appropriate chapters of the SHMCAP.



2. Planning Context

This chapter provides an overview of key considerations for hazard mitigation and climate adaptation planning in the Commonwealth, including the organization of government in Massachusetts and introduction of the Commonwealth’s Climate Change Strategy. Table 2-1 identifies the Commonwealth’s Executive Offices and agencies that are primarily responsible for hazard mitigation and climate adaptation planning in the state. Sections on recent and projected development trends and climate change projections are also included to provide a summary of changes that have occurred or are projected to occur in Massachusetts that may affect risk and vulnerability, as determined in the risk assessment that was conducted for this integrated State Hazard Mitigation and Climate Adaptation Plan (SHMCAP).

Table 2-1: Commonwealth Government Roles for Hazard Mitigation and Climate Adaptation Planning

Executive Office / Agency	Role
Massachusetts Emergency Management Agency (MEMA)	MEMA ensures the state is prepared to withstand, respond to, and recover from all types of emergencies and disasters, and is responsible for maintaining the Commonwealth’s State Hazard Mitigation Plan.
Executive Office of Energy and Environmental Affairs (EOEEA) and the Executive Office of Public Safety and Security (EOPSS)	Per Governor Baker’s <i>Executive Order 569, Establishing an Integrated Climate Change Strategy for the Commonwealth</i> , EOEEA and EOPSS are responsible for maintaining a statewide climate adaptation plan.

2.1 Organization of State Government

Massachusetts was designated a commonwealth in 1780 when the Massachusetts constitution was ratified. The term is used to describe a body of people constituting a nation or state.

Massachusetts has three branches of government—the Executive, Legislative, and Judicial Branches—as well as constitutional officers and independent agencies and commissioners, which are part of the Executive Branch, but not subject to its oversight or control. The Commonwealth elects six constitutional officers every 4 years (see Table 2-2).

Table 2-2: Constitutional Officers as of September 2018

Title	Name
Governor	Charlie Baker
Lieutenant Governor	Karyn Polito
Secretary of the Commonwealth	William Francis Galvin
Treasurer and Receiver General	Deborah Goldberg
Attorney General	Maura Healey
Auditor	Suzanne Bump

The General Court, which consists of a 40-member Senate and a 160-member House of Representatives, is the legislative body of Massachusetts. Senators and Representatives are elected every 2 years. The Legislative Branch creates State laws and makes changes to existing laws. The Judicial Branch consists of the Supreme Judicial Court, Appeals Court, Executive Office of the Trial Court, seven Trial Court departments, Massachusetts Probation Services, and the Office of Jury Commissioner. The Supreme Judicial Court consists of Chief Justice Ralph D. Gants and six associate justices. The Governor, with the advice and consent of an executive council, appoints all justices. The Executive Branch of the state government oversees the programs and services offered by the State. Table 2-3 lists the Executive Offices and their functions.

The State House in Boston is the primary seat of Massachusetts government. The State Legislature and offices of the Governor are located at the State House.

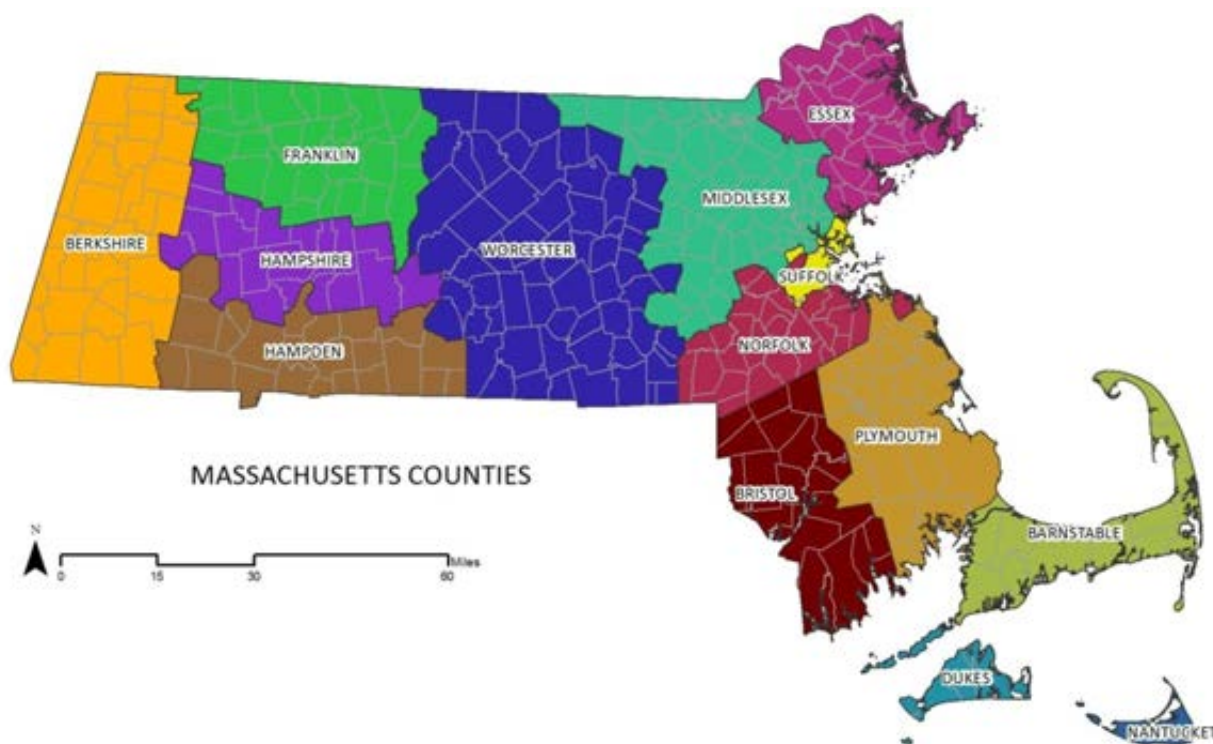
Table 2-3: Executive Offices of Massachusetts

Executive Office	Function
Executive Office of Administration and Finance	Oversees the financial and administrative aspects of State government.
Executive Office of Education	Manages and sets the standards for State-backed education, and provides support for administrators, teachers, parents, and students.
Executive Office of Energy and Environmental Affairs	Manages and preserves the Commonwealth's open spaces, enforces pollution laws, ensures new development projects do not harm the environment, and promotes eco-friendly energy production and conservation.
Executive Office of Health and Human Services	Oversees health and general support services to help people meet basic needs.
Executive Office of Housing and Economic Development	Supports job creation and economic development by fostering an environment conducive to business creation and expansion, and helps to drive housing construction that addresses the needs of residents.
Executive Office of Labor and Workforce Development	Manages the Commonwealth's workforce and labor departments to ensure that employers, workers, and the unemployed have the tools and training needed to succeed in the Massachusetts economy.
Executive Office of Public Safety and Security	Keeps the people of Massachusetts informed about public safety issues, and provides services to protect residents from natural and man-made threats.
Massachusetts Department of Transportation	Oversees roads, public transit, aeronautics, and transportation licensing and registration across the state.
Executive Office of Technology Services and Security	Provides secure and quality digital information, services, and tools to customers and constituents when and where they need them.

Source: Mass.gov, 2018

2.1.1 Counties

There are 14 counties in Massachusetts (see Figure 2-1). Many counties' governments are no longer in existence. However, county government continues to exist in Barnstable, Bristol, Dukes, Nantucket, Norfolk, and Plymouth Counties. In all counties, regardless of where there is a county government, there is a sheriff elected by the voters of the county.

Figure 2-1: Map of Counties in Massachusetts

Source: MassGIS, 2018

Home rule legislation allows officials or voters in a county to establish a regional charter commission to study its government. The commission can submit one of three model charters for voter approval in that county at a statewide election, or it can submit a special charter, which must first be approved by the State Legislature. Cities and towns may choose a regional council or government charter, which is binding on cities or towns where a majority of voters approve it. The regional council of governments can provide services to cities and towns, such as planning, public safety, engineering, water, and waste disposal. The participating communities pay assessments based on local property valuations. The legislature approved special charters to allow several counties to become regional councils of government (SEC, 2016).

2.1.2 Municipalities

Municipalities are the unit of government primarily responsible for providing local services. There are 351 cities and towns in Massachusetts, each with its own governing body. Typically, elected mayors govern Massachusetts' cities, and elected officials called selectmen govern the towns; however, there are exceptions, including town managers and city councils. A board of selectmen is usually elected for terms ranging from 1 to 3 years, and citizens participate in an annual town meeting. The open town meeting is the active legislature in a town. Some communities have a representative open town meeting, while others have a true "open" town meeting (SEC, 2016).

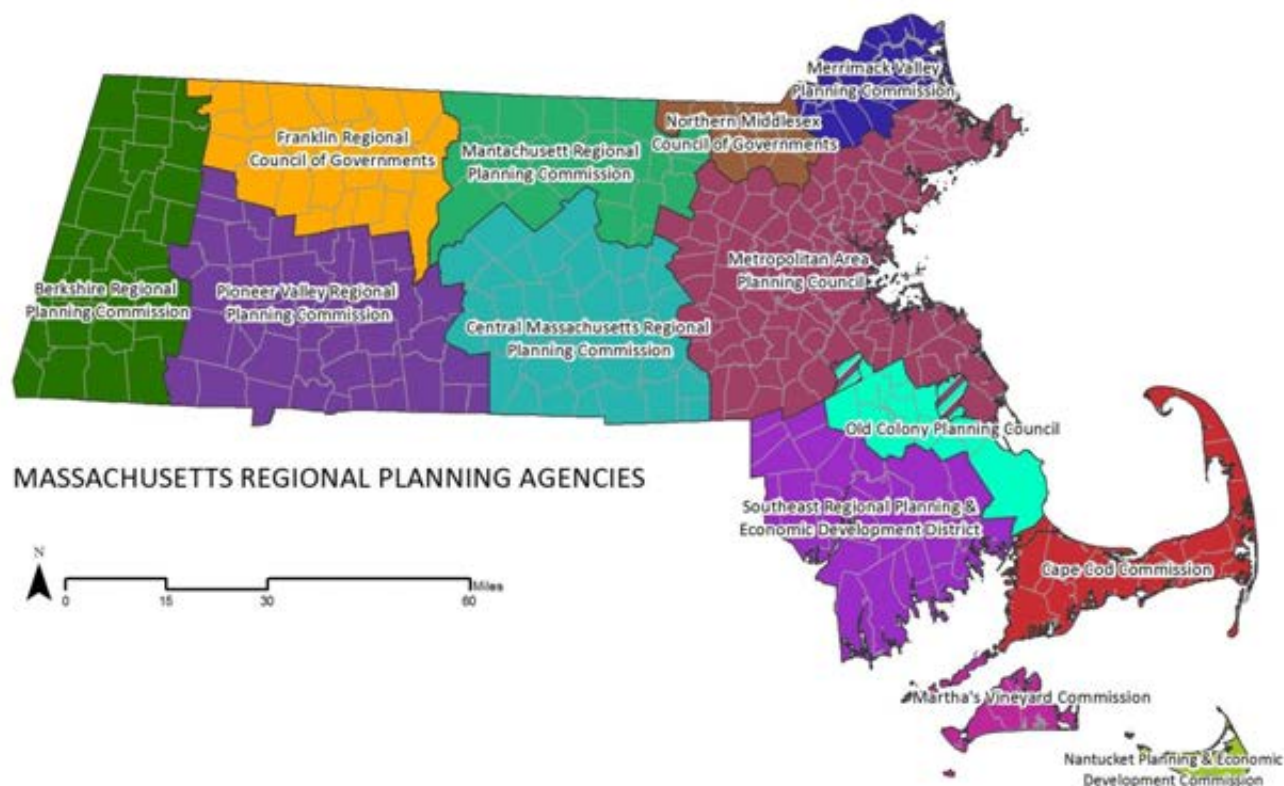
2.1.3 Indian Tribal Governments

The Commonwealth of Massachusetts has two federally recognized Indian Tribes within its boundary: the Mashpee Wampanoag Tribe, and the Wampanoag Tribe of Gay Head (Aquinnah). Federally recognized tribes are those recognized by the U.S. Bureau of Indian Affairs (BIA) for certain Federal government purposes. Federal tribal recognition grants to tribes the right to self-government, as well as certain benefits that include funding and services from the BIA and other federal agencies, either directly or through contracts, grants, or compacts.

2.1.4 Planning Regions

Chapter 40B of the Massachusetts General Laws established 13 planning regions throughout the Commonwealth in 1963 (see Figure 2-2). The Regional Planning Agency for each planning region works in concert with partnering jurisdictions and organizations to complete planning tasks, such as development of regional mitigation plans, transportation planning, economic growth studies, land use and energy planning, historic preservation, open space and natural resources, water and coastal resources, and mapping/geographic information system (GIS). These planning regions also support the Commonwealth's District Local Technical Assistance Program to pursue a variety of municipal shared service initiatives and planning projects through a region-wide solicitation process. Regional Planning Agencies are established as commissions or councils, and serve an advisory role. Each commission or council is composed of a representative from each member community.

Figure 2-2: Map of Planning Regions in Massachusetts



Source: MassGIS, 2018

2.1.5 The Commonwealth's Climate Change Strategy

The Commonwealth's Global Warming Solutions Act (GWSA) of 2008 created a framework for reducing greenhouse gas (GHG) emissions. The GWSA requires a 25 percent reduction in GHGs from all sectors of the economy below the 1990 baseline emission level in 2020, and at least an 80 percent reduction in 2050, with the goal of helping to avoid the worst impacts of climate change.

In September 2011, the Executive Office of Energy and Environmental Affairs (EOEEA) released the first Climate Adaptation Report for Massachusetts, fulfilling an important mandate of the GWSA. The report was developed by a Climate Change Advisory Committee that included a broad array of practitioners, scientists, non-governmental organizations, and Federal, State, and local governments. Findings from the report made clear that while the Commonwealth does its part to reduce and stabilize GHG emissions, it must also think seriously about how Massachusetts as a state will be impacted by climate change, the causes of which are global, and how it will prepare for and respond to local impacts.

In September 2016, Massachusetts Governor Charlie Baker signed [Executive Order 569](#), which established an integrated climate change strategy for the Commonwealth. This executive order

expands on the objectives of the GWSA to reduce GHG emissions, and directs the EOEEA to continue and accelerate efforts to mitigate and reduce GHG emissions. This includes establishing statewide GHG emissions limits for 2030 and 2040, and to promulgate regulations to ensure compliance with the 2020 emissions limit. Section 3 of the Executive Order directs the EOEEA to coordinate efforts across the Commonwealth to strengthen the resilience of communities, prepare for the impacts of climate change, and prepare for and mitigate damage from extreme weather events. This integrated hazard mitigation plan and climate adaptation plan has been developed in response to this recognition of the need and benefits of addressing climate change through an integrated strategy across sectors that brings together all parts of State and local government, and capitalizes on the expertise and institutional knowledge of the Executive Office of Public Safety and Security and the Massachusetts Emergency Management Agency. This plan satisfies the Executive Order 569 directive to publish a statewide climate adaptation plan.

Executive Order 569 also directs GHG emissions reductions and natural hazard resilience planning to wherever possible employ strategies that conserve and sustainably employ the natural resources of the Commonwealth to enhance climate adaptation, build resilience, and mitigate climate change. Natural resources, open spaces, and nature-based solutions provide multiple services that include resilience benefits, public health services, and contribute to environmental and restoration economies.

2.2 Recent and Projected Development Trends

2.2.1 Population and Population Trends

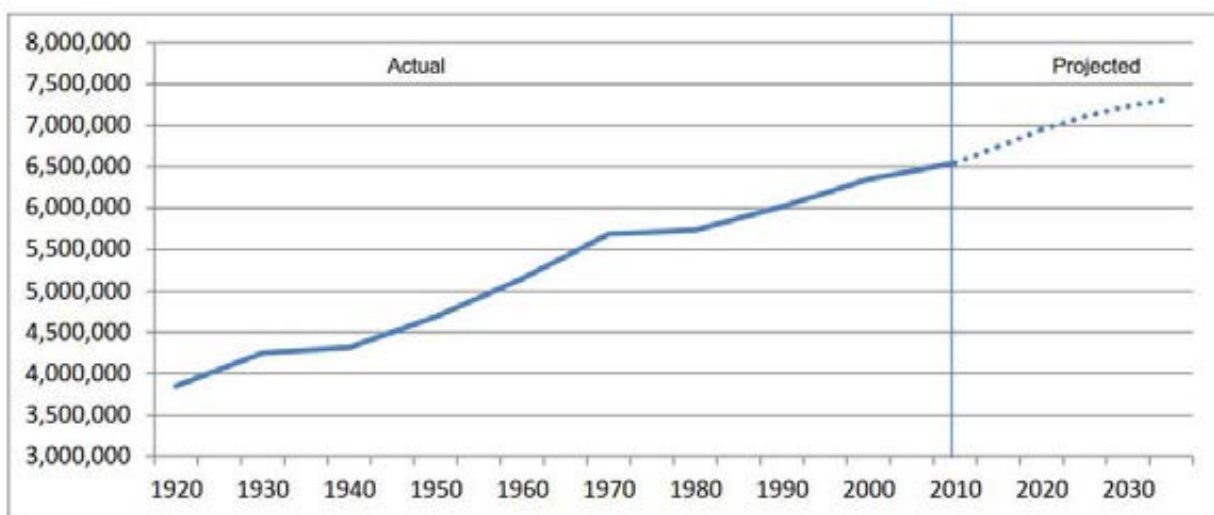
Massachusetts is a small, densely populated and growing state. Between 2000 and 2010, the population of Massachusetts increased by 3.1 percent, or nearly 200,000 people (U.S. Census 2000, 2010). Although in recent years it has been the fastest growing state in the Northeast (UMDI, 2015), the state has a relatively slow growth rate compared to the national growth rate of 9.7 percent between 2000 and 2010. According to the most recent American Community Survey 5-Year Estimates, the population of the state was 6,742,143 (ACS, 2012-2016). Middlesex County is the most populous county in the state, accounting for approximately 23 percent of the estimated population in 2016, while Dukes and Nantucket Counties comprise less than 1 percent of the population. The statewide density is approximately 864 people per square mile, and ranges from 101 people per square mile in Franklin County to 13,180 people per square mile in Suffolk County (see Table 2-4).

Local, regional, and statewide populations in Massachusetts were prepared by the University of Massachusetts Donahue Institute in 2015. The projected statewide population from 2015 through 2035 is displayed on Figure 2-3. According to these projections, the state's population is

Table 2-4: Population and Population Density by County

County	Population			Land Area (Square Miles)	Population Density in 2016 (People/Square Mile) ^{3,4}
	2000 ¹	2010 ²	2016 ³		
Barnstable	222,230	215,888	214,703	394	545
Berkshire	134,953	131,219	128,563	927	139
Bristol	534,678	548,285	554,868	553	1,003
Dukes	14,987	16,535	17,137	103	166
Essex	723,419	743,159	769,362	492	1,562
Franklin	71,535	71,372	70,916	699	101
Hampden	456,228	463,490	468,072	617	759
Hampshire	152,251	158,080	161,035	527	305
Middlesex	1,465,396	1,503,085	1,567,610	818	1,917
Nantucket	9,520	10,172	10,694	46	232
Norfolk	650,308	670,850	691,218	396	1,745
Plymouth	472,822	494,919	506,657	659	769
Suffolk	689,807	722,023	767,719	58	13,180
Worcester	750,963	798,552	813,589	1,511	539
State	6,349,097	6,547,629	6,742,143	7,801	864

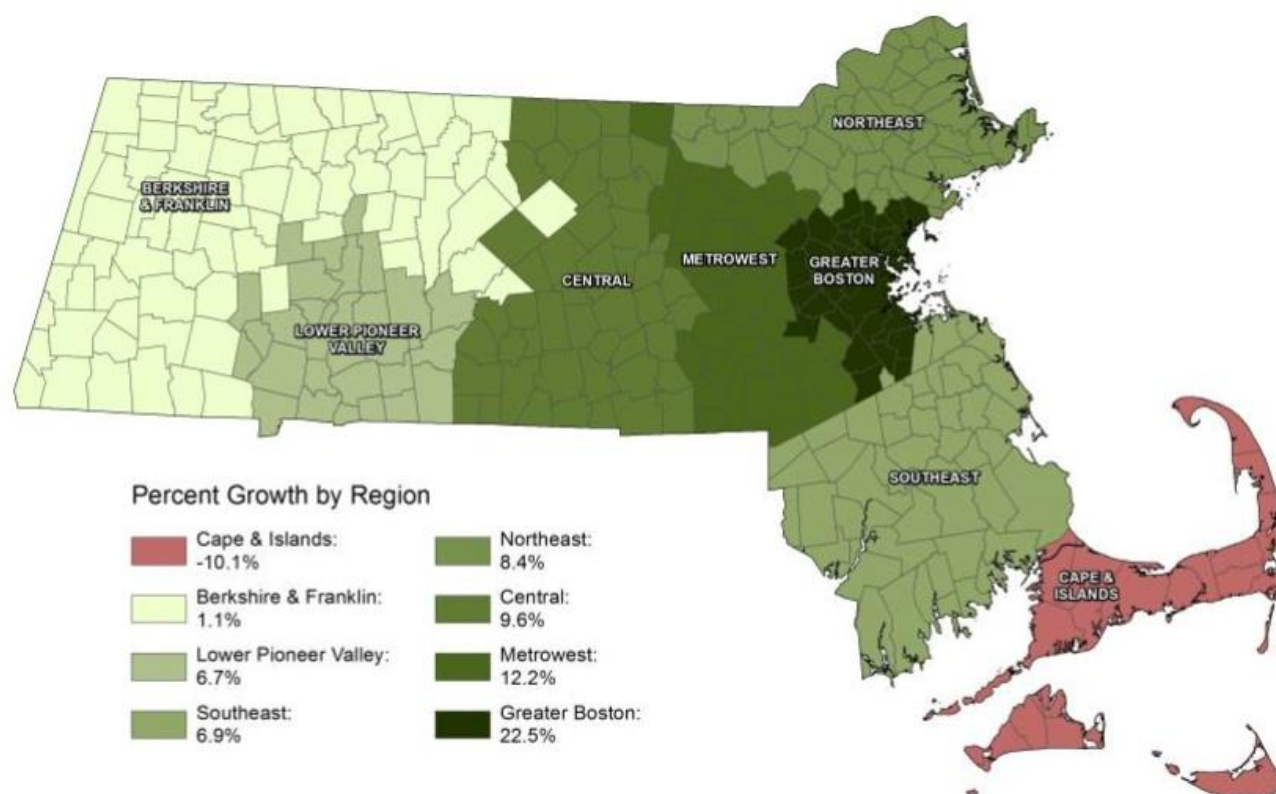
Source: ¹2000 Census; ²2010 Census; ³American Community Survey 2012-2016 5-Year Estimates; ⁴U.S. Census TIGERweb

Figure 2-3: Past and Projected Population

Source: U.S. Census; UMass Donahue Institute, 2015

projected to increase by 11.8 percent between 2010 and 2035, exceeding 7.3 million in 2035. Factors that affect growth rates include natural increase associated with a greater number of births than deaths; and a net positive immigration, attributable to positive international immigrations into the state, in spite of the domestic out-migration to other areas of the U.S. Figure 2-4 shows the projected growth by region through 2035. The population of the Greater Boston area is projected to increase by 22.5 percent during this time period, while the population of the Cape and Islands is projected to decrease by 10 percent (UMDI, 2015). Projected growth and development in the Greater Boston area may result in increased vulnerability in this region of the state due to the increased population and infrastructure exposed to a hazard or climate change impact. Additionally, increases in development that lead to an increased area of impervious surfaces may exacerbate the impacts of hazards, such as flooding and extreme heat. Development in areas that are currently affected by natural hazards, or are projected to be subject to those hazards in the future, can drastically increase the risk posed by those hazards, and can increase the vulnerability of populations in those hazard-prone areas.

Figure 2-4: Projected Percent Growth by Region 2010-2035



Source: UMass Donahue Institute, 2015

A gradual slow-down in growth is projected in the 2020s and 2030s due to the state's aging population, which impacts both birth and death rates. The effect of aging will be more pronounced in Massachusetts because the state already has an older population than the national average. (UMDI, 2015). By 2035, the percentage of the population aged 65 and over is projected to account for 23.0 percent of the state's population, compared to 13.8 percent in 2010. Because the population aged 65 and over is considered to be more vulnerable to natural hazards and the secondary impacts of natural hazards, an increase in this population has implications for hazard mitigation ranging from evaluation management and assistance to the availability of cooling centers. This will likely increase the burden on emergency responders, hospitals, and communities assisting this population.

VULNERABLE POPULATIONS

Figure 2-5 illustrates how exposure, sensitivity, and adaptive capacity determine the vulnerability of populations to natural hazards and climate change. A range of factors can result in the increased vulnerability of certain populations. For example, individuals who have less physical and socioeconomic resiliency due to factors such as age, mobility, access to transportation, income level, race, or health status are more vulnerable to the impacts of natural hazards and climate change. Table 2-5 provides a snapshot of vulnerable populations by county across the Commonwealth. This table provides a comparison of the percentages of the population of each county that are potentially vulnerable due to a range of factors. The counties with a greater percentage of vulnerable populations compared to the statewide percentage are shaded blue. Counties with a greater percentage of vulnerable populations than the average across counties are underlined. This analysis reveals that Suffolk County has a greater percentage of vulnerable individuals compared to the overall state percentage in all indicators except the percentage of the population age 65 and older. For example, information from the U.S. Census that reported 9.5 percent of the Spanish-speaking population in Suffolk County speaks English at a level that is less than “very well” must be considered when developing hazard mitigation and climate adaptation plans and outreach programs. Refer to *Chapter 4: Risk Assessment* for specific analysis of the populations vulnerable to each natural hazard and its related climate change impacts.

Figure 2-5: Assessment of Climate Change Vulnerability



Table 2-5: Vulnerable Populations by County

County	Percent of the Total Population Under Age 5	Percent of the Total Population Age 65+	Percent of the Population for Whom Poverty Status is Determined that are Living Below the Poverty Level	Percent of the Civilian, Non-institutionalized Population with a Disability	Percent of the Spanish Speaking Population Over Age 5 that Speaks English Less Than "Very Well"	Percent of the Total Population that is Non-White or White and Another Race	Percent of Occupied Housing Units that are Occupied by Renters	Percent of Total Households With No computer	Percent of Occupied Housing Units With No Vehicle Available
Barnstable	3.8	<u>27.8</u>	8.2	<u>13.8</u>	0.6	7.6	20.8	7.6	5.6
Berkshire	4.4	<u>20.9</u>	<u>12.4</u>	<u>15.2</u>	1.2	8.5	31.6	<u>11.0</u>	9.8
Bristol	<u>5.3</u>	15.7	<u>12.5</u>	<u>14.2</u>	2.1	13.6	<u>37.9</u>	<u>12.5</u>	<u>11.3</u>
Dukes	4.0	<u>20.4</u>	9.1	8.4	0.2	11.9	23.5	n.d.	2.4
Essex	<u>5.7</u>	15.6	11.3	<u>12.1</u>	<u>7.0</u>	<u>20.0</u>	<u>36.8</u>	9.1	<u>11.0</u>
Franklin	4.5	<u>18.2</u>	11.3	<u>14.0</u>	0.5	6.3	31.4	<u>13.8</u>	6.7
Hampden	<u>5.8</u>	15.3	<u>17.6</u>	<u>15.7</u>	<u>6.0</u>	<u>20.2</u>	<u>38.4</u>	<u>13.9</u>	<u>13.6</u>
Hampshire	3.6	14.8	<u>14.7</u>	10.9	0.6	11.5	33.8	7.9	8.0
Middlesex	<u>5.6</u>	14.0	8.2	9.1	2.2	<u>21.6</u>	<u>37.6</u>	7.6	<u>10.6</u>
Nantucket	<u>5.1</u>	14.0	10.3	8.1	<u>4.2</u>	14.7	<u>36.1</u>	n.d.	8.2
Norfolk	<u>5.4</u>	15.7	6.7	9.7	0.7	<u>20.0</u>	31.5	7.3	9.3
Plymouth	<u>5.3</u>	16.2	8.0	11.3	0.8	15.4	24.1	7.8	6.2
Suffolk	<u>5.5</u>	11.0	<u>20.1</u>	<u>12.4</u>	<u>9.5</u>	<u>44.6</u>	<u>64.2</u>	9.8	<u>33.0</u>
Worcester	<u>5.5</u>	14.1	11.4	<u>11.9</u>	<u>3.1</u>	15.3	<u>35.3</u>	<u>10.0</u>	8.9
Average	5.0	16.7	11.6	11.9	2.8	16.5	34.5	9.9	10.3
Massachusetts	5.4	15.1	11.4	11.6	3.5	20.7	37.9	9.3	12.5

Blue-shaded box denotes percentages that are higher than the overall percentage statewide. Underline denotes higher than the average of all counties.

Source: American Community Survey 2012-2016 5-Year Estimates

Vulnerable populations include Environmental Justice (EJ) populations. In Massachusetts, EJ populations are determined by identifying all block groups from the 2010 Census that meet any of the following criteria:

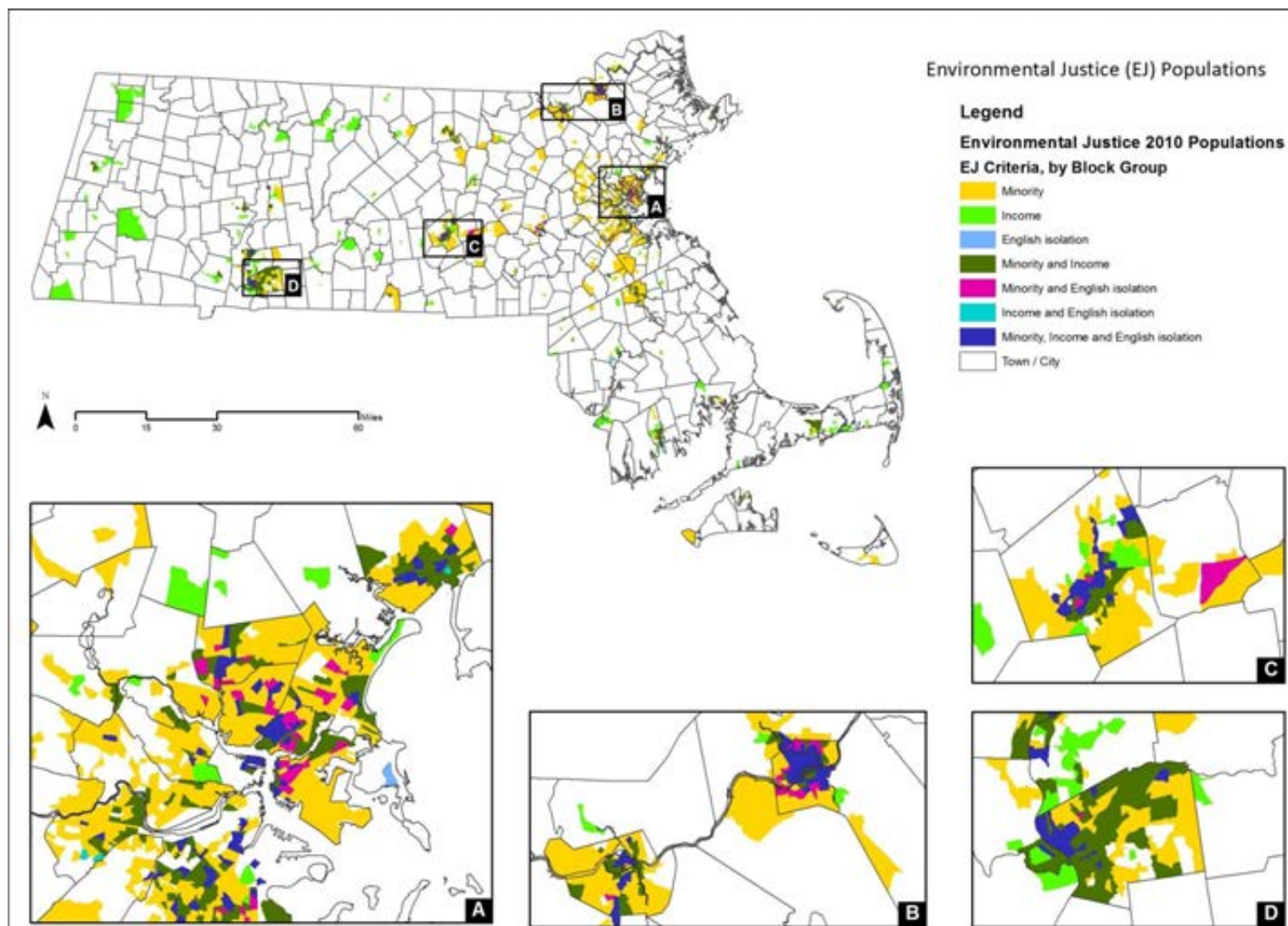
- Annual median household income is equal to or less than 65 percent of the statewide median (\$62,072 in 2010); or
- 25 percent or more of the residents identify as a race other than white; or
- 25 percent or more of households have no one over the age of 14 who speaks English only, or very well (EOEEA, 2018).

EJ communities are vulnerable to hazards due to a range of factors, which may include lack of personal transportation or access to resources, preexisting health conditions, or difficulty translating and understanding emergency alerts or procedures.

There is a total of 1,838 EJ block groups in 138 municipalities in Massachusetts. The population in these block groups accounts for nearly half of the population in these municipalities. In Aquinnah, Chelsea, Everett, Lawrence, and Randolph, 100 percent of the block groups are EJ communities. Many EJ block groups meet more than one EJ criteria, and 38 EJ communities meet all three (income, minority population, English isolation). Figure 2-6 displays EJ communities (EOEEA, 2018).

Refer to Chapter 4 for a discussion of the populations vulnerable to each hazard and its related climate change impacts.

Figure 2-6: Environmental Justice Communities (2010 Census Block Groups)



2.2.2 Housing and Development Highlights

HOUSING

Between 2000 and 2010, the total number of housing units in the state increased by 186,265 units: from 2,621,989 to 2,808,254 units. The average annual increase in housing units during this time was 0.71 percent. The American Community Survey 2012-2016 5-Year Estimates reports that the state has an estimated 2,836,658 units, an increase of approximately 28,400 units from 2010 at a rate of 0.1 percent per year (U.S. Census, 2000; 2010).

Nearly 10 percent of housing units in the state are vacant (see Table 2-6). The high vacancy rates for Barnstable, Dukes, and Nantucket Counties shown in Table 2-6 may reflect the high seasonal populations. Owner-occupancy rates range from a low of 35.8 percent in Suffolk County to a high of 79.2 percent in Barnstable County. Conversely, Suffolk County has the highest percentage of renter-occupied housing units in the state (see Table 2-6).

Table 2-6: Housing Characteristics by County

County	Total Housing Units	Percent of Housing Units that are Vacant	Total Occupied Housing Units	Percent of Housing Units that are Owner Occupied	Percent of Housing Units that are Renter Occupied
Barnstable	161,632	41.6	94,351	79.2	20.8
Berkshire	68,391	19.8	54,854	68.4	31.6
Bristol	231,247	7.9	212,933	62.1	37.9
Dukes	17,536	65.0	6,134	76.5	23.5
Essex	308,459	6.5	288,291	63.2	36.8
Franklin	33,684	9.8	30,389	68.6	31.4
Hampden	192,032	7.7	177,153	61.6	38.4
Hampshire	62,915	7.1	58,448	66.2	33.8
Middlesex	619,399	5.1	587,735	62.4	37.6
Nantucket	11,844	67.6	3,836	63.9	36.1
Norfolk	273,280	4.8	260,061	68.5	31.5
Plymouth	202,564	10.0	182,252	75.9	24.1
Suffolk	324,390	7.6	299,658	35.8	64.2
Worcester	329,285	8.0	302,794	64.7	35.3
Massachusetts	2,836,658	9.8	2,558,889	60.9	37.9

Source: American Community Survey 2012-2016 5-Year Estimates

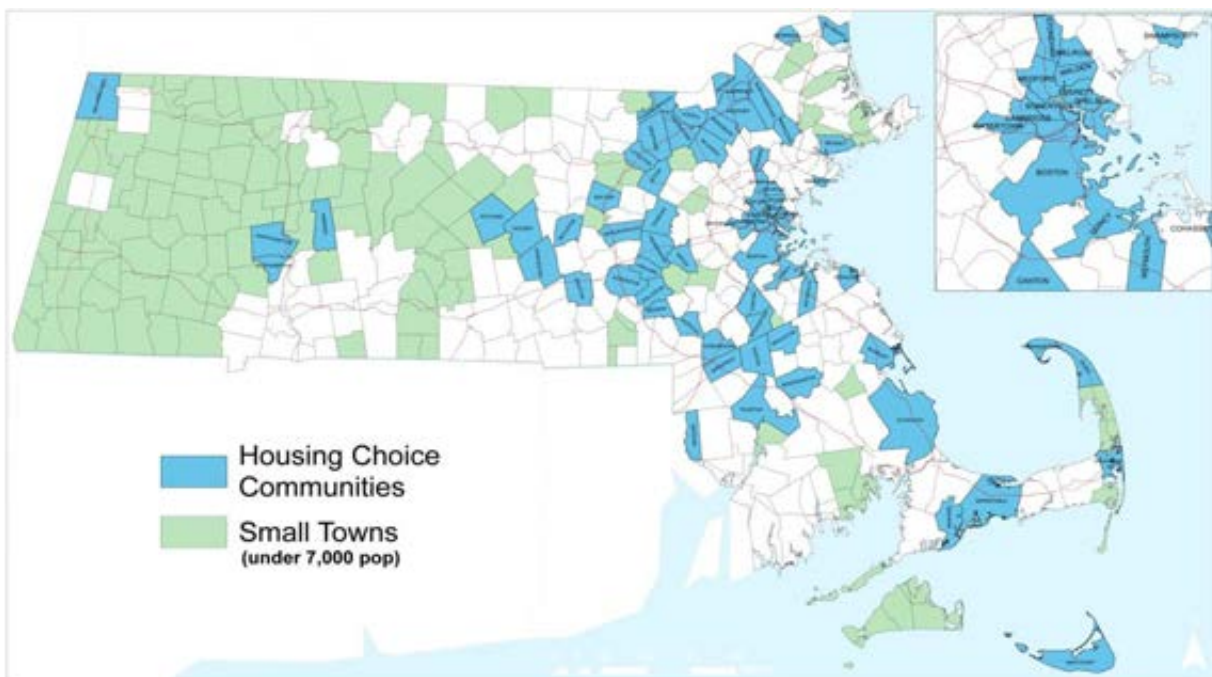
STATEWIDE INITIATIVES, ACCOMPLISHMENTS, AND TRENDS THAT SHAPE THE COMMONWEALTH'S LANDSCAPE

Policies, initiatives, and programs influence development trends and patterns. Targeted economic development, housing programs, transportation improvements, coastal land use planning, and numerous other planning efforts shape the physical landscape of the Commonwealth and influence residential settlement. Examples of statewide initiatives and accomplishments are briefly described in this section. This section is not intended to serve as a comprehensive review of all development initiatives, but to highlight trends and initiatives that have the potential to influence the vulnerability of people, the built environment, and the natural environment to hazards discussed in this SHMCAP.

Housing Choice Initiatives

As part of the Baker-Polito Administration's Housing Choice Initiative, 67 communities have been designated as Housing Choice Communities. This designation is part of a comprehensive effort to create 135,000 new housing units by 2025, while promoting sustainable development that reduces land, energy, and natural resource consumption. Small towns with a population under 7,000 are also eligible for additional funding through the Small Town Housing Choice capital grant program. Figure 2-7 displays Housing Choice Communities and small towns eligible for additional funding (HCI, 2018).

Figure 2-7: Housing Choice Communities and Small Towns



Source: Mass.gov, 2018

Transformative Development Initiative Districts

In 2014, the Commonwealth's economic development and finance authority, MassDevelopment, launched the Transformative Development Initiative (TDI), a place-based development program for Gateway Cities designed to be a tool for economic development. Ten cities were selected for a 3-year TDI pilot program in 2014. Since MassDevelopment initiated a TDI Fellow program in 2015, 11 fellows have been placed in communities to provide assistance. In May of 2018, additional TDI Districts were announced, including Chelsea, Fitchburg, Lawrence, and Worcester; and existing TDI districts in Brockton, Holyoke, Lynn, New Bedford, Pittsfield, and Springfield were extended (MassDevelopment, 2018).

Shoreline Change Project

The coast of Massachusetts continues to be subject to intense development. To assist coastal managers, shorefront landowners, and potential property owners with making informed decisions about coastal land use and development, the Office of Coastal Zone Management (CZM) initiated the Shoreline Change Project in 1989. CZM delineated and mapped shoreline trends from the mid-1800s to 2009, and released updated shoreline data in 2013. This shoreline analysis found that the highest statistically significant long-term (mid-1900s to the early 2000s) rates of erosion occurred on Nantucket, Outer Cape Cod, and Martha's Vineyard. The highest statistically significant rates of erosion over the short term (between 1970 and 1982 to the early 2000s) occurred on the North Shore, Outer Cape Cod, and Nantucket. The Shoreline Change Project presents shoreline change rates at 50-meter intervals along ocean-facing sections of the coast (USGS, 2013). Updated rates of change will be released in 2018, and this information can be used to understand historical and recent migration of shorelines, hot spots of erosion, and the influence of coastal structures (e.g., seawalls and revetments), and to guide smart development (CZM, 2018a).

Port and Harbor Planning Program

As part of the CZM Port and Harbor Planning Program, Massachusetts has 10 Designated Port Areas (DPAs): Gloucester Inner Harbor, Salem Harbor, Lynn, Mystic River, Chelsea Creek, East Boston, South Boston, Weymouth Fore River, New Bedford-Fairhaven, and Mount Hope Bay. DPAs have been designated to promote and protect water-dependent industrial uses. CZM works with municipalities to take a comprehensive approach to planning for DPAs through a DPA Master Plan, which is one component of a Municipal Harbor Plan. The primary goals of Port and Harbor Planning are to help ensure that waterfront areas in the Commonwealth grow in a safe, environmentally sound, and economically prosperous manner; and to balance potentially competing uses in a port or harbor (CZM, 2018b).

Land Conservation Trends

As of May 2018, almost 26 percent of the Commonwealth's 5 million acres of land were protected as conservation or parkland. Between 2007 and 2018, more than 162,479 acres (254 square miles) of land were permanently conserved. For a sense of scale, Suffolk County is 58 square miles.

Community Compact Initiative

In 2015, Governor Baker established the Community Compact Initiative to give cities and towns the chance to make needed improvements in a range of areas through collaboration with and support from the Commonwealth. Communities that participate choose one or more best practices, which include energy and environment, housing and economic development, transportation and citizens' safety, and regionalization/shared services.

Massachusetts Downtown Initiative

The Department of Housing and Community Development provides a range of services and assistance to communities seeking help on how to revitalize their downtowns through the Massachusetts Downtown Initiative. In 2016, 13 communities were awarded technical assistance grants for engaging in revitalization in areas that included design, business improvement district management, economics of downtown, parking, small business support, and wayfinding. The 2016 grantees were: Auburn, Holliston, Hudson, Middleborough, Saugus, Stoughton, Beverly, Essex, Sturbridge, Stoneham, Agawam, Wellesley, and Woburn.

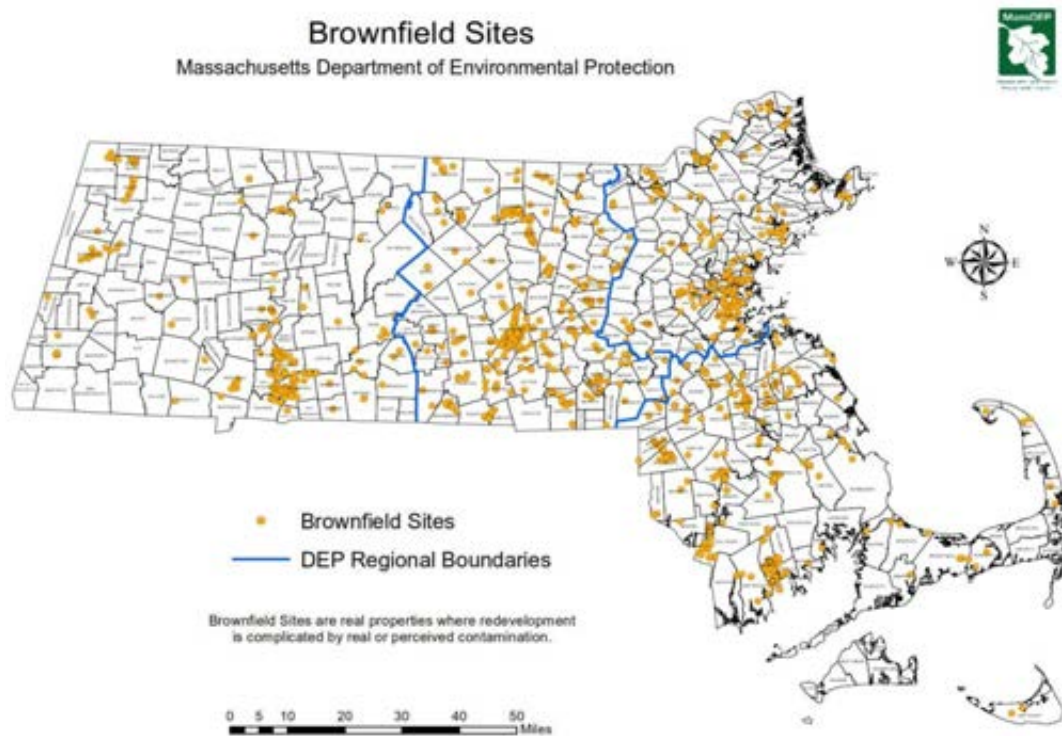
Last Mile Infrastructure Grant Program

The Last Mile Infrastructure Grant Program, administered by the Executive Office of Housing and Economic Development, aims to increase access to broadband in communities that are unserved or underserved. The program has provided grants since its inception in 2015. These grants have resulted in increased access to the internet and to information about hazards and emergency response (EOHED, 2018).

Brownfields Cleanup and Redevelopment

Since 1993, more than 35,000 brownfields sites have been cleaned up in Massachusetts. As of January 2017, the Department of Environmental Protection (DEP) brownfields list identifies more than 1,000 sites across the state (displayed on Figure 2-8). The presence of contamination on these sites may exacerbate the impacts of natural hazards.

Figure 2-8: Known Brownfields Sites in Massachusetts



Source: DEP, 2018

Transportation Trends

Sustainable Development

The Massachusetts Department of Transportation (MassDOT) supports climate resilience through investments that improve system reliability and modernize the Commonwealth's transportation infrastructure. Approximately 79 percent of MassDOT's proposed \$17.3 billion in capital spending over the next 5 years is targeted at these two priorities. This includes improving interstate highway and airport pavement conditions, bridge reconstruction and replacement, new and rehabilitated revenue vehicles for the Massachusetts Bay Transit Authority (MBTA) and Regional Transit Authorities (RTAs), and upgrades to track and signal and power systems across the commuter rail and transit system. MassDOT continues to conduct climate vulnerability assessments that will help target future expenditure on assets that are most at risk from a changing climate.

MassDOT's investments in infrastructure can also have a measured impact on GHG emissions. By improving walking and cycling facilities, MassDOT makes short trips by these zero carbon modes a safer, more realistic option for Massachusetts residents and communities. To this end, MassDOT has programmed \$240 million dollars for bicycle and pedestrian infrastructure over the next 5 years. In addition, by expanding transit in places where transit use is financially

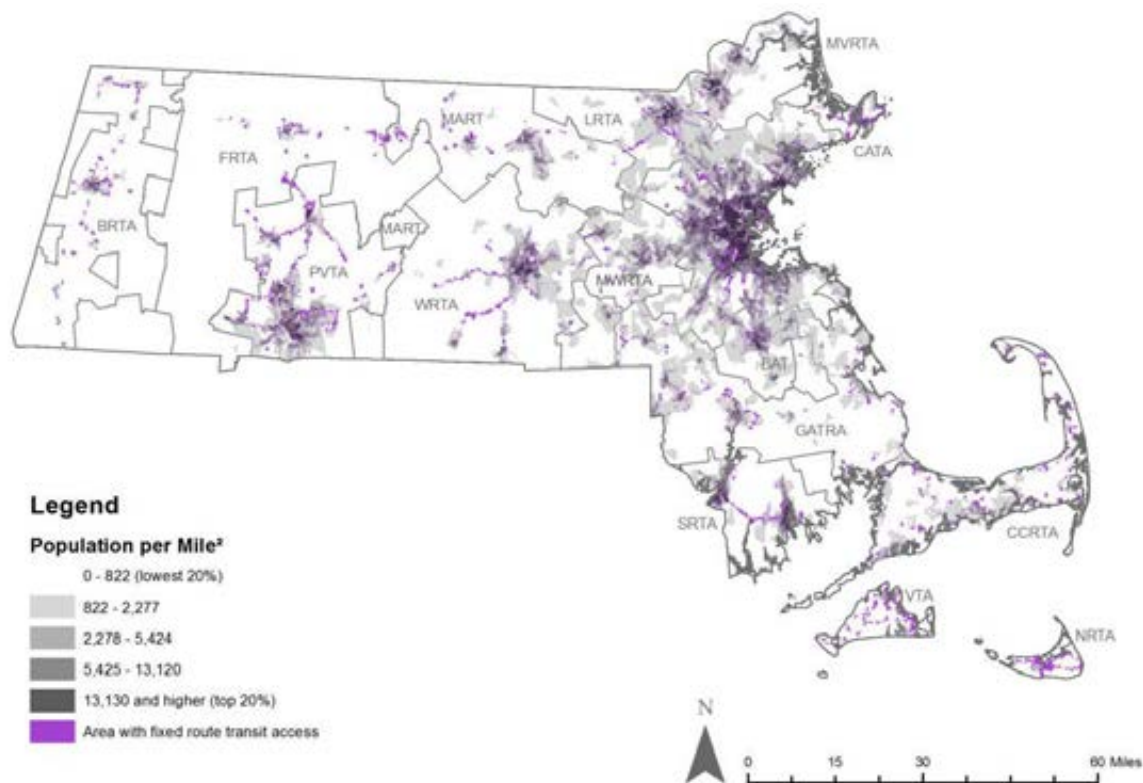
sustainable and where transit-oriented development will be encouraged, MassDOT can support land use change that makes driving less necessary.

Access to Transit

According to the MassDOT Annual Performance Tracker, residents' access to transit (fixed-route bus service) increased 1.4 percent from 2016 to 2017. Figure 2-9 displays statewide access to transit. More than 52.8 percent of residents have access to transit (MassDOT, 2018), and proximity to transit is increasingly desired by residents (MAPC, 2016). As of 2017, MBTA operated 175 bus routes. However, annual ridership on fixed-route buses decreased for 8 out of the 15 RTAs from 2012 to 2016. Similarly, MBTA ridership decreased by 1 percent from 2016 to 398 million in 2017 (MassDOT, 2018). The 2017-2021 State Transportation Improvement Plan (STIP) includes \$2.3 billion for transit systems statewide (MassDOT, 2016).

Between 2010 and 2016, there was a 17.5 percent increase in Amtrak ridership at 14 stations in the state. Priority projects for the future include establishing more frequent rail service from New Haven into Springfield, and extending passenger rail service from Springfield to Greenfield (MassDOT, 2018).

Figure 2-9: Population Density and Access to Fixed-Route Transit



Source: MassDOT, 2018

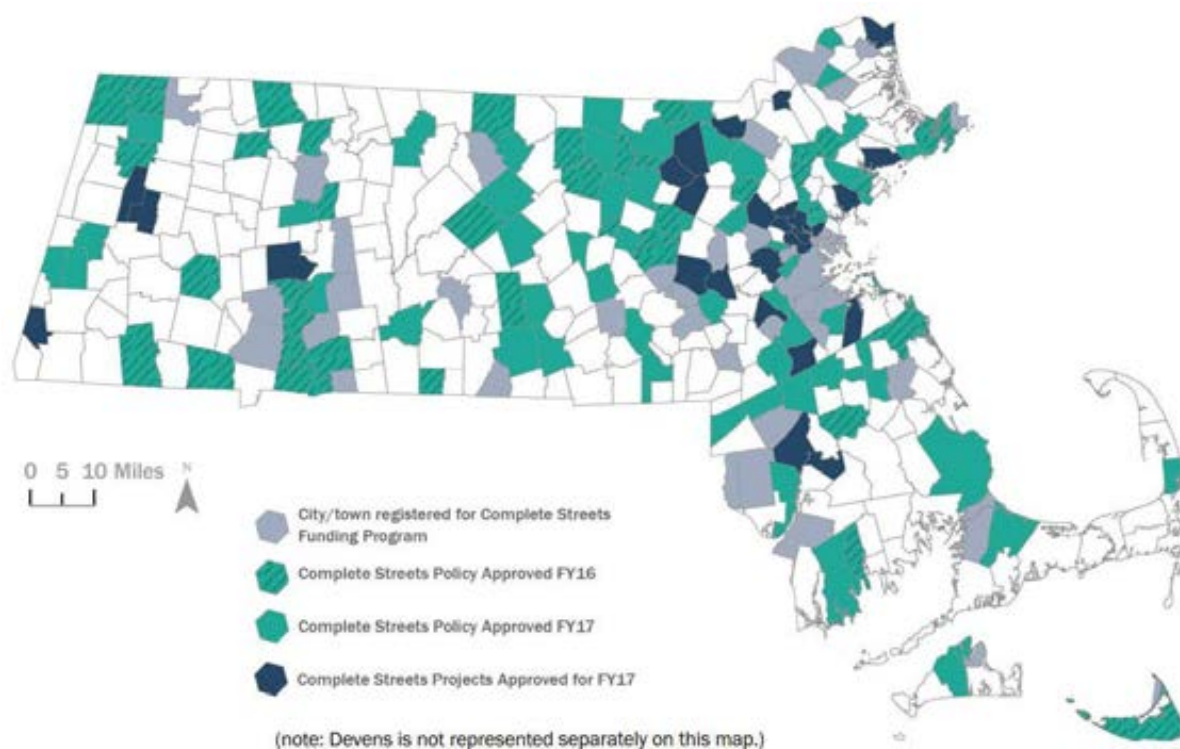
Bridge Improvements

Nearly 9 percent of Massachusetts bridges (more than 400) are considered structurally deficient (MAPC, 2018). A total of \$760 million has been allocated for improvements to bridge health in the STIP (MassDOT, 2016). MassDOT owns 3,491 bridges in the state (MassDOT, 2018).

Complete Streets

A component of a sustainable community, Complete Streets is a program to provide safe access for all users. Figure 2-10 displays communities with Complete Streets policies and projects.

Figure 2-10: Communities with Complete Streets Policies and Projects



Source: MassDOT, 2018

Building Resilience at the Local and Regional Level

Communities and regional planning agencies are increasingly placing emphasis on the need for resiliency planning. For example, the City of Boston made climate adaptation a key theme in its recently adopted citywide plan, and continues to invest heavily in its Climate Ready Boston initiative to help Boston prepare for the future impacts of climate change. Similarly, the Metropolitan Area Planning Council's (MAPC's) goal is that municipalities will take a long-term perspective on growth that considers climate change when making development and policy decisions. In its Regional Indicators report, MAPC highlights the need for a collaborative approach to prevent damage from future disasters, and to build resilience. Further, MAPC aims

to mitigate hazards by having no structurally deficient dams and limited new growth in floodplains (MAPC, 2008).

The Commonwealth provides technical assistance and funding to municipalities for resiliency planning through various programs, including the CZM Coastal Resilience Grant Program and the Municipal Vulnerability Preparedness (MVP) Program. The CZM Coastal Resilience Grant Program provides the 78 coastal communities with funding to advance local efforts to address coastal flooding, erosion, and sea level rise through the StormSmart Coasts Program. As of June 2018, there are 156 communities participating in the MVP Program that have completed or are in the process of completing climate change vulnerability assessments. Refer to *Chapter: 10 Coordination of Local Hazard Mitigation and Climate Adaptation Planning* for additional information about this program.

2.3 Climate Change Projections

2.3.1 Resilient MA Climate Change Clearinghouse for the Commonwealth

In 2017, the Commonwealth launched the Massachusetts Climate Change Clearinghouse ([resilient MA](#)), an online gateway for policymakers,



local planners, and the public to identify and access climate data, maps, websites, tools, and documents on climate change adaptation and mitigation. The goal of [resilient MA](#) is to support scientifically sound and cost-effective decision-making, and to enable users to plan and prepare for climate change impacts.

The [resilient MA](#) site provides access to resources relevant to adaptation and building resiliency for climate change in Massachusetts. This includes information about GHG emissions and atmospheric concentrations, projected temperature and precipitation changes, climate change impacts such as sea level rise and extreme weather events, and other changes. It also catalogs specific vulnerabilities, risks, and strategies for and across industry sectors (including agriculture, forestry, local government, education, energy, recreation, and transportation) and for local governance priorities, including public health, public safety/emergency management, infrastructure, coastal zones, natural resources/habitats, and water resources.

The website's target audiences are local planners, decision makers, and state agency staff. It is intended to help decision makers identify vulnerable infrastructure, residential areas, and ecosystems; evaluate the risks posed by climate change; and develop strategies and implementation plans for their community. It is also a resource for policymakers, analysts, scientists, planners, businesses, and the general public.

2.3.2 Massachusetts Climate Projections

Changes in precipitation, temperature, sea level rise, and storm surge due to climate change are summarized in this section. Climate projections are derived from emerging research conducted by the Northeast Climate Adaptation Science Center at the University of Massachusetts, Amherst. The data used in downscaled projections for Massachusetts are based on simulations from the latest generation of climate models included in the Coupled Model Intercomparison Project Phase 5, which form the basis of projections summarized in the Intergovernmental Panel on Climate Change Fifth Assessment Report (2013). The projections available through [resilient MA](#) and summarized in this SHMCAP represent the best estimates for a range of scenarios for how GHG emissions may change over time, based on human decision-making. Additional information about the data and climate models is available on the [resilient MA](#) website.

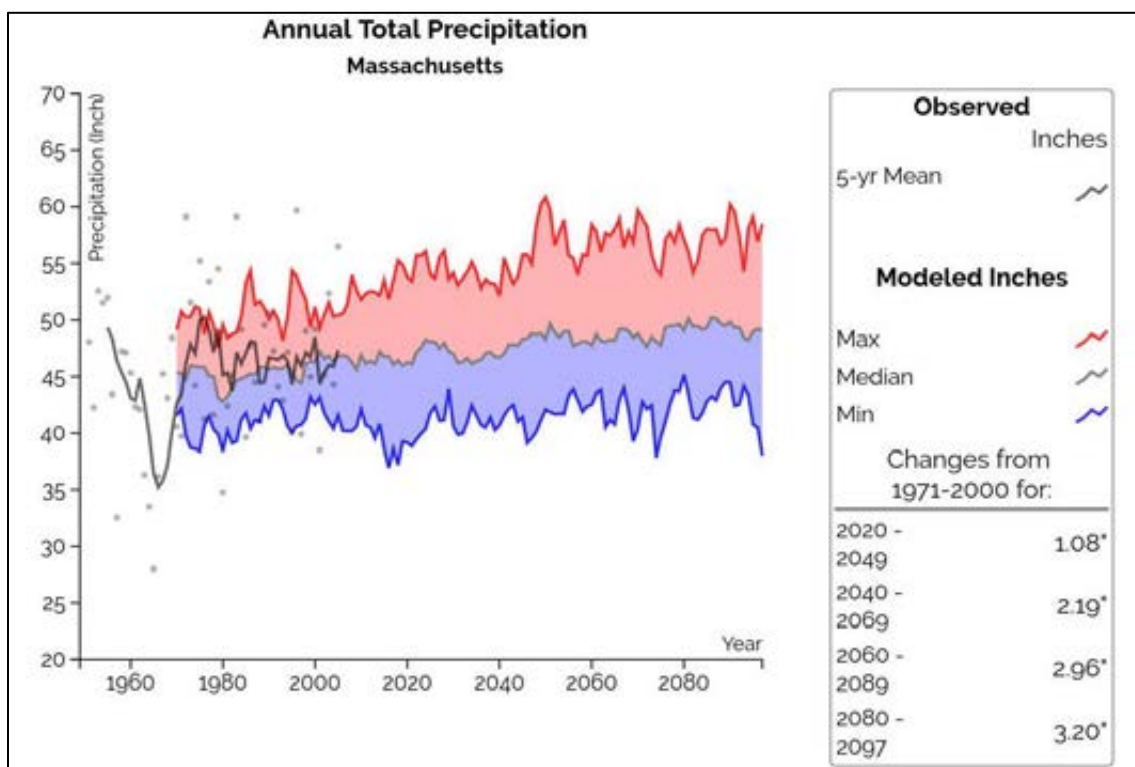
PRECIPITATION

Precipitation is expected to increase over this century. Total annual precipitation is projected to increase by 1 to 6 inches by mid-century, and by 1.2 to 7.3 inches by the end of this century (see Figure 2-11). This will result in up to 54.3 inches of rain per year, compared to the 1971-2001 average annual precipitation rate of 47 inches per year in Massachusetts. Precipitation during winter and spring is expected to increase, while precipitation during summer and fall is expected to decrease over this century.

By mid-century, the state can expect to receive greater than 1 inch of rain on an average of up to 10 days per year. The number of days with rainfall accumulation over 1 inch may reach 11 days by the end of this century, which represents an increase of 4 days from the observed average between 1971 and 2000.

The number of continuous dry days is projected to increase to nearly 20 days per year at the end of this century, compared to the observed average of 16.64 days per year from 1971 to 2001. Under a lower emissions scenario, however, little change in the average time between rain events is expected over this century (see Table 2-7). The eastern half of the state is expected to experience a greater number of consecutive dry days than the western side of the state.

Figure 2-11: Annual Total Precipitation



Source: resilient MA, 2018

Table 2-7: Continuous Dry Days by Planning Year

Planning Year	2030s	2050s	2070s	2090s
Projected Range of Consecutive Dry Days	16.44-17.94	16.34-18.64	15.94-18.94	16.34-19.64

Source: resilient MA, 2018

TEMPERATURE

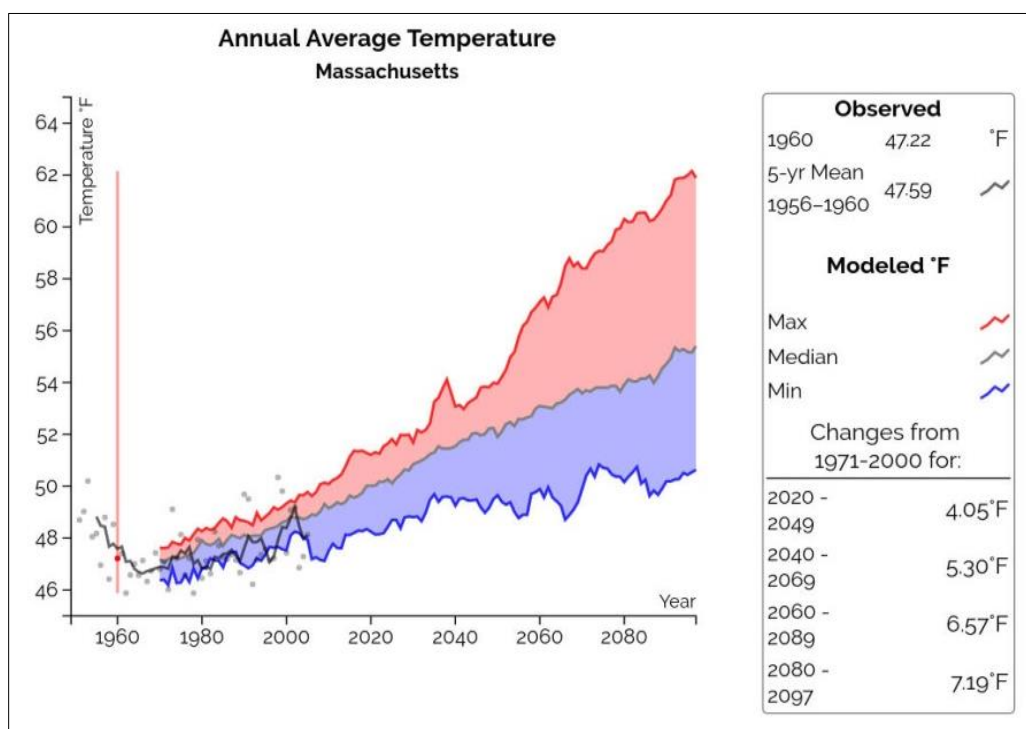
The average, maximum, and minimum temperatures in Massachusetts are likely to increase significantly over the next century (resilient MA, 2018). Table 2-8 displays the projected increase in annual and seasonal temperature by mid-century and the end of this century, compared to the baseline average temperature from 1971-2000. The average annual temperature is projected to increase from 47.6 degrees Fahrenheit (°F) to 50.4 to 53.8°F (2.8 to 6.2°F change) by mid-century, and to 51.4 to 58.4°F (3.8 to 10.8°F change) by the end of this century. This trend is shown on Figure 2-12. Winter temperatures are projected to increase at a greater rate than spring, summer, or fall. By the end of this century, the long-term average minimum winter temperature of 17.1°F is projected to increase by 4.6 to 11.4°F (up to a 66 percent increase),

Table 2-8: Maximum Daily Projected Temperature Changes through 2100

Climate Indicator		Observed Value 1971-2000 Average	Mid-Century Projected and Percent Change in 2050s (2040-2069)	End of Century Projected and Percent Change in 2090s (2080-2099)*
Average Temperature	Annual	47.6 °F	Increase by 2.8 to 6.2 °F Increase by 6 to 13 %	Increase by 3.8 to 10.8 °F Increase by 8 to 23 %
	Winter	26.6 °F	Increase by 2.9 to 7.4 °F Increase by 11 to 28 %	Increase by 4.1 to 10.6 °F Increase by 15 to 40 %
	Spring	45.4 °F	Increase by 2.5 to 5.5 °F Increase by 6 to 12 %	Increase by 3.2 to 9.3 °F Increase by 7 to 20 %
	Summer	67.9 °F	Increase by 2.8 to 6.7 °F Increase by 4 to 10 %	Increase by 3.7 to 12.2 °F Increase by 6 to 18 %
	Fall	50 °F	Increase by 3.6 to 6.6 °F Increase by 7 to 13 %	Increase by 3.9 to 11.5 °F Increase by 8 to 23 %
Maximum Temperature	Annual	58.0 °F	Increase by 2.6 to 6.1 °F Increase by 4 to 11 %	Increase by 3.4 to 10.7 °F Increase by 6 to 18 %
	Winter	36.2 °F	Increase by 2.5 to 6.8 °F Increase by 7 to 19 %	Increase by 3.5 to 9.6 °F Increase by 10 to 27 %
	Spring	56.1 °F	Increase by 2.3 to 5.4 °F Increase by 4 to 10 %	Increase by 3.1 to 9.4 °F Increase by 6 to 17 %
	Summer	78.9 °F	Increase by 2.6 to 6.7 °F Increase by 3 to 8 %	Increase by 3.6 to 12.5 °F Increase by 4 to 16 %
	Fall	60.6 °F	Increase by 3.4 to 6.8 °F Increase by 6 to 11 %	Increase by 3.8 to 11.9 °F Increase by 6 to 20 %
Minimum Temperature	Annual	37.1 °F	Increase 3.2 to 6.4 °F Increase by 9 to 17 %	Increase by 4.1 to 10.9 °F Increase by 11 to 29 %
	Winter	17.1 °F	Increase by 3.3 to 8.0 °F Increase by 19 to 47 %	Increase by 4.6 to 11.4 °F Increase by 27 to 66 %
	Spring	34.6 °F	Increase by 2.6 to 5.9 °F Increase by 8 to 17 %	Increase by 3.3 to 9.2 °F Increase by 9 to 26 %
	Summer	56.8 °F	Increase by 3 to 6.9 °F Increase by 5 to 12 %	Increase by 3.9 to 12 °F Increase by 7 to 21 %
	Fall	39.4 °F	Increase by 3.5 to 6.5 °F Increase by 9 to 16 %	Increase by 4.0 to 11.4 °F Increase by 10 to 29 %

* A 20-yr mean is used for the 2090s because the climate models end at 2100.

Source: resilient MA, 2018

Figure 2-12: Projected Annual Average Temperature

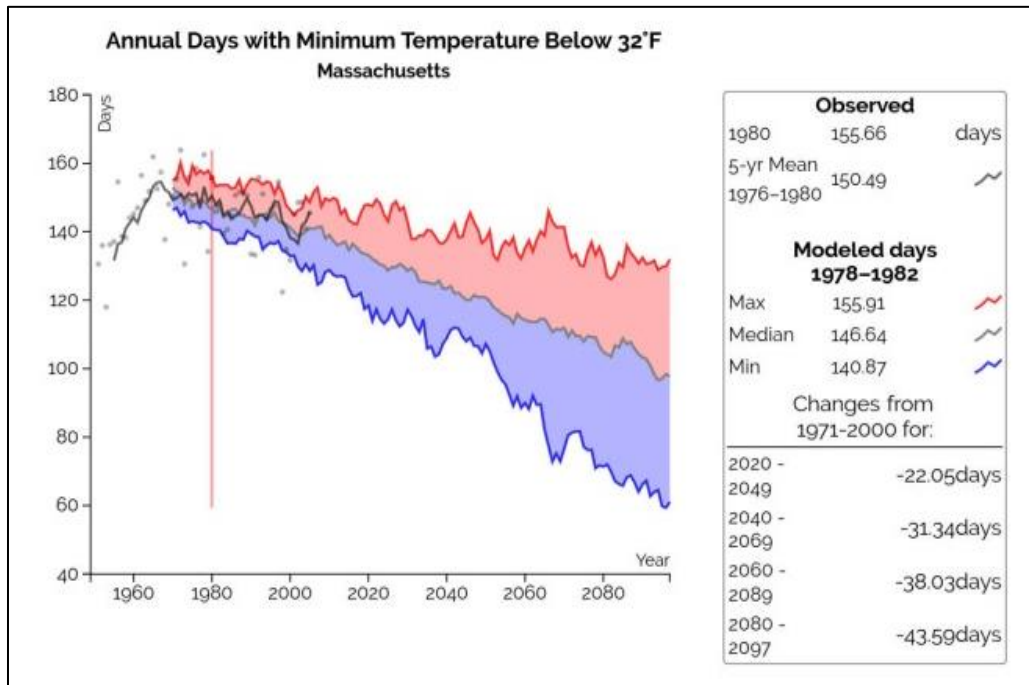
Source: resilient MA, 2018

resulting in a minimum winter temperature of between 21.7°F and 28.5°F. The number of days per year with daily minimum temperatures below freezing (32°F) is projected to decrease by 19 to 40 days (down to 106 days total) by the 2050s, and 24 to 62 days (down to 84 days total) by the 2090s, from the average observed range from 1971 to 2000. Figure 2-13 displays this trend of fewer days below freezing.

Although minimum temperatures are projected to increase at a greater rate than maximum temperatures in all seasons, significant increases in maximum temperatures are anticipated. Summer highs are projected to reach 85.6°F by mid-century, and 91.4°F by the end of this century, compared to the historical average of 78.9°F. Figure 2-14 displays the projected increase in number of days per year over 90°F. The number of days per year with daily maximum temperatures over 90°F is projected to increase by 7 to 26 days (up to 31 days total) by the 2050s, and by 11 to 64 days (up to 69 days total) by the 2090s, compared to the average observed range from 1971 to 2000 of 5 days per year. Maximum temperatures in winter are projected to increase by 9.6°F by the end of this century.

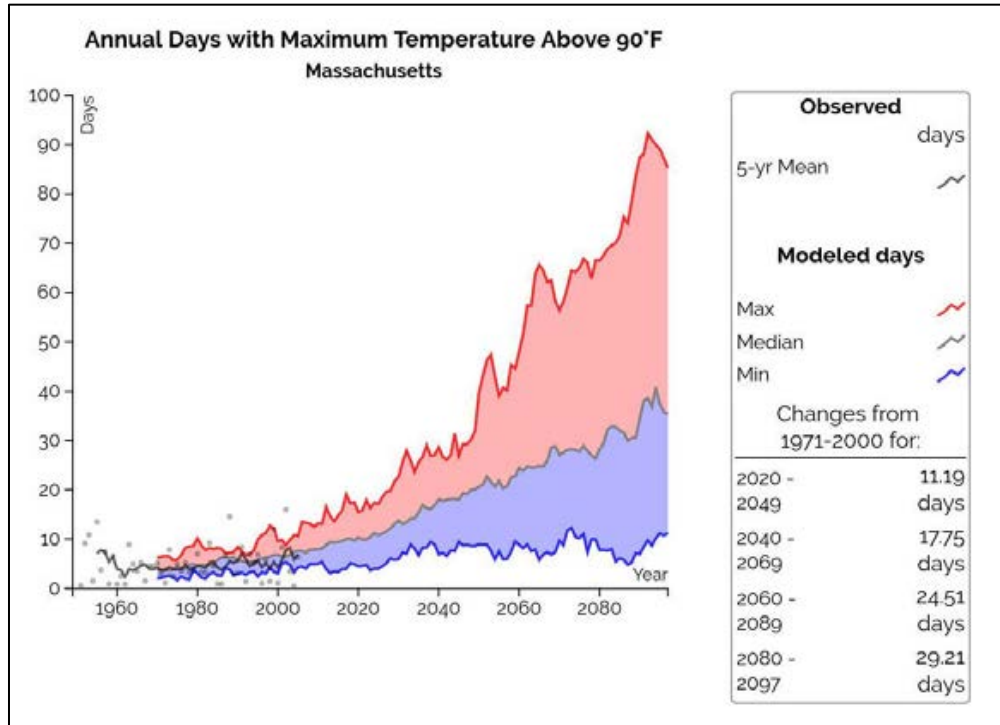
As temperatures increase, the growing season will expand. The number of growing degree days is projected to be 23 to 52 percent higher at the end of this century relative to the 1971-2000 average, as shown on Figure 2-15.

Figure 2-13: Projected Annual Days with Temperature Below 32°F

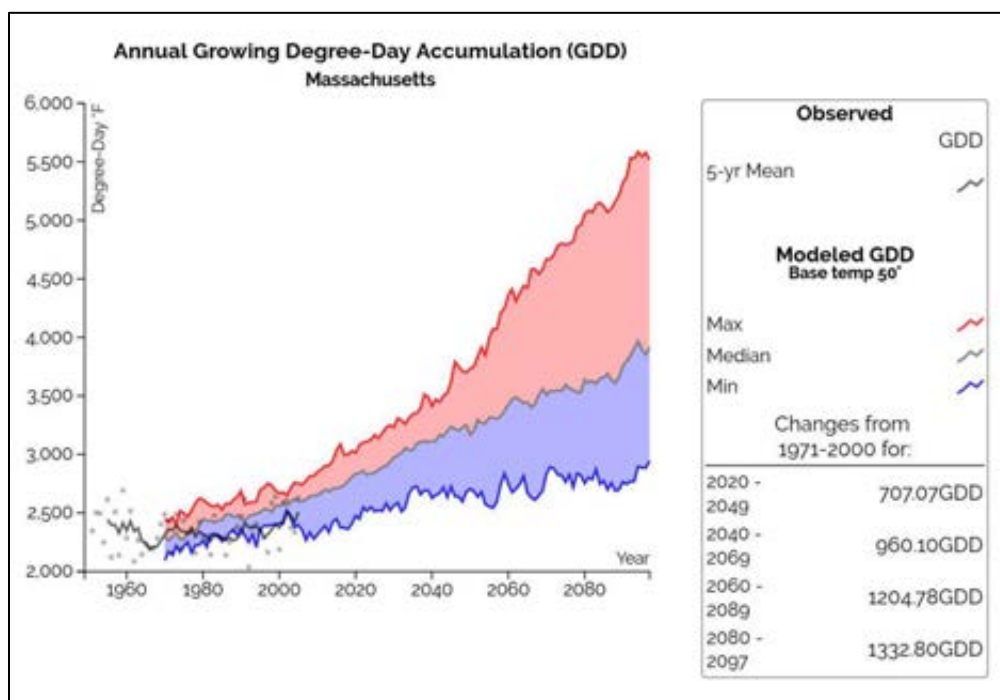


Source: resilient MA, 2018

Figure 2-14: Projected Annual Days with Temperature Above 90°F



Source: resilient MA, 2018

Figure 2-15: Projected Annual Growing Degree-Day Accumulation

Source: resilient MA, 2018

SEA LEVEL RISE

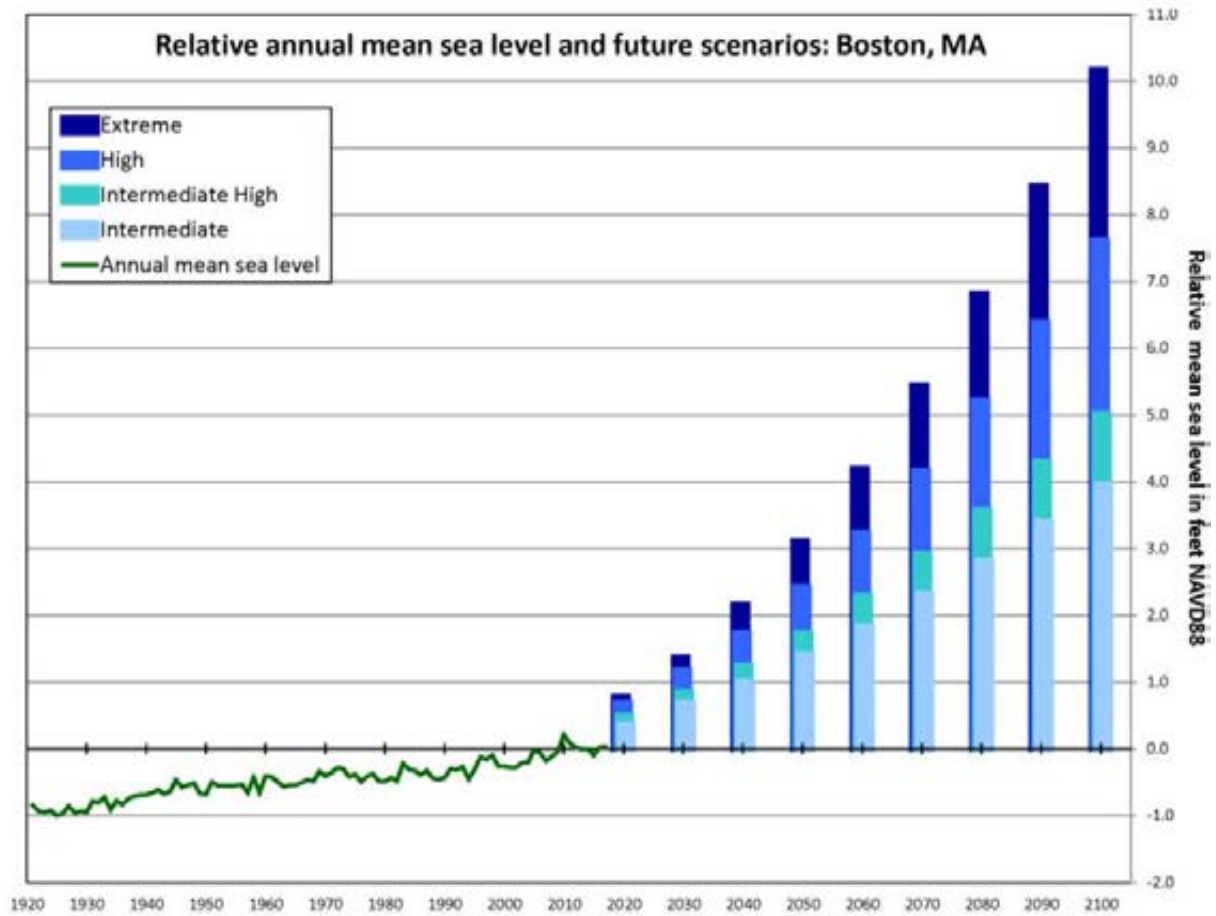
The rate of sea level rise is projected to increase with climate change. Along the Boston coast, sea level rise is expected to reach 2.4 feet by 2050 and 7.6 feet by 2100 under a high scenario (see Table 2-9). Figures 2-16 through 2-18 display similar relative mean sea level and future scenarios at three tide stations in the state: Boston, Woods Hole, and Nantucket. Refer to the [Massachusetts Climate Change Projections - Statewide and for Major Drainage Basins](#) for additional details.

Table 2-9: Northeast Climate Adaptation Science Center Relative Mean Sea Level Projections for Boston, MA, Tide Station

Boston Relative Mean Sea Level (feet NAVD88)									
Scenario	Summary	2030	2040	2050	2060	2070	2080	2090	2100
Intermediate	Intermediate scenario primarily based on medium and high emissions scenarios and accounts for possible higher ice sheet contributions to sea level rise	0.7	1.0	1.4	1.8	2.3	2.8	3.4	4.0
Intermediate-High	Intermediate-high scenario primarily based on high emissions scenarios and accounts for possible higher ice sheet contributions to sea level rise	0.8	1.2	1.7	2.3	2.9	3.6	4.3	5.0
High	High scenario primarily based on high emissions scenarios and accounts for possible higher ice sheet contributions to sea level rise	1.2	1.7	2.4	3.2	4.2	5.2	6.4	7.6
Extreme (Maximum physically plausible)	Highest scenario primarily based on high emissions scenarios and accounts for possible higher ice sheet contributions to sea level rise and consistent with estimates of physically possible "worst case"	1.4	2.2	3.1	4.2	5.4	6.8	8.4	10.2

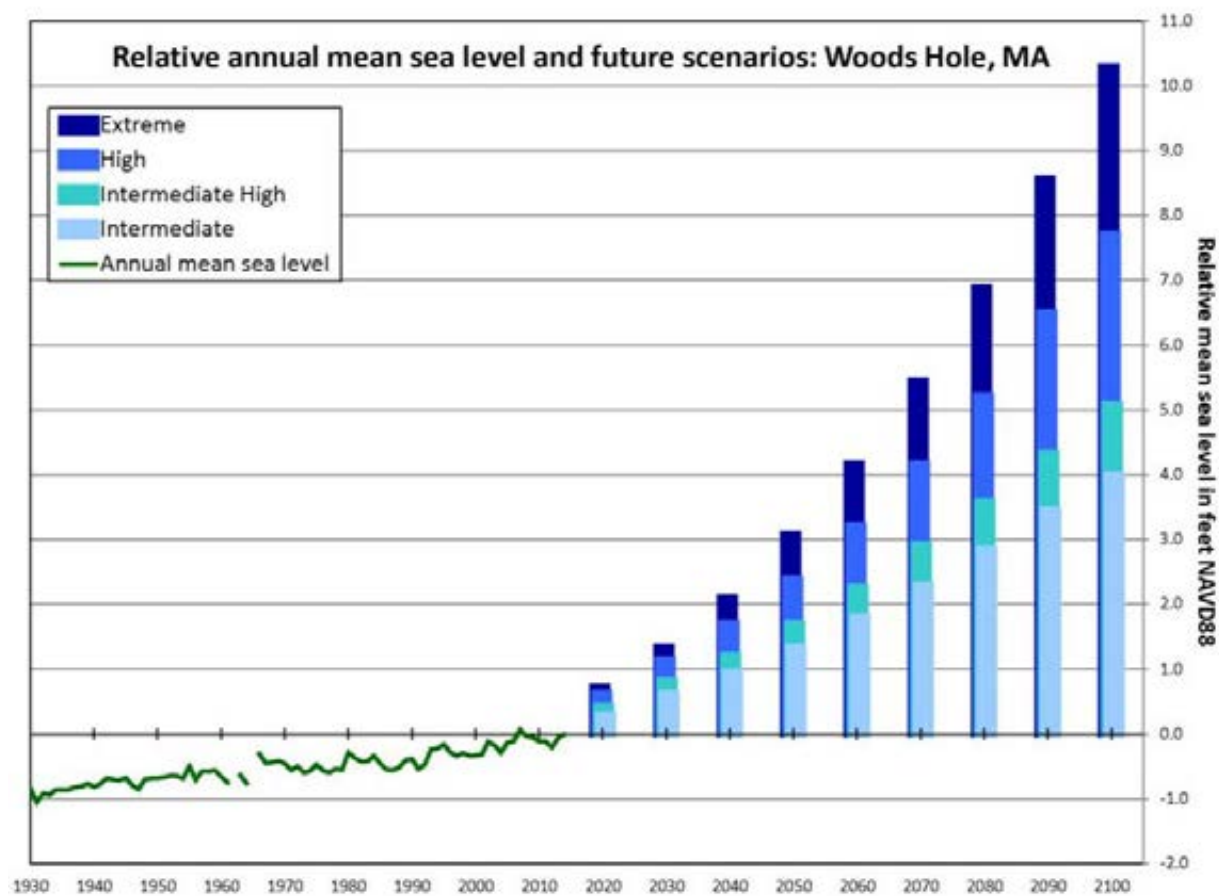
Source: resilient MA, 2018

Figure 2-16: Relative Mean Sea Level and Future Scenarios for Boston, MA



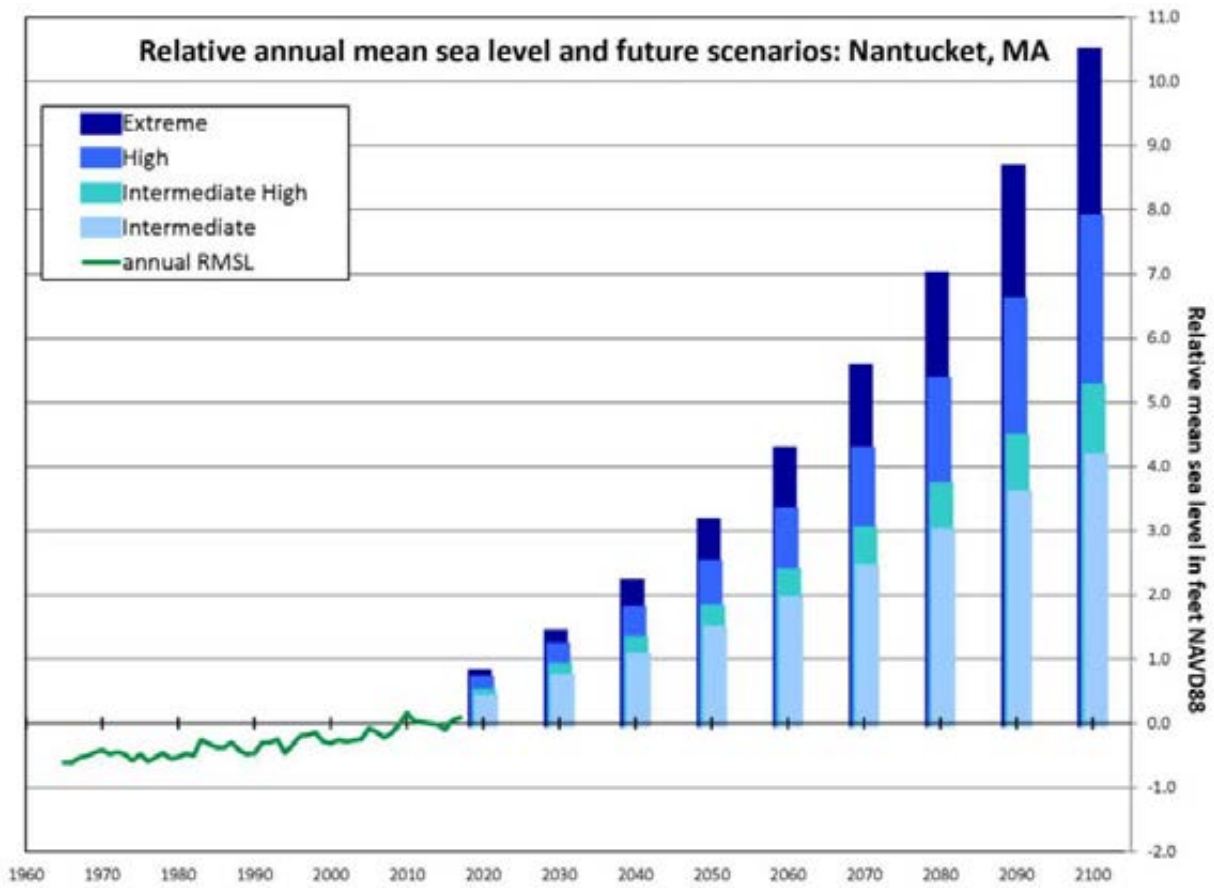
Source: resilient MA, 2018

Figure 2-17: Relative Mean Sea Level and Future Scenarios for Woods Hole, MA



Source: resilient MA, 2018

Figure 2-18: Relative Mean Sea Level and Future Scenarios for Nantucket, MA



Source: resilient MA, 2018

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3. Introduction to Risk Assessment

3.1 Natural Hazard Identification Process

To identify natural hazards of concern for the Hazard Identification and Risk Assessment (HIRA), the Project Management Team (PMT) and its consulting team reviewed the 2013 State Hazard Mitigation Plan (SHMP), the 2017 Massachusetts Threat and Hazard Identification and Risk Assessment, and the 2017 Commonwealth of Massachusetts Comprehensive Emergency Management Plan. Natural hazards are natural events that threaten lives, property, and other assets. Often, natural hazards can be predicted. They tend to occur repeatedly in the same geographical locations because they are related to weather patterns or physical characteristics of an area. The assessment conducted for the 2013 SHMP recognized the following 11 natural hazards that could potentially impact the Commonwealth of Massachusetts:

- Coastal Erosion
- Dam Failure
- Earthquake
- Fire
- Flood
- Hurricane
- Landslide
- Nor'easter
- Severe Weather
- Severe Winter
- Tsunami

All of the hazards identified and assessed in the 2013 SHMP were determined to be relevant for the HIRA for the 2018 State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) through a PMT kickoff meeting and subsequent risk assessment methodology development. However, some of these hazards were reclassified and/or regrouped (for example, “flood” was broken out into separate “inland flooding” and “coastal flooding” hazard profiles), and a new hazard—invasive species—was added. The natural hazards assessed in this 2018 SHMCAP are identified on the following page.

A key distinction between the 2013 HIRA and the 2018 HIRA is the inclusion of an additional lens through which natural hazards were assessed: climate change, or the statistically significant variation in climate data or patterns over multiple decades due to climate variability or human activity. The Northeast Climate Adaptation Science Center (NE CASC) developed downscaled climate data that were used in the development of this plan and risk assessment, and form a new basis and format for the categorization of natural hazards as they relate to the primary climate change interactions discussed in Section 3.2.

The 2018 hazard profiles are based on a wide range of information and data, including best available science and most current information on hazards, impacts, and the vulnerability of jurisdictions. As part of the SHMCAP planning process, the Massachusetts Emergency Management Agency (MEMA) undertook a review of more than 20 recently approved local hazard mitigation plans, and identified and synthesized common vulnerabilities from these plans for each hazard recognized in the SHMCAP (see *Chapter: 10 Coordination of Local Hazard Mitigation and Climate Adaptation Planning* for additional detail). This information from local plans was also considered in development of the hazard profiles. The primary data collection window for this plan was from May 1 through August 18, 2017. In some sections, supplemental data were integrated into the plan for the purpose of capturing some of the significant weather events that occurred in the winter of 2017-2018, as well as other data that became available following the primary data collection window.

State facilities data used in the risk assessment were provided by Division of Capital Asset Management and Maintenance (DCAMM). The PMT asked that each hazard profile be revised to include significant hazard events that have occurred since the last plan update, include new hazard zone maps, incorporate the likely impacts of climate change on each hazard, and update other information as necessary. Subject-matter experts from various disciplines provided relevant data, including updated studies and reports, and reviewed and updated the completed hazard profiles. This expert review enhanced the accuracy and relevance of information; validated the criteria used to assess vulnerability; and enabled conformity with federal requirements. Extensive geographic information system (GIS) data from state, regional, and local sources were used. These data sources are detailed in the risk assessment methodology provided in Appendix A.

Natural Hazards Assessed



Inland Flooding



Tsunami



Severe Winter Storm



Drought



**Average/Extreme
Temperatures**



Tornadoes



Landslide



Wildfires



Other Severe Weather



Coastal Flooding



Invasive Species



Earthquake



Coastal Erosion



Hurricanes/Tropical Storms

3.2 Climate Change and Natural Hazard Taxonomy

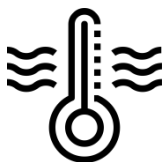
The HIRA is organized based on primary climate change interactions. A categorization of traditional natural hazards, within the context of climate change, was included to demonstrate the connections between traditional natural hazard analysis and climate change projections. This categorization also aligns with the four climate change categories included on the Commonwealth's resilient MA Climate Change Clearinghouse website (<http://www.resilientma.org/>). Those categories are illustrated as follows.



Changes in Precipitation: Changes in the amount, frequency, and timing of precipitation—including both rainfall and snowfall—are occurring across the globe as temperatures rise and other climate patterns shift in response.



Sea Level Rise: Climate change will drive rising sea levels, and rising seas will have wide-ranging impacts on communities, natural resources, and infrastructure along the Commonwealth's 1,519 tidal shoreline miles.





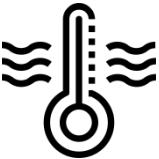

Rising Temperatures: Average global temperatures have risen steadily in the last 50 years, and scientists warn that the trend will continue unless greenhouse gas emissions are significantly reduced. The 9 warmest years on record all occurred in the last 20 years (2017, 2016, 2015, 2014, 2013, 2010, 2009, 2005, and 1998), according to the U.S. National Oceanographic and Atmospheric Administration (NOAA).



Extreme Weather: Climate change is expected to increase extreme weather events across the globe, as well as right here in Massachusetts. There is strong evidence that storms—from heavy downpours and blizzards to tropical cyclones and hurricanes—are becoming more intense and damaging, and can lead to devastating impacts for residents across the state.

The hazards presented in this risk assessment, and the order in which they appear, are based on the taxonomy presented in Table 3-1.

Table 3-1: Climate Change and Natural Hazard Taxonomy

Primary Climate Change Interaction	Natural Hazard	Other Climate Change Interactions	Representative Climate Change Impacts
 Changes in Precipitation	Inland Flooding	Extreme Weather	Flash flooding, urban flooding, drainage system impacts (natural and human-made), lack of groundwater recharge, impacts to drinking water supply, public health impacts from mold and worsened indoor air quality, vector-borne diseases from stagnant water, episodic drought, changes in snow-rain ratios, changes in extent and duration of snow cover, degradation of stream channels and wetland
	Drought	Rising Temperatures, Extreme Weather	
	Landslide	Rising Temperatures, Extreme Weather	
 Sea Level Rise	Coastal Flooding	Extreme Weather	Increase in tidal and coastal floods, storm surge, coastal erosion, marsh migration, inundation of coastal and marine ecosystems, loss and subsidence of wetlands
	Coastal Erosion	Changes in Precipitation, Extreme Precipitation	
	Tsunami	Rising Temperatures	
 Rising Temperatures	Average/Extreme Temperatures	N/A	Shifting in seasons (longer summer, early spring, including earlier timing of spring peak flow), increase in length of growing season, increase of invasive species, ecosystem stress, energy brownouts from higher energy demands, more intense heat waves, public health impacts from high heat exposure and poor outdoor air quality, drying of streams and wetlands, eutrophication of lakes and ponds
	Wildfires	Changes in Precipitation	
	Invasive Species	Changes in Precipitation, Extreme Weather	
 Extreme Weather	Hurricanes/Tropical Storms	Rising Temperatures, Changes in Precipitation	Increase in frequency and intensity of extreme weather events, resulting in greater damage to natural resources, property, and infrastructure, as well as increased potential for loss of life
	Severe Winter Storm / Nor'easter	Rising Temperatures, Changes in Precipitation	
	Tornadoes	Rising Temperatures, Changes in Precipitation	
	Other Severe Weather (Including Strong Wind and Extreme Precipitation)	Rising Temperatures, Changes in Precipitation	
Non-Climate-Influenced Hazards	Earthquake	Not Applicable	There is no established correlation between climate change and this hazard

3.3 Sectors Assessed

Five key sectors were evaluated as part of the risk assessment. These sectors are introduced in the following sections, and risk assessment findings for each sector are included in the hazard profiles in *Chapter: 4 Risk Assessment*.

3.3.1 Populations



For each hazard, and to the extent practicable for this plan update, the impacts on human health, particularly vulnerable populations, were evaluated and incorporated into each hazard profile. Federal Emergency Management Agency's (FEMA's) GIS-based Hazus program was used for the analysis of several hazards in the risk assessment, and Hazus calculates data for a population located within a hazard extent. These Hazus analysis results are included in a hazard profile when applicable. The Hazus analysis results are supplemented by information regarding vulnerable populations (including but not limited to disabled, low-income, communities of color, and low English proficiency populations) that could potentially be more severely impacted by each hazard under current and future conditions. Among other factors, these populations may require extra time or outside assistance during evacuations or during events that cause power outages or isolation, and are considered to be more likely to seek or require emergency services. They are also more likely to live in risk-prone areas with poor infrastructure and higher levels of air pollution.

As discussed in *Chapter 2: Planning Context* vulnerability is influenced by three factors: exposure or contact with the hazard; sensitivity or degree to which people or communities are affected by the exposure to the hazard; and capacity to adapt or the ability of communities, institutions, or people to adjust and respond to and recover from potential hazards. As summarized in Table 3-2, the major health impacts from natural hazards and climate change include:

- **Heat-related illnesses and death** from an increase in extreme temperatures and poor air quality (USGCRP, 2016; DPH, 2017).
- **Increases in food- and waterborne illnesses and other infectious diseases** from altering geographic and seasonal distributions of existing vectors and vector-borne diseases (USGCRP, 2016).
- **Injuries and accidental premature death** associated with extreme weather events. Extreme weather events can result in acute health impacts, such as injuries and accidental premature death during an event (e.g., drowning during floods). In addition, health impacts can also occur during disaster preparation and post-event cleanup. Other impacts include damage to property, destruction of assets, loss of infrastructure and public services, social and economic impacts, environmental degradation, and other factors (USGCRP, 2016).

Table 3-2: Populations Vulnerable to Natural Hazards and Climate Change

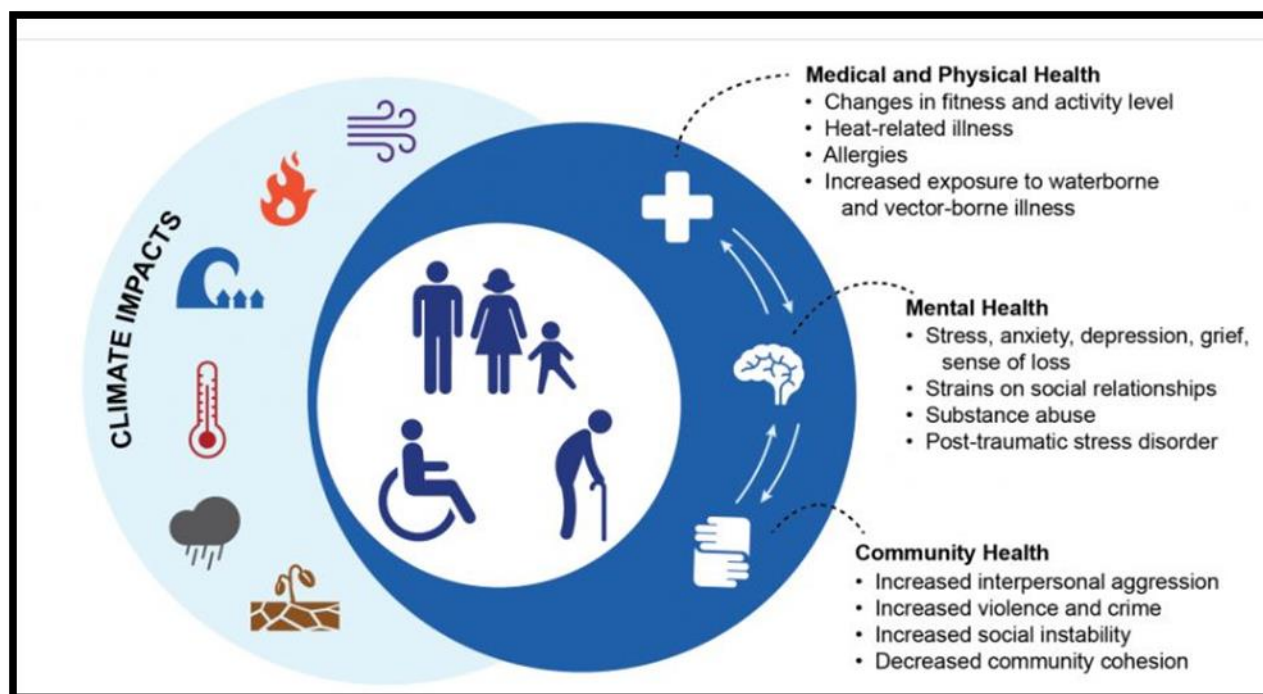
Vulnerability Category	Vulnerable Population	Heat-related illnesses	Changes in the prevalence and geographical distribution of food- and waterborne illnesses and other infectious diseases	Injuries and accidental premature death	Exacerbation of chronic diseases (respiratory and cardiovascular diseases, diabetes)	Mental health and stress-related disorders
Age	Individuals over 65	X	X	X	X	X
	Individuals over 65 and living alone	X		X	X	X
	Children under 5	X	X	X		
Socioeconomic Status	People living in poverty	X	X	X	X	X
	The homeless	X	X	X	X	X
	People with limited English proficiency	X	X	X	X	X
	People lacking access to air conditioning	X			X	X
Race	Communities of color	X	X	X	X	X
Place	People living in an urban area with limited green space	X			X	X
	People living near high-traffic roadways				X	X
Current Health Status	Adults with chronic diseases (e.g., respiratory and cardiovascular diseases; compromised immune systems)	X	X	X	X	X
	Children with respiratory disease (e.g., asthma)	X			X	X
	Individuals using electricity-dependent medical equipment and/or medications that need refrigeration	X		X	X	X
	Individuals with disabilities or mobility problems	X	X	X	X	X
	Individuals with mental health challenges	X		X		X

- **Exacerbation of chronic diseases** (USGCRP, 2016; DPH, 2017).
- **Mental health and stress-related disorders** ranging from minimal stress and distress symptoms to clinical disorders such as anxiety, depression, post-traumatic stress, and suicidality. Specific groups of people who are at higher risk for distress and other adverse mental health consequences from exposure to climate-related or weather-related disasters include children, the elderly, women (especially pregnant and post-partum women), people with preexisting mental illness, the economically disadvantaged, the homeless, and first responders. Populations living in areas most susceptible to specific climate change events are at increased risk for adverse mental health outcomes (Neria and Shultz, 2012; Neria, Nandi, and Galea, 2008; USGCRP, 2016).

Table 3-2 also identifies the vulnerable populations for each of the major health impacts associated with natural hazards and climate change.

Figure 3-1 illustrates the need for adaptation strategies to consider the multiple and complex risks to the health and well-being of vulnerable populations that are posed by natural and climate-related hazards.

Figure 3-1: Potential Impacts of Climate Change on Physical, Mental, and Community Health



Source: USGCRP, 2016

3.3.2 Government



The government sector includes such State-owned assets as transportation (e.g., roads, bridges, and rail), buildings, landholdings, and other infrastructure, such as pump stations and dams. The Commonwealth of Massachusetts owns and operates more than 13,000 parcels and 6,000 structures. DCAMM provides state agencies with public building design, construction, maintenance, and real estate services; and manages an inventory of state property infrastructure and critical facilities. There are more than 190 types of facilities in the DCAMM database that are included in this risk and vulnerability assessment.

3.3.3 Built Environment



The built environment sector includes critical facilities owned by the Commonwealth and critical infrastructure sectors that provide or link to key lifeline services, social welfare, and economic development. The State-owned critical facilities assessed were derived from the State's property infrastructure and critical facilities inventory data set provided by DCAMM. The DCAMM data were more accurate in terms of location and more current than the default critical facility inventories in Hazus. The facility types used include military facilities, police facilities, fire facilities, hospitals, emergency operation centers, and colleges/universities. Critical infrastructure sectors that were qualitatively assessed when applicable and where information was available include:

- Agriculture (including farms, land, crops, livestock, and operations)
- Energy (production, transmission, storage, and distribution, including power plants, substations, electric lines, natural gas systems, and fuel systems)
- Public safety (including public safety facilities and communications)
- Public health (including public health facilities and services provided)
- Transportation (including roads, highways, bridges, tunnels, subways, commuter and commercial rail, ferries, buses, airports, and ports)
- Water infrastructure (including water sources, pump stations, storage tanks or reservoirs, distribution systems, and drinking water)

3.3.4 Natural Resources and Environment



The natural resources and environment sector includes land-based assets owned by the State. It also includes key habitats and natural landscapes documented in the State's BioMap 2 (Conserving the Biodiversity of Massachusetts in a Changing World) and Areas of Critical Environmental Concern, as well as species identified in the State's Wildlife Action Plan.

3.3.5 Economy



The components in the economy sector include economic loss resulting from damage to critical state assets, the built environment, municipal resources, natural resources, and other sectors. Many sectors of the economy are dependent on the integrity of natural resources. For example, if a coastal resource such as a beach is damaged beyond repair by a storm, that beach will no longer attract tourists and the local and state economy may experience a loss of revenue from tourism and recreation.

3.4 Methodologies Used

3.4.1 Data Choices and Limitations

The following data limitations were identified and strategies developed to assist in future plan updates:

- Digital Flood Insurance Rate Maps are not available for all counties; however, the Commonwealth is currently working with FEMA to update maps, and will continue throughout the next update cycle to be a technical partner in enhancing this project.
- The DCAMM facility database was used to generate critical facility counts in the exposure areas for various hazards; however, this data set only includes State-owned facilities. Therefore, private critical facilities, such as hospitals, or critical facilities managed at the local level, such as K-12 schools, are not included in these counts.
- Hazard data for some hazards, such as coastal erosion and coastal flooding, were limited. The Massachusetts Office of Coastal Zone Management and Department of Transportation (MassDOT) are currently developing more detailed models for each of these hazards, and these models should be used in future plan updates. This item is listed in the strategy portion of the plan as a 2018 new project.
- Throughout this risk assessment, climate data were derived from emerging research conducted by NE CASC at the University of Massachusetts, Amherst. The results of NE CASC analysis will ultimately be published as a formal report, and data will be

accessible using the [resilient MA Climate Change Clearinghouse](#). These resources will likely contain additional information that will be useful for future plan updates.

- Information from Tribal Hazard Mitigation Plans was not included in the risk assessment, but it is incorporated in Chapter 10.

3.4.2 General Inventories

Data from various FEMA-approved local and multi-jurisdictional multi-hazard mitigation plans were incorporated with existing statewide data sets as applicable. The most up-to-date and accurate information available for this update was compiled from several federal sources. The following are key information sources used:

- Historical disaster records and documents, including, but not limited to, reports and spreadsheets maintained by MEMA as they relate to assistance made available following disasters
- Literature developed by state and national hazard experts containing the best available science and most current knowledge of hazards
- Current hazard zone maps, including new ShakeMaps, SLOSH (Sea, Lake and Overland Surges from Hurricanes) models, and Digital Flood Data
- Written and oral communication from state and national hazard experts
- State facilities inventory developed by DCAMM, with information provided by state agencies
- FEMA
- Hazard Research Laboratory, Department of Geography, University of South Carolina
- National Drought Mitigation Center, University of Nebraska-Lincoln
- NOAA and its agencies/programs (National Climatic Data Center and National Weather Service)
- U.S. Forest Service
- U.S. Census 2010
- U.S. Department of Agriculture
- U.S. Geological Survey, U.S. Department of the Interior
- U.S. Army Corps of Engineers

- Other state offices, including Agriculture, Commerce/Economic Development, Health, Ecology, and Social and Health Services agencies

3.4.3 Techniques and Approaches

A 2018 SHMCAP Risk Assessment Methodology document was developed and finalized in October 2017, and was subsequently revised as needed over the course of the project (Appendix A). The document was considered a “living” document throughout much of the plan update process, because the methodologies required refinement on receipt and application of referenced data sets. For many of the hazards addressed, some data used in the analysis have not changed significantly since the 2013 SHMP update. For those hazards whose underlying data has not changed, updates were primarily limited to data interpretation, inclusion of climate change analysis, and the addition of any recent hazard occurrences, as appropriate. Asset data required for exposure and vulnerability analysis were provided by state agencies, as well as the State Agency Vulnerability Assessment Survey Tool developed as part of this effort.

For the purposes of climate change analysis, the assumption made was that the baseline year would be defined as 2017. For those identified hazards likely to be impacted by climate change, it was assumed that vulnerability and risk would be looked at for the following time horizons, as data permitted: 2030, 2050, 2070, and 2100.

Details of the methodologies executed for each hazard as part of the risk assessment update are presented in Appendix A. Applicable state mitigation planning requirements and Emergency Management Accreditation Program (EMAP) standards for each hazard are identified in this appendix.

3.5 Hazard Profile Organization and Key Terms

Each hazard profile section included in Chapter 4 varies slightly, based on the nature of each individual hazard; but in general, each section includes background information for that hazard, secondary hazards, exposure and vulnerability, impacts to key sectors, and other areas of concern as appropriate. A summary sheet is also provided for each hazard that presents key information and findings from the risk assessment conducted for that hazard, including identification of areas and jurisdictions that are most at risk to the hazard.

The hazard profile sections examine the natural hazards that have the potential to impact the Commonwealth, identify counties and populations that are most vulnerable to each hazard, and estimate potential losses from the hazards at the state and local levels.

Extensive GIS analysis and Hazus modeling were performed, integrating information from federal, state, and local sources. Each hazard profile contains updated maps or data, where

applicable; and presents risks, in addition to areas most vulnerable to the hazard. The vulnerability of various jurisdictions of the state to each hazard was addressed depending on the available data and other information that were used for the statewide risk assessment. All hazard profiles were updated for the 2018 SHMCAP with any new available information, and data from the 2013 SHMP were retained where it was appropriate and still deemed current.

The following definitions apply for terms used in the risk assessment:

- **Climate adaptation:** Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
- **Climate change:** A change in the state of the climate that can be identified by statistical changes of its properties that persist for an extended period, whether due to natural variability or as a result of human activity.
- **Climate change impact:** Consequences of climate change on natural and human systems.
- **Consequence:** The effect of a hazard occurrence. Consequence is demonstrated by the impact on population, physical property (e.g., state facilities, local jurisdiction assets and general building stock, and critical facilities), responders, operations, the environment, the economy, and public confidence in state governance. A consequence analysis meets the EMAP standard for hazards identified in state plans.
- **Exposure:** The extent to which something is in direct contact with natural hazards or their related climate change impacts. Exposure is often determined by examining the number of people or assets that lie within a geographic area affected by a natural hazard, or by determining the magnitude of the climate change impact. For example, measurements of flood depth outside a building or number of heat waves experienced by a county are measurements of exposure.
- **Location:** The area of potential or demonstrated impact within the region in which the analysis is being conducted. In some instances, the area of impact is in a geographically defined area, such as a floodplain. In other instances, such as for severe weather, there is no established geographic boundary associated with the hazard, because it can impact the entire Commonwealth.
- **Natural hazard:** Natural hazards are natural events that threaten lives, property, and other assets. Often, natural hazards can be predicted. They tend to occur repeatedly in the same geographical locations because they are related to weather patterns or physical characteristics of an area.
- **Natural resources:** These are components of natural systems that exist without human involvement. For the purpose of this survey, key natural resource categories include forested

ecosystems, aquatic ecosystems, coastal ecosystems, wetland ecosystems, and old field ecosystems.

- **Risk:** The potential for an unwanted outcome resulting from a hazard event, as determined by its likelihood and associated consequences; and expressed, when possible, in dollar losses. Risk represents potential future losses, based on assessments of probability, severity, and vulnerability. In some instances, dollar losses are based on the actual demonstrated impact, such as through the use of the Hazus model. In other cases, dollar losses are demonstrated through exposure analysis due to the inability to determine the extent to which a structure is impacted.
- **Probability:** Probability is used as a synonym for likelihood, or the estimated potential for an incident to occur.
- **Sensitivity:** Sensitivity refers to the impact on a system, service, or asset when exposed to natural hazards. For example, if a facility is exposed to storm surge, how will its ability to function be affected? The level of sensitivity indicates how much or to what extent the occurrence of a hazard would exceed a critical threshold (if known) for something such that it would disrupt the ability of the system, service, or asset to continue normal operation. If the critical threshold is not exceeded, then the sensitivity to a certain hazard is low, even if it is exposed.
- **Severity/Extent:** The extent or magnitude of a hazard, as measured against an established indicator (e.g., Richter Scale, Saffir-Simpson Hurricane Scale, or Regional Snowfall Index).
- **Vulnerability:** The propensity or predisposition to be adversely affected; for example, as applied to building performance (functionality), damage, or the number of people injured. Vulnerability is a function of exposure, sensitivity, and adaptive capacity.



4. Risk Assessment

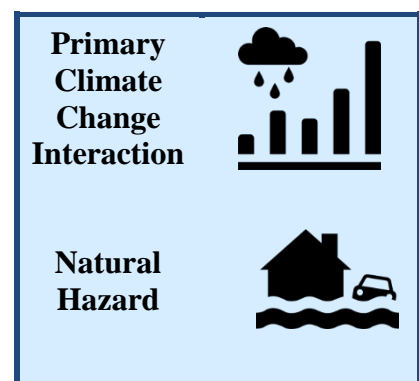
The risk assessment for the Massachusetts State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) examines the natural hazards that have the potential to impact the Commonwealth, identifies regional areas (i.e., per Massachusetts County) and specific populations that are most vulnerable to climate impacts, and estimates the associated economic losses. This chapter is organized by climate change interaction category, as explained in Section 3.2 and outlined in Table 3-1. A summary sheet is provided for each hazard, which outlines key information and findings from the risk assessment conducted for that hazard.

4.1 Primary Climate Change Interaction: Changes in Precipitation

4.1.1 Inland Flooding (Including Dam Overtopping)

GENERAL BACKGROUND

Nationally, inland flooding causes more damage annually than any other severe weather event (U.S. Climate Resilience Toolkit, 2017). Between 2007 and 2014, the average annual cost of flood damages in Massachusetts was more than \$9.1 million (NOAA, 2014). Inland flooding is the result of moderate precipitation over several days, intense precipitation over a short period, or melting snowpack (U.S. Climate Resilience Toolkit, 2017). Developed, impervious areas can contribute to inland flooding (U.S. Climate Resilience Toolkit,





CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
In Massachusetts, flooding is caused by Nor'easters, ice jams hurricanes/tropical storms, or other heavy precipitation events. Spring snowmelt, rain on snow or frozen ground, impervious surfaces, and steep slopes with minimal soil can exacerbate flooding.	Between 1954 and 2017, Essex County experienced the most FEMA flood disaster declarations (18), followed by Norfolk County with 16.	Based on historical disaster declarations, the Commonwealth experiences a substantial flood event once every 3 years.

Potential Effects of Climate Change

	CHANGES IN PRECIPITATION → MORE INTENSE AND FREQUENT DOWNPOURS	More intense downpours often lead to inland flooding as soils become saturated and stop absorbing more water, river flows rise, and urban stormwater systems become overwhelmed. Flooding may occur as a result of heavy rainfall, snowmelt or coastal flooding associated with high wind and storm surge.
	EXTREME WEATHER → MORE FREQUENT SEVERE STORMS	Climate change is expected to result in an increased frequency of severe storm events. This would directly increase the frequency of flooding events, and could increase the chance that subsequent precipitation will cause flooding if water stages are still elevated.
	CHANGES IN PRECIPITATION → EPISODIC DROUGHTS	Vegetated ground cover has been shown to significantly reduce runoff. If drought causes vegetation to die off, this flood-mitigating capacity is diminished.

Exposure and Vulnerability by Key Sector

	POPULATIONS	General At-Risk Population: Populations living in or near floodplain areas; people traveling in flooded areas or living in urban areas with poor stormwater drainage. Vulnerable Populations: Populations with low socioeconomic status who may consider the economic impacts of evacuating; people over age 65 who may require medical attention; households with young children who have difficulty evacuating; populations with low English language fluency who may not receive or understand warnings to evacuate.
	GOVERNMENT	According to the DCAMM facility inventory, 196 state facilities are exposed to the inland flooding hazard. Middlesex County contains the most state-owned buildings exposed to this hazard (64), followed by Norfolk (26) and Hampshire (25) Counties.
	BUILT ENVIRONMENT	Twenty-five critical facilities, including 10 police facilities and 6 military facilities, are exposed to the inland flooding hazard. The greatest proportion of these facilities occurs in Middlesex County (8). Flooding can also wash out sections of roadway and bridges, as well as cause extensive damage to utilities and disruption of critical services, such as liquid fuel delivery, non-emergency health care services, and child care. Increased river flooding is likely to cause soil erosion, soil loss, and crop damage. Stormwater drainage systems and culverts that are not sized to accommodate larger storms are likely to experience flood damage as extreme precipitation events increase.
	NATURAL RESOURCES AND ENVIRONMENT	Severe floods cause a wide range of environmental impacts. Animals can lose their habitats if habitat elements are swept away or destroyed. Riverbank and soil erosion transform existing habitats and deposit sediment in downstream areas. If high levels of nutrients are present in the soil, this can also lead to eutrophication in downstream ecosystems.
	ECONOMY	Economic losses due to a flood include, but are not limited to damages to buildings (and their contents) and infrastructure, agricultural losses, business interruption (including loss of wages), impacts on tourism, and tax base. Using building replacement value as a proxy for economic exposure, Middlesex, Essex and Norfolk Counties are the most economically exposed to this hazard.

2017). Increases in precipitation and extreme storm events will result in increased inland flooding. Common types of inland flooding are described in the following subsections.

Riverine Flooding

Riverine flooding often occurs after heavy rain. Areas of the state with high slopes and minimal soil cover (such as found in western Massachusetts) are particularly susceptible to flash flooding caused by rapid runoff that occurs in heavy precipitation events and in combination with spring snowmelt, which can contribute to riverine flooding. Frozen ground conditions can also contribute to low rainfall infiltration and high runoff events that may result in riverine flooding. Some of the worst riverine flooding in Massachusetts' history occurred as a result of strong nor'easters and tropical storms in which snowmelt was not a factor. Tropical storms can produce very high rainfall rates and volumes of rain that can generate high runoff when soil infiltration rates are exceeded. Inland flooding in Massachusetts is forecast and classified by the National Weather Service's (NWS) Northeast River Forecast Center as minor, moderate, or severe based upon the types of impacts that occur. Minor flooding is considered a "nuisance only" degree of flooding that causes impacts such as road closures and flooding of recreational areas and farmland. Moderate flooding can involve land with structures becoming inundated. Major flooding is a widespread, life-threatening event. River forecasts are made at many locations in the state where there are United States Geological Survey (USGS) river gauges that have established flood elevations and levels corresponding to each of the degrees of flooding.

Urban Drainage Flooding

Urban drainage flooding entails floods caused by increased water runoff due to urban development and drainage systems that are not capable of conveying high flows. Drainage systems are designed to remove surface water from developed areas as quickly as possible to prevent localized flooding on streets and other urban areas. They make use of a closed conveyance system that channels water away from an urban area to surrounding streams, bypassing natural processes of water infiltration into the ground, groundwater storage, and evapotranspiration (plant water uptake and respiration). Since drainage systems reduce the amount of time the surface water takes to reach surrounding streams, flooding can occur more quickly and reach greater depths than if there were no urban development at all (Wright, 2008).

In urban areas, basement, roadway, and infrastructure flooding can result in significant damage due to poor or insufficient stormwater drainage.

- **Overbank flooding** occurs when water in rivers and streams flows into the surrounding floodplain or into "any area of land susceptible to being inundated by floodwaters from any source." (FEMA, 2011b)
- **Flash floods** are characterized by "rapid and extreme flow of high water into a normally dry area, or a rapid rise in a stream or creek above a predetermined flood level." (FEMA, 2011b).

Ground Failures

Flooding and flood-related erosion can result from various types of ground failures, which include mud floods and mudflows, and to a much lesser degree, subsidence, liquefaction, and fluvial erosion.

- **Mud floods** are floods that carry large amounts of sediment, which can at times exceed 50 percent of the mass of the flood, and often occur in drainage channels and adjacent to mountainous areas. **Mudflows** are a specific type of landslide that contains large amounts of water and can carry debris as large as boulders. Both mudflows and mud floods result from rain falling on exposed terrain, such as terrain impacted by wildfires or logging. Mud floods and mudflows can lead to large sediment deposits in drainage channels. In addition to causing damage, these events can exacerbate subsequent flooding by filling in rivers and streams.
- **Subsidence** is the process where the ground surface is lowered from natural processes, such as consolidation of subsurface materials and movements in the Earth's crust, or from man-made activities, such as mining, inadequate fill after construction activity, and oil or water extraction. When ground subsides, it can lead to flooding by exposing low-lying areas to groundwater, tides, storm surges, and areas with a high likelihood of overbank flooding.
- **Liquefaction**, or when water-laden sediment behaves like a liquid during an earthquake, can result in floods of saturated soil, debris, and water if it occurs on slopes. Floods from liquefaction are especially common near very steep slopes.
- **Fluvial erosion** is the process in which the river undercuts a bank, usually on the outside bend of a meander, causing sloughing and collapse of the riverbank. Fluvial erosion can also include scouring and downcutting of the stream bottom, which can be a problem around bridge piers and abutments. In hillier terrain where streams may lack a floodplain, fluvial erosion may cause more property damage than inundation. Furthermore, fluvial erosion can often occur in areas that are not part of the 100- or 500-year floodplain.

Ice Jam

An ice jam is an accumulation of ice that acts as a natural dam and restricts the flow of a body of water. There are two types of ice jams: a freeze-up jam and a breakup jam. A freeze-up jam usually occurs in early winter to midwinter during extremely cold weather when super-cooled water and ice formations extend to nearly the entire depth of the river channel. This type of jam can act as a dam and begin to back up the flowing water behind it. The second type, a breakup jam, forms as a result of the breakup of the ice cover at ice-out, causing large pieces of ice to move downstream, potentially piling up at culverts, around bridge abutments, and at curves in river channels. Breakup ice jams occur when warm temperatures and heavy rains cause rapid snowmelt. The melting snow, combined with the heavy rain, causes frozen rivers to swell. The

rising water breaks the ice layers into large chunks, which float downstream and often pile up near narrow passages and obstructions (bridges and dams). Ice jams may build up to a thickness great enough to raise the water level and cause flooding upstream of the obstruction. The Ice Jam Database, maintained by the Ice Engineering Group at the U.S. Army Corps of Engineers (USACE) Cold Regions Research and Engineering Laboratory currently consists of more than 18,000 records from across the U.S.

Dam Overtopping

A dam is an artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material for the purpose of storage or control of water. There are two primary types of dam failure: catastrophic failure, characterized by the sudden, rapid, and uncontrolled release of impounded water, or design failure, which occurs as a result of minor overflow events. Dam overtopping is caused by floods that exceed the capacity of the dam, and it can occur as a result of inadequate spillway design, settlement of the dam crest, blockage of spillways, and other factors. Overtopping accounts for 34 percent of all dam failures in the U.S.

There are a number of ways in which climate change could alter the flow behavior of a river, causing conditions to deviate from what the dam was designed to handle. For example, more extreme precipitation events could increase the frequency of intentional discharges. Many other climate impacts—including shifts in seasonal and geographic rainfall patterns—could also cause the flow behavior of rivers to deviate from previous hydrographs. When flows are greater than expected, spillway overflow events (often referred to as “design failures”) can occur. These overflows result in increased discharges downstream and increased flooding potential. Therefore, although climate change will not increase the probability of catastrophic dam failure, it may increase the probability of design failures.

Additional information on dam failure is included in *Chapter 5: Technological and Human-Caused Hazards*.

Additional Causes of Flooding

Additional causes of flooding include beaver dams or levee failure. Beaver dams obstruct the flow of water and cause water levels to rise. Significant downstream flooding can occur if beaver dams break.

Floodplains

Floodplains by nature are vulnerable to inland flooding. Floodplains are the low, flat, and periodically flooded lands adjacent to rivers, lakes, and oceans. These areas are subject to geomorphic (land-shaping) and hydrologic (water flow) processes. Floodplains may be broad, as when a river crosses an extensive flat landscape, or narrow, as when a river is confined in a canyon. These areas form a complex physical and biological system that not only supports a

variety of natural resources, but also provides natural flood storage and erosion control. When a river is separated from its floodplain by levees and other flood control facilities, these natural benefits are lost, altered, or significantly reduced. When floodwaters recede after a flood event, they leave behind layers of rock and mud. These gradually build up to create a new floor of the floodplain. Floodplains generally contain unconsolidated sediments known as alluvium (accumulations of sand, gravel, loam, silt, and/or clay), often extending below the bed of the stream. These sediments provide a natural filtering system, with water percolating back into the ground and replenishing groundwater supplies.

Floodplain Ecosystems

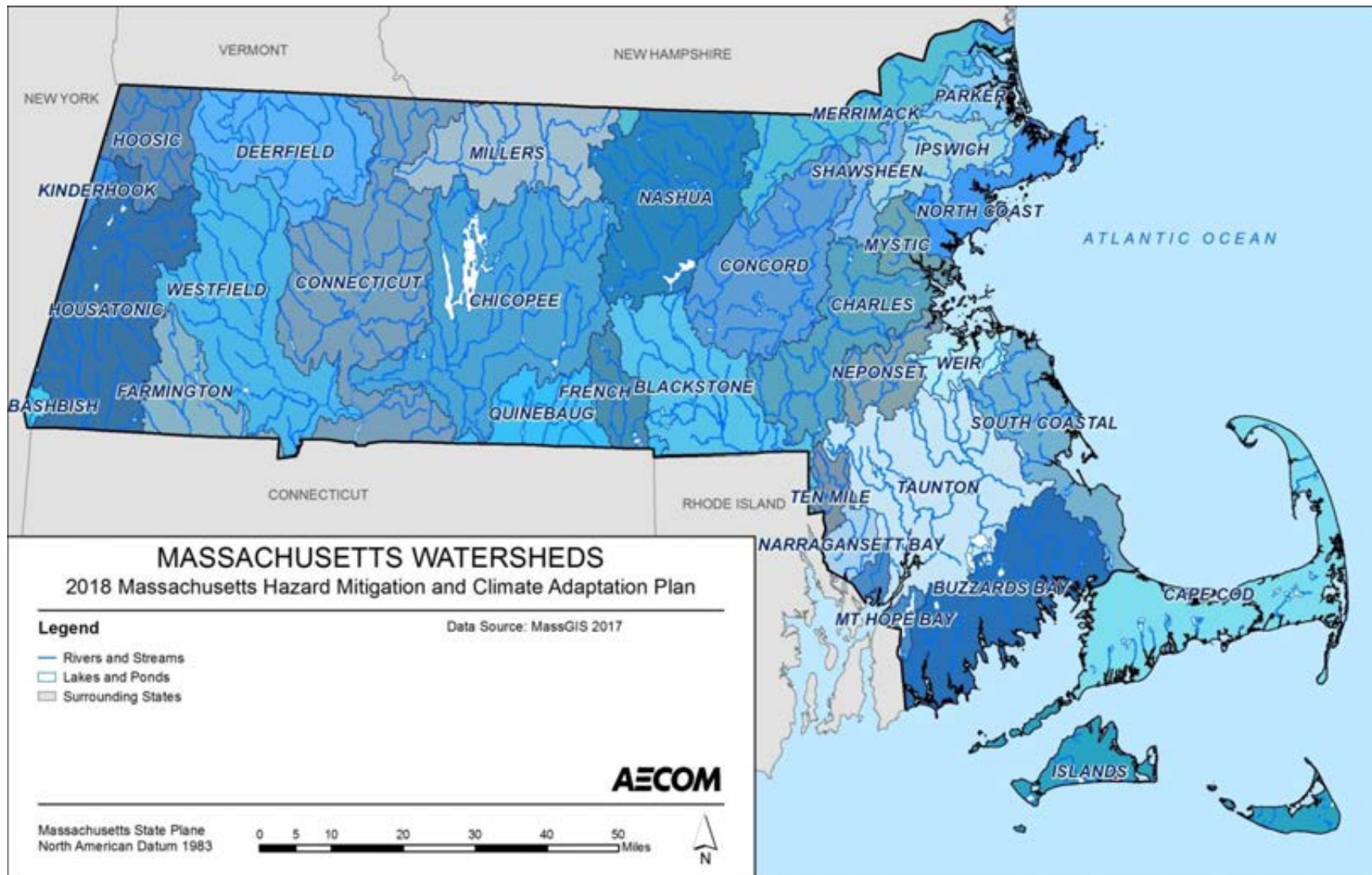
As the name implies, flooding is a natural and important part of wetland ecosystems that form along rivers and streams. Floodplains can support ecosystems that are rich in plant and animal species. Wetting the floodplain soil releases an immediate surge of nutrients from the rapid decomposition of organic matter that has accumulated over time. When this occurs, microscopic organisms thrive and larger species enter a rapid breeding cycle. Opportunistic feeders (particularly fish or birds) often utilize the increased food supply. The production of nutrients peaks and falls away quickly, but the surge of new growth that results endures for some time. Species growing in floodplains are markedly different from those that grow outside floodplains. For instance, riparian trees (trees that grow in floodplains) tend to be very tolerant of root disturbance and grow quickly in comparison to non-riparian trees.

HAZARD PROFILE

Location

Human development within historic floodplains has resulted in increased potential risks to public safety and infrastructure. Such development has occurred for centuries along rivers in Massachusetts, resulting in reduced natural flood storage capacity and increased exposure to flood risks. Inland flooding affects the majority of communities in the Commonwealth. Massachusetts has 27 regionally significant watershed areas (see Figure 4-1). Two major river systems in the state are the Connecticut River and the Merrimack River. The Connecticut River flows south from the New Hampshire/Vermont state line through Massachusetts and Connecticut to Long Island Sound. Tributaries of the Connecticut River that are located in Massachusetts include the Deerfield, Millers, Chicopee, and Westfield Rivers. The Merrimack River flows south from the White Mountains of New Hampshire into northeast Massachusetts before discharging to the Atlantic Ocean. The Nashua and Shawsheen Rivers are tributaries of the Merrimack River in Massachusetts.

Figure 4-1: Massachusetts Watersheds



The Taunton River watershed in the coastal plain of southeastern Massachusetts is the second largest watershed in the state. This watershed is vulnerable to the effects of climate change, including flooding, increased precipitation, and sea level rise due to its location and topography (RTI International, 2014). The Blackstone River, on the other hand, is located farther inland and is likely not subject to sea level rise impacts in Massachusetts. However, the presence of numerous dams and the location, which is within highly industrialized south-central Massachusetts, makes the area susceptible to flooding. The soils of the Blackstone River Watershed, combined with large swaths of paved surface, lead to rapid overland flow and an increase in river discharge. In contrast, the south coastal, Cape Cod, and Islands basins are composed of thick sand deposits with high infiltration rates. As a result, rivers in these watersheds are less flashy and flood-prone. Coastal flooding, discussed in Section 4.2.1, is generally more of a problem in these areas.

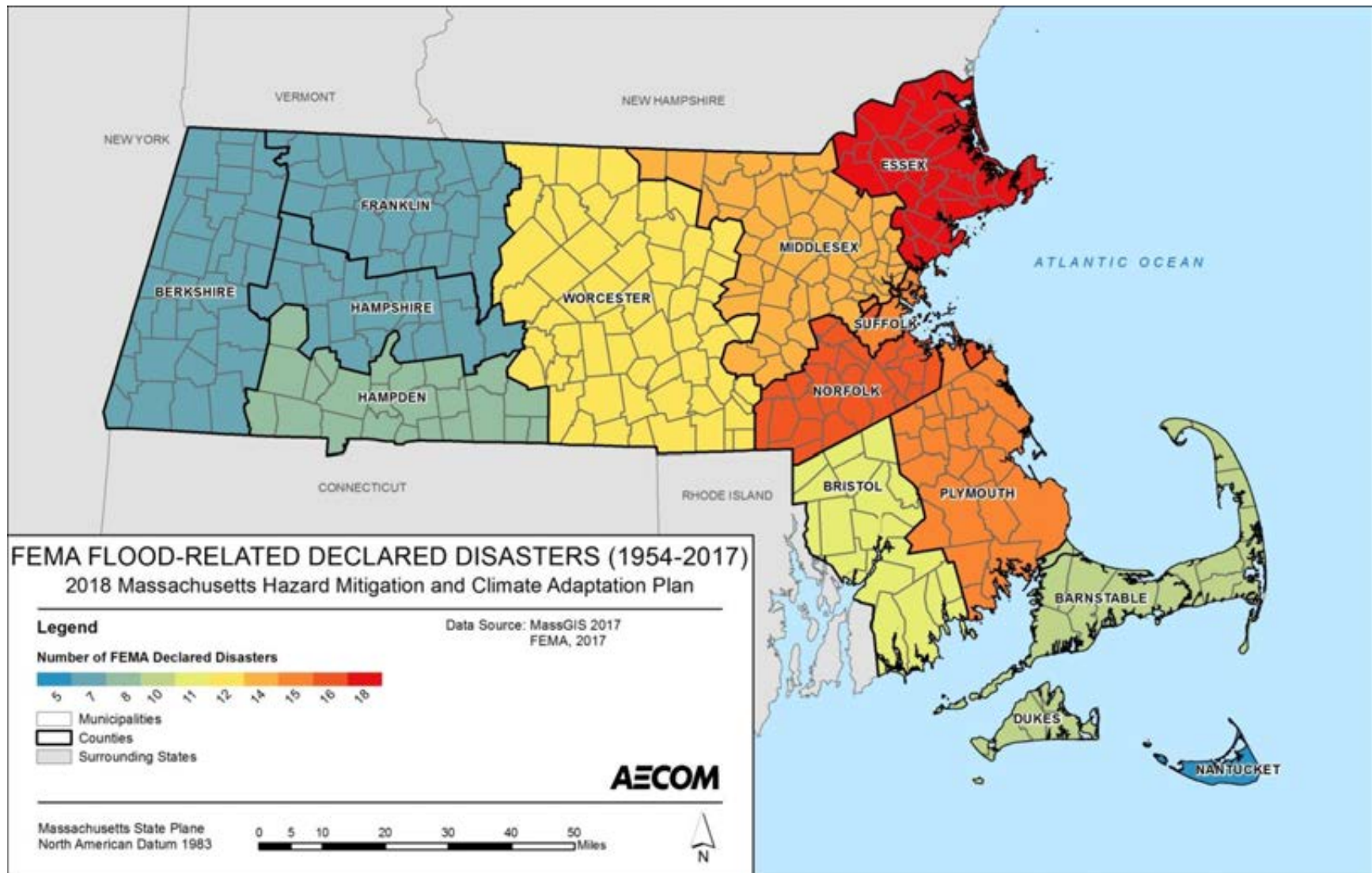
Previous Occurrences

Flooding in Massachusetts is often the direct result of frequent weather events, such as coastal storms, nor'easters, tropical storms, hurricanes, heavy rains, and snowmelt. Rainfall events are the most consistently influential drivers of riverine flooding in the Commonwealth. The state receives approximately 48 inches of rain per year on average, with average monthly rainfall between 3 and 4 inches in all regions of the state. However, heavy rainfall events occur regularly. As a result, riverine flooding affects the majority of the communities in the Commonwealth.

Between 1954 and 2018, Massachusetts has had 22 major flood (or flood-related) events. Figure 4-2 illustrates the number of Federal Emergency Management Agency (FEMA) declared flood-related disasters by county. Figure 4-2 also includes coastal flooding events. See Section 4.2.1 for more information. Additional information on these events is also provided in Appendix B.

According to the USACE Ice Jam Database, there were 220 ice jams in Massachusetts between 1920 and 2017 (USACE, 2018).

Figure 4-2: Number of FEMA Flood Declared Disasters by County



Frequency of Occurrences

For the purposes of the SHMCAP, the frequency of hazard events of disaster declaration proportions is defined by the number of federally declared disaster events for the Commonwealth over a specified period of time. In the northeast, precipitation released by storms has increased by 17 percent from the baseline level recorded in the period from 1901 to 1960 to present-day levels measured from 2011 to 2012 (USGCRP, 2014).

The historical record indicates the Commonwealth has experienced 22 coastal and inland flood-related disaster declaration events from 1954 to 2017. Therefore, based on these statistics, the Commonwealth may experience a flood event of disaster declaration proportions approximately once every 3 years. However, as shown in Figure 4-2, the frequency of flooding varies significantly based on watershed, riverine reach, and location along each reach. Additionally, it is important to note that floods of lesser magnitude occur at a much higher frequency; in the last 10 years alone (2007 to 2017), the National Oceanic and Atmospheric Administration (NOAA) Storm Events Database reports that there were 433 flood events, which is an average of more than 43 floods per year.

Flooding inherently occurs as a result of other natural phenomena, such as hurricanes and tropical storms, thunderstorms, nor'easters, severe winter storms, or anthropogenic influences, such as dam failure, and inadequate design of infrastructure, such as culverts, encroachment, and impervious cover. Changes in the frequency of flooding under climate change are dependent on the changes in frequency in these other natural hazards, which are detailed in the applicable sections of this plan. However, an overall increase in the frequency of heavy precipitation events will have a cumulative impact on the frequency of flooding, as it is possible that water stages could still be elevated from a previous event (known as antecedent conditions) and soils would already be saturated. If this were the case when another storm arrived, less precipitation would result in a flood.

Severity/Extent

Inland flooding in Massachusetts is forecast and classified by the NWS's Northeast River Forecast Center as minor, moderate, or severe based upon the types of impacts that occur. Minor flooding is considered "disruptive" flooding that causes impacts such as road closures and flooding of recreational areas and farmland. Moderate flooding can involve land with structures becoming inundated. Major flooding is a widespread, life-threatening event. River forecasts are made at many locations in the state containing USGS river gauges with established flood elevations and levels that correspond to each of the degrees of flooding.

As indicated, the principal factors affecting flood damage are flood depth and velocity. The deeper and faster that flood flows become, the more damage they can cause. Shallow flooding with high velocities can cause as much damage as deep flooding with slow velocity. This is especially true when a channel migrates over a broad floodplain, redirecting high-velocity flows and transporting debris and sediment.

The frequency and severity of flooding are measured using a discharge probability, which is the probability that a certain river discharge (flow) will be equaled or exceeded in a given year. Flood studies use historical records to determine the probability of occurrence for the different discharge levels. The flood frequency equals 100 divided by the discharge probability. For example, the 100-year discharge (discussed further in the following subsection) has a 1 percent chance of being equaled or exceeded in any given year. The “annual flood” is the greatest flood event expected to occur in a typical year. These measurements reflect statistical averages only; it is possible for two or more floods with a 100-year or higher recurrence interval to occur in a short time period. The same flood can have different recurrence intervals at different points on a river.

Flood flows in Massachusetts are measured at numerous USGS stream gauges. The gauges operate routinely, but particular care is taken to measure flows during flood events to calibrate the stage-discharge relationships at each location and to document actual flood conditions. In the aftermath of a flood event, the USGS will typically determine the recurrence interval of the event using data from a gauge’s period of historical record.

Overall, it is anticipated that the severity of flood-inducing weather events and storms will increase as a result of climate change. Research has shown that rainfall is increasingly concentrated into the most severe events (Easterling, 2017). While trends in overall precipitation are less clear, the increase in severe rainfall events will exacerbate the risk of flooding.

The 100-Year Flood

The 100-year flood is the flood that has a 1 percent chance of being equaled or exceeded each year. The 100-year flood is the standard used by most federal and state agencies. For example, it is used by the National Flood Insurance Program (NFIP) to guide floodplain management and determine the need for flood insurance.

The extent of flooding associated with a 1 percent annual probability of occurrence (the base flood or 100-year flood) is called the 100-year floodplain, which is used as the regulatory boundary by many agencies. Also referred to as the Special Flood Hazard Area (SFHA), this boundary is a convenient tool for assessing vulnerability and risk in flood-prone communities. Many communities have maps that show the extent and likely depth of flooding for the base flood. This extent generally includes both the stream channel and the flood fringe, which is the stream-adjacent area that will be inundated during a 100-year (or 1 percent annual chance) flood event but does not effectively convey floodwaters.

The 500-Year Flood

The term “500-year flood” is the flood that has a 0.2 percent chance of being equaled or exceeded each year. Flood insurance purchases are not required by the Federal Government in the 500-year floodplain, but could be required by individual lenders.

Base flood elevations and the boundaries of the 1 percent annual chance (100-year) and the 0.2 percent annual chance (500-year) floodplains are shown on Flood Insurance Rate Maps (FIRMs), which are the principal tools for identifying the extent and location of the flood hazard. The FIRMs depict SFHAs—areas subject to inundation from the 1 percent annual chance flood (also known as the base flood or the 100-year flood).

Both the 100-year and the 500-year floodplains are determined based on past events. As a result, the flood maps do not reflect projected changes in precipitation events, sea level rise, and increased temperature, which will impact flood risk.

Warning Time

Due to the sequential pattern of meteorological conditions needed to cause serious flooding, it is unusual for a flood to occur without warning. Flash flooding, which occurs when excessive water fills either normally dry creeks or river beds or dramatically increases the water surface elevation on currently flowing creeks and river, can be less predictable. However, potential hazard areas can be warned in advanced of potential flash-flooding danger. Flooding is more likely to occur due to a rain storm when the soil is already wet and/or streams are already running high from recent previous rains. NOAA's Northeast River Forecast Center provides flood warnings for Massachusetts, relying on monitoring data from the USGS stream gauge network. Notice of potential flood conditions is generally available 5 days in advance. State agency staff also monitor river, weather, and forecast conditions throughout the year.

Notification of potential flooding is shared among state agency staff, including the Massachusetts Emergency Management Agency (MEMA) and the Office of Dam Safety. The NWS provides briefings to state and local emergency managers and provides notifications to the public via traditional media and social networking platforms. MEMA also distributes information regarding potential flooding to local emergency managers, the press, and the public.

Increased drought frequency may also exacerbate the impacts of flood events, as droughts can cause vegetation that would otherwise have helped mitigate flooding to die off. Vegetated, undeveloped areas have been found to reduce runoff to less than 1 percent of total rainfall by increasing rainfall absorption (UKCIP, n.d.). These vegetated areas not only reduce the risk of downstream flooding but also increase the rate of groundwater recharge, which in turn increases an area's resilience to future drought events. Climate projections indicate that rainfall totals will increase overall and that more rain will fall in large rain events, which are the type of event that leads to flooding. By the end of this century (2080-2099), the annual number of days with precipitation over 1 inch is projected to increase by 1 to 4 days relative to the 1971-2000 average. Days with precipitation over 2 inches are expected to increase by 0 to 1 day, and days with precipitation over 4 inches are projected to increase by less than 1 day at the end of this century (EOEEA, 2018).

SECONDARY HAZARDS

The most problematic secondary hazards for flooding are fluvial erosion, river bank erosion, and landslides affecting infrastructure and other assets (e.g., agricultural fields) built within historic floodplains. Without the space required along river corridors for natural physical adjustment, such changes in rivers after flood events can be more harmful than the actual flooding. For instance, fluvial erosion attributed to Hurricane Irene caused an excess of \$23 million in damages along Route 2. The impacts from these secondary hazards are especially prevalent in the upper courses of rivers with steep gradients, where floodwaters may pass quickly and without much damage, but scour the banks, edging buildings, and structures closer to the river channel or cause them to fall in. Landslides can occur following flood events when high flows oversaturate soils on steep slopes, causing them to fail. These secondary hazards also affect infrastructure. Roadways and bridges are impacted when floods undermine or wash out supporting structures. Dams may fail or be damaged, compounding the flood hazard for downstream communities. Failure of wastewater treatment plants from overflow or overtopping of hazardous material tanks and the dislodging of hazardous waste containers can occur during floods as well, releasing untreated wastewater or hazardous materials directly into storm sewers, rivers, or the ocean. Flooding can also impact public water supplies and the power grid.

EXPOSURE AND VULNERABILITY

Historically, people tended to settle in floodplains for a number of reasons: available water, fertile land, water transportation, and developable land. In addition, during the Industrial Revolution, factories and cities were often constructed along river corridors to take advantage of the power that was generated by flowing water. This development pattern is particularly evident in Massachusetts, and many dams and canals constructed for industrial purposes remain in the landscape. As a result, Massachusetts' floodplains tend to be heavily developed and highly populated. Human activity in floodplains interferes with the natural function of these areas, and the interference is exacerbated in our more developed communities. Development and impervious surfaces affect the rate of surface runoff and delivery of water to a river channel, and they also diminish the natural ability of the land to store and slowly release water. Development can reduce the space available for floodwater storage within a floodplain and limit the ability of a river to adjust physically over time. These factors all contribute to increased flooding risks. As described in Section 4.1.2, drought, natural infiltration, and retention are reduced by impervious cover (pavement, buildings) on the land surface and by the interruption of natural small-scale drainage patterns in the landscape caused by development and drainage infrastructure. Highly urbanized areas with traditional stormwater drainage systems tend to experience higher peak flood levels and more extreme hydrology overall. Development can interface effectively with a floodplain as long as steps are taken to mitigate the adverse impacts of development activities on floodplain functions.

Methodology

To assess the Commonwealth's exposure to the flood hazard, an analysis was conducted with the most current floodplain boundaries, as shown in Table 4-1. These data include the locations of the FEMA flood zones, the 100-year flood zones or 1 percent annual chance event areas (including both A Zones and V Zones), and the 500-year flood zones or 0.2 percent annual chance event areas. Using ArcMap geographic information System (GIS) software, these data were overlaid with data on the population, general building stock, state-owned facilities, and critical facilities to determine exposure.

The newest FEMA FIRMs or Standard Digital Flood Insurance Rate Maps (DFIRMs) were used in this analysis. Where DFIRMs were not available, FEMA Quality 3 data were used.

Communities in Franklin County have original paper maps in the form of Flood Boundary and Floodway Maps, Flood Hazard Boundary Maps, and FIRMs that were created by FEMA in the 1970s and 1980s. These communities also have some historic Flood Insurance Studies on file; however, none of these has been converted to digital form. The Department of Conservation and Recreation (DCR) has most of these maps on file and regularly provides FIRMette-style copies on request for Franklin County communities. In addition, Franklin County maintains a digital floodplain layer displaying the 1 percent chance flood event for the Connecticut River. Due to this data incongruity, Franklin County is not included in the exposure or vulnerability analyses in this section.

Table 4-1 and Figure 4-3 summarize the data used for this risk assessment. Figure 4-4 displays the 1 percent and 0.2 percent flood hazard areas across the Commonwealth. The coastal flood hazard areas are discussed separately in Section 4.2.1.

Table 4-1: Flood Data Used for Risk Assessment

County	Data Used for 2018 Plan Update	Latest FEMA Study Effective Date
Barnstable	DFIRM	July 16, 2014
Berkshire	Quality 3 (Q3)	Maps are dated early 1980s
Bristol	DFIRM	July 16, 2015
Dukes	DFIRM	July 16, 2014
Essex	DFIRM	July 16, 2014
Franklin	No digital FEMA flood data	Maps are dated 1970s or early 1980s
Hampden	DFIRM	July 16, 2014
Hampshire	Q3	Maps are dated 1970s or early 1980s
Middlesex	DFIRM	July 6, 2016
Nantucket	DFIRM	July 6, 2016
Norfolk	DFIRM	July 16, 2015
Plymouth	DFIRM	July 16, 2015
Suffolk	DFIRM	November 4, 2016
Worcester	DFIRM and Q3 The DFIRM is only available for a portion of the County (Auburn, Berlin, Blackstone, Bolton, Boylston, Charlton, Clinton, Douglas, Dudley, Grafton, Harvard, Hopedale, Lancaster, Leicester, Mendon, Milford, Millbury, Millville, Northborough, Northbridge, Oxford, Paxton, Shrewsbury, Southborough, Southbridge, Spencer, Sturbridge, Sutton, Upton, Uxbridge, Webster, West Boylston, Westborough, and Worcester); Q3 data were used for the remainder of the County (generally early 1980s maps).	March 16, 2016

Figure 4-3: FEMA Flood Map Status for the Commonwealth of Massachusetts

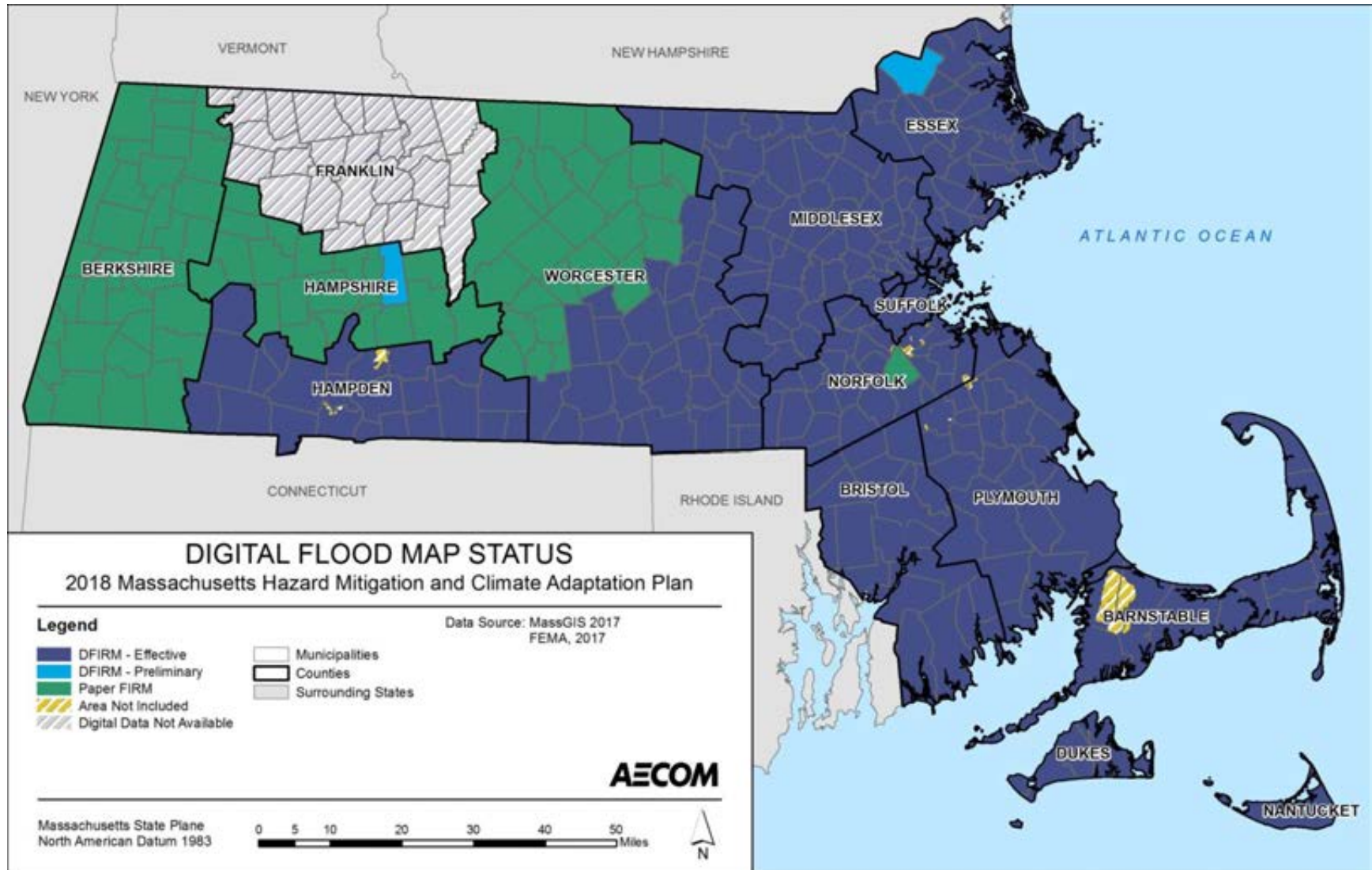
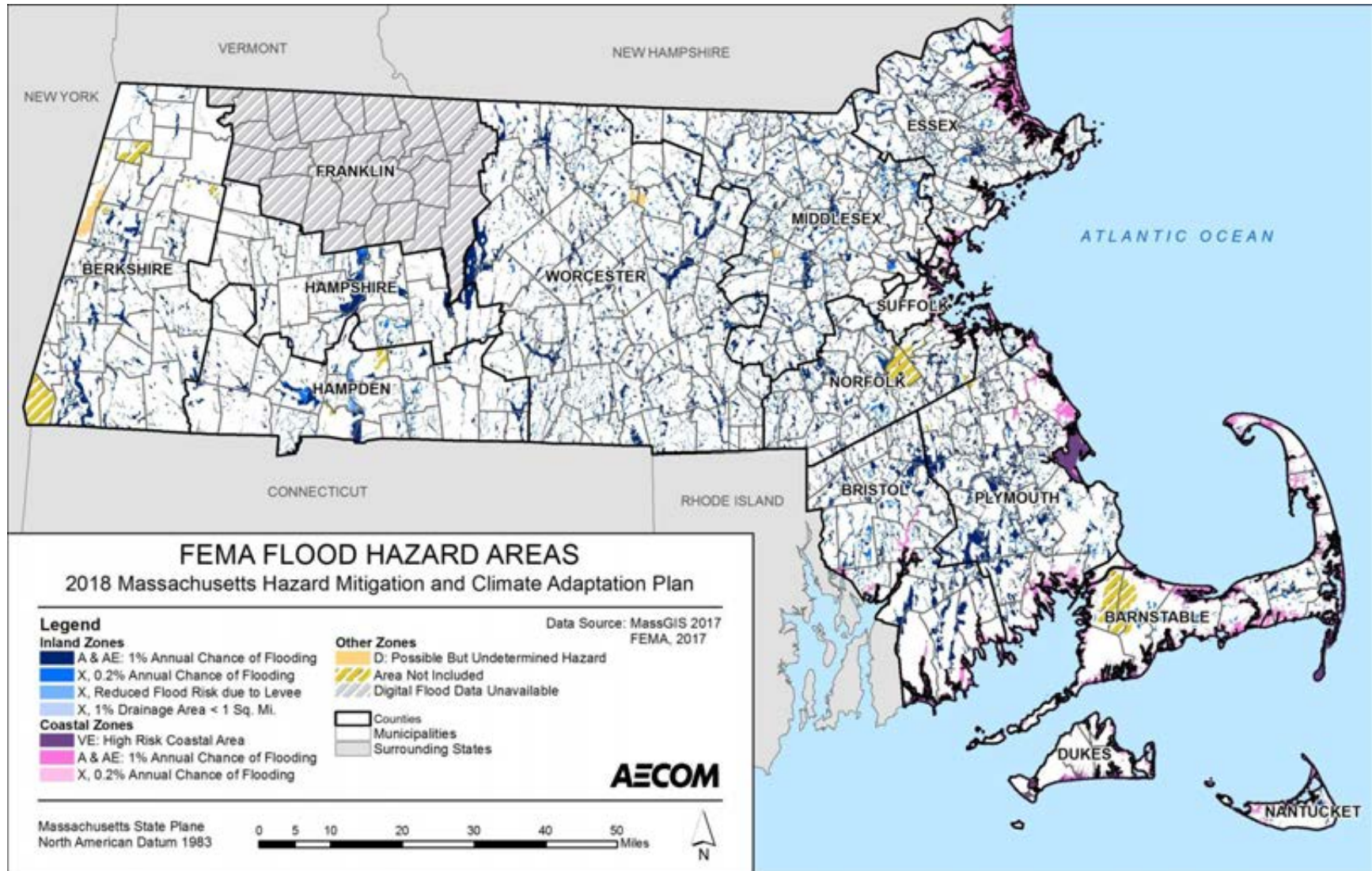


Figure 4-4: FEMA Flood Hazard Areas in the Commonwealth of Massachusetts



Populations



The impact of flooding on life, health, and safety is dependent upon several factors, including the severity of the event and whether or not adequate warning time is provided to residents. Populations living in or near floodplain areas may be impacted during a flood event. People traveling in flooded areas and those living in urban areas with poor stormwater drainage may be exposed to floodwater. People may also be impacted when transportation infrastructure is compromised from flooding.

To estimate the population exposed to the 1 percent and 0.2 percent annual chance flood events, the flood hazard boundaries were overlaid upon the 2010 U.S. Census block population data in GIS (U.S. Census, 2010). Census blocks do not follow the boundaries of the floodplain. The portion of the census block within the floodplain was used to approximate the population contained therein. For example, if 50 percent of a census block of 1,000 people was located within a floodplain, the estimated population exposed to the hazard would be 500. Table 4-2 lists the estimated population located within the 1 percent and 0.2 percent flood zones by county.

Table 4-2: Estimated Population Exposed to the 1 Percent and 0.2 Percent Annual Chance Inland Flood Events

County	Total 2010 Population	1 Percent Annual Chance Flood Event A Zone		0.2 Percent Annual Chance Flood Event X500 Zone	
		Population	% of Total	Population ⁽¹⁾	% of Total
Barnstable	215,888	149	0.1	1,141	0.5
Berkshire	131,219	7,985	6.1	2,311	1.8
Bristol	548,285	12,580	2.3	3,472	0.6
Dukes	16,535	—	N/A	11	0.1
Essex	743,159	18,667	2.5	15,385	2.1
Franklin	71,372	N/A	N/A	N/A	N/A
Hampden	463,490	8,178	1.8	14,622	3.2
Hampshire	158,080	5,315	3.4	2,604	1.6
Middlesex	1,503,085	38,798	2.6	34,182	2.3
Nantucket	10,172	11	0.1	129	1.3
Norfolk	670,850	17,409	2.6	9,845	1.5
Plymouth	494,919	15,954	3.2	4,231	0.9
Suffolk	722,023	1,875	0.3	603	0.1
Worcester	798,552	18,020	2.3	9,107	1.1
Total	6,547,629	144,941	2.2	97,644	1.5

¹Represents population within the X500 Zone. Population in the A Zone would also be exposed to a 0.2 percent annual chance flood event.

Sources: 2010 U.S. Census, MassGIS

Vulnerable Populations

Of the population exposed, the most vulnerable include people with low socioeconomic status, people over the age of 65, young children, people with medical needs, and those with low English language fluency. For example, people with low socioeconomic status are more vulnerable because they are likely to consider the economic impacts of evacuation when deciding whether or not to evacuate. The population over the age of 65 is also more vulnerable because some of these individuals are more likely to seek or need medical attention because they may have more difficulty evacuating or the medical facility may be flooded. Those who have low English language fluency may not receive or understand the warnings to evacuate. Vulnerable populations may also be less likely to have adequate resources to recover from the loss of their homes and jobs.

Populations that live or work in proximity to facilities that use or store toxic substances are at greater risk of exposure to these substances during a flood event. The [Massachusetts Toxic Users and Climate Vulnerability Factors](#) map displays wastewater treatment plants; major facilities that treat, use, or store hazardous waste; and classified oil and/or hazardous material sites within the FEMA flood zones (EOEEA, n.d.).

Health Impacts

The total number of injuries and casualties resulting from typical riverine flooding is generally limited due to advance weather forecasting, blockades, and warnings. The historical record from 1993 to 2017 indicates that there have been two fatalities associated with flooding (occurring in May 2006) and five injuries associated with two flood events (occurring within 2 weeks of each other in March 2010).

However, flooding can result in direct mortality to individuals in the flood zone. This hazard is particularly dangerous because even a relatively low-level flood can be more hazardous than many residents realize. For example, while 6 inches of moving water can cause adults to fall, 1 foot to 2 feet of water can sweep cars away. Downed powerlines, sharp objects in the water, or fast-moving debris that may be moving in or near the water all present an immediate danger to individuals in the flood zone.

Events that cause loss of electricity and flooding in basements, which are where heating systems are typically located in Massachusetts homes, increase the risk of carbon monoxide poisoning. Carbon monoxide results from improper location and operation of cooking and heating devices (grills, stoves), damaged chimneys, or generators.

According to the U.S. Environmental Protection Agency (EPA), floodwater often contains a wide range of infectious organisms from raw sewage. These organisms include intestinal bacteria, MRSA (methicillin-resistant staphylococcus aureus), strains of hepatitis, and agents of typhoid, paratyphoid, and tetanus (OSHA, 2005). Floodwaters may also contain agricultural or

industrial chemicals and hazardous materials swept away from containment areas. Individuals who evacuate and move to crowded shelters to escape the storm may face the additional risk of contagious disease; however, seeking shelter from storm events when advised is considered far safer than remaining in threatened areas. Individuals with pre-existing health conditions are also at risk if flood events (or related evacuations) render them unable to access medical support. Flooded streets and roadblocks can also make it difficult for emergency vehicles to respond to calls for service, particularly in rural areas.

Flood events can also have significant impacts after the initial event has passed. For example, flooded areas that do not drain properly can become breeding grounds for mosquitos, which can transmit vector-borne diseases. Exposure to mosquitos may also increase if individuals are outside of their homes for longer than usual as a result of power outages or other flood-related conditions. Finally, the growth of mold inside buildings is often widespread after a flood. Investigations following Hurricane Katrina and Superstorm Sandy found mold in the walls of many water-damaged homes and buildings. Mold can result in allergic reactions and can exacerbate existing respiratory diseases, including asthma (CDC, 2004). Property damage and displacement of homes and businesses can lead to loss of livelihood and long-term mental stress for those facing relocation. Individuals may develop post-traumatic stress, anxiety, and depression following major flooding events (Neria et al., 2008).

Government



Flooding can cause direct damage to state-owned facilities and result in roadblocks and inaccessible streets that impact the ability of public safety and emergency vehicles to respond to calls for service.

To assess the exposure of the state-owned facilities provided by the Division of Capital Asset Management and Maintenance (DCAMM) and the Office of Leasing, an analysis was conducted in December 2017 with the most current floodplain boundaries. Using ArcMap GIS software, the flood hazard area data were overlaid with the state facility data, and the appropriate flood zone determination was assigned to each facility. Table 4-3 summarizes the number of state buildings located in the 1 percent and 0.2 percent annual chance flood zones by county, and the replacement value of those buildings. This analysis indicates that Middlesex and Hampshire Counties contain the most state facilities exposed to the inland flood hazard based on their location within the A-Zone or 500-year flood zone.

Table 4-3: State Facilities in Flood Zones

County	In A Zone		In 500-Year Zone	
	Count	Replacement Value	Count	Replacement Value
Barnstable	—	—	—	—
Berkshire	17	\$8,980,938	2	\$497,733
Bristol	1	—	3	\$201,439
Dukes	—	—	—	—
Essex	6	\$20,858,353	9	\$83,949,395
Franklin	—	—	—	—
Hampden	6	\$1,535,503	6	\$13,571,921
Hampshire	22	\$4,409,577	3	\$500,271
Middlesex	46	\$32,669,227	18	\$24,252,176
Nantucket	—	—	—	—
Norfolk	18	\$7,244,847	8	\$6,503,593
Plymouth	1	\$17,137	1	\$7,881,144
Suffolk	4	\$1,078,925	5	\$533,343
Worcester	14	\$45,575,206	6	\$8,988,231
Total	135	\$122,369,713	61	\$146,879,246

Sources: MassGIS, 2017; DCAMM facility inventory, 2017

The Built Environment



Buildings, infrastructure, and other elements of the built environment are vulnerable to inland flooding. At the site scale, buildings that are not elevated or flood-proofed and those located within the floodplain are highly vulnerable to inland flooding. These buildings are likely to become increasingly vulnerable as riverine flooding increases due to climate change (resilient MA, 2018). At a neighborhood to regional scale, highly developed areas and areas with high impervious surface coverage may be most vulnerable to flooding. Even moderate development that results in as little as 3 percent impervious cover can lead to flashier flows and river degradation, including channel deepening, widening, and instability (Vietz and Hawley, 2016). Additionally, changes in precipitation will threaten key infrastructure assets with flood and water damage. Climate change has the potential to impact public and private services and business operations. Damage associated with flooding to business facilities, large manufacturing areas in river valleys, energy delivery and transmission, and transportation systems has economic implications for business owners as well as the state's economy in general (resilient MA, 2018).

Many dams within the Commonwealth have aged past their design life. As a result, they are less resilient to hazards such as inland flooding and extreme precipitation, and may not provide adequate safety following these disasters. These structures, if impacted by disasters, can affect human health, safety, and economic activity due to increased flooding and loss of infrastructure functions. These dams require termination or restoration to improve their infrastructure and better equip them to withstand the hazards that the Commonwealth will face due to climate change.

NFIP data are useful for determining the location of areas vulnerable to flood and severe storm hazards. Table 4-4 summarizes the NFIP policies, claims, repetitive loss (RL) properties, and severe repetitive loss (SRL) properties in each county associated with all flood events (inland and coastal flooding). A RL property is a property for which two or more flood insurance claims of more than \$1,000 have been paid by the NFIP within any 10-year period since 1978. A SRL property is defined as one that “has incurred flood-related damage for which 4 or more separate claims payments have been paid under flood insurance coverage, with the amount of each claim payment exceeding \$5,000 and with cumulative amount of such claims payments exceeding \$20,000; or for which at least 2 separate claims payments have been made with the cumulative amount of such claims exceeding the reported value of the property” (FEMA). Housing unit projections for 2016 from the U.S. Census were used to represent the total housing units in each county. It should be noted that policy and claim data reflect the time period from 1978 to 2017, while RL and SRL values are calculated using a rolling 10-year period.

Table 4-4: NFIP Policies, Claims, and Repetitive Loss Statistics

County	Number of Housing Units (2016 Projections)	Policies	% of Housing Units	Claims	Total Loss Payments	Repetitive Losses	Severe Repetitive Losses
Barnstable	162,500	11,687	7.2	2,777	\$29,564,534	476	30
Berkshire	68,458	841	1.2	387	\$3,057,651	—	—
Bristol	232,068	4,112	1.8	1,419	\$11,816,448	196	4
Dukes	17,713	968	5.5	165	\$1,692,172	42	—
Essex	309,644	9,900	3.2	4,717	\$73,422,235	1543	126
Franklin	33,746	199	0.6	101	\$3,759,871	6	—
Hampden	192,079	1053	0.5	245	\$2,364,442	29	—
Hampshire	63,087	502	0.8	186	\$1,682,749	53	4
Middlesex	625,409	7,575	1.2	3,383	\$32,370,019	1008	90
Nantucket	12,075	1,010	8.4	542	\$16,741,745	186	21
Norfolk	274,987	6,598	2.4	2,707	\$16,700,041	820	86
Plymouth	204,122	10,193	5.0	10,569	\$134,811,536	4064	950
Suffolk	331,329	7,447	2.2	3,978	\$21,965,551	1465	88
Worcester	330,809	1,664	0.5	681	\$10,019,148	192	6
Total	2,858,026	63,749	2.2	31,857	\$359,968,142	10,080	1,405

Source: National Flood Insurance Program, FEMA Region I, 2010 U.S. Census

Barnstable, Plymouth and Essex Counties have the highest percentage of policies. The majority of the RL and SRL properties are located in eastern Massachusetts, with the largest number along the coast in Plymouth, Essex and Suffolk Counties.

Figures 4-5 and 4-6 show the number of RL and SRL properties in each municipality.

Figure 4-5: NFIP Repetitive Loss Areas

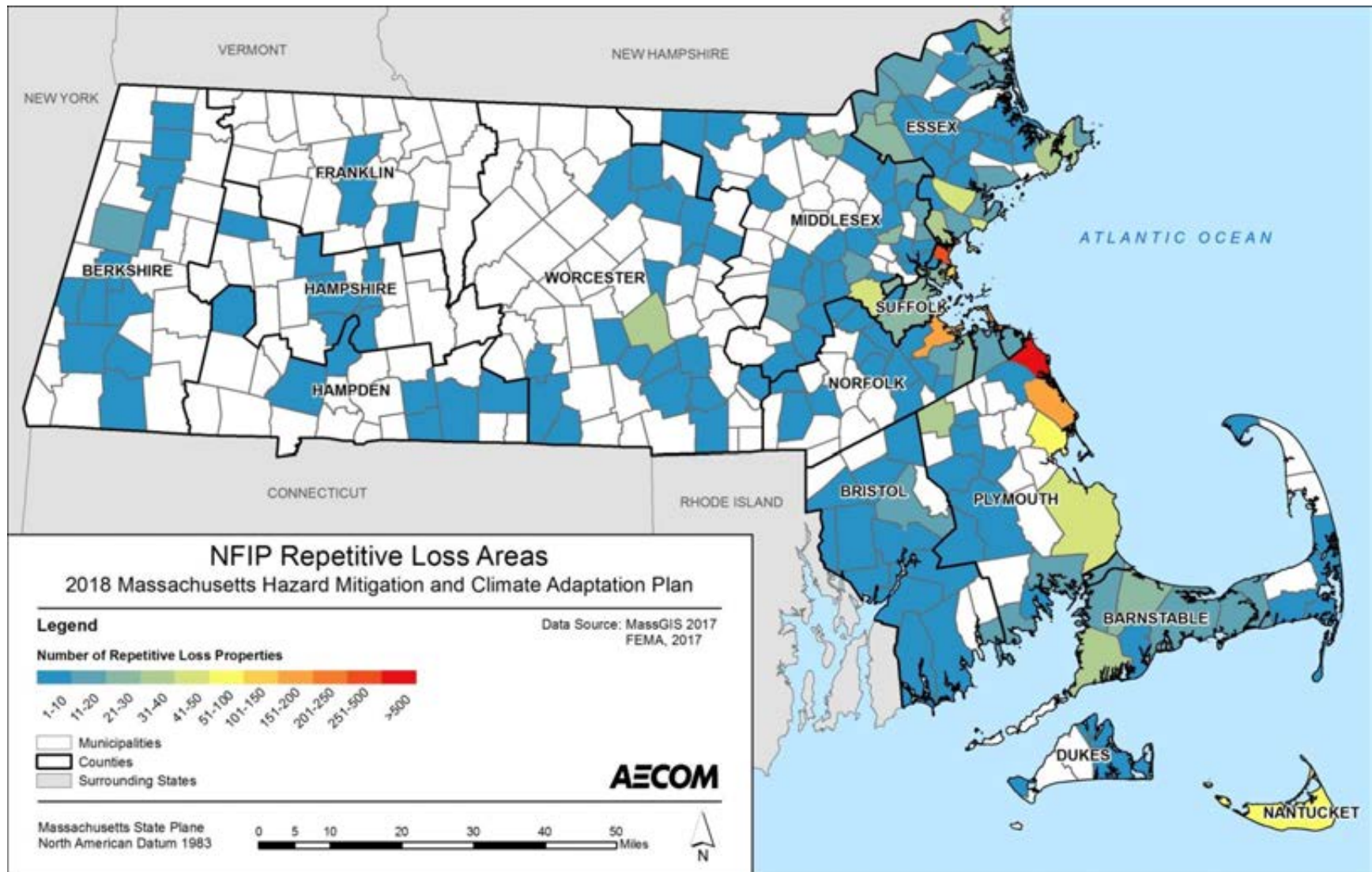


Figure 4-6: NFIP Severe Repetitive Loss Areas

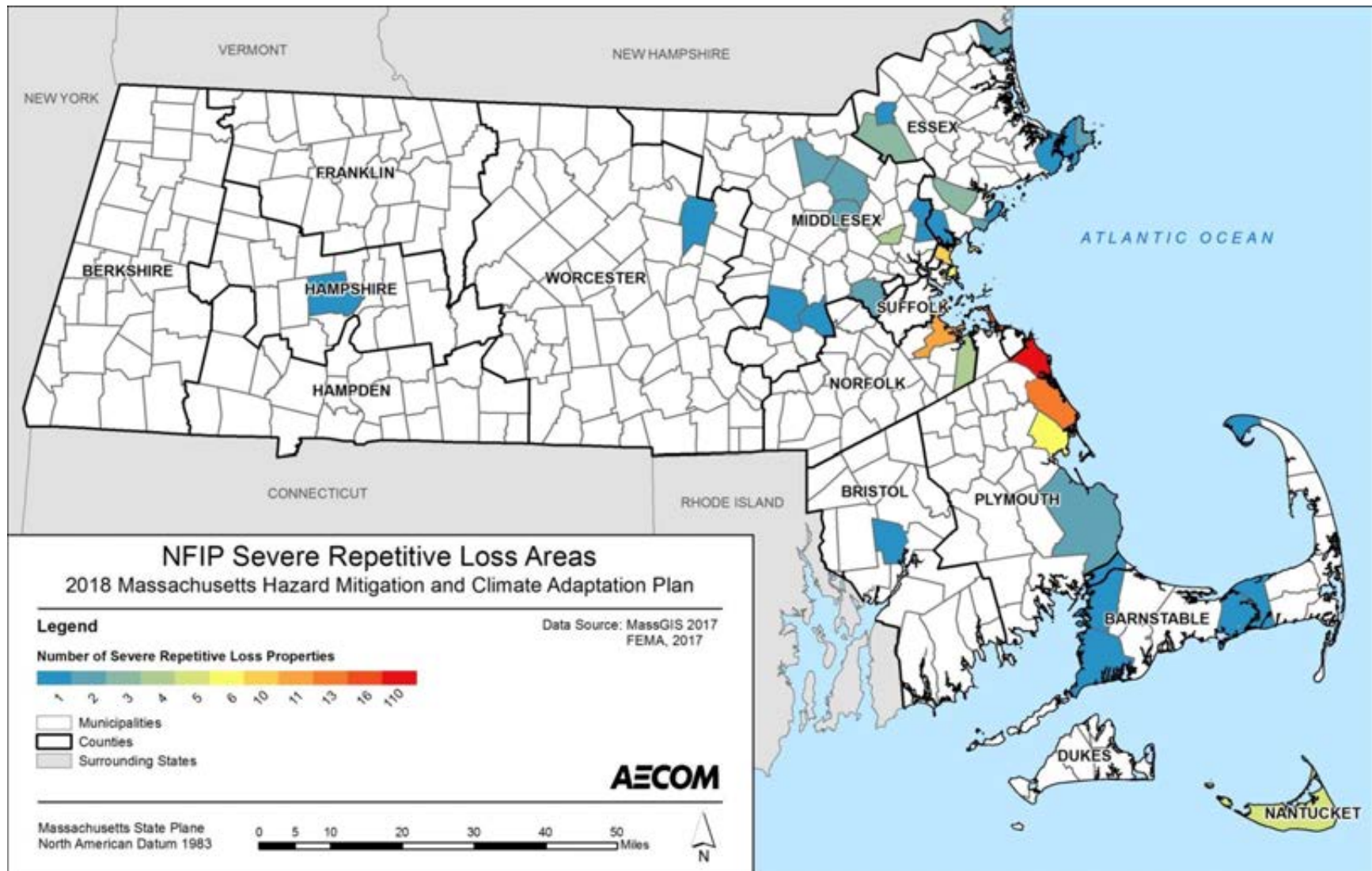


Table 4-5 includes updated data for all RL and SRL properties as of 2017 (i.e., properties affected by both inland and/or coastal flooding). This table shows the municipalities with the 15 highest number of repetitive loss properties. These municipalities are the same as those identified in the 2013 State Hazard Mitigation Plan (SHMP), although orders have shifted. Overall, it appears that the number of RL and SRL properties has increased over the reporting period. A number of phenomena could explain this trend, including actual increases in flooding frequency and severity or an increase in awareness of NFIP programs among at-risk homeowners.

Table 4-5: NFIP Repetitive Loss and Severe Repetitive Loss Data

Community	2009			2012			2017		
	SRL Properties	RL Properties	RL Claims	SRL Properties	RL Properties	RL Claims	SRL Properties	RL Properties	RL Claims
Scituate	52	503	1,551	82	490	1,708	110	526	2,036
Revere	16	288	935	17	293	962	10	294	974
Hull	7	235	713	16	238	778	16	247	833
Marshfield	3	156	442	7	158	474	13	185	629
Quincy	1	144	408	11	169	513	11	174	540
Winthrop	5	136	396	5	140	411	6	142	429
Peabody	1	37	131	2	44	179	3	46	191
Nantucket	1	47	113	0	49	122	5	69	186
Duxbury	1	42	121	1	42	126	6	52	179
Billerica	1	41	110	2	50	151	2	51	154
Nahant	1	46	133	2	46	136	6	46	146
Swampscott	1	37	108	0	44	128	2	44	133
Plymouth	2	34	91	0	37	100	2	44	131
Salisbury	*	*	*	2	34	100	2	36	113
Newton	2	30	81	2	42	109	2	43	112

Notes: Top 20 repetitive loss communities for 2018, ordered by number of repetitive loss properties, are provided in the table. Data listed for 2009 are through December 2009. Data listed for 2012 are through November 30, 2012. Data listed for 2017 are through September 30, 2017. RL = Repetitive Loss; SRL = Severe Repetitive Loss. Asterisk (*) = data not available.

Source: National Flood Insurance Program, FEMA Region I

To estimate the elements of the built environment exposed to the flood hazard, the flood hazard boundaries were overlaid upon the military facilities, police facilities, fire facilities, hospitals, and colleges contained in the most current DCAMM inventory. Table 4-6 summarizes the number of facilities in each zone by county, and Table 4-7 summarizes the number of facilities in each zone by type.

Table 4-6: Critical Facilities Exposed to Inland Flooding by County

County	A Zone	X500 Zone
Barnstable	—	—
Berkshire	1	—
Bristol	—	—
Dukes	—	—
Essex	—	3
Franklin	—	—
Hampden	1	3
Hampshire	—	—
Middlesex	6	2
Nantucket	—	—
Norfolk	2	1
Plymouth	1	1
Suffolk	—	—
Worcester	2	2
Total	13	12

Sources: MassGIS 2017, DCAMM facility inventory 2017

Table 4-7: Critical Facilities Exposed to Inland Flooding by Facility Type

Facility Type	A Zone	X500 Zone
Military	3	3
Police Facilities	5	5
Fire Facilities	1	1
Hospitals	1	—
College Facilities	2	2
Social Services	1	1
Total	13	12

Sources: MassGIS 2017, DCAMM facility inventory 2017

As noted in the State's 2011 Climate Change Adaptation Report, climate change impacts, including increased frequency of extreme weather events, are expected to raise the risk of damage to transportation systems, energy-related facilities, communication systems, a wide range of structures and buildings, solid and hazardous waste facilities, and water supply and wastewater management systems. A majority of the infrastructure in Massachusetts and throughout the country has been sited and designed based on historic weather and flooding patterns (EOEEA, 2011). As a result, infrastructure and facilities may lack the capacity to handle greater volumes of water or the required elevation to reduce vulnerability to flooding. Examples of climate change impacts to sectors of the built environment are summarized below.

Agriculture

Inland flooding is likely to impact the agricultural sector. Increased river flooding is likely to cause soil erosion, soil loss, and crop damage (resilient MA, 2018). In addition, wetter springs may delay planting of crops, resulting in reduced yields.

Energy

Flooding can increase bank erosion and also undermine buried energy infrastructure, such as underground power, gas, and cable infrastructure. Basement flooding can destroy electrical panels and furnaces. This can result in releases of oil and hazardous wastes to floodwaters. Inland flooding can also disrupt delivery of liquid fuels.

Public Health

The impacts to the built environment extend into other sectors. For example, flooding may increase the vulnerability of commercial and residential buildings to toxic mold buildup, leading to health risks, as described in the *Populations* section of the inland flooding hazard profile. Inland flooding may also lead to contamination of well water and contamination from septic systems (DPH, 2014).

Public Safety

Flash flooding can have a significant impact on public safety. Fast-moving water can sweep up debris, hazardous objects, and vehicles, and carry them toward people and property. Flooding can impact the ability of emergency response personnel to reach stranded or injured people. Drownings may also occur as people attempt to drive through flooded streets or escape to higher ground.

Transportation

Heavy precipitation events may damage roads, bridges, and energy facilities, leading to disruptions in transportation and utility services (resilient MA, 2018). Roads may experience greater ponding, which will further impact transportation. If alternative routes are not available, damage to roads and bridges may dramatically affect commerce and public health and safety.

Bridges are inherently vulnerable to flooding. Table 4-8 lists the state-owned bridges that are exposed to the inland flooding hazard.

Table 4-8: Number of Bridges in the Inland Flood Hazard Areas by County

County	Total Exposed	A Zone			X500 Zone		
		Federal	State	Local	Federal	State	Local
Barnstable	—	—	—	—	—	—	—
Berkshire	223	—	70	135	—	7	11
Bristol	106	—	41	63	—	—	2
Dukes	—	—	—	—	—	—	—
Essex	114	—	52	43	—	14	5
Franklin	2	—	—	2	—	—	—
Hampden	81	—	—	76	—	2	3
Hampshire	149	2	56	84	—	4	3
Middlesex	282	1	121	153	—	7	—
Nantucket	—	—	—	—	—	—	—
Norfolk	97	—	41	55	—	1	—
Plymouth	88	—	24	64	—	—	—
Suffolk	27	—	19	7	—	1	—
Worcester	402	3	148	229	—	12	10
Total	1571	6	572	911	—	48	34

Sources: MassGIS, 2017; National Bridge Inventory

Water Infrastructure

Stormwater drainage systems and culverts that are not sized to accommodate larger storms are likely to experience flood damage as extreme precipitation events increase (resilient MA, 2018). Both culverts that are currently undersized and culverts that are appropriately sized may be overwhelmed by larger storms. Gravity-fed water and wastewater infrastructure that is located in low lying areas near rivers and reservoirs may experience increased risks. Combined sewer overflows may increase with climate change, resulting in water quality degradation and public health risks (resilient MA, 2018).

Natural Resources and Environment



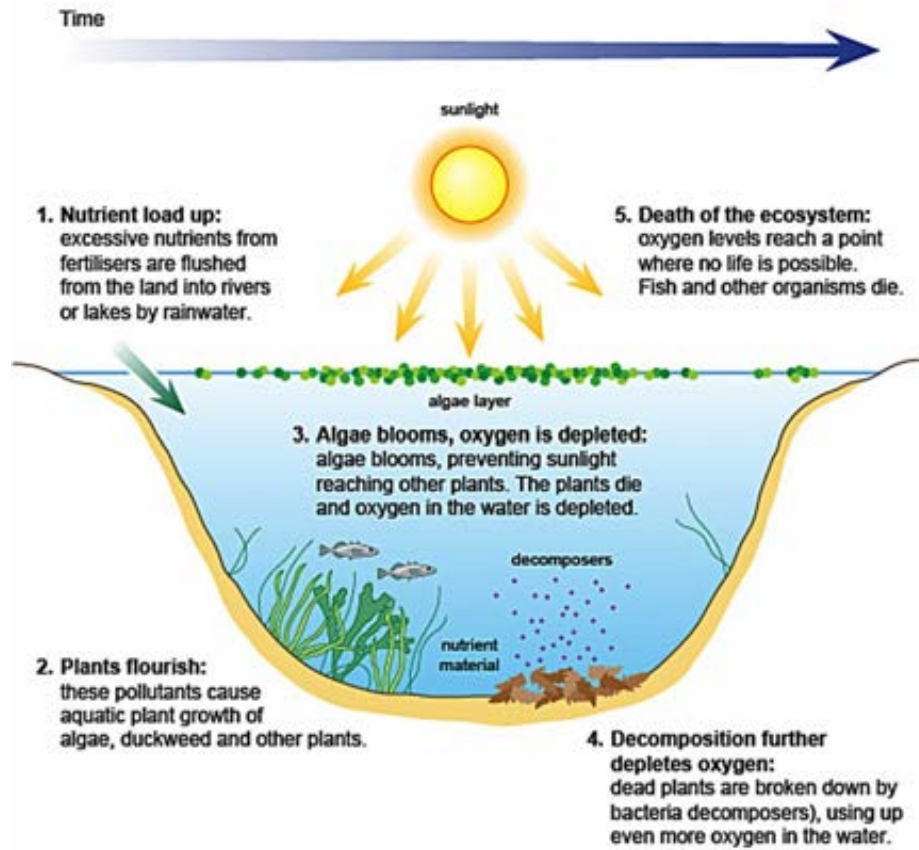
Flooding is part of the natural cycle of a balanced environment. However, severe flood events can also result in substantial damage to the environment and natural resources, particularly in areas where human development has interfered with natural flood-related processes. As described earlier in this section, severe weather events are expected to

become more frequent as a result of climate change; therefore, flooding that exceeds the adaptive capacity of natural systems may occur more often.

One common environmental effect of flooding is riverbank and soil erosion. Riverbank erosion occurs when high, fast water flows scour the edges of the river, transporting sediment downstream and reshaping the ecosystem. In addition to changing the habitat around the riverbank, this process also results in the deposition of sediment once water velocities slow. This deposition can clog riverbeds and streams, disrupting the water supply to downstream habitats. Soil erosion occurs whenever floodwaters loosen particles of topsoil and then transport them downstream, where they may be redeposited somewhere else or flushed into the ocean. Flooding can also influence soil conditions in areas where floodwaters pool for long periods of time, as continued soil submersion can cause oxygen depletion in the soil, reducing the soil quality and potentially limiting future crop production.

Flooding can also affect the health and well-being of wildlife. Animals can be directly swept away by flooding or lose their habitats to prolonged inundation. Floodwaters can also impact habitats nearby or downstream of agricultural operations by dispersing waste, pollutants, and nutrients from fertilizers. While some of these substances, particularly organic matter and nutrients, can actually increase the fertility of downstream soils, they can also result in severe impacts to aquatic habitats, such as eutrophication. Figure 4-7 illustrates how an influx of nutrients can trigger the eutrophication process.

Figure 4-7: The Eutrophication Process



Source: British Broadcasting Corporation

Tables 4-9 through 4-11 document the exposure of Areas of Critical Environmental Concern, BioMap2 Core Habitat, and BioMap2 Critical Natural Landscape to the 1 percent annual chance flood event and the 0.2 percent annual chance flood event in inland flood hazard areas based on GIS analysis.

Table 4-9: Natural Resources Exposure – Areas of Critical Environmental Concern

Name	County	Total Acreage	1 Percent Annual Chance Flood Event		0.2 Percent Annual Chance Flood Event	
			A Zone		X500 Zone	
			Acres	% of Total	Acres	% of Total
Bourne Back River	Barnstable	1,608.8	—	—	38.4	2.4
Canoe River Aquifer	Bristol	14,591.6	2,547.3	17.5	428.7	2.9
Canoe River Aquifer	Norfolk	2,599.4	232.8	9.0	395.9	15.2
Cedar Swamp	Middlesex	260.1	214.2	82.4	2.5	1.0
Cedar Swamp	Worcester	1,389.7	1,221.2	87.9	23.4	1.7
Central Nashua River Valley	Worcester	12,887.1	4,070.6	31.6	557.9	4.3
Cranberry Brook Watershed	Norfolk	1,040.7	145.0	13.9	115.4	11.1
Ellisville Harbor	Plymouth	573.0	—	—	1.0	0.2
Fowl Meadow and Ponkapoag Bog	Norfolk	8,149.0	2,905.4	35.7	712.7	8.7
Fowl Meadow and Ponkapoag Bog	Suffolk	183.0	42.4	23.2	33.4	18.3
Golden Hills	Essex	225.5	4.6	2.0	28.7	12.7
Golden Hills	Middlesex	266.1	0.5	0.2	—	—
Great Marsh	Essex	19,529.7	10.8	0.1	—	—
Herring River Watershed	Barnstable	1,233.2	11.3	0.9	10.2	0.8
Herring River Watershed	Plymouth	3,211.7	537.1	16.7	200.6	6.2
Hinsdale Flats Watershed	Berkshire	14,493.1	1,585.2	10.9	216.4	1.5
Hockomock Swamp	Bristol	10,732.5	4,558.3	42.5	97.6	0.9
Hockomock Swamp	Plymouth	6,231.5	4,022.1	64.5	—	—
Kampoosa Bog Drainage Basin	Berkshire	1,344.4	148.7	11.1	32.3	2.4
Karner Brook Watershed	Berkshire	6,993.9	386.8	5.5	33.7	0.5
Miscoe, Warren And Whitehall Watersheds	Middlesex	458.5	—	—	94.9	20.7
Miscoe, Warren And Whitehall Watersheds	Worcester	8,248.1	530.0	6.4	228.3	2.8
Neponset River Estuary	Norfolk	584.4	—	—	5.0	0.9
Petapawag	Middlesex	25,675.7	3,981.0	15.5	849.1	3.3
Pleasant Bay	Barnstable	3,757.1	—	—	73.6	2.0
Pocasset River	Barnstable	144.8	—	—	6.8	4.7
Schenob Brook Drainage Basin	Berkshire	13,732.2	2,382.9	17.4	79.2	0.6
Squannassit	Middlesex	33,161.3	4,357.7	13.1	1,291.3	3.9
Squannassit	Worcester	4,260.2	332.0	7.8	155.4	3.6

Name	County	Total Acreage	1 Percent Annual Chance Flood Event A Zone		0.2 Percent Annual Chance Flood Event X500 Zone	
			Acres	% of Total	Acres	% of Total
Three Mile River Watershed	Bristol	14,273.2	1,518.0	10.6	1,091.4	7.6
Upper Housatonic River	Berkshire	12,275.7	2,450.6	20.0	137.0	1.1
Waquoit Bay	Barnstable	1,622.4	—	—	0.1	0.0
Weir River	Plymouth	400.7	5.5	1.4	—	—
Wellfleet Harbor	Barnstable	4,550.9	188.7	4.1	—	—
Weymouth Back River	Norfolk	178.0	6.4	3.6	—	—
Weymouth Back River	Plymouth	576.9	44.2	7.7	—	—

Table 4-10: Natural Resources Exposure – BioMap2 Core Habitat

Name	County	Total Acreage	1 Percent Annual Chance Flood Event A Zone		0.2 Percent Annual Chance Flood Event X500 Zone	
			Acres	% of Total	Acres	% of Total
Aquatic Core	Barnstable	10,760.0	2,093.6	19.5	3,415.3	31.7
Aquatic Core	Berkshire	27,271.1	16,489.2	60.5	598.8	2.2
Aquatic Core	Bristol	11,266.0	6,988.8	62.0	166.5	1.5
Aquatic Core	Essex	23,397.8	7,213.3	30.8	583.7	2.5
Aquatic Core	Franklin	22,908.5	109.1	0.5	0.1	0.0
Aquatic Core	Hampden	11,702.4	8,258.8	70.6	411.0	3.5
Aquatic Core	Hampshire	13,823.4	9,802.8	70.9	369.0	2.7
Aquatic Core	Middlesex	11,699.1	9,572.2	81.8	316.2	2.7
Aquatic Core	Nantucket	626.3	80.0	12.8	37.9	6.1
Aquatic Core	Norfolk	6,992.3	5,428.0	77.6	243.4	3.5
Aquatic Core	Plymouth	27,564.3	15,240.8	55.3	1,316.3	4.8
Aquatic Core	Suffolk	567.0	437.9	77.2	7.0	1.2
Aquatic Core	Worcester	35,189.9	28,009.8	79.6	1,045.2	3.0
Forest Core	Barnstable	9,358.2	—	—	5.2	0.1
Forest Core	Berkshire	115,526.2	750.1	0.6	141.7	0.1
Forest Core	Bristol	20,057.0	4,211.9	21.0	1,232.9	6.1
Forest Core	Essex	11,085.6	1,612.1	14.5	771.5	7.0
Forest Core	Hampden	8,927.0	355.6	4.0	—	—

Name	County	Total Acreage	1 Percent Annual Chance Flood Event A Zone		0.2 Percent Annual Chance Flood Event X500 Zone	
			Acres	% of Total	Acres	% of Total
Forest Core	Hampshire	31,733.6	564.9	1.8	71.9	0.2
Forest Core	Middlesex	14,314.6	763.9	5.3	763.3	5.3
Forest Core	Norfolk	3,942.6	166.0	4.2	351.3	8.9
Forest Core	Plymouth	20,647.7	5,788.1	28.0	274.8	1.3
Forest Core	Worcester	43,703.3	1,222.7	2.8	1,226.8	2.8
Priority Natural Communities	Barnstable	10,944.0	0.6	0.0	166.1	1.5
Priority Natural Communities	Berkshire	6,012.8	1,457.8	24.2	10.4	0.2
Priority Natural Communities	Bristol	3,906.4	1,941.6	49.7	442.4	11.3
Priority Natural Communities	Essex	18,759.2	286.9	1.5	73.4	0.4
Priority Natural Communities	Franklin	5,407.4	1.9	0.0	—	—
Priority Natural Communities	Hampden	2,524.5	238.1	9.4	30.4	1.2
Priority Natural Communities	Hampshire	1,069.86	513.9	—	5.2	—
Priority Natural Communities	Middlesex	617.0	487.9	79.1	28.2	4.6
Priority Natural Communities	Nantucket	1,630.3	0.1	0.0	1.8	0.1
Priority Natural Communities	Norfolk	921.8	614.6	66.7	52.5	5.7
Priority Natural Communities	Plymouth	23,473.0	3,885.8	16.6	272.4	1.2
Priority Natural Communities	Worcester	4,655.6	2,156.1	46.3	722.1	15.5
Species of Conservation Concern	Barnstable	88,027.0	1,792.4	2.0	4,019.1	4.6
Species of Conservation Concern	Berkshire	101,661.6	20,275.8	19.9	970.6	1.0
Species of Conservation Concern	Bristol	46,019.3	14,584.4	31.7	953.0	2.1
Species of Conservation Concern	Essex	61,417.7	12,680.1	20.6	1,844.1	3.0
Species of Conservation Concern	Franklin	70,543.5	152.4	0.2	6.3	0.0
Species of Conservation Concern	Dukes	43,315.5	—	—	31.5	0.1
Species of Conservation Concern	Hampden	56,378.8	10,795.2	19.1	1,675.0	3.0
Species of Conservation Concern	Hampshire	60,925.4	20,516.6	33.7	2,143.3	3.5
Species of Conservation Concern	Middlesex	80,649.1	20,636.6	25.6	3,961.9	4.9

Name	County	Total Acreage	1 Percent Annual Chance Flood Event A Zone		0.2 Percent Annual Chance Flood Event X500 Zone	
			Acres	% of Total	Acres	% of Total
Species of Conservation Concern	Nantucket	22,933.2	891.1	3.9	637.3	2.8
Species of Conservation Concern	Norfolk	22,990.7	7,113.3	30.9	1,308.9	5.7
Species of Conservation Concern	Plymouth	98,328.1	24,404.3	24.8	2,832.5	2.9
Species of Conservation Concern	Suffolk	2,334.1	146.1	6.3	7.0	0.3
Species of Conservation Concern	Worcester	109,967.3	39,412.7	35.8	3,844.9	3.5
Vernal Pool	Barnstable	60.6	—	—	7.1	11.7
Vernal Pool	Berkshire	1,918.2	127.9	6.7	20.1	1.0
Vernal Pool	Bristol	7,363.4	826.6	11.2	614.4	8.3
Vernal Pool	Essex	6,461.0	653.9	10.1	285.1	4.4
Vernal Pool	Hampden	1,745.0	18.6	1.1	8.7	0.5
Vernal Pool	Hampshire	2,537.4	86.1	3.4	5.5	0.2
Vernal Pool	Middlesex	5,295.6	241.5	4.6	151.3	2.9
Vernal Pool	Norfolk	1,260.9	103.2	8.2	114.8	9.1
Vernal Pool	Plymouth	2,306.2	51.0	2.2	55.5	2.4
Vernal Pool	Worcester	6,055.2	228.4	3.8	78.0	1.3
Wetlands	Barnstable	2,595.9	47.4	1.8	223.2	8.6
Wetlands	Berkshire	13,440.8	7,611.4	56.6	287.6	2.1
Wetlands	Bristol	15,440.9	9,295.4	60.2	1,875.3	12.1
Wetlands	Essex	8,429.7	4,571.7	54.2	975.3	11.6
Wetlands	Franklin	3,956.2	0.1	0.0	1.7	0.0
Wetlands	Hampden	2,920.6	1,646.2	56.4	243.2	8.3
Wetlands	Hampshire	2,947.7	1,621.8	55.0	413.8	14.0
Wetlands	Middlesex	7,864.3	5,422.1	68.9	960.7	12.2
Wetlands	Nantucket	972.3	244.6	25.2	225.3	23.2
Wetlands	Norfolk	4,056.9	3,159.71	—	266.6	6.6
Wetlands	Plymouth	23,776.4	14,033.2	59.0	734.8	3.1
Wetlands	Worcester	14,992.4	10,123.1	67.5	2,067.0	13.8

Table 4-11: Natural Resources Exposure – BioMap2 Critical Natural Landscape

Name	County	Total Acreage	1 Percent Annual Chance Flood Event		0.2 Percent Annual Chance Flood Event	
			A Zone		X500 Zone	
			Acres	% of Total	Acres	% of Total
Aquatic Buffer	Barnstable	15,910.8	2,310.9	14.5	3,990.4	25.1
Aquatic Buffer	Berkshire	54,738.6	20,313.4	37.1	1,013.9	1.9
Aquatic Buffer	Bristol	20,468.8	9,902.8	48.4	366.5	1.8
Aquatic Buffer	Essex	32,046.2	8,515.8	26.6	942.0	2.9
Aquatic Buffer	Franklin	48,769.1	112.4	0.2	0.1	0.0
Aquatic Buffer	Hampden	23,192.8	10,360.7	44.7	793.5	3.4
Aquatic Buffer	Hampshire	30,948.9	13,229.6	42.7	767.9	2.5
Aquatic Buffer	Middlesex	16,657.9	11,585.3	69.5	620.2	3.7
Aquatic Buffer	Nantucket	1,578.7	197.4	12.5	64.5	4.1
Aquatic Buffer	Norfolk	10,263.4	6,722.3	65.5	479.9	4.7
Aquatic Buffer	Plymouth	41,381.2	18,680.9	45.1	1,745.0	4.2
Aquatic Buffer	Suffolk	626.3	453.2	72.4	9.0	1.4
Aquatic Buffer	Worcester	60,793.8	32,802.1	54.0	1,526.9	2.5
Coastal Adaptation Analysis	Barnstable	20,054.7	14.5	0.1	34.2	0.2
Coastal Adaptation Analysis	Bristol	8,612.7	481.4	5.6	60.0	0.7
Coastal Adaptation Analysis	Essex	22,326.2	377.3	1.7	28.7	0.1
Coastal Adaptation Analysis	Nantucket	4,365.8	279.1	6.4	227.4	5.2
Coastal Adaptation Analysis	Norfolk	787.1	10.8	1.4	0.6	0.1
Coastal Adaptation Analysis	Plymouth	12,732.9	89.6	0.7	6.5	0.1
Landscape Blocks	Barnstable	82,481.2	1,224.2	1.5	1,457.9	1.8
Landscape Blocks	Berkshire	345,685.3	12,986.9	3.8	1,241.8	0.4
Landscape Blocks	Bristol	85,667.1	16,744.0	19.5	2,665.8	3.1
Landscape Blocks	Essex	41,937.3	4,011.7	9.6	1,320.6	3.1
Landscape Blocks	Franklin	221,827.3	135.7	0.1	0.1	0.0
Landscape Blocks	Hampden	136,833.0	6,503.0	4.8	961.6	0.7
Landscape Blocks	Hampshire	124,440.4	11,335.3	9.1	822.5	0.7
Landscape Blocks	Middlesex	36,866.4	3,626.2	9.8	1,410.9	3.8
Landscape Blocks	Nantucket	11,571.2	494.6	4.3	458.4	4.0
Landscape Blocks	Norfolk	8,250.4	521.0	6.3	751.2	9.1
Landscape Blocks	Plymouth	124,678.0	28,414.8	22.8	2,356.9	1.9
Landscape Blocks	Worcester	204,731.2	31,668.0	15.5	4,630.1	2.3

Name	County	Total Acreage	1 Percent Annual Chance Flood Event A Zone		0.2 Percent Annual Chance Flood Event X500 Zone	
			Acres	% of Total	Acres	% of Total
Tern Foraging	Nantucket	2,703.2	14.6	0.5	0.0	0.0
Tern Foraging	Plymouth	5,482.2	7.1	0.1	—	—
Wetland Buffer	Barnstable	6,021.8	94.2	1.6	873.4	14.5
Wetland Buffer	Berkshire	34,375.7	10,239.2	29.8	491.7	1.4
Wetland Buffer	Bristol	29,531.6	12,530.8	42.4	2,409.6	8.2
Wetland Buffer	Essex	17,056.9	5,959.8	34.9	1,482.2	8.7
Wetland Buffer	Franklin	9,593.6	5.3	0.1	3.7	0.0
Wetland Buffer	Hampden	8,679.6	2,875.9	33.1	382.6	4.4
Wetland Buffer	Hampshire	9,286.6	2,796.9	30.1	729.5	7.9
Wetland Buffer	Middlesex	15,811.7	8,118.9	51.3	1,434.4	9.1
Wetland Buffer	Nantucket	3,088.1	478.0	15.5	341.5	11.1
Wetland Buffer	Norfolk	7,298.5	4,168.1	57.1	558.9	7.7
Wetland Buffer	Plymouth	45,543.6	19,166.2	42.1	1,585.5	3.5
Wetland Buffer	Worcester	40,938.7	16,244.4	39.7	3,195.1	7.8

Economy



Economic losses due to a flood include, but are not limited to, damages to buildings (and their contents) and infrastructure, agricultural losses, business interruptions (including loss of wages), impacts on tourism, and impacts on the tax base. Flooding can also cause extensive damage to public utilities and disruptions to the delivery of services. Loss of power and communications may occur, and drinking water and wastewater treatment facilities may be temporarily out of operation. Flooding can shut down major roadways and the subway or commuter rail systems, making it difficult or impossible for people to get to work. Floodwaters can wash out sections of roadway and bridges, and the removal and disposal of debris can also be an enormous cost during the recovery phase of a flood event. Agricultural impacts range from crop and infrastructure damage to loss of livestock. Extreme precipitation events may result in crop failure, inability to harvest, rot, and increases in crop pests and disease. In addition to having a detrimental effect on water quality and soil health and stability, these impacts can result in increased reliance on crop insurance claims.

Damages to buildings can affect a community's economy and tax base; therefore, an analysis was conducted to determine the exposure of the building inventory of the Commonwealth of Massachusetts to the flood hazard. To estimate the buildings exposed to the 1 percent and 0.2 percent annual chance flood events, the flood hazard boundaries were overlaid upon the Hazus

default general building stock inventory. Census blocks do not follow the boundaries of the floodplain; therefore, the same estimating methodology used for population in Table 4-4 was used to determine overall economic exposure. Table 4-12 shows the results of this analysis.

Table 4-12: Building Replacement Cost Value in Inland Flood Hazard Areas (\$1,000s)

County	A Zone	X500 Zone	Total
Barnstable	\$46,801	\$367,974	\$414,775
Berkshire	\$2,179,664	\$633,723	\$2,813,387
Bristol	\$2,906,110	\$765,065	\$3,671,175
Dukes	—	\$2,288	\$2,288
Essex	\$5,259,039	\$4,265,378	\$9,524,417
Franklin*	N/A	N/A	N/A
Hampden	\$2,083,291	\$3,350,736	\$5,434,027
Hampshire	\$568,134	\$247,623	\$815,757
Middlesex	\$11,846,388	\$9,918,049	\$21,764,437
Nantucket	\$6,969	\$93,236	\$100,205
Norfolk	\$6,092,244	\$2,928,319	\$9,020,563
Plymouth	\$3,637,576	\$905,555	\$4,543,131
Suffolk	\$365,780	\$162,654	\$528,434
Worcester	\$6,041,666	\$2,920,237	\$8,961,903
Total	\$41,033,796	\$26,561,096	\$67,594,892

Source: MassGIS, 2017; FEMA Hazus loss estimation methodology

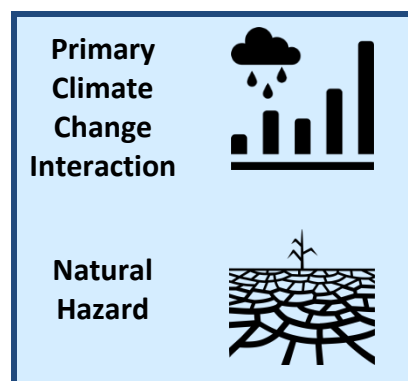
*Digital flood hazard boundary information was not available for Franklin County.

N/A = not available

4.1.2 Drought

GENERAL BACKGROUND

Droughts can vary widely in duration, severity, and local impact. They may have widespread social and economic significance that requires the response of numerous parties, including water suppliers, firefighters, farmers, and residents. Droughts are often defined as periods of deficient precipitation. How this deficiency is experienced can depend on factors such as land use change, the existence of dams, and water supply withdrawals or diversions. For example, impervious surfaces associated with development can exacerbate the effects of drought due to decreased groundwater recharge.







Natural Hazard Summary


DROUGHT

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
There are many ways to define a drought; however, the root cause of most droughts is an extended period of deficient precipitation.	The entire Commonwealth is exposed to this hazard. Each drought can affect some or all regions of the Commonwealth at different intensities.	The last emergency level drought was in the 1960s, but since then multiple severe droughts have occurred, including two at the Warning level and four at the watch level. Although shorter in duration, the severity of the 2016 drought was equivalent to that of the 1960s. However, less severe droughts occur more often. Based on historical precipitation data analyzed in the Drought Management Plan, there is approximately an 8% change of a Watch level drought occurring in any given month.

Potential Effects of Climate Change

	RISING TEMPERATURES AND CHANGES IN PRECIPITATION → PROLONGED DROUGHT	The frequency and intensity of droughts are projected to increase during summer and fall in the Northeast as higher temperatures lead to greater evaporation and earlier winter and spring snowmelt, and precipitation patterns become more variable and extreme.
	RISING TEMPERATURES AND CHANGES IN PRECIPITATION → REDUCED SNOWPACK	Due to climate change, the proportion of precipitation falling as snow and the extent of time snowpack remains are both expected to decrease. This reduces the period during which snowmelt can recharge groundwater supplies, bolster streamflow, and provide water for the growing period.

Exposure and Vulnerability by Key Sector 

	POPULATIONS	General At-Risk Population: State-wide exposure. Vulnerable Populations: Residents with a private water supply, such as a well; persons who receive water through a public provider; populations with respiratory health conditions.
	GOVERNMENT	Drought impacts on government facilities are limited, with the exception of facilities like parks or greenhouses that rely on specific environmental conditions. However, droughts contribute to conditions that can be conducive to wildfire and fire-fighting can be hampered by water shortage.
	BUILT ENVIRONMENT	Some infrastructure may not be built to operate during drought conditions. For example, a reservoir's intake pipe may be higher than the reservoir water level in a severe drought. Similar conditions may occur for cooling water intake for energy production. For groundwater water supply deeper wells may be needed or alternate supplies found for emergency backup during severe droughts. Drier summers and intermittent droughts may strain irrigation water supplies, stress crops, and delay harvests.
	NATURAL RESOURCES AND ENVIRONMENT	Prolonged droughts can have severe impacts on groundwater and surface water dependent ecosystems and natural resources, as most organisms require water throughout their life cycle. Forests managed for timber or other economic uses could experience reduced growth rates or mortality during periods of drought.
	ECONOMY	The economic impacts of drought can be significant in the agriculture, recreation, forestry, and energy sectors. Economic impacts might also include purchasing water during drought emergencies. Crop failure can also result in an increase in food prices, placing economic stress on a broader portion of the economy.

The National Drought Mitigation Center references five common, conceptual definitions of drought categorized by Wilhite and Glantz in 1985:

Meteorological drought is a measure of departure of precipitation from normal. It is defined solely on the degree of dryness. Due to climatic differences, what might be considered a drought in one location of the country may not be a drought in another location.

Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on the surface or subsurface water supply, and occurs when these water supplies are below normal. This type of drought is related to the effects of precipitation shortfalls on stream flows and on reservoir and groundwater levels.

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, such as precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, and reduced ground water or reservoir levels. It occurs when there is not enough water available for a particular crop to grow at a particular time. Agricultural drought is defined in terms of soil moisture deficiencies relative to the water demands of plant life, primarily crops.

Socioeconomic drought is associated with the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. This differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. The supply of many economic goods depends on the weather (e.g., water, forage, food grains, fish, and hydroelectric power). Socioeconomic drought occurs when the demand for an economic good exceeds the supply as a result of a weather-related shortfall in the water supply.

Ecological drought is an episodic deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedbacks in natural and/or human systems (Crausbay et al., 2017).

There are also multiple operational definitions of drought. An operational definition attempts to quantitatively characterize the onset and end of droughts as well as the severity or levels during the drought.

Groundwater Recharge and Infiltration

Drought is a natural phenomenon, but its impacts are exacerbated by the volume and rate of water withdrawn from these natural systems over time as well as the reduction in infiltration from precipitation that is available to recharge these systems. Groundwater withdrawals for drinking water can reduce groundwater levels, impacting water supplies as well as base flow (flow of groundwater) in streams. A reduction in base flow is significant, especially in times of drought, as this is often the only source of water to the stream. In extreme situations,

groundwater levels can fall below stream channel bottom, and groundwater becomes disconnected from the stream, resulting in a dry channel.

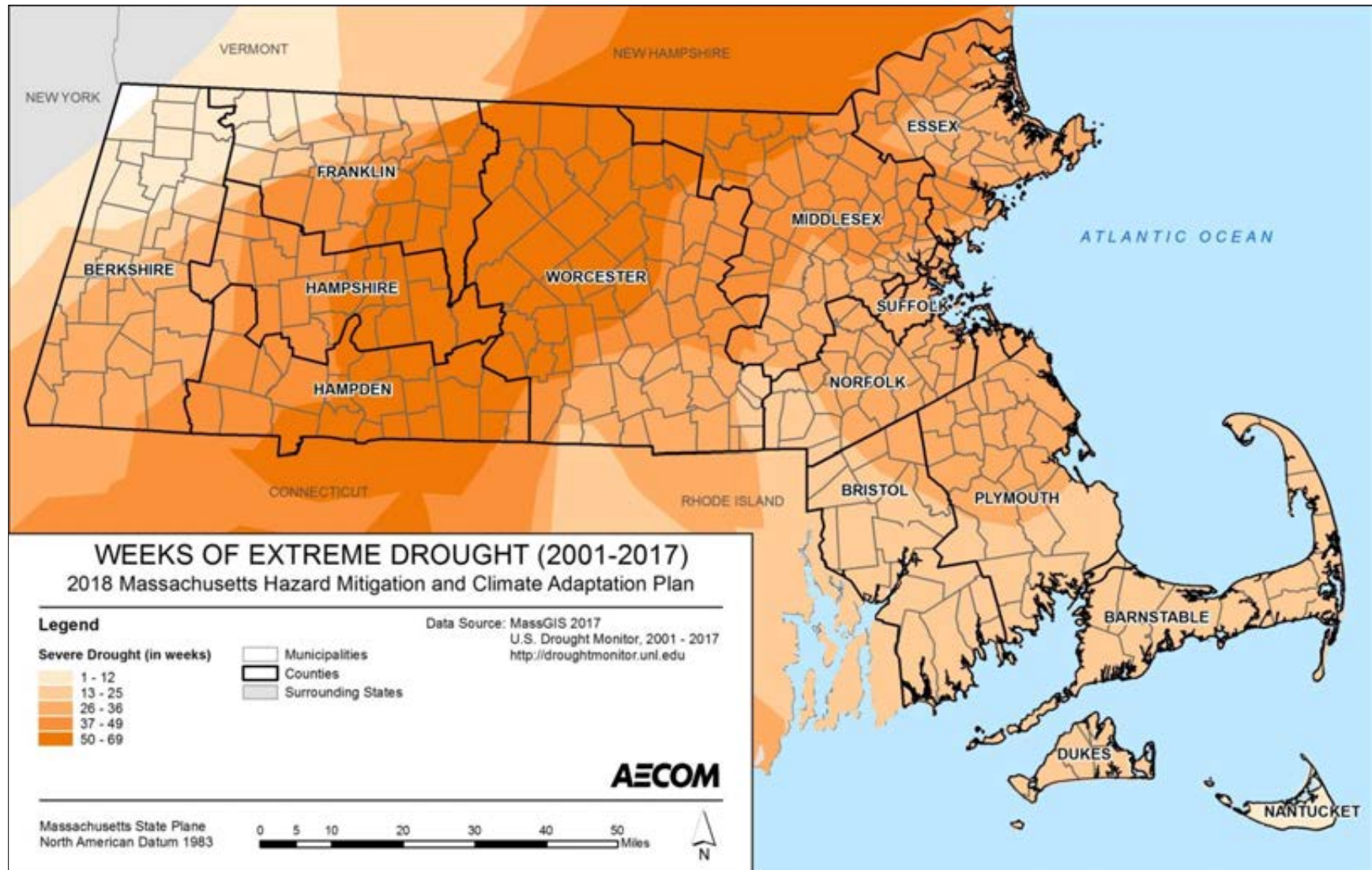
Natural infiltration is reduced by impervious cover (pavement, buildings) on the land surface and by the interruption of natural small-scale drainage patterns in the landscape caused by development and drainage infrastructure. Sewer collection systems can also reduce groundwater levels when groundwater infiltrates into them. Also, when drains are connected to the sanitary system, groundwater and precipitation are transported to wastewater treatment plants where effluent is typically discharged to surface water bodies and not returned to the groundwater. Highly urbanized areas with traditional stormwater drainage systems tend to result in higher peak flood levels during rainfall events and rapid decline of groundwater levels during periods of low precipitation. Thus, the hydrology in these areas becomes more extreme during floods and droughts (ERG and Horsley Witten Group, 2017). The importance of increasing infiltration is widely recognized, and the implementation of green infrastructure practices to help address this problem is discussed further in later portions of this plan.

HAZARD PROFILE

Location

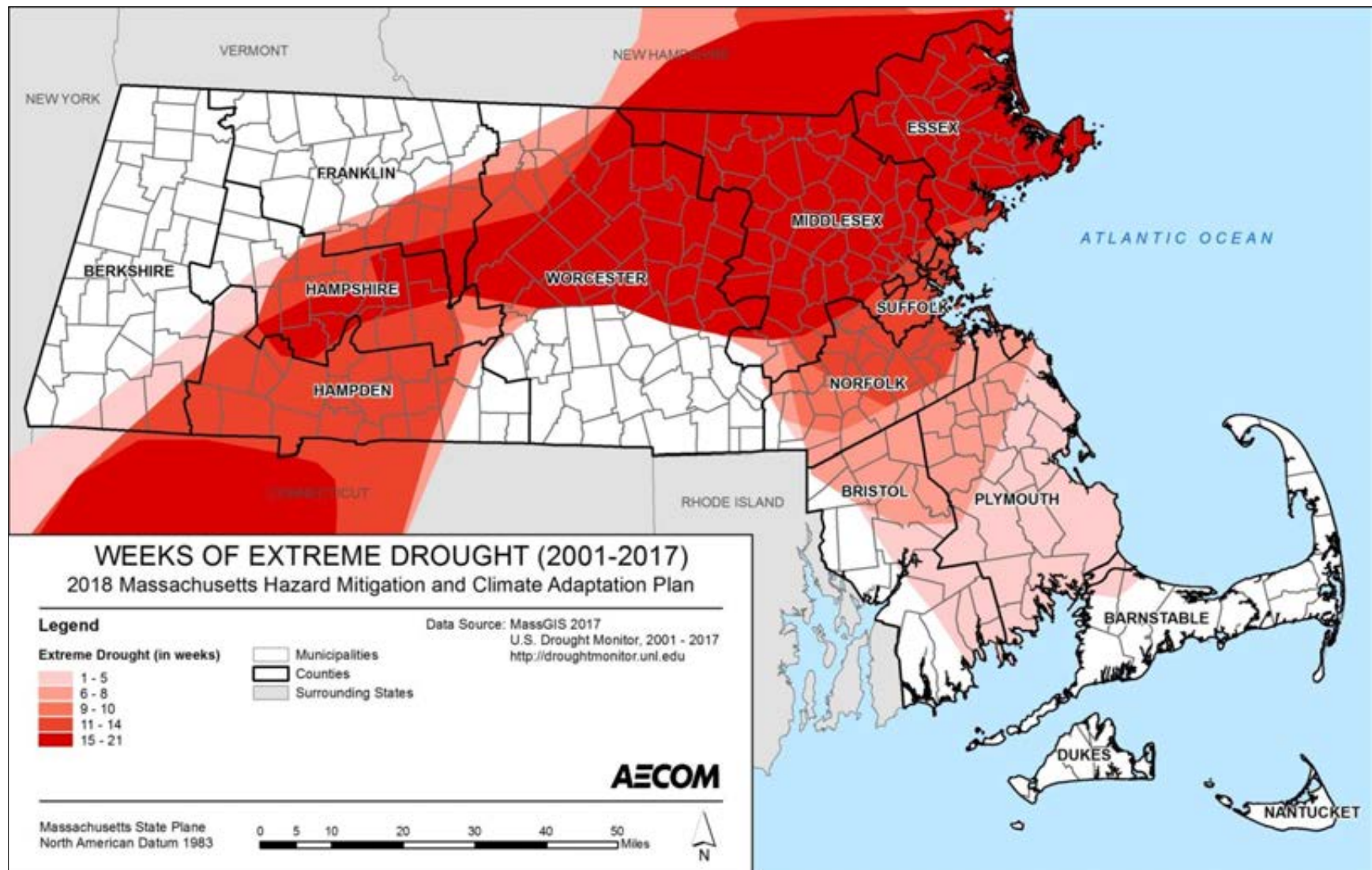
Although Massachusetts is a relatively small state, regions of Massachusetts can experience significantly different weather patterns due to topography, distance from coastal influence, as well as a combination of regional, national, and global weather patterns. As a result, the Massachusetts Drought Management Plan (DMP) assesses drought conditions in six regions—Western, Connecticut River Valley, Central, Northeast, Southeast, and Cape and Islands. A regional approach allows customization of drought actions and conservation measures to address particular situations in each region. In addition, the DMP allows for the determination of a drought on a watershed basis. Figures 4-8 and 4-9 provide an overview of drought-prone regions in the Commonwealth.

Figure 4-8: Weeks of Severe Drought (2001-2017)



Source: U.S. Drought Monitor, 2017

Figure 4-9: Weeks of Extreme Drought (2001-2017)



Source: U.S. Drought Monitor, 2017

Previous Occurrences

The Commonwealth of Massachusetts has never received a Presidential Disaster Declaration for a drought-related disaster; however, the Commonwealth has experienced several substantial droughts over the past 100 years and has recorded events dating back to 1879 (see Table 4-13).

Table 4-13: Droughts in Massachusetts Based on Instrumental Records

Date	Area Affected	Recurrence Interval (years)	Remarks	Reference
1879-83	—	—		Kinnison (1931) as cited in USGS 1989
1908-12	—	—		Kinnison (1931) as cited in USGS 1989
1929-32	Statewide	10 to >50	Water-supply sources altered in 13 communities. Multistate.	USGS 1989
1939-44	Statewide	15 to >50	More severe in eastern and extreme western Massachusetts. Multistate.	USGS 1989
1957-59	Statewide	5 to 25	Record low water levels in observation wells, northeastern Massachusetts.	USGS 1989
1961-69	Statewide	35 to >50	Water-supply shortages common. Record drought. Multistate.	USGS 1989
1980-83	Statewide	10 to 30	Most severe in Ipswich and Taunton River basins; minimal effect in Nashua River basin. Multistate.	USGS 1989
1985-88	Housatonic River basin	25	Duration and severity as yet unknown. Streamflow showed mixed trends elsewhere.	USGS 1989
1995	—	—	Based on statewide average precipitation	DMP 2013
1998-1999	—	—	Based on statewide average precipitation	DMP 2013
Dec 2001 - Jan 2003	Statewide	—	Level 2 drought (out of 4 levels) was reached statewide for several months	DCR 2017
Oct 2007 - Mar 2008	Statewide except West and Cape and Islands regions	—	Level 1 drought (out of 4 levels)	DCR 2017
Aug 2010 - Nov 2010	Connecticut River Valley, Central and Northeast regions	—	Level 1 drought (out of 4 levels)	DCR 2017
Oct 2014 - Nov 2014	Southeast and Cape and Islands regions	—	Level 1 drought (out of 4 levels)	DCR 2017
Jul 2016 - Apr 2017	Statewide	—	Level 3 drought (out of 4 levels)	DCR 2017

Notes: (1) “—” denotes data not available; (2) USGS 1989 determined dry periods from streamflow and precipitation records. Dry periods that exceeded a recurrence interval of 10 years were deemed droughts; (3) DMP 2013 analyzed precipitation data only and as a statewide average of stations; (4) DCR 2017 compiled data based on historical drought declarations by the State under the protocol in its 2013 Drought Management Plan. DCR = Department of Conservation and Recreation; USGS = United States Geological Survey.

Beginning in 1960 in western Massachusetts and in 1962 in eastern Massachusetts through 1969, Massachusetts experienced the most significant drought on record (USGS, 2004). The severity and duration of the drought caused significant impacts on both water supplies and agriculture. Although short or relatively minor droughts occurred over the next 50 years, the next long-term event began in March 2015, when Massachusetts began experiencing widespread abnormally dry conditions. In July 2016, based on a recommendation from the Drought Management Task Force (DMTF), the Secretary of EOEEA declared a Drought Watch for Central and Northeast Massachusetts and a Drought Advisory for Southeast Massachusetts and the Connecticut River Valley. Drought warnings were issued in five out of six drought regions of the state. Many experts stated that this drought was the worst in more than 50 years. However, the DMTF was able to declare an end to the drought in May 2017, since the entire Commonwealth had returned to “normal” conditions due to wetter-than-normal conditions in the spring of 2017.

The evolution of this drought can be seen in the yearly statistics shown in Table 4-14. For example, in September 2016, 100 percent of the Commonwealth was categorized above “abnormally dry” and 90 percent was categorized as “severe drought” or higher. In summer 2017, these metrics indicate that the Commonwealth experienced no drought conditions.

Table 4-14: Evolution of 2016-2017 Drought

Time	Percent of Commonwealth at a Given Drought Level					
	None	D0 (Abnormally Dry) or above	D1 (Moderate Drought) or above	D2 (Severe Drought) or above	D3 (Extreme Drought) or above	D4 (Exceptional Drought)
September 2016	0%	100%	98%	90%	52%	0%
December 2016	1%	99%	98%	69%	36%	0%
May 2017	100%	0%	0%	0%	0%	0%

Source: U.S. Drought Monitor, 2017

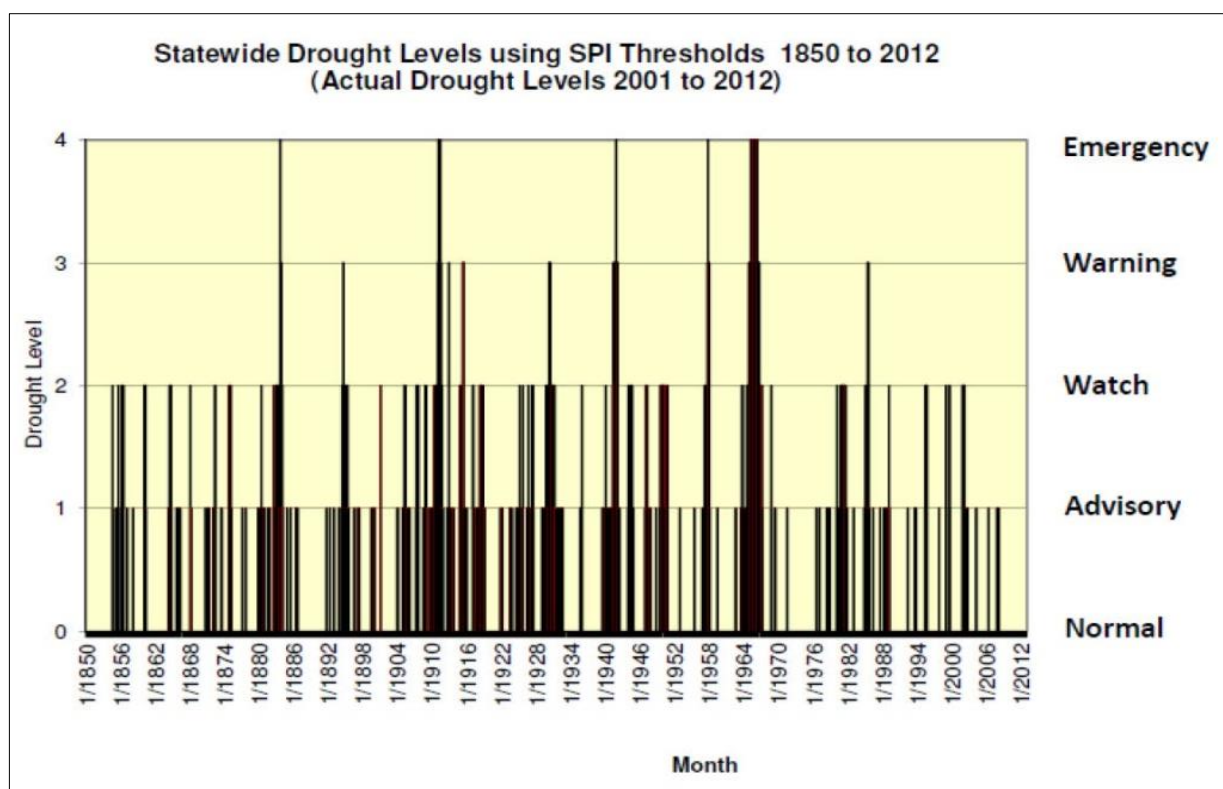
Frequency of Occurrences

Using data collected since 1850, the probability of the precipitation index of the DMP exceeding the threshold at each drought level was calculated, as shown in Table 4-15. On a monthly basis over the 162-year period of record from 1850 to 2012, there is a 2 percent chance of being in a drought warning level. Figure 4-10 shows the statewide drought levels using the Standardized Precipitation Index (SPI) thresholds.

Table 4-15: Frequency of Drought Events Exceeding the Precipitation Index of the Drought Management Plan

Drought Level	Frequency Since 1850	Probability of Occurrence in a Given Month
Drought Emergency	5 occurrences	1% chance
Drought Warning	5 occurrences	2% chance
Drought Watch	46 occurrences	8% chance

Source: EOEEA and MEMA 2013

Figure 4-10: Statewide Drought Levels Using Standardized Precipitation Index (SPI) Thresholds, 1850-2012

Source: Massachusetts Drought Management Plan, 2013

The Global Change Research Program (GCRP) has identified a number of ways in which the Massachusetts drought hazard is likely to evolve in response to climate change (Horton et al., 2014). Although total annual precipitation is anticipated to increase over the next century (as discussed in Section 4.4.4, Other Severe Weather), seasonal precipitation is predicted to include more severe and unpredictable dry spells. More rain falling over shorter time periods will reduce groundwater recharge, even in undeveloped areas, as the ground becomes saturated and unable to absorb the same amount of water if rainfall were spread out. The effects of this trend will be exacerbated by projected reduction in snowpack, which can serve as a significant water source during the spring melt to buffer against sporadic precipitation. Also, the snowpack melt is occurring faster than normal, resulting not only in increased flooding but a reduced period in which the melt can recharge groundwater and the amount of water naturally available during the spring growing period. Reduced recharge can in turn affect base flow in streams that are critical to sustain ecosystems during dry periods and groundwater-based water supply systems. Reservoir-based water supply systems will also need to be assessed to determine whether they can continue to meet projected demand by adjusting their operating rules to accommodate the projected changes in precipitation patterns and associated changes in hydrology. Finally, rising temperatures will also increase evaporation, exacerbating drought conditions.

Severity/Extent

In Massachusetts, drought is defined by a combined look at several indices, as detailed in the Massachusetts DMP (EOEEA and MEMA, 2013). The indices are:

1. SPI for 3-, 6-, and 12-month time periods
2. Precipitation as a percent of normal (or historic average) for 2-, 3-, 6-, and 12-month time periods
3. Crop Moisture Index
4. Keetch-Byram Drought Index
5. Groundwater levels
6. Stream flow
7. Reservoir levels

These indices are analyzed on a monthly basis to generate a hydrological conditions report and used to determine the onset, severity, and end of droughts. Five levels of increasing drought severity are defined in the DMP—Normal, Advisory, Watch, Warning and Emergency. The drought levels are associated with state actions, as outlined in the DMP. In Massachusetts, recommendations of drought levels are made by the DMTF to the Secretary of the Executive Office of Energy and Environmental Affairs (EOEEA), who declares the drought level for each region of the state. Refer to [Table 3 of the DMP](#) for a comparison of these indices.

Other entities may measure drought conditions by these or other criteria more relevant to their operations. For example, water utilities may calculate the days of supply remaining. Farmers

may assess soil moisture and calculate the water deficit for specific plants to determine irrigation needs or decide to change their crop based on the deficit or harvest early for non-irrigated crops.

The severity of a drought depends on the degree of moisture deficiency, duration, spatial extent and location relative to resources or assets. The drought of the 1960s is the drought of record because all of these factors contributed at historic levels—moisture deficiency, duration, spatial extent and impact. The severity of the 2016-2017 drought is due to impacts on natural resources (record low stream flows and groundwater levels), many water supplies, farms, and agriculture and to the swift onset of the drought. The five drought levels in the 2013 DMP provide a basic framework for taking actions to assess, communicate, and respond to drought conditions. Under the “Normal” condition, data are routinely collected, assessed, and distributed. When drought conditions are identified, the four drought levels escalate moving to heightened action, which may include increased data collection and assessment, interagency communication, public education and messaging, recommendations for water conservation measures, and a state of emergency issued by the Governor. At the “Emergency” level, mandatory water conservation measures may be enacted. These regionally declared drought levels and associated state actions are intended to communicate and provide guidance to the public and stakeholders across industries to enable them to respond early and effectively and to reduce impacts. Individual public water suppliers may have their own drought management plan, drought levels, and associated actions, which they may follow at all levels except at the Emergency level when mandatory actions may be required.

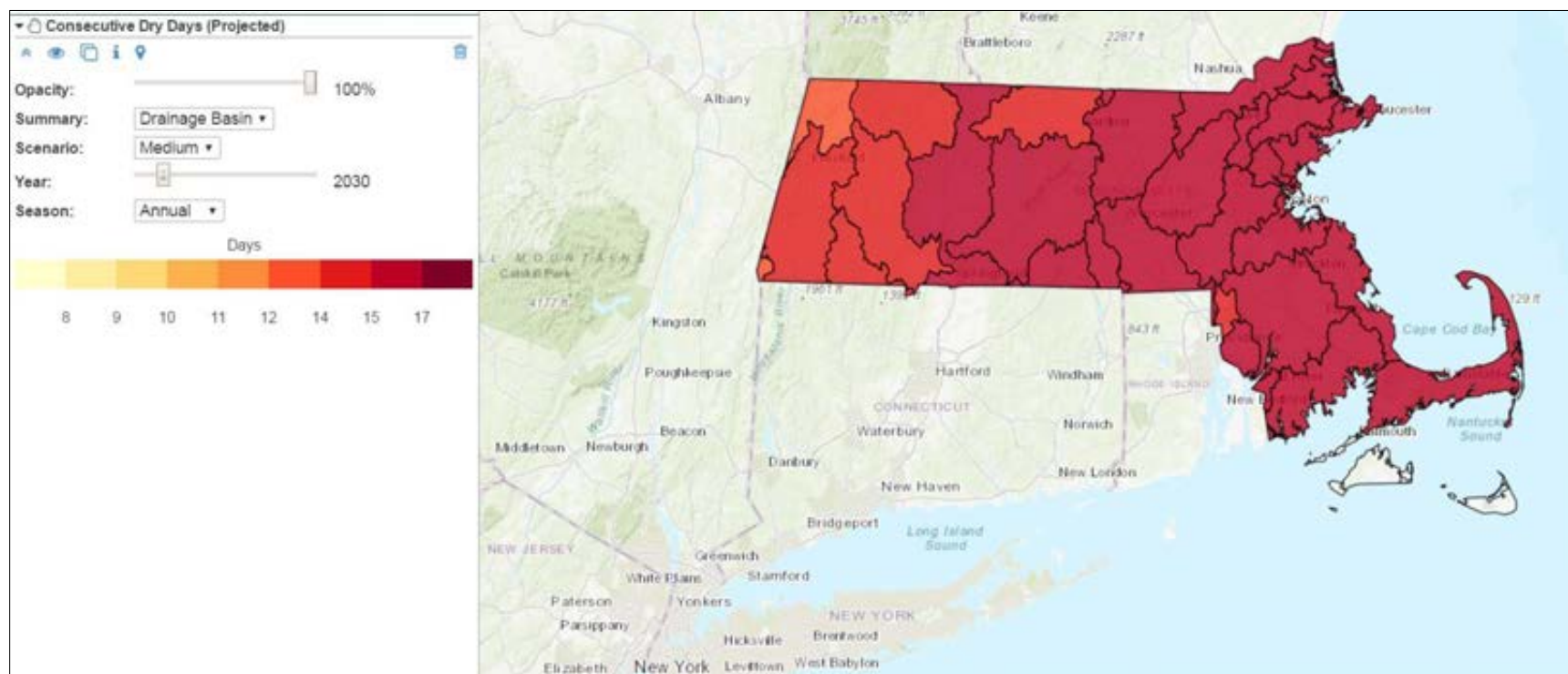
The likely range of consecutive dry days per year is projected to increase by up to nearly 20 days per year in 2090, compared to the annual statewide baseline of approximately 16 days per year from 1971 to 2001. Table 4-16 indicates the projected number of consecutive dry days according to the “high” and “low” limits of the Northeast Climate Adaptation Science Center (NE CASC) data. Figures 4-11 through 4-14 show how this indicator is expected to vary across the Commonwealth. These projections suggest that the average time between rain events is likely to remain fairly constant; however, individual drought events could still increase in frequency and severity. As shown in Figures 4-11 through 4-14, the eastern portion of the Commonwealth experiences longer dry periods than the western portion, and this trend is likely to continue in the future. These regional variations in precipitation patterns provide an additional reminder that average values for continuous dry days may not accurately characterize conditions in any given situation.

Table 4-16: Projected Continuous Dry Days by Planning Year

Planning Year	2030	2050	2070	2100
Projected Range of Consecutive Dry Days	16.44-17.94	16.34-18.64	15.94-18.94	16.34-19.64

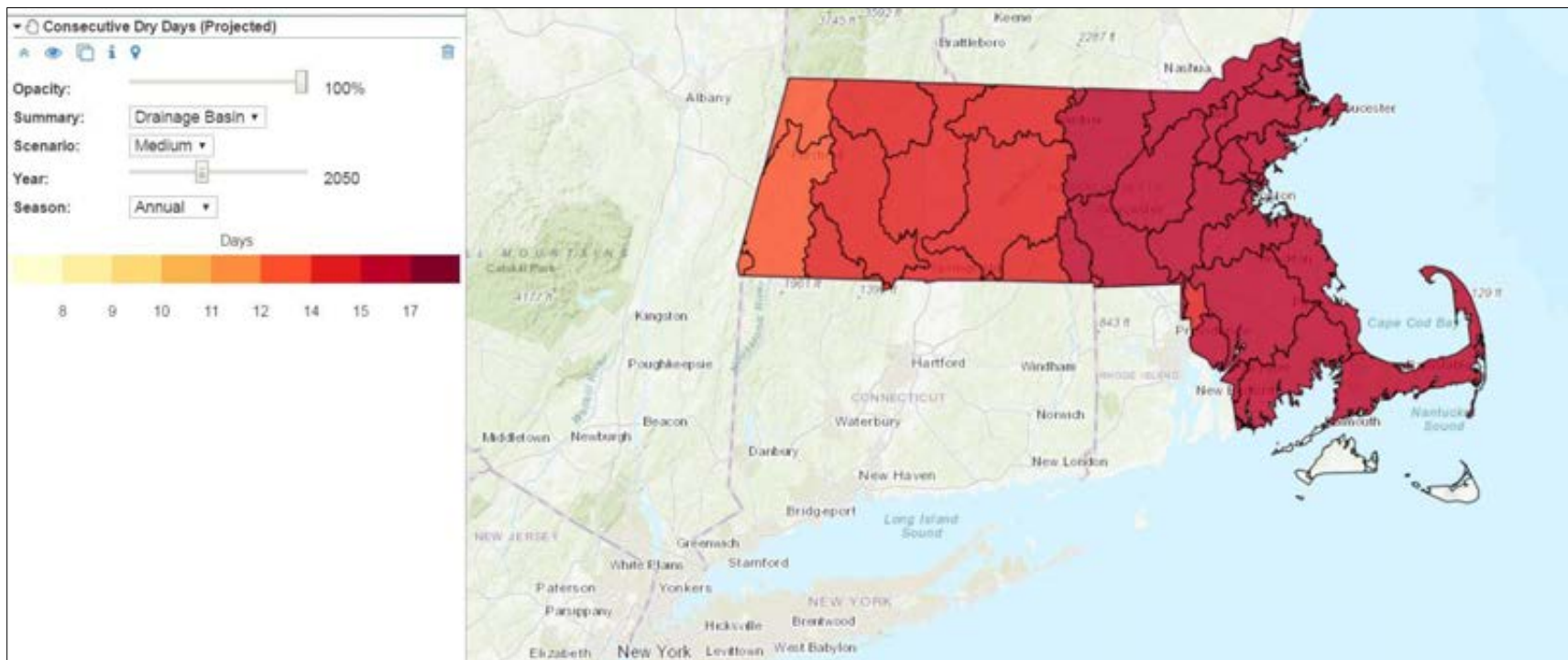
Source: resilient MA, 2018

Figure 4-11: Projected Annual Consecutive Dry Days – 2030



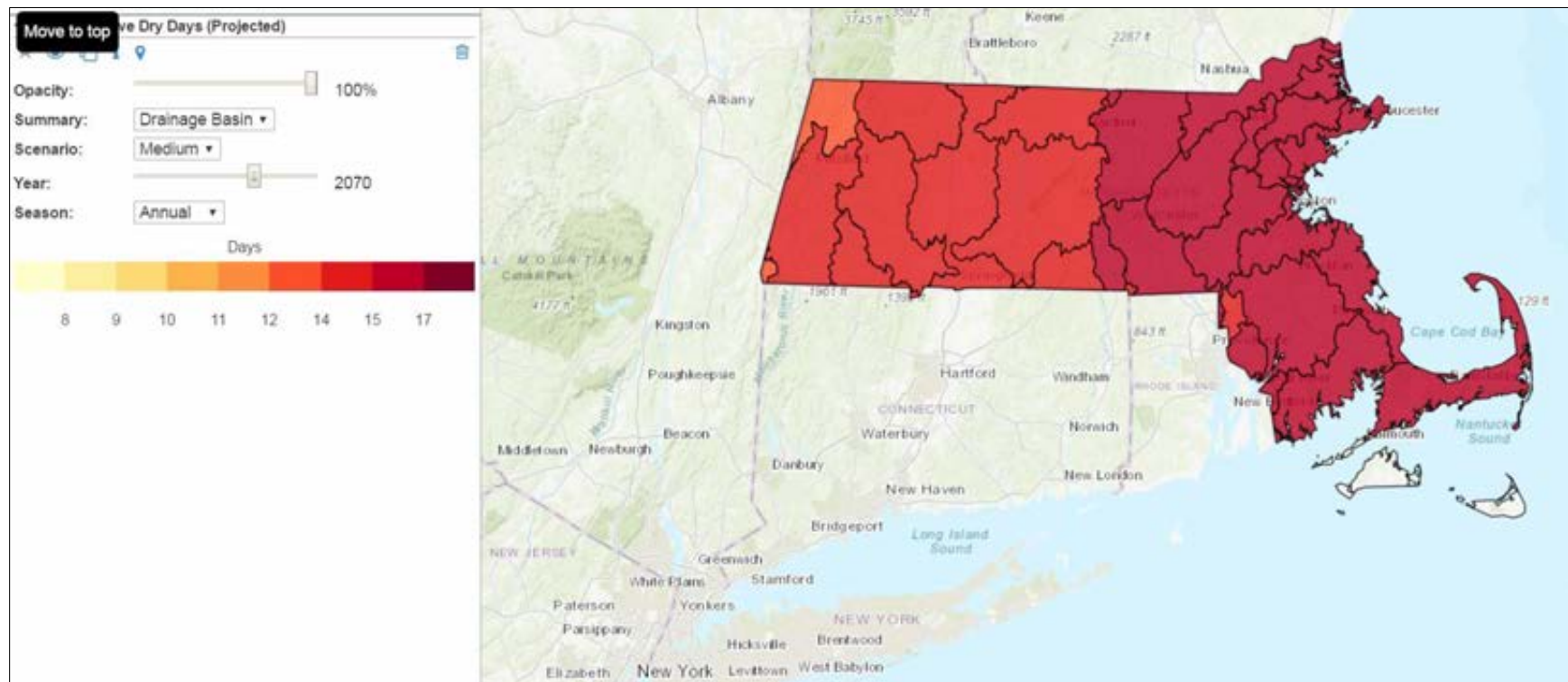
Source: resilient MA, 2018

Figure 4-12: Projected Annual Consecutive Dry Days –2050



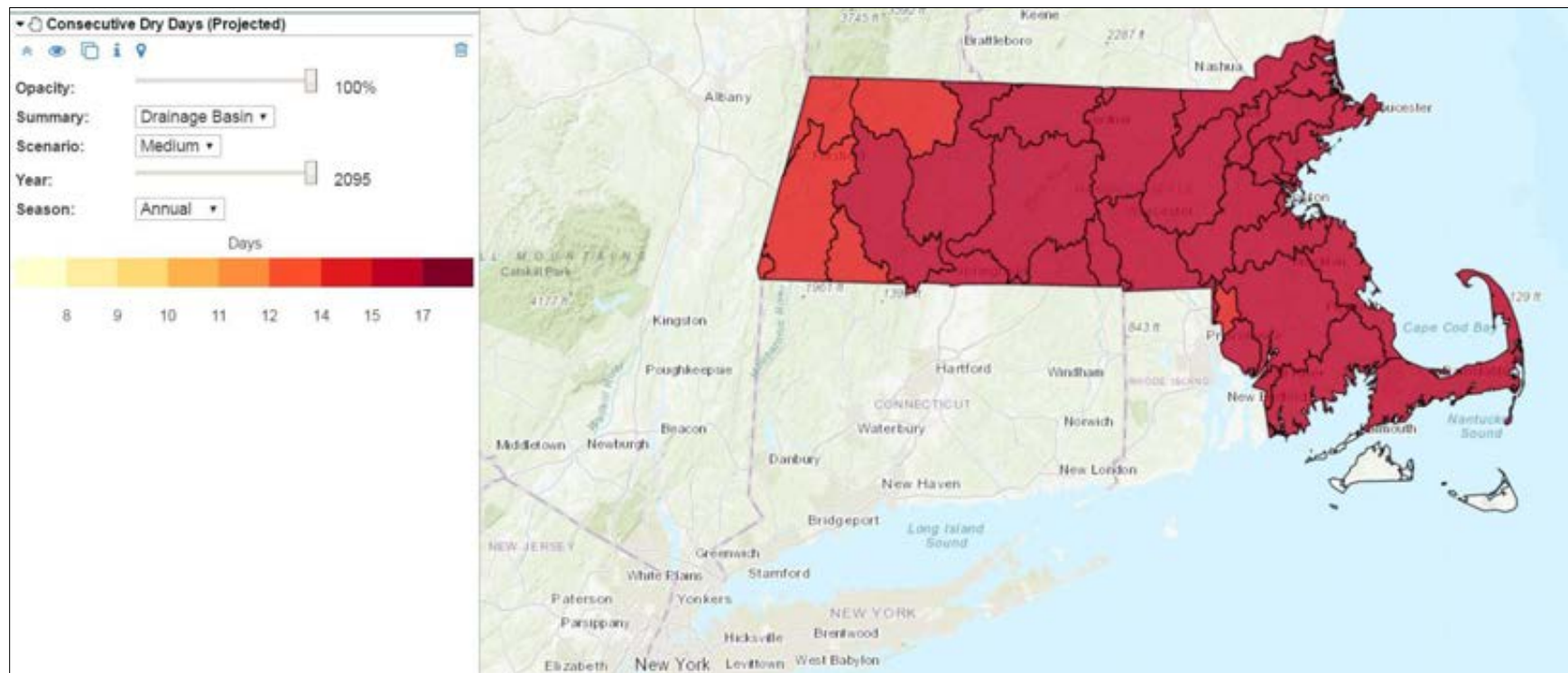
Source: resilient MA, 2018

Figure 4-13: Projected Annual Consecutive Dry Days – 2070



Source: resilient MA, 2018

Figure 4-14: Projected Annual Consecutive Dry Days – 2100



Source: resilient MA, 2018

Warning Time

Typically, droughts develop over long periods of time relative to other hazards. For example, drought development can be tracked over months and levels of drought may be increased to warn of growing or impending negative impacts that may require more intensive interventions. However, more recently, “flash droughts” are changing these norms (AMS, 2017). Flash droughts may develop quickly or quickly intensify a developing or existing drought. The most recent example is that of the 2016-2017 drought. Dry conditions from late 2015 lingered through the winter, with scattered groundwater levels reporting below normal and less than normal snowpack heading into spring 2016. Impacts were first seen in March 2016 in stream flows, groundwater levels, and reservoirs showing the long-term deficit from 2015 (lack of recharge resulting in low groundwater and base flow and lack of spring melt). Then, as precipitation dramatically dropped below normal from June through September 2016, the entire state experienced record low stream flows and groundwater levels. The combination of dry conditions and sudden loss of precipitation resulted in relatively quick impacts. NOAA and others are now advancing the science of early warning for droughts similar to the early warnings for floods and earthquakes to better project flash droughts. Based on projected climate change, the distributions of precipitation events will continue to become more extreme, with periods of minimal rain alternating with extreme rain events. Therefore, developing ways to project and adapt to flash droughts may be critical for sectors such as agriculture and water supply. The Massachusetts Water Resources Commission publishes the hydrologic conditions report monthly, which includes the seven drought indices and the National Climate Prediction Center’s U.S. Monthly and Seasonal Drought Outlooks. The National Drought Mitigation Center produces a weekly Drought Monitor map. Although this resource does not include groundwater and reservoir levels, it can be used to monitor general changes in conditions during droughts between the monthly hydrologic conditions reports. In accordance with the DMP, drought declarations are made on a monthly basis.

SECONDARY HAZARDS

Another hazard commonly associated with drought is wildfire. A prolonged lack of precipitation dries out soil and vegetation, which becomes increasingly susceptible to ignition as the duration of the drought extends.

A drought may increase the probability of a wildfire occurring. For additional information on the wildfire hazard, see Section 4.3.2.

EXPOSURE AND VULNERABILITY

The number and type of impacts increase with the persistence of a drought as the effect of the precipitation deficit cascades down parts of the watershed and associated natural and socioeconomic assets. For example, a precipitation deficiency may result in a rapid depletion of

soil moisture that may be discernible relatively quickly to agriculture. The impact of this same deficiency on reservoir levels may not affect hydroelectric power production, drinking water supply availability, or recreational uses for many months.

Populations



Because droughts can be widespread and long-term events without discrete boundaries, individual populations that are likely to be exposed cannot be isolated. Thus, the entire population of Massachusetts can be considered to be exposed to drought events.

However, as discussed in the following subsection, the vulnerability of populations to this hazard can vary significantly based on water supply sources and municipal water use policies.

Vulnerable Populations

Drought conditions can cause a shortage of water for human consumption and reduce local firefighting capabilities. Public water suppliers (PWSs) provide water for both of these services and may struggle to meet system demands while maintaining adequate pressure for fire suppression and meeting water quality standards. The populations on public water supplies are as vulnerable as the emergency response plans of their PWS. The Massachusetts Department of Environmental Protection (DEP) requires all PWSs to maintain an emergency preparedness plan. Residential well owners are as vulnerable as their ability to re-drill or temporarily relocate.

Health Impacts

According to the Centers for Disease Control and Prevention (CDC), droughts can have a wide range of health impacts (CDC, 2017). The impacts of reduced water levels are complex and depend on the water source. Supplies generated from direct riverine withdrawals may experience increased pollutant concentrations because of a reduction in water available for the dilution of authorized discharges under the National Pollutant Discharge Elimination System or naturally occurring constituents. These increased concentrations may affect water supply treatment and exposure via recreational swimming and fishing. Cyanobacteria blooms can render surface water drinking supplies unusable and necessitate the purchase of emergency water supplies, as occurred in the Midwest in 2014 (EcoWatch, 2014). Water levels may also drop below supply intakes. In addition, stagnant water bodies may develop and increase the prevalence of mosquito breeding, thus increasing the risk for vector-borne illnesses. Finally, unexpectedly low water levels may result in injuries for recreational users engaged in activities like boating, swimming, or jumping in water.

With declining groundwater levels, residential well owners may experience dry wells or sediment in their water due to the more intense pumping required to pull water from the formation and to raise water from a deeper depth. Wells may also develop a concentration of pollutants, which may include nitrates and heavy metals (including uranium) depending on local geology.

The loss of clean water for consumption and for sanitation may be a significant impact depending on the affected population's ability to quickly drill a deeper or a new well or to relocate to unaffected areas.

During a drought, dry soil and the increased prevalence of wildfires can increase the amount of irritants (such as pollen or smoke) in the air. Reduced air quality can have widespread deleterious health impacts, but is particularly significant to the health of individuals with pre-existing respiratory health conditions like asthma (CDC, n.d.). Lowered water levels can also result in direct environmental health impacts, as the concentration of contaminants in swimmable bodies of water will increase when less water is present.

Government



All facilities are expected to be operational during a drought event, although state parks or other facilities dependent on wells for their water supply may face water shortages.

Additionally, droughts contribute to conditions conducive to wildfires. All critical facilities in and adjacent to the wildland-urban interface are considered vulnerable to wildfire. See 4.3.2 regarding the wildfire hazard in the Commonwealth. Water restrictions during times of drought may require minor modifications to the operation of Commonwealth facilities, such as modified landscaping practices, but facilities would likely remain operational. Governmental facilities that rely on water to perform their core function, such as public swimming pools or grass athletic fields, may face additional challenges during times of water restriction.

The Built Environment



The impacts of drought on sectors of the built environment are described below.

Droughts also contribute to conditions conducive to wildfires. All elements in and adjacent to the wildland-urban interface are considered vulnerable to wildfire. See Section 4.3.2 regarding the wildfire hazard in the Commonwealth.

Agriculture

Drier summers and intermittent droughts may strain irrigation water supplies, stress crops, and delay harvests (resilient MA, 2018). Droughts affect the ability of farmers to provide fresh produce to neighboring communities. Insufficient irrigation will impact the availability of produce, which may result in higher demand than supply. This can drive up the price of food, leading to economic stress on a broader portion of the economy. Food banks may also experience a shortage in produce and a diminished capacity to provide food to pantries and other charities. Farmers with wells that are dry are advised to contact the Massachusetts Department of Agricultural Resources to explore microloans through the Massachusetts Drought Emergency Loan Fund or to seek federal Economic Injury Disaster Loans.

Energy

Public water supply systems and other systems that rely on water for cooling power plants may be compromised during a drought if water intakes drop below waterlines.

Public Health

More frequent intermittent droughts may create local water supply shortages, and such shortages could have major public health impacts (resilient MA, 2018).

Public Safety

Public water supply systems and other systems that rely on water availability for fire suppression may be compromised during a drought if water intakes drop below waterlines.

Water Infrastructure

Drought affects both groundwater sources and smaller surface water reservoir supplies. Water supplies for drinking, agriculture, and water-dependent industries may be depleted by smaller winter snowpacks and drier summers (resilient MA, 2018). Reduced precipitation during a drought means that water supplies are not replenished at a normal rate. This can lead to a reduction in groundwater levels and problems such as reduced pumping capacity or wells going dry. Shallow wells are more susceptible than deep wells. Suppliers may struggle to meet system demands while maintaining adequate water supply pressure for fire suppression requirements. Private well supplies may dry up and need to either be deepened or supplemented with water from outside sources. In extreme cases, potable water could be supplied by other suppliers through emergency intermunicipal connections or by bulk-trucked water suppliers via distribution centers for residents. The Massachusetts Water Resources Authority has a DMP that sets mandatory water use reduction rates for three drought emergency stages. Water use reductions are triggered based on seasonal levels of the Quabbin Reservoir. In addition, municipalities may need to raise water rates due to strained water supplies and the costs of developing new supplies (resilient MA, 2018).

Populations on a private water supply are likely more vulnerable to droughts than those on a public supply. During a drought, water sources such as small reservoirs that are replenished by surface flows and wells that draw from underground aquifers can be slow to recharge, causing water levels to become quite low. As a result, individuals and farmers with private wells are particularly vulnerable to the drought hazard. Private water supply wells are not as reliable as public wells, and public water supply wells are not as reliable as public reservoirs. Private wells and the groundwater levels of private wells are not monitored by any state or local entity, which leaves consumers vulnerable to drought impacts without any oversight. In 2017, DCR's Office of Water Resources surveyed municipal Boards of Health to gauge the impact of the 2016-2017 drought on private wells. Approximately half of the 91 respondents indicated that one or more private wells in their municipalities were compromised due to quantity and/or quality issues.

Eight municipalities had 10 or more wells affected, and 20 wells were affected in one municipality.

EOEEA's drought website provides resources for residents whose wells have gone dry during a drought, including the suggestion to hook up to a water connection at a local fire department or school, or to purchase water. These are costly solutions that take time to implement and may not be financially feasible. Moreover, these situations may most heavily impact people with little means (e.g., rural, elderly, and disabled individuals) who have no means of paying for a drilled well to reach remaining water supplies when their shallower wells have failed.

Natural Resources and Environment



Drought has a wide-ranging impact on a variety of natural systems. Some of those impacts can include the following (Clark et al., 2016):

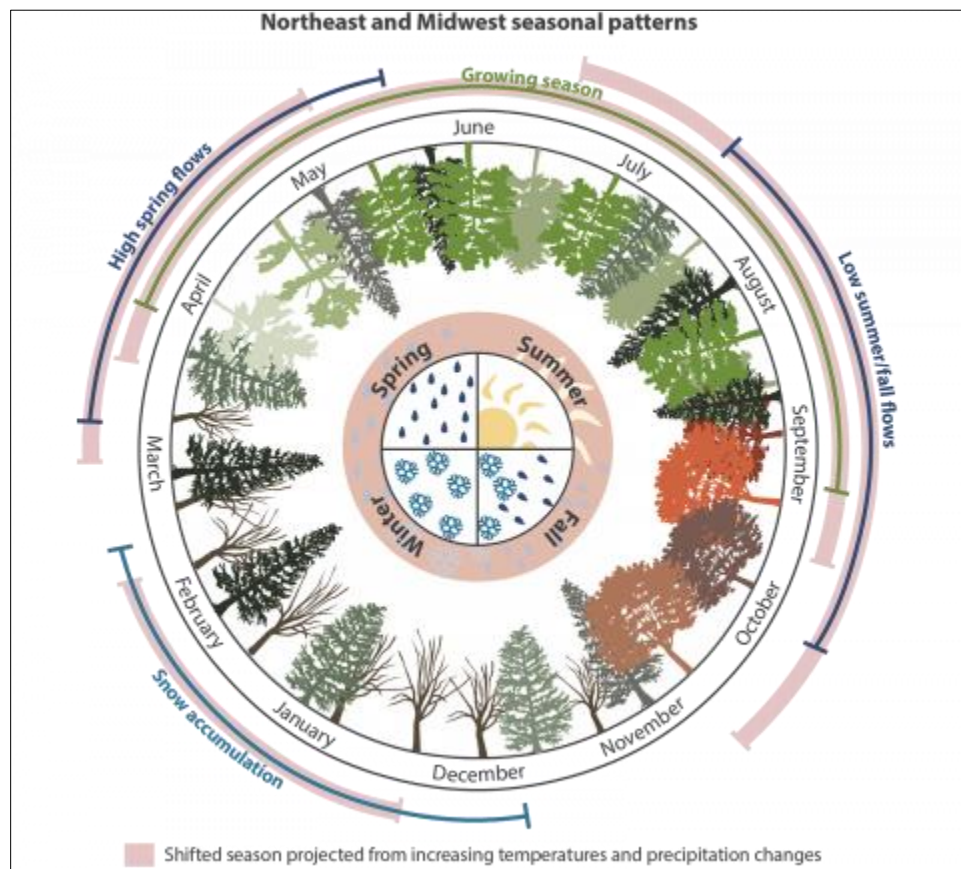
- Reduced water availability, specifically, but not limited to, habitat for aquatic species
- Decreased plant growth and productivity
- Increased wildfires
- Greater insect outbreaks
- Increased local species extinctions
- Lower stream flows and freshwater delivery to downstream estuarine habitats
- Changes in the timing, magnitude, and strength of mixing (stratification) in coastal waters
- Increased potential for hypoxia (low oxygen) events
- Reduced forest productivity
- Direct and indirect effects on goods and services provided by habitats (such as timber, carbon sequestration, recreation, and water quality from forests)
- Limited fish migration or breeding due to dry streambeds or fish mortality caused by dry streambeds

In addition to these direct natural resource impacts, a wildfire exacerbated by drought conditions could cause significant damage to the Commonwealth's environment as well as economic damage related to the loss of valuable natural resources. Wildfire damage to the forests and lands around the Quabbin, Wachusett, and Ware Reservoirs may lead to lower water quality in those reservoirs, which are critical supplies during times of drought for both "regular" and drought-impacted customers.

Climate change is also likely to result in a shift in the timing and durations of various seasons (as shown in Figure 4-15). This change will likely have repercussions on the life cycles of both flora

and fauna within the Commonwealth. While there could be economic benefits from a lengthened growing season, a lengthened season also carries a number of risks. The probability of frost damage will increase, as the earlier arrival of warm temperatures may cause many trees and flowers to blossom prematurely only to experience a subsequent frost. Additionally, pests and diseases may also have a greater impact in a drier world, as they will begin feeding and breeding earlier in the year (Land Trust Alliance, n.d.).

Figure 4-15: Conceptual Diagram Illustrating Shifts in Northeast and Midwest Seasonal Patterns Due to Climate Change.



Source: Massachusetts Wildlife Climate Action Tool, n.d.

Economy

\$ The economic impacts of drought can be substantial, and would primarily affect the agriculture, recreation and tourism, forestry, and energy sectors. For example, drought can result in farmers not being able to plant crops or in the failure of planted crops. This results in loss of work for farmworkers and those in related food-processing jobs. Crop failure is also likely to result in an increase in produce prices, which may render these items unaffordable for certain members of the population. Increasing globalization of the food system reduces the impact of isolated drought events on food prices, but the financial impact on farmers may be

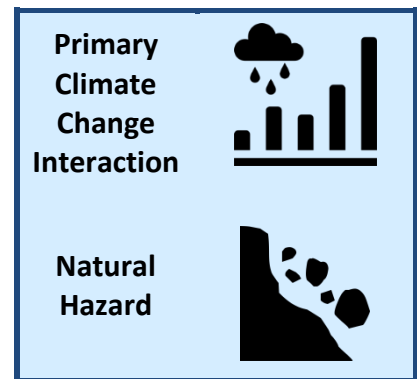
greater as a result. Reduced water quality or habitat loss may also impact Massachusetts fisheries.

In any season, a drought can also harm recreational companies that rely on water (e.g., ski areas, swimming pools, water parks, and river rafting companies) as well as landscape and nursery businesses because people will not invest in new plants if water is not available to sustain them. Social and environmental impacts are also significant, but data on the extent of damages is more challenging to collect. Although the impacts can be numerous and significant, dollar damage estimates are not tracked or available.

4.1.3 Landslide

GENERAL BACKGROUND

The term landslide includes a wide range of ground movements, such as rock falls, deep failure of slopes, and shallow debris flows. The most common types of landslides in Massachusetts include translational debris slides, rotational slides, and debris flows. Most of these events are caused by a combination of unfavorable geologic conditions (silty clay or clay layers contained in glaciomarine, glaciolacustrine, or thick till deposits), steep slopes, and/or excessive wetness leading to excess pore pressures in the subsurface. In 2013, the Massachusetts Geological Survey prepared an updated map of potential landslide hazards for the Commonwealth (funded by FEMA's Hazard Mitigation Grant Program) to provide the public, local governments, and emergency management agencies with the location of areas where slope movements have occurred or may possibly occur in the future under conditions of prolonged moisture and high-intensity rainfall. Historical landslide data for the Commonwealth suggests that most landslides are preceded by 2 or more months of higher than normal precipitation, followed by a single, high-intensity rainfall of several inches or more (Mabee and Duncan, 2013). This precipitation can cause slopes to become saturated.





Landslides associated with slope saturation occur predominantly in areas with steep slopes underlain by glacial till or bedrock. Bedrock is relatively impermeable relative to the unconsolidated material that overlies it. Similarly, glacial till is less permeable than the soil that forms above it. Thus, there is a permeability contrast between the overlying soil and the underlying, and less permeable, unweathered till and/or bedrock. Water accumulates on this less permeable layer, increasing the pore pressure at the interface. This interface becomes a plane of weakness. If conditions are favorable, failure will occur (Mabee, 2010).

Natural Hazard Summary






LANDSLIDE

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
Most landslides in Massachusetts are caused by a combination of unfavorable geologic conditions, steep slopes, and/or excessive wetness in the subsurface.	The highest prevalence of unstable slopes is found in area around Mount Greylock and the nearby portion of the Deerfield River, the US Highway 20 corridor near Chester, as well as the main branches of the Westfield River.	Notable landslides in Massachusetts occur approximately every other year. However, because many landslides are minor and occur unobserved in remote areas, the true number of landslide events is probably higher.

Potential Effects of Climate Change

	CHANGES IN PRECIPITATION AND EXTREME WEATHER → SLOPE SATURATION	Regional climate change models suggest that Massachusetts will likely experience more frequent and intense storms throughout the year. This change could result in more frequent soil saturation conditions, which are conducive to an increased frequency of landslides.
	RISING TEMPERATURES → REDUCED VEGETATION EXTENT	An increased frequency of drought events is likely to reduce the extent of vegetation throughout the Commonwealth. The loss of the soil stability provided by vegetation could also increase the probability of landslides wherever these events occur.

Exposure and Vulnerability by Key Sector 

	POPULATIONS	General At-Risk Population: Populations who reside or travel near steep slopes. Vulnerable Populations: People who rely on potentially impacted roads for vital transportation needs.
	GOVERNMENT	Six state-owned facilities, located at Natural Bridge State Forest, Joseph Allen Skinner State Park (2), Mount Sugarloaf Reservation (2), and the Wachusett Reservoir, are located within unstable slope areas.
	BUILT ENVIRONMENT	Landslides can cause direct losses to roads, buildings, and other elements of the built environment as well as indirect socio-economic losses related to road closures that interfere with travel or downed power lines. Landslides can impact agriculture and forestry as well as water infrastructure.
	NATURAL RESOURCES AND ENVIRONMENT	Landslides can affect many facets of the environment, including the landscape itself, water quality, and habitat health. Transported soil may harm aquatic habitats, and mass movement of sediment may result in stripping of forests and other vegetated systems.
	ECONOMY	Direct costs include the actual damage sustained by buildings, property, and infrastructure. Indirect costs from a large landslide event could include clean-up costs, business interruption, loss of tax revenues, reduced property values, and loss of productivity.

Occasionally, landslides occur as a result of geologic conditions and/or slope saturation. Adverse geologic conditions exist wherever there are lacustrine or marine clays, as clays have relatively low strength. These clays often formed in the deepest parts of the glacial lakes that existed in Massachusetts following the last glaciation. These lakes include Bascom, Hitchcock, Nashua, Sudbury, Concord, and Merrimack, among many other unnamed glacial lakes. The greater Boston area is also underlain by the Boston Blue Clay, a glaciomarine clay. The northeastern coast of Massachusetts is also underlain by marine clays. When oversteepened or exposed in excavations, these vulnerable areas often produce classic rotational landslides.

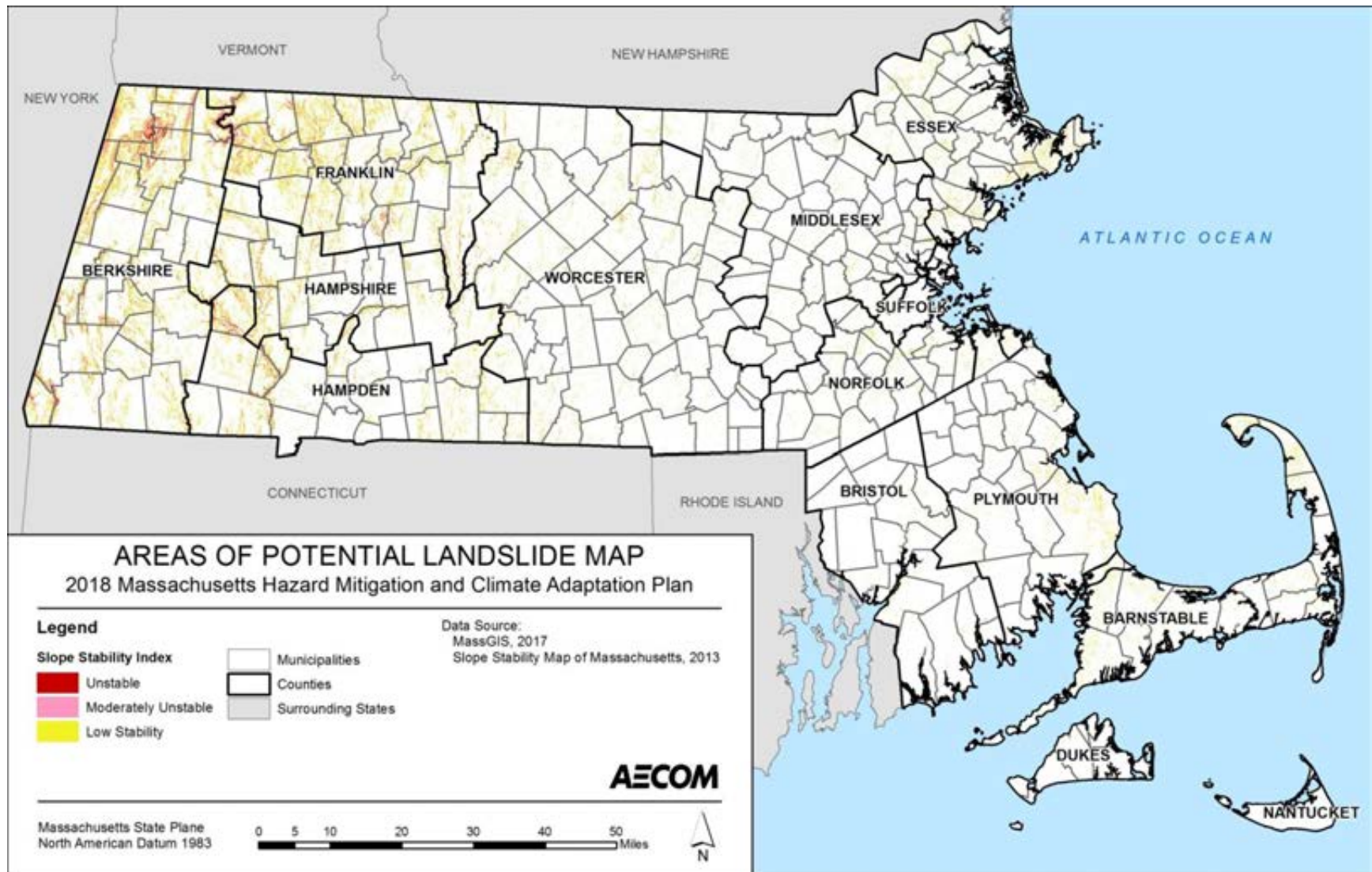
Landslides can also be caused by external forces, including both undercutting (due to flooding or wave action) and construction. Undercutting of slopes during flooding or coastal storm events is a major cause of property damage. Streams and waves erode the base of the slopes, causing them to oversteepen and eventually collapse. This is particularly problematic in unconsolidated glacial deposits, which cover the majority of the Commonwealth. This type of failure occurs frequently in Cape Cod, Nantucket, Martha's Vineyard, Scituate, and Newbury, and along major river valleys.

Construction-related failures occur predominantly in road cuts excavated into glacial till where topsoil has been placed on top of the till. Examples can be found along the Massachusetts Turnpike. Other construction-related failures occur in utility trenches excavated in materials that have very low cohesive strength and an associated high water table (usually within a few feet of the surface). This situation occurs in sandy deposits with very few fine sediments, and can occur in any part of the Commonwealth.

HAZARD PROFILE

In 2013, the Massachusetts Geological Survey and University of Massachusetts Amherst (UMass Amherst) published a Slope Stability Map of Massachusetts. This project, which was funded by the FEMA Hazard Mitigation Grant Program, was designed to provide statewide mapping and identification of landslide hazards that can be used for community level planning as well as prioritizing high-risk areas for mitigation. That map, with a legend detailing the significance of each color, is included as Figure 4-16. These sources are referenced throughout this section. The maps produced from this project should be viewed as a first-order approximation of potential landslide hazards across the state at a scale of 1:125,000. They are not intended for site-specific engineering design, construction, or decision-making. The maps are provided only as a guide to areas that may be prone to slope instability when subjected to prolonged periods of antecedent wetness followed by high-intensity rainfall.

Figure 4-16: Slope Stability Map



Map Color Code	Predicted Stability Zone	Relative Slide Ranking ¹	Stability Index Range ²	Factor of Safety (FS) ³	Probability of Instability ⁴	Predicted Stability With Parameter Ranges Used in Analysis	Possible Influence of Stabilizing or Destabilizing Factors ⁵
	Unstable	High	0	Maximum FS<1	100%	Range cannot model stability	Stabilizing factors required for stability
	Upper Threshold of Instability		0 - 0.5	>50% of FS≤1	>50%	Optimistic half of range required for stability	Stabilizing factors may be responsible for stability
	Lower Threshold of Instability	Moderate	0.5 - 1	≥50% of FS>1	<50%	Pessimistic half of range required for instability	Destabilizing factors are not required for instability
	Nominally Stable	Low	1 - 1.25	Minimum FS=1	—	Cannot model instability with most conservative parameters specified	Minor destabilizing factors could lead to instability
	Moderately Stable		1.25 - 1.5	Minimum FS=1.25	—	Cannot model instability with most conservative parameters specified	Moderate destabilizing factors are required for instability
	Stable	Very Low	>1.5	Minimum FS=1.5	—	Cannot model instability with most conservative parameters specified	Significant destabilizing factors are required for instability

¹**Relative Slide Ranking**—This column designates the relative hazard ranking for the initiation of shallow slides on unmodified slopes.

²**Stability Index Range**—The stability index is a numerical representation of the relative hazard for shallow translational slope movement initiation based on the factors of safety computed at each point on a 9-meter (~30-foot) digital elevation model grid derived from the National Elevation Dataset. The stability index is a dimensionless number based on factors of safety generated by SINMAP that indicates the probability that a location is stable, considering the most and least favorable parameters for stability input into the model. The breaks in the ranges of values for the stability index categories are the default values recommended by the program developers.

³**Factors of Safety**—The factor of safety is a dimensionless number computed by SINMAP using a modified version of the infinite slope equation that represents the ratio of the stabilizing forces that resist slope movement to destabilizing forces that drive slope movement (Pack et al., 2001). A FS>1 indicates a stable slope, a FS<1 indicates an unstable slope, and a FS=1 indicates the marginally stable situation where the resisting forces and driving forces are in balance.

⁴**Probability of Instability**—This column shows the likelihood that the factor of safety computed within this map unit is less than one (FS<1, i.e., unstable) given the range of parameters used in the analysis. For example, a <50% probability of instability means that a location is more likely to be stable than unstable given the range of parameters used in the analysis.

⁵**Possible Influence of Stabilizing and Destabilizing Factors**—Stabilizing factors include increased soil strength, root strength, or improved drainage. Destabilizing factors include increased wetness or loading, or loss of root strength.

Source: Massachusetts Geologic Survey and UMass Amherst, 2013; Pack et al., 2001

Location

The Slope Stability Map (see Figure 4-16) categorizes areas of Massachusetts into stability zones, and the categorization is correlated to the probability of instability in each zone. The probability of instability metric indicates how likely each area is to be unstable, based on the parameters used in the analysis. Thus, although specific landslide events cannot be predicted, this map shows where slope movements are most likely to occur after periods of high-intensity rainfall. According to the map, these unstable areas are located throughout the Commonwealth. However, the highest prevalence of unstable slopes is generally found in the western portion of the Commonwealth, including the area around Mount Greylock and the nearby portion of the Deerfield River, the U.S. Highway 20 corridor near Chester, as well as the main branches of the Westfield River.

Previous Occurrences

Nationwide landslides constitute a major geologic hazard, as they are widespread, occur in all 50 states, and cause approximately \$1 billion to \$2 billion in damages and more than 25 fatalities on average each year. In Massachusetts, landslides tend to be more isolated in size and pose threats to highways and structures that support fisheries, tourism, and general transportation. Landslides commonly occur shortly after other major natural disasters, such as earthquakes and floods, which can exacerbate relief and reconstruction efforts. Many landslide events may have occurred in remote areas, causing their existence or impact to go unnoticed. Therefore, this hazard profile may not identify all ground failure events that have impacted the Commonwealth. Expanded development and other land uses may contribute to the increased number of landslide incidences and/or the increased number of reported events in the recent record.

Frequency of Occurrences

Landslides are often triggered by other natural hazards such as earthquakes, heavy rain, floods, or wildfires, so landslide frequency is often related to the frequency of these other hazards. In general, landslides are most likely during periods of higher than average rainfall. The ground must be saturated prior to the onset of a major storm for a significant landslide to occur.

Emerging research from Cardiff University suggests that the frequency of landslides is not likely to increase substantially as a result of future climate change. Researchers found that while an increase in the frequency of storms weakens soil stability, landslides are more directly linked to the accumulation of soil on hillsides over hundreds to thousands of years (Parker et al., 2016). However, slope saturation by water is already a primary cause of landslides in the Commonwealth. Regional climate change models suggest that New England will likely experience warmer, wetter winters in the future as well as more frequent and intense storms throughout the year. This increase in the frequency and severity of storm events could result in more frequent soil saturation conditions, which are conducive to an increased frequency of landslides. Additionally, an overall warming trend is likely to increase the frequency and duration of droughts and wildfire, both of which could reduce the extent of vegetation throughout the Commonwealth. The loss of the soil stability provided by vegetation could also increase the probability of landslides wherever these events occur.

For the purposes of the SHMCAP, the probability of future occurrences is defined by the number of events over a specified period of time. Looking at the recent record, from 1996 to 2012, there were eight noteworthy events that triggered one or more slides in the Commonwealth. However, because many landslides are minor and occur unobserved in remote areas, the true number of landslide events is probably higher. Based on conversations with the Massachusetts Department of Transportation (MassDOT), it is estimated that about 30 or more landslide events occurred in the period between 1986 and 2006 (Hourani, 2006). This roughly equates to one to three landslide events each year.

Severity/Extent

Natural variables that contribute to the overall extent of potential landslide activity in any particular area include soil properties, topographic position and slope, and historical incidence. Predicting a landslide is difficult, even under ideal conditions. As a result, estimations of the potential severity of landslides are informed by previous occurrences as well as an examination of landslide susceptibility. Information about previous landslides, such as the information and images from 2011 landslides (after Hurricane Irene) shown in Table 4-17 and Figure 4-17, can provide insight as to both where landslides may occur and what types of damage may result. It is important to note, however, that landslide susceptibility only identifies areas potentially affected and does not imply a time frame when a landslide might occur. The distribution of susceptibility across the Commonwealth is depicted on the Slope Stability Map, with areas of higher slope instability considered to also be more susceptible to the landslide hazard.

As shown in Table 4-17, a range of parameters was used to measure and characterize landslides after an event.

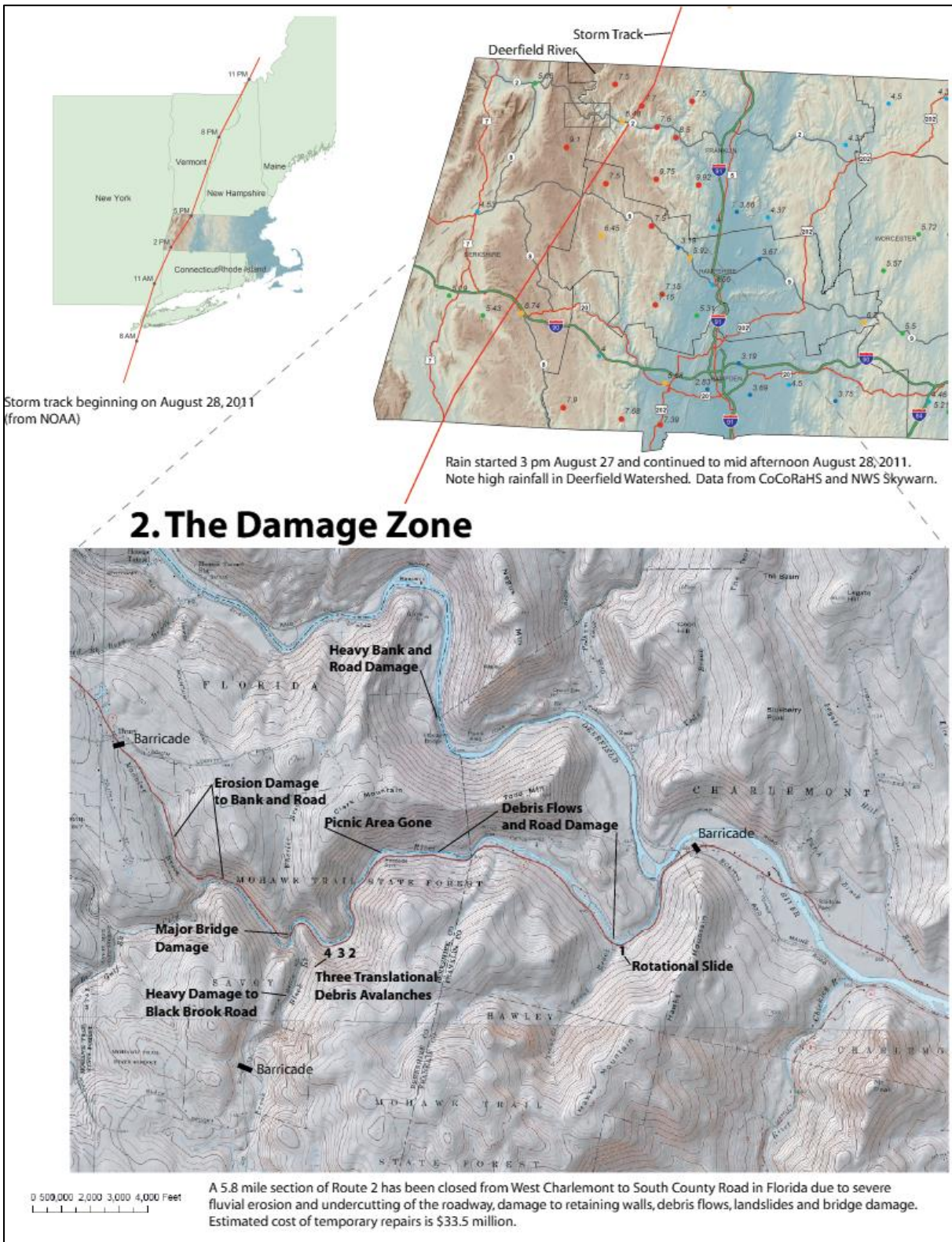
Table 4-17: Statistics on August 2011 Landslides

The statistics on all the slides. Nearly 2500 feet in combined length, 3 acres of coverage and about 9800 cubic yards of material moved.

Parameter	Slide 2	Slide 3	Slide 4
Bottom Width (ft)	120	58	48
Top Width (ft)	45	42	38
Ave. Slope Angle (°)	28	33	33
Horizontal Length (ft)	868	813	520
Slope Length (ft)	902	969	620
Elevation Difference (ft)	460	522	337
Area (sq.ft)	66,881	39,854	25,149
Area (Ac)	1.54	0.91	0.58
Thickness Range (ft)	1.5-2.5	1.5-2.5	1.5-2.5
Min. Volume (CY)	3716	2214	1397
Max. Volume (CY)	6193	3690	2329
Ave. Volume (CY)	4954	2952	1863

Source: Mabee, 2012 (portion of the poster entitled Geomorphic Effects of Tropical Storm Irene on Western Massachusetts: Landslides and Fluvial Erosion along the Deerfield and Cold Rivers, Charlemont and Savoy, MA)

Figure 4-17: 2011 Landslide Location Overview



Source: Mabee 2012 (portion of the poster entitled Geomorphic Effects of Tropical Storm Irene on Western Massachusetts: Landslides and Fluvial Erosion along the Deerfield and Cold Rivers, Charlemont and Savoy, MA)

Warning Time

Mass movements can occur suddenly or slowly. The velocity of movement may range from a slow creep of inches per year to many feet per second, depending on slope angle, material, and water content. Some methods used to monitor mass movements can provide an idea of the type of movement and the amount of time prior to failure. It is also possible to determine the areas that are at risk during general time periods. Assessing the geology, vegetation, and amount of predicted precipitation for an area can help in these predictions. However, there is no practical warning system for individual landslides. The current standard operating procedure is to monitor situations on a case-by-case basis, and respond after the event has occurred. Generally accepted warning signs for landslide activity include the following:

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavements, or sidewalks
- Soil moving away from foundations
- Ancillary structures, such as decks and patios, tilting and/or moving relative to the main house
- Tilting or cracking of concrete floors and foundations
- Broken waterlines and other underground utilities
- Leaning telephone poles, trees, retaining walls, or fences
- Offset fence lines
- Sunken or down-dropped road beds
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content)
- Sudden decrease in creek water levels even though rain is still falling or has just recently stopped
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb
- A faint rumbling sound that increases in volume as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together

SECONDARY HAZARDS

Landslides do not typically trigger other natural hazards. However, they can cause several types of secondary effects, such as blocking access to roads, which can isolate residents and businesses

and delay commercial, public, and private transportation. This could result in economic losses for businesses. Other potential problems resulting from landslides are power and communication failures. Vegetation or poles on slopes can be knocked over, resulting in possible losses to power and communication lines. Power outages may also result in inappropriate use of combustion heaters, cooking appliances, and generators in indoor or poorly ventilated areas, leading to increased risks of carbon monoxide poisoning. Landslides also have the potential of destabilizing the foundation of structures, which may result in monetary losses for residents.

EXPOSURE AND VULNERABILITY

Populations



The Commonwealth's exposure to landslides was determined by overlaying the slope stability map on layers indicative of area populations (2010 U.S. Census) and government facilities (DCAMM, 2017 [facility inventory]). Table 4-18 summarizes the Commonwealth's estimated population in unstable slope areas that may be more prone to landslides.

Table 4-18: 2010 Population in Unstable Slope Areas

County	Population	Unstable Areas		Moderately Unstable		Low Instability	
		Number	% Total	Number	% Total	Number	% Total
Barnstable	215,888	4	0.0	628	0.3	1,883	0.9
Berkshire	131,219	100	0.1	1,710	1.3	2,285	1.7
Bristol	548,285	86	0.0	1,136	0.2	2,373	0.4
Dukes	16,535	0	0.0	13	0.1	14	0.1
Essex	743,159	290	0.0	7,708	1.0	13,739	1.8
Franklin	71,372	69	0.1	984	1.4	1,466	2.1
Hampden	463,490	223	0.0	2,200	0.5	3,097	0.7
Hampshire	158,080	44	0.0	591	0.4	1,075	0.7
Middlesex	1,503,085	112	0.0	3,490	0.2	7,498	0.5
Nantucket	10,172	0	0.0	1	0.0	3	0.0
Norfolk	670,850	113	0.0	1,800	0.3	4,766	0.7
Plymouth	494,919	40	0.0	1,678	0.3	3,791	0.8
Suffolk	722,023	99	0.0	869	0.1	2,329	0.3
Worcester	798,552	90	0.0	2,626	0.3	5,460	0.7
Total	6,547,629	1,270	0.0	25,434	0.4	49,779	0.8

Source: 2010 U.S. Census, Slope Stability Map, 2017

Vulnerable Populations

Populations who rely on potentially impacted roads for vital transportation needs are considered to be particularly vulnerable to this hazard. The number of lives endangered by the landslide hazard is increasing due to the state's growing population and the fact that many homes are built on property atop or below bluffs or on steep slopes subject to mass movement.

Health Impacts

People in landslide hazard zones are exposed to the risk of dying during a large-scale landslide; however, damage to infrastructure that impedes emergency access and access to health care is the largest health impact associated with this hazard. Mass movement events in the vicinity of major roads could deposit many tons of sediment and debris on top of the road. Restoring vehicular access is often a lengthy and expensive process. For example, following a 5 million-cubic-yard landslide on Highway 1 in Big Sur, California, state officials found that restoring access would take more than a year and cost approximately \$40 million (Forgione, 2017).

Government

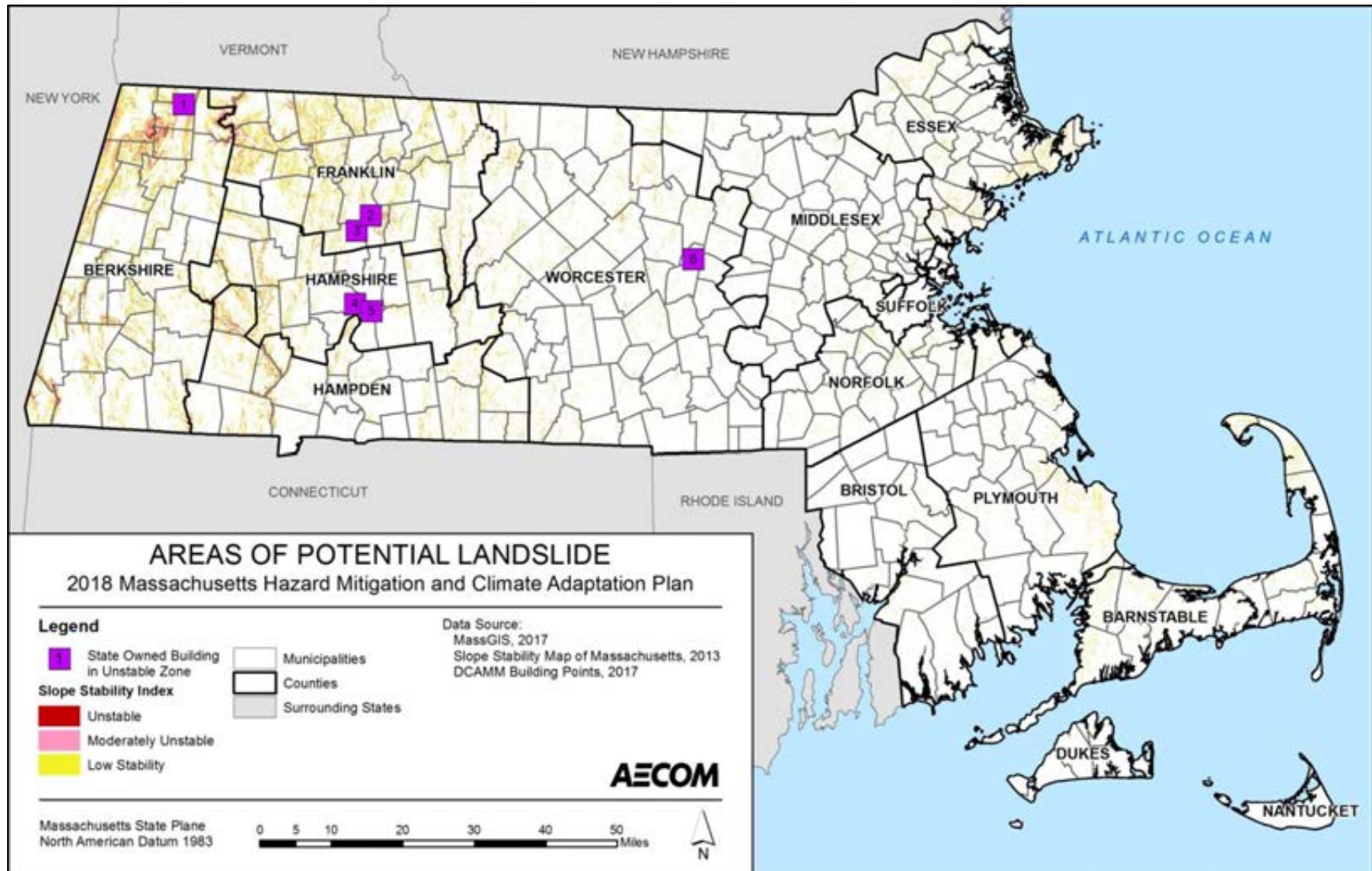


Vulnerable areas include inland roads in identified medium-to-high-risk areas, such as the towns surrounding Mount Greylock as well as bridges, tunnels, and some coastal roads. MassDOT is responsible for 9,578 lane miles of roadway, including interstate and limited-access freeways, and is responsible for maintaining these roads if they are impacted by debris from a landslide. MassDOT is also responsible for more than 5,000 bridges that are in areas at risk of landslides.

To assess the exposure of the state-owned facilities identified by DCAMM and the Office of Leasing, an analysis was conducted with the approximate landslide hazard areas. Using ArcMap, GIS software, the Slope Stability Map was overlaid with state-owned facilities data, as shown in Figure 4-18. The following six state-owned facilities were found to be located within four unstable slope areas shown in Figure 4-18:

8. Natural Bridge State Forest – Contact Building (replacement value: \$32,385.74)
9. Mount Sugarloaf Reservation
 - Observation Tower Deck (replacement value: \$626,832.94)
 - Observation Pavilion (replacement value: unknown)
10. Joseph Allen Skinner State Park
 - Shed (replacement value: \$10,606.36)
 - Pavilion (replacement value: unknown)
11. Wachusett Reservoir Watershed – Reservoir Building Aqueduct (replacement value: \$2,075,848.41).

Figure 4-18: Overview of State-Owned Buildings in Unstable Zones.



Source: DCAMM, 2017 (facility inventory)

In addition to these highly exposed facilities, an additional 47 facilities were found to be located on “moderately” unstable slopes, and 190 were found to be located on areas of “low” instability. It should be noted that state facilities located adjacent to these areas of instability may also be exposed to the landslide hazard, as falling debris may extend beyond the area identified by the modeling.

The Built Environment



Landslides can result in direct losses as well as indirect socioeconomic losses related to damaged infrastructure. Infrastructure located within areas shown as unstable on the Slope Stability Map should be considered to be exposed to the landslide hazard. Highly vulnerable areas of the Commonwealth include mountain road, coastal roads, and transportation infrastructure, both because of their exposure to this hazard and the fact that there may be limited transportation alternatives if this infrastructure becomes unusable.

Critical facilities were considered to be located within the landslide hazard area if any building on a property was within the GIS overlay of the hazard area. Although a single property may contain multiple buildings that are exposed to landslides, the property is shown as a single “critical facility” in Tables 4-19 and 4-20. Similarly, if portions of a property fall within different hazard levels, the entire property is counted at the highest applicable hazard level. Areas with high proportions of these vulnerable buildings are considered to have a higher overall vulnerability because a higher amount of damage would increase repair costs and potentially impact the local tax base and economy.

Table 4-19: Number of Critical Facilities Exposed to the Landslide Hazard by Facility Type

Facility Type	Unstable Areas	Moderately Unstable	Low Instability
Police Facilities	—	—	8
Fire Departments	—	—	—
Hospitals	—	—	—
Schools (K-12)	—	—	—
Colleges	—	2	6
Social Services	—	1	3
Total	—	3	17

Source: Slope Stability Map 2017; DCAMM, 2017 (facility inventory)

Table 4-20: Number of Critical Facilities Exposed to the Landslide Hazard by County

County	Unstable Areas	Moderately Unstable	Low Instability
Barnstable	—	1	1
Berkshire	—	—	—
Bristol	—	—	—
Dukes	—	—	—
Essex	—	1	4
Franklin	—	—	—
Hampden	—	1	2
Hampshire	—	—	2
Middlesex	—	—	2
Nantucket	—	—	—
Norfolk	—	—	—
Plymouth	—	—	1
Suffolk	—	—	2
Worcester	—	—	3
Total	—	3	17

Source: Slope Stability Map 2017; DCAMM, 2017 (facility inventory)

Agriculture

Landslides that affect farmland can result in significant loss of livelihood and long-term loss of productivity. Forests can also be significantly impacted by landslides.

Energy

The energy sector is vulnerable to damaged infrastructure associated with landslides.

Transmission lines are generally elevated above steep slopes, but the towers supporting them can be subject to landslides. A landslide may cause a tower to collapse, bringing down the lines and causing a transmission fault. Transmission faults can cause extended and broad area outages.

Public Health

Landslides can result in injury and loss of life. Landslides can impact access to power and clean water and also increase exposure to vector-borne diseases.

Public Safety

Access to major roads is crucial to life safety after a disaster event and to response and recovery operations. The ability of emergency responders to reach people and property impacted by landslides can be impaired by roads that have been buried or washed out by landslides. The

instability of areas where landslides have occurred can also limit the ability of emergency responders to reach survivors.

Transportation

Landslides can significantly impact roads and bridges. Landslides can block egress and ingress on roads, isolating neighborhoods and causing traffic problems and delays for public and private transportation. These impacts can result in economic losses for businesses. Mass movements can knock out bridge abutments or significantly weaken the soil supporting them, making them hazardous for use. Table 4-21 provides a summary of the bridges located in the landslide hazard areas and is followed by additional information on the 13 bridges located in unstable areas.

Table 4-21: Number of Bridges Exposed to the Landslide Hazard by County

County	Unstable Areas	Moderately Unstable	Low Instability
Barnstable	—	7	14
Berkshire	2	9	58
Bristol	2	8	65
Dukes	—	—	—
Essex	3	20	108
Franklin	—	12	47
Hampden	3	23	56
Hampshire	1	10	30
Middlesex	1	19	82
Nantucket	—	—	—
Norfolk	—	12	43
Plymouth	—	14	48
Suffolk	—	1	3
Worcester	1	23	104
Total	13	158	658

Source: National Bridge Inventory

Of the 13 bridges listed in the National Bridge Inventory (NBI) database that are located in unstable areas, 7 were classified as “Functionally Obsolete.” This classification is a status used to describe a bridge that is no longer functionally adequate for its purpose, but the classification does not imply anything about the structural stability of the bridge. A bridge classified as functionally obsolete may be structurally sound and safe for use, but it may also be the source of traffic jams, may lack adequate emergency shoulders, or may lack sufficient clearance for an oversized vehicle (NBI, n.d.). None of these bridges is classified as “Structurally Deficient,” a classification that could suggest that a bridge would be particularly vulnerable to damage by

landslides. Sixteen structurally deficient bridges are located in moderately unstable areas, and 43 structurally deficient bridges are located in areas of low instability (NBI, n.d.). Many smaller bridges (e.g., bridges with spans ranging from 10 to 20 feet) and culverts are not listed in the NBI but are likely to be located in areas ranging from low instability to unstable. Therefore, the number of bridges exposed to instability is an underestimate of the possible impacts to road and stream crossing infrastructure in the Commonwealth. Damage or destruction of these smaller crossings will result in road closures and isolation of communities, especially in rural areas.

The possibility of a landslide in the vicinity of a highway represents a significant economic vulnerability for the Commonwealth. For example, from 1986 to 1990, the estimated MassDOT average annual cost of highway contracts to address landslide problems was \$1 million. In addition, the average annual MassDOT maintenance expense needed to keep highways safe from landslide-related activities was \$2 million. These estimates only apply to state highways. The cost associated with remediation work and cleanup of debris from only four landslide-related events during the October 2005 rain event that affected Massachusetts was \$2.3 million (Nabil Hourani, written communication, December 18, 2006). The damage to a 6-mile stretch of Route 2 caused by tropical storm Irene (2011), which included debris flows, four landslides, and fluvial erosion and undercutting of infrastructure, cost \$23 million for initial repairs.

Water Infrastructure

Surface water bodies may become directly or indirectly contaminated by landslides. Landslides can reduce the flow of streams and rivers, which can result in upstream flooding and reduced downstream flow. This may impact the availability of drinking water. Water and wastewater infrastructure may be physically damaged by mass movements.

Natural Resources and Environment



Landslides can affect a number of different facets of the environment, including the landscape itself, water quality, and habitat health. Following a landslide, soil and organic materials may enter streams, reducing the potability of the water and the quality of the aquatic habitat. Additionally, mass movements of sediment may result in the stripping of forests, which in turn impacts the habitat quality of the animals that live in those forests (Geertsema and Vaugeouis, 2008). Flora in the area may struggle to re-establish following a significant landslide because of a lack of topsoil.

Economy



A landslide's impact on the economy and estimated dollar losses are difficult to measure. As stated earlier, landslides can impose direct and indirect impacts on society. Direct costs include the actual damage sustained by buildings, property, and infrastructure. Indirect costs, such as clean-up costs, business interruption, loss of tax revenues, reduced property values, and loss of productivity are difficult to measure. Additionally, ground failure threatens transportation corridors, fuel and energy conduits, and communication lines (USGS, 2003).

For the purposes of this analysis, the replacement cost value of the general building stock located within zones of instability, as depicted on the Slope Stability Map (see Figure 4-16), represents the Commonwealth's vulnerability to this hazard. Table 4-22 summarizes these values by county. Based on building inventory replacement costs, Essex County has the highest overall economic exposure to the landslide hazard.

Table 4-22: Building and Content Replacement Cost Value in Landslide Hazard Areas

County	Unstable Areas	Moderately Unstable	Low Instability	Total
Barnstable	\$2,165,000	\$249,215,000	\$703,471,000	\$954,851,000
Berkshire	\$21,697,000	\$338,275,000	\$471,421,000	\$831,393,000
Bristol	\$40,780,000	\$347,503,000	\$658,472,000	\$1,046,755,000
Dukes	\$11,000	\$4,240,000	\$6,346,000	\$10,597,000
Essex	\$66,544,000	\$1,775,299,000	\$3,266,545,000	\$5,108,388,000
Franklin	\$22,557,000	\$243,549,000	\$347,003,000	\$613,109,000
Hampden	\$37,238,000	\$482,384,000	\$797,931,000	\$1,317,553,000
Hampshire	\$3,006,000	\$56,452,000	\$90,883,000	\$150,341,000
Middlesex	\$22,519,000	\$866,127,000	\$1,986,723,000	\$2,875,369,000
Nantucket	\$48,925,000	\$606,000	\$4,728,000	\$54,259,000
Norfolk	\$10,612,000	\$527,340,000	\$1,255,213,000	\$1,793,165,000
Plymouth	\$19,628,000	\$440,866,000	\$882,754,000	\$1,343,248,000
Suffolk	\$43,579,000	\$177,198,000	\$490,836,000	\$711,613,000
Worcester	\$2,165,000	\$754,858,000	\$1,315,223,000	\$2,072,246,000
Total	\$341,426,000	\$6,263,912,000	\$12,277,549,000	\$18,882,887,000

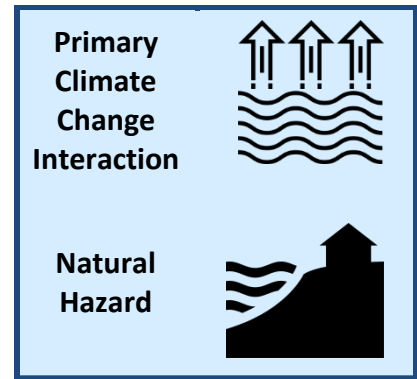
Source: FEMA Hazus loss estimation methodology

4.2 Primary Climate Change Interaction: Sea Level Rise

4.2.1 Coastal Flooding


GENERAL BACKGROUND

Coastal flooding generally occurs along the coasts of oceans, bays, estuaries, coastal rivers, and large saltwater inlets. Coastal floods are defined by the submersion of land along the ocean coast and other inland waters caused by the movement of seawater over and above normal present-day tide action. Coastal flooding is often characterized as minor or major based on the magnitude (elevation), duration, and frequency of the flooding that is experienced. Sea level rise driven by climate change will exacerbate existing coastal flooding and coastal hazards.



The rise in relative mean sea level is projected to range from approximately 1 to 3 feet in the near term (between 2000 and 2050), and from 4 to 10 feet by the end of this century (between 2000 and 2100) across the Commonwealth's coastline (EOEEA, 2018). As the sea level has continued to increase, there has been a corresponding increase in minor (or disruptive) coastal flooding associated with higher than normal monthly tides. Flooding impacts associated with these tides are becoming more noticeable and often result in the flooding of roads and parking lots with bimonthly spring tides. Greater flood levels (spatial and temporal) associated with more episodic, major, or event-based natural disturbances, such as hurricanes, nor'easters, and seismic waves, will impact built infrastructure directly, often with devastating effects. In addition to contributing to high-tide flooding, sea level rise will also exacerbate storm-related flooding due to the higher tidal elevation. Other impacts associated with more severe coastal flooding include beach erosion; loss or submergence of wetlands and other coastal ecosystems; saltwater intrusion into drinking water and wastewater infrastructure; high water tables; loss of coastal recreation areas, beaches, protective sand dunes, parks, and open space; and loss of coastal structures (sea walls, piers, bulkheads, and bridges) and buildings.

Climate change is projected to exacerbate the severity of storms and severe rainfall events. Therefore, it is anticipated that all forms of flooding will increase in severity as a result of climate change. Additional information on how climate change is expected to influence precipitation is provided in Sections 4.4.1, 4.4.2, and 4.4.4. Many of these hazards have historically impacted the coastline more severely than inland areas. In addition, flooding generated by these events will be compounded by higher sea levels, as described elsewhere in this section.





Natural Hazard Summary






COASTAL FLOODING

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
There are two primary types of coastal flooding: routine tidal flooding and flooding caused by storm events. The former is caused by regular tidal cycles, while the latter can result from precipitation, storm surge, or a combination of the two.	The entire Massachusetts coastline is exposed to this hazard. Historically, the highest concentration of coastal flooding events has occurred in Eastern Plymouth County.	Coastal flooding occurs frequently along the Massachusetts coast. According to the National Climatic Data Center, the Commonwealth has experienced an average of 6 flooding events per year over the past decade.

Potential Effects of Climate Change

	SEA LEVEL RISE ➔ INCREASE IN FREQUENCY AND SEVERITY OF COASTAL FLOODING	Sea level rise will increase the frequency and severity of both routine tidal flooding and storm-related flooding. Downscaled climate projections suggest that Boston may experience between 4.0 and 10.2 feet of sea level rise by 2100.
	EXTREME WEATHER ➔ STORM SURGE	Climate change is likely to increase the frequency of severe storm events, including hurricanes and nor'easters. As a result, storm surge sufficient to cause coastal flooding is likely to occur more often.

Exposure and Vulnerability by Key Sector

	POPULATIONS	General At-Risk Population: Populations in coastal communities, especially those in coastal flood hazard areas. Vulnerable Populations: Populations who lack reliable access to emergency information, such as populations with low English language fluency or low Internet service; populations who face challenges in evacuating, such as people over age 65, those with young children, or households without a vehicle; populations who will have difficulty recovering from displacement, including renters, the elderly, people with disabilities, and low income families.
	GOVERNMENT	According to the DCAMM inventory, a total of 201 state government buildings are located within the FEMA-defined coastal flood zone. The highest concentrations of these facilities are in Suffolk County (48) and Bristol County (42).
	BUILT ENVIRONMENT	A total of 13 critical facilities, including police stations, fire stations, and state-owned college facilities, are located within the coastal flood zone. The majority of these facilities are located in Suffolk County (6) and Essex County (3). As sea level rise progresses, roadways, subway and highway tunnels, Logan International Airport, and other critical elements in our transportation network could be inundated. Water infrastructure systems may eventually need relocation.
	NATURAL RESOURCES AND ENVIRONMENT	Coastal flooding is a natural element of the coastal environment. However, both increased storm-related flooding and sea level rise represent threats to coastal natural resources, as many coastal habitats are dependent on specific inundation frequencies. These habitats, and the species that rely on them, will be threatened by sea level rise.
	ECONOMY	Due to the concentration of development in the coastal zone, economic exposure from this hazard is high. Using general building stock as a proxy for overall economic exposure, Suffolk and Barnstable Counties are the most at-risk to economic damage from the coastal flooding hazard. This damage will likely include both direct impacts, such as damage to homes and government buildings, as well as lost tourism revenue and impacts to local businesses.

Relative sea level (or the local difference in elevation between the sea surface and land surface) projections for the Commonwealth provide insight into overall trends in rising sea levels along the hazard profile.

Location

The NOAA National Climate Data Center (NCDC) characterizes coastal flooding events as flooding of coastal areas due to the vertical rise above the normal water level caused by strong, persistent onshore wind, a high astronomical tide, and/or low atmospheric pressure, resulting in damage, erosion, flooding, fatalities, or injuries. Coastal areas are defined as those portions of coastal land zones (coastal county/parish) adjacent to the waters, bays, and estuaries of the oceans. The NCDC has records in its database of coastal storm events on 55 days since 1996. Ten events were recorded between 1996 and 1998. The database has no coastal storm event data for the years from 1997 to 2005. Table 4-23 lists the geographic distribution of coastal flooding events from 2006 to 2017. Based on this data, Plymouth County has experienced the most events since 2006 (42 events), followed by Essex County (27 events).

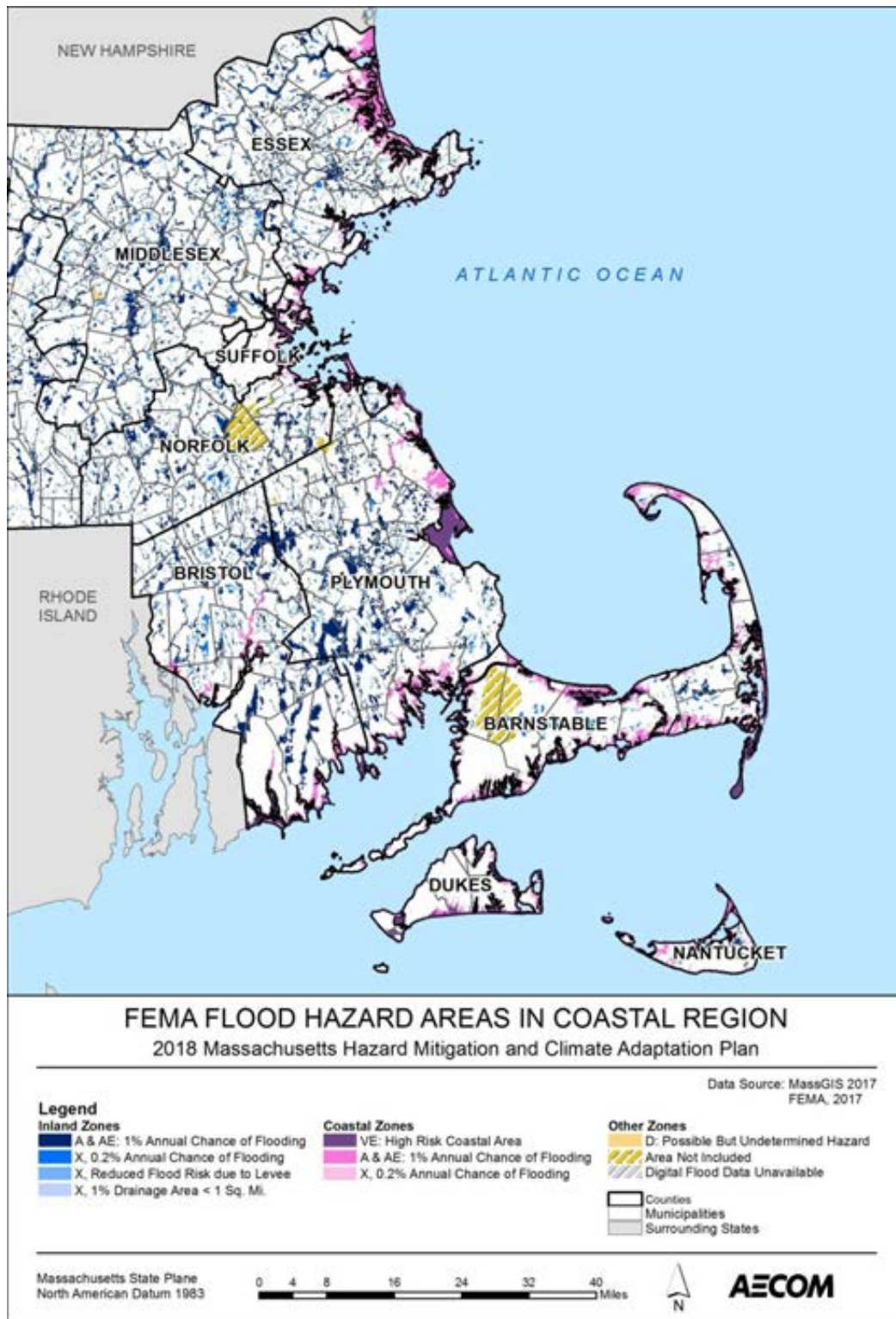
Table 4-23: National Climate Data Center—Reported Coastal Flooding Events by County

National Climate Data Center (NCDC) Region	Number of Coastal Flooding Events, 2006-2017
Barnstable	21
Dukes	12
Eastern Essex	27
Eastern Norfolk	21
Eastern Plymouth	36
Nantucket	20
Southern Bristol	7
Southern Plymouth	6
Suffolk	22

Source: NCDC, 2017

Figure 4-19 displays flood hazard areas designated by FEMA. Refer to Figures 4-24 through 4-35 for detailed maps.

Figure 4-19: FEMA Flood Hazard Areas in the Coastal Region of the Commonwealth of Massachusetts



Sea Level Rise

Sea level rise will impact coastal areas across the Commonwealth. Many local variables influence the extent of damages from coastal flooding associated with sea level rise. Elevated coastal landforms, such as coastal banks and salt marshes, have the ability to buffer increased tidal levels as well as storm surges. As tidal ranges expand, water levels downstream of dams, bridges, and culverts may increase, reducing the drainage capacity of these structures and the upstream storage capacity. As a result, flooding over riverbanks may increase during heavy precipitation or snowmelt events. Where tidal restrictions do not exist, sea level rise may extend the reach of salt water up rivers.

A recent analysis for Massachusetts conducted by the NE CASC produced a probabilistic assessment of future relative sea level rise at several tide gauge locations within the Commonwealth. Table 4-24 shows relative (or local) mean sea level projections for the Boston, MA, tide station based on four National Climate Assessment global scenarios with associated probabilistic model outputs from the NE CASC. Each of the scenarios—Intermediate, Intermediate-High, High, and Extreme—is cross-walked with two to three probabilistic model outputs. Modeling considered two future concentrations of greenhouse gas (GHG) emissions (referred to as representative concentration pathways [RCP]) and two methods of accounting for Antarctic ice sheet contributions to sea level rise. The values presented in Table 4-24 reflect a high emissions pathway (RCP 8.5). A 19-year reference time period for sea level (tidal epoch) centered on the year 2000 was used to reduce biases caused by tidal, seasonal, and interannual climate variability. Sea level projections for the Boston tide station are referenced to the North American Vertical Datum of 1988 (NAVD88). The decadal distribution of these projections by scenario is shown in Figure 4-20.

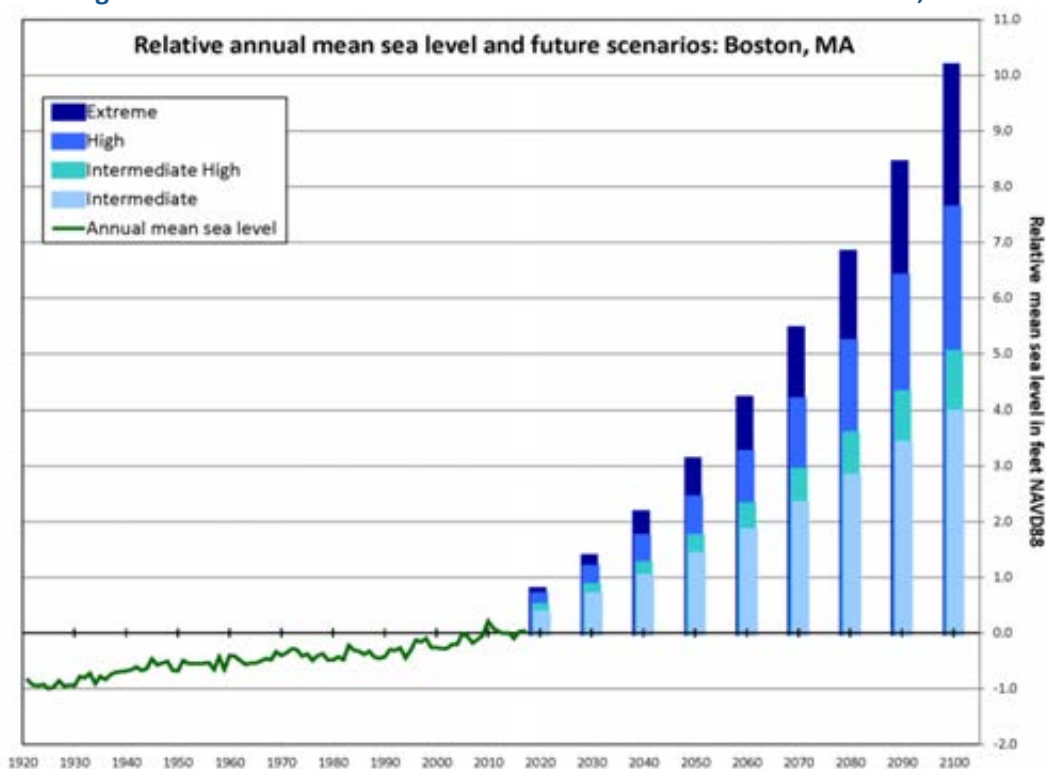
There is little variability among the projections from the different tide stations. Furthermore, there is little variability among scenarios (based on groupings of model outputs) before midcentury. Mean sea level rise across the Commonwealth's coastline could reach 1.3-3.1 feet by 2050 and 4.0 to 10.5 feet by 2100. Depending on the scenario selected, the anticipated year at which these sea level rise scenarios occur in Massachusetts varies. Therefore, those interested in conditions at a specific site are encouraged to explore the [resilient MA Climate Change Clearinghouse](#) for additional detail.

Many local factors, such as land subsidence, can influence the relative rate of sea level rise at a specific location. Maps depicting locations vulnerable to tidal inundation with 1-foot and 3-foot increases (approximately the expected range by 2050) in sea level rise are included in the *Future Inundation Maps* section of the coastal flooding hazard profile.

Table 4-24: NE CASC Relative Mean Sea Level Projections for Boston, MA Tide Station

Boston Relative Mean Sea Level (feet NAVD88)									
Scenario	Summary	2030	2040	2050	2060	2070	2080	2090	2100
Intermediate	Intermediate scenario primarily based on medium and high emissions scenarios and accounts for possible higher ice sheet contributions to sea level rise (Unlikely to exceed 83% probability given a high emissions pathways)	0.7	1.0	1.4	1.8	2.3	2.8	3.4	4.0
Intermediate-High	Intermediate-high scenario primarily based on high emissions scenarios and accounts for possible higher ice sheet contributions to sea level rise (Extremely unlikely to exceed 95% probability given a high emissions pathway)	0.8	1.2	1.7	2.3	2.9	3.6	4.3	5.0
High	High scenario primarily based on high emissions scenarios and accounts for possible higher ice sheet contributions to sea level rise (Extremely unlikely to exceed 99.5% probability given a high emissions pathway)	1.2	1.7	2.4	3.2	4.2	5.2	6.4	7.6
Extreme (Maximum physically plausible)	Highest scenario primarily based on high emissions scenarios and accounts for possible higher ice sheet contributions to sea level rise and consistent with estimates of physically possible "worst case" (Exceptionally unlikely to exceed 99.9% probability given a high emissions pathway)	1.4	2.2	3.1	4.2	5.4	6.8	8.4	10.2

Source: resilient MA, 2018

Figure 4-20: Relative Mean Sea Level and Future Scenarios for Boston, MA

Source: resilient MA, 2018

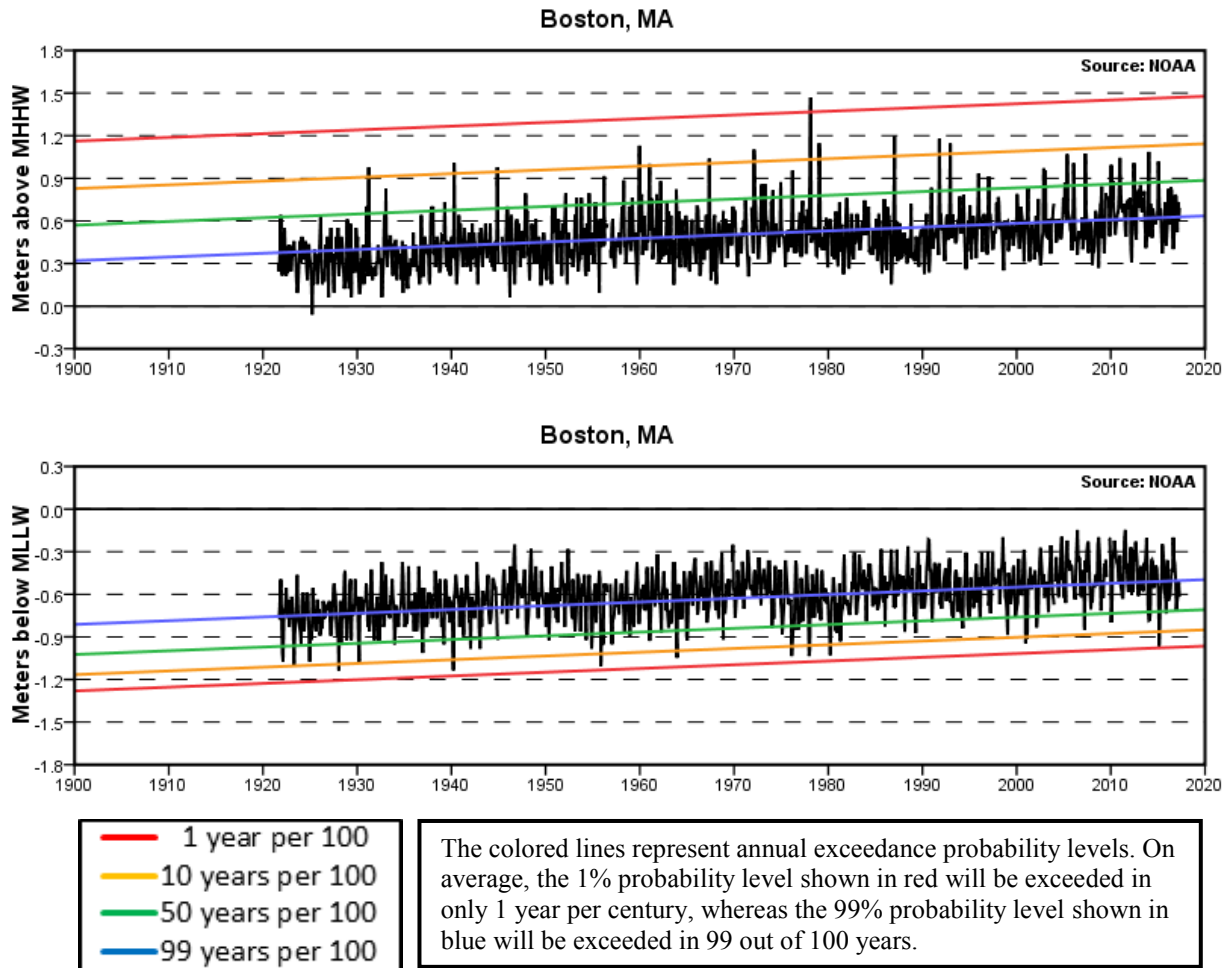
Previous Occurrences

A total of 172 recorded coastal flooding events for the Commonwealth occurred between 2006 and 2017, according to the criteria described in the *Location* section of the coastal flooding hazard profile. These events are listed in Appendix B. General trends in coastal flooding and sea level rise are discussed below.

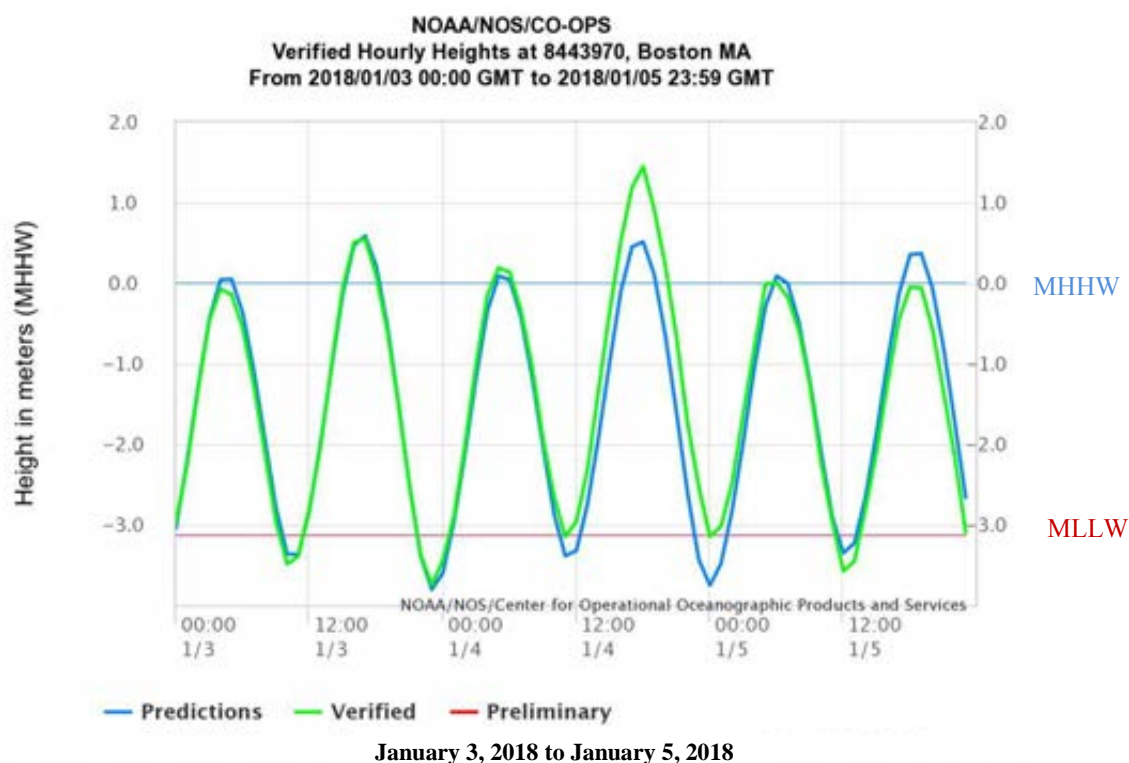
Since the late 1800s, tide gauges around the world have detected a persistent trend of sea level rise at a rate of about 1.7 +/- 0.2 millimeters per year (mm/year) (EOEEA, 2013). Over the last century, Boston has exhibited greater sea level rise than this historical global trend. Between 1921 and 2017, a relative sea level rise trend of 2.82 mm/year with a 95 percent confidence interval of +/- 0.16 mm/year (equivalent to 0.93 feet over a 100-year period) was observed in Boston (NOAA, 2018a).

The graphs in Figure 4-21(a) show monthly water level extremes relative to meters above the Mean Higher High Water (MHHW) datum and meters below the Mean Lower Low Water (MLLW) datum during this time period, with the annual exceedance probability levels (1 percent, 10 percent, 50 percent, and 99 percent). Figure 4-21(b) shows the predicted and verified astronomical high water levels that occurred during the “bomb cyclone” event in January 2018, when water levels reached 1.448 meters (~4.8 feet) above the MHHW level.

Figure 4-21(a): Extreme Water Levels at Boston Tide Gauge (MLLW and MHHW)



Source: Tidesandcurrents.noaa.gov

Figure 4-21(b): Extreme Water Levels at Boston Tide Gauge (Verified Hourly Heights)

Source: NOAA Tides and Currents, Verified Hourly Heights, May 2018

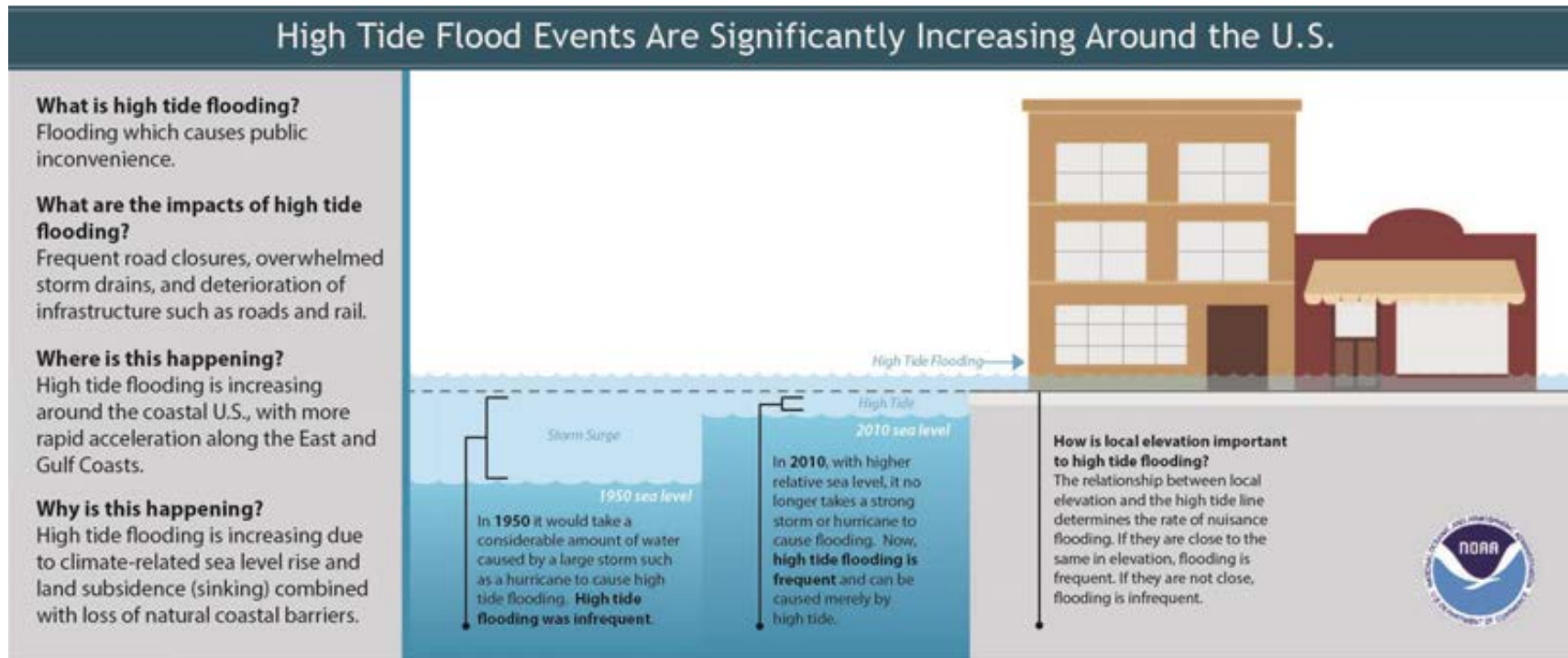
Frequency of Occurrences

Records of coastal flood events from 1950 through 2017 are available from the NCDC Storm Events Database. During this time, 172 events were reported on 55 days in 11 counties in Massachusetts, with an annual average frequency of 0.8 days with events per year. Between 1953 and 2017, there were six Major Disaster Declarations and one Emergency Declaration specific to flooding in the Commonwealth.

As sea level rise continues, the frequency of minor coastal flooding will increase, as shown in Figure 4-22. This change will occur because the mean sea level is higher, decreasing the additional tidal influence needed to cause flooding. The NOAA infographic demonstrates how this phenomenon occurs. Another NOAA study found that 19 of 23 NOAA gauges along the Northeast Atlantic Coast from Boston, MA, to the Chesapeake Bay Bridge, VA, have detected an accelerating rate of disruptive flooding (NOAA, 2014). Although the number of disruptive flood days is lower in New England, researchers attribute much of that difference to higher water elevation thresholds for disruptive flooding in the area.

The frequency of coastal flood event occurrences is also influenced by the natural orbit of the Earth and the gravitational pull of the moon and sun, which creates exceptionally high tides.

Figure 4-22: Increasing Frequency of Disruptive Flooding Events



Source: NOAA Ocean Service 2017

These events, known as “King Tides,” typically occur during a perigean spring tide, when the moon is new or full and closest to the Earth (NOAA, 2018b).

Severity/Extent

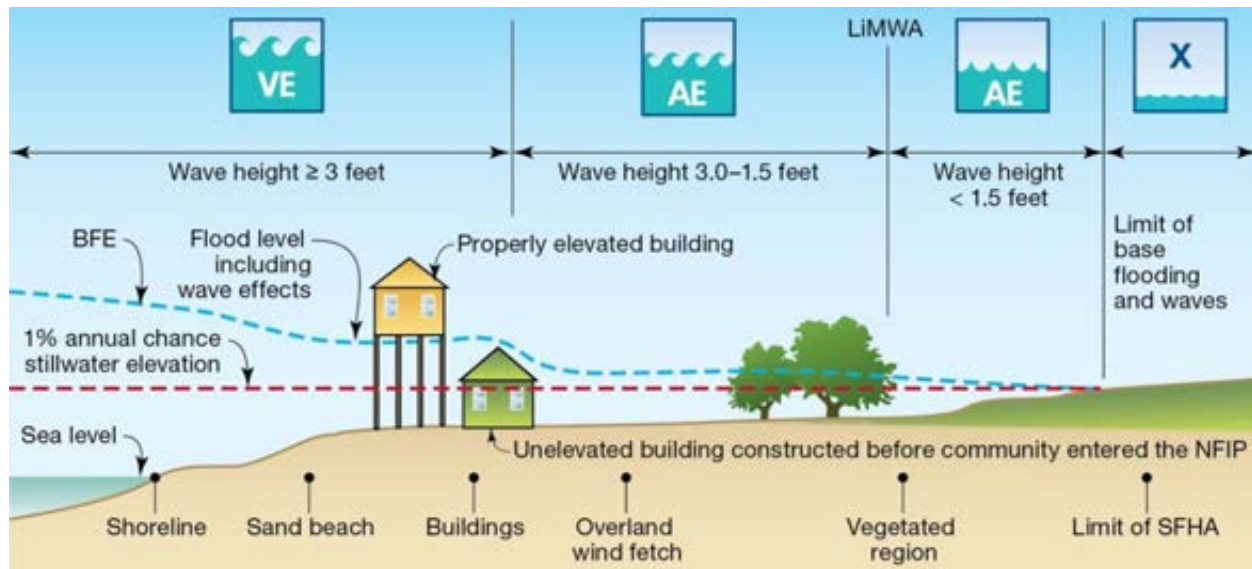
Coastal flooding can be measured by a range of metrics, including magnitude (water level elevation), duration of the event or inundation period, and frequency of occurrence. NOAA maintains up-to-date records of water levels at five tide stations in Massachusetts (Boston (843970), Chatham, Lydia Cove (8447435), Fall River (8447386), Nantucket Island (8449130), and Woods Hole (8447930)) on its “Tides and Currents” webpage, including extreme water levels data relative to the MHHW level.

The extent of coastal flooding is identified by Special Flood Hazard Areas (described in the following subsection) as well as future sea level rise inundation maps.

Existing Flood Maps

FEMA defines the Coastal High Hazard Area (V Zone) as a SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast and any other portion of the SFHA that is subject to high-velocity wave action from storms or seismic sources. The boundary of a V Zone is generally based on wave heights (3 feet or greater) or wave run-up depths (3 feet or greater). V Zones can also be mapped based on the wave overtopping rate (when waves run up and over a dune or barrier). A Zones and AE Zones identify portions of the SFHA that are not within the Coastal High Hazard Area. Regulatory requirements of NFIP for buildings located in A Zones and AE Zones are the same for both coastal and riverine flooding hazards. In September of 2017, the Coastal A Zones and AE Zones were further divided in Massachusetts coastal areas with the limit of moderate wave action (LiMWA) line. The area between the LiMWA and the landward limit of the V Zone is often referred to as the Coastal A Zone in many building codes. This area is subject to wave heights between 1.5 and 3 feet during the base flood (FEMA P-55, 2011). The area between the LiMWA and the landward limit of the A Zone is known as the Minimal Wave Action area, and is subject to wave heights less than 1.5 feet during the base flood (FEMA P-55, 2011). Figure 4-23 is a typical cross section illustrating the V Zone, the Coastal A Zone, and the AE or Zone A, and the effects of energy dissipation and regeneration of a wave as it moves inland. Wave elevations are decreased by obstructions such as vegetation and rising ground elevation. Figure 4-19 is a map of all flood zones in the coastal region of the Commonwealth.

Figure 4-23: FEMA Flood Zones along the Coast



Source: FEMA, n.d.

In addition to providing the basis for flood insurance premiums, these flood zones are referenced in the Massachusetts State Building Code and used to ensure, among other things, that new and substantially improved structures are elevated based on the magnitude of the hazard. Under the Massachusetts State Building Code, the top of the first floor in residential structures must be located 1 foot above the base flood elevation (BFE) in A and AE Zones and the lowest horizontal structural member must be 2 feet above the BFE in V Zones.

Future Inundation Maps

In addition to using existing flood maps and real-time flood data to assess the severity of past events, future inundation maps are another tool used to assess the extent of the hazard areas along the coast that are likely to experience coastal flooding in the future. Figures 4-24 through 4-31 (developed using NOAA data) show the extent of static tidal inundation with 1-foot and 3-foot increases in sea level, consistent with the projection range of mean sea level in the near term.

Warning Time

Although coastal flooding and inland flooding mechanisms are very different, the warning times available for coastal floods are generally similar to those for inland flood events. Most warning times for coastal flooding could be described as more than 24 hours due to awareness of incoming storms and how they correlate with the tides and whether King Tides are possible. Inland flooding is the same with the exception of flash flooding, which can have a warning time of less than 6 hours.

Figure 4-24: Inundation Extent of 1-Foot Sea Level Rise Relative to MHHW (Map 1)

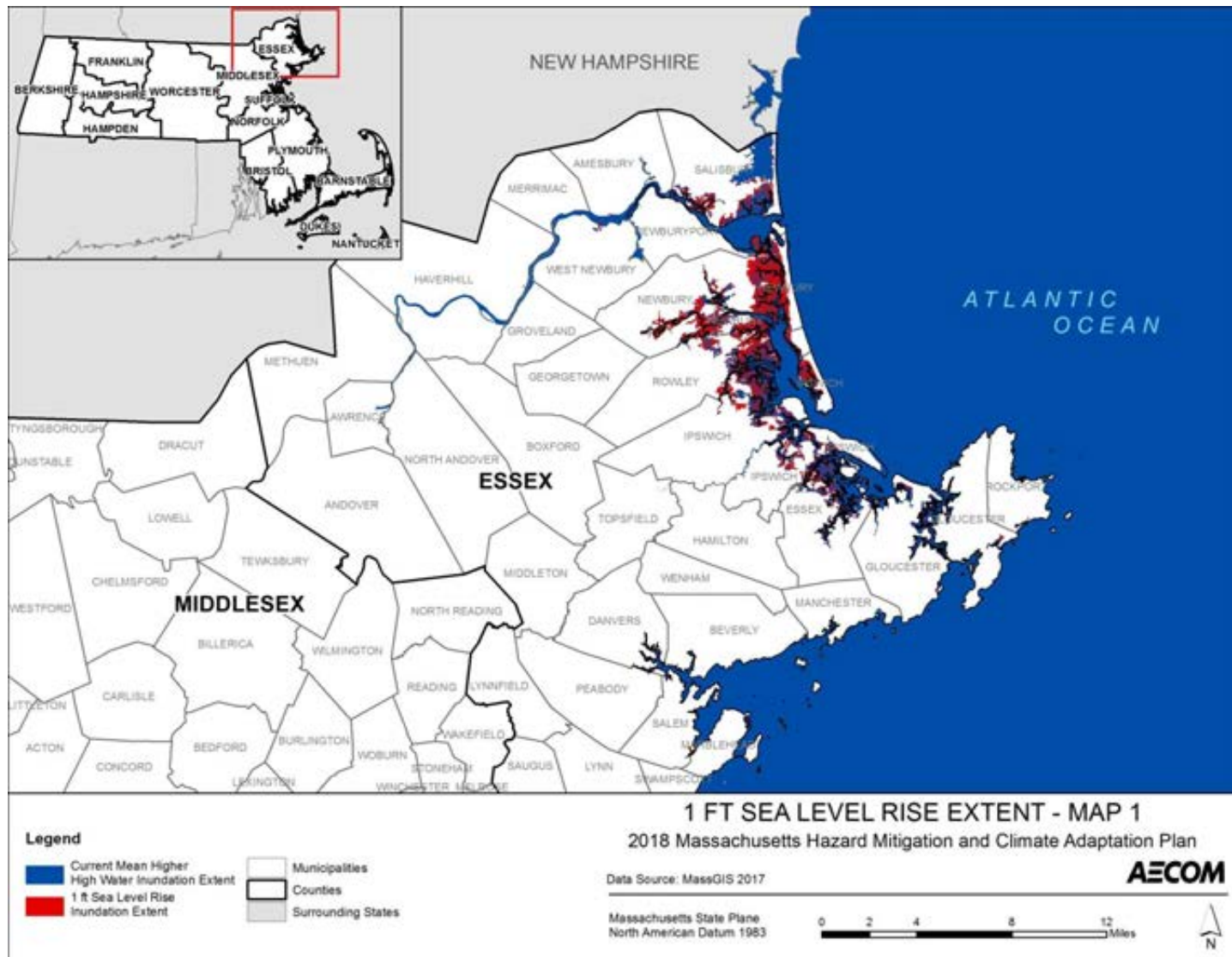


Figure 4-25: Inundation Extent of 3-Foot Sea Level Rise Relative to MHHW (Map 1)

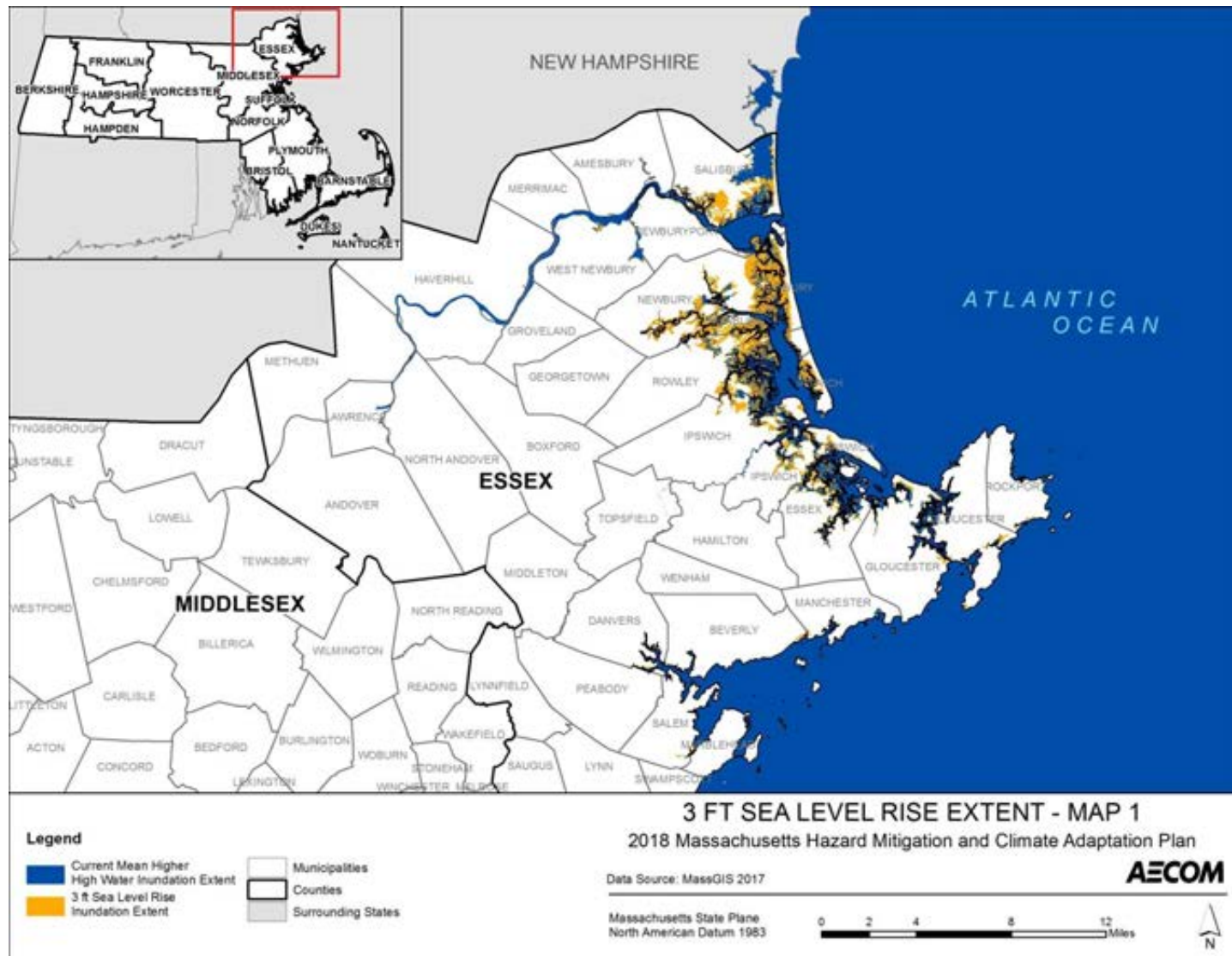


Figure 4-26: Inundation Extent of 1-Foot Sea Level Rise Relative to MHHW (Map 2)

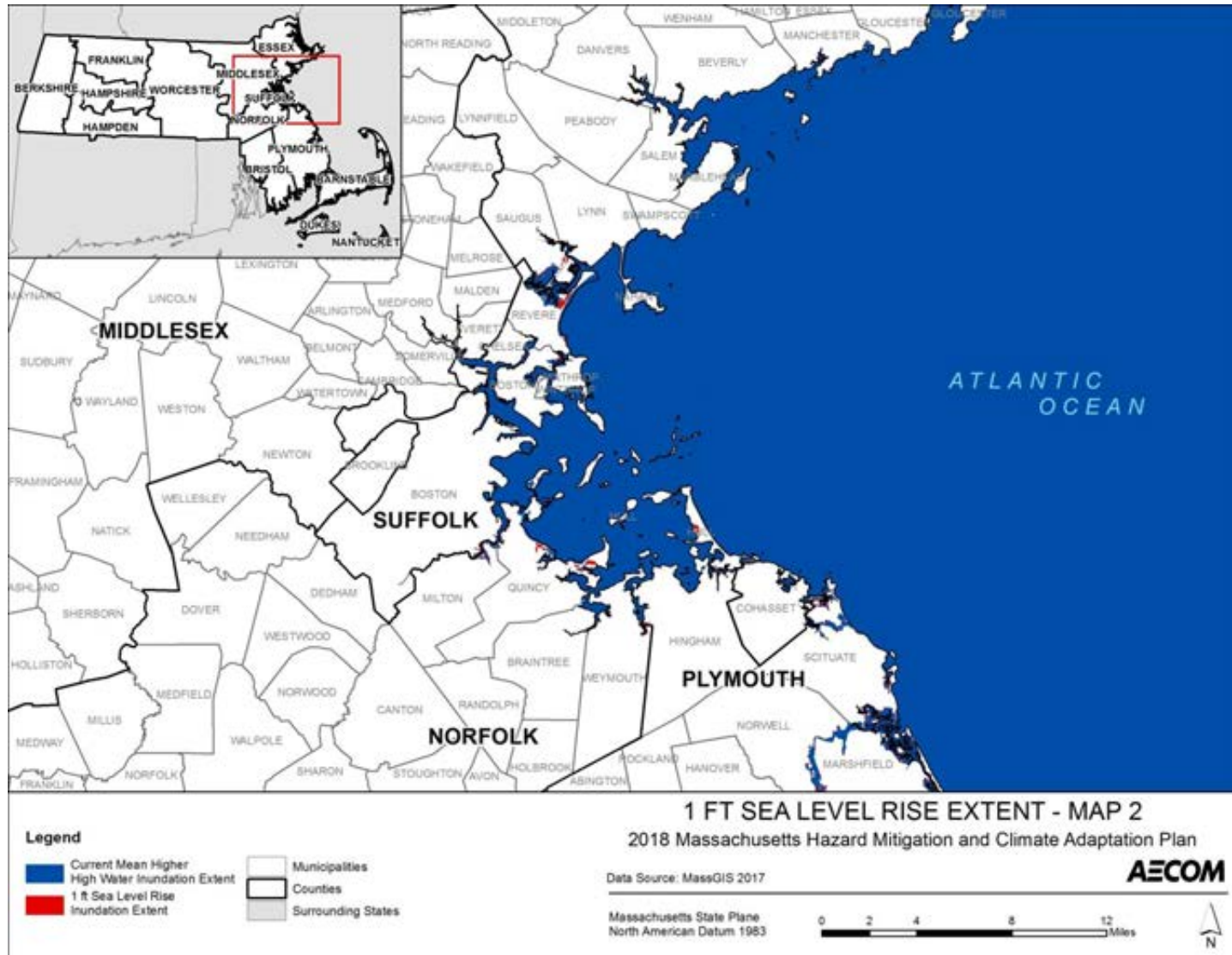


Figure 4-27: Inundation Extent of 3-Foot Sea Level Rise Relative to MHHW (Map 2)

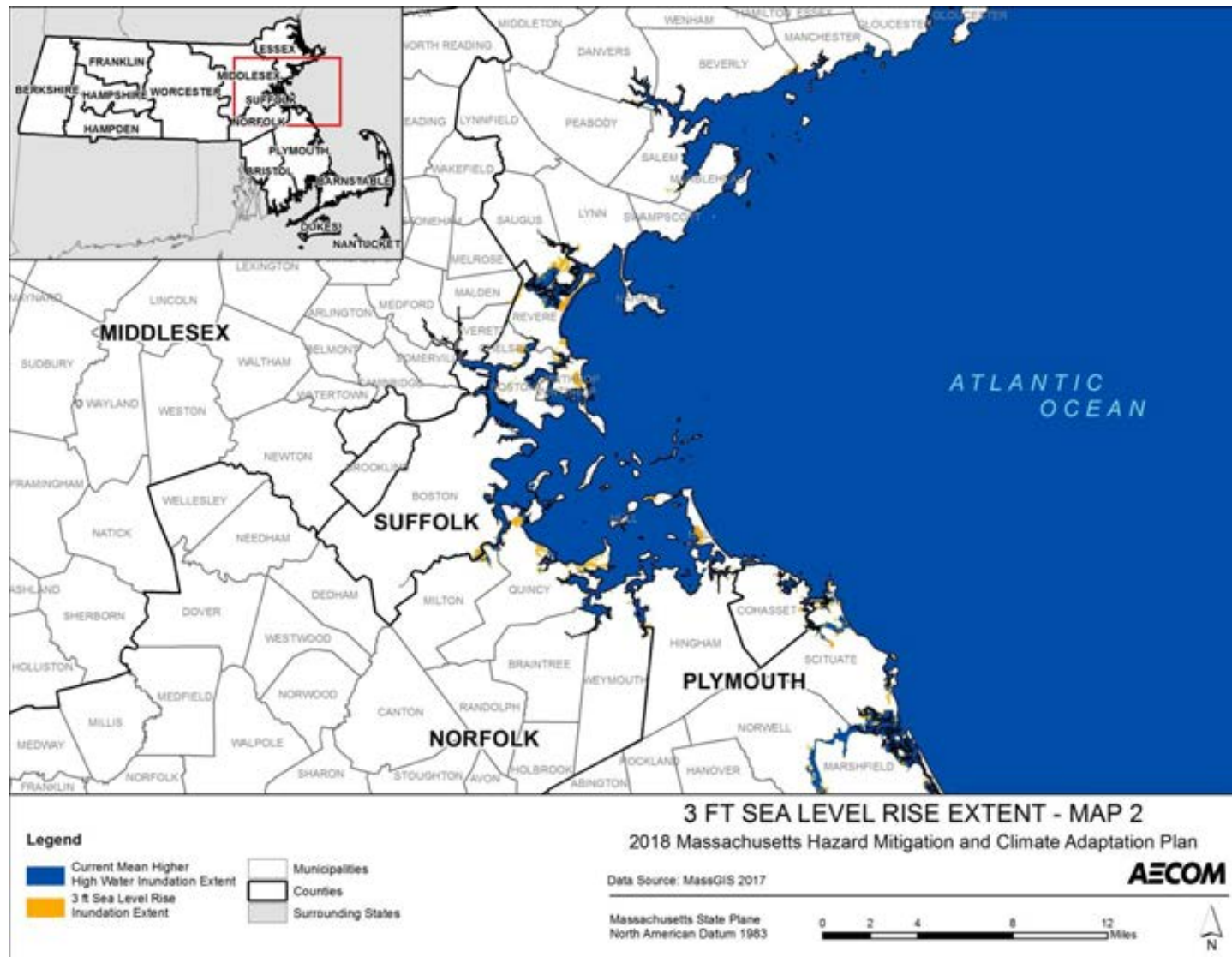


Figure 4-28: Inundation Extent of 1-Foot Sea Level Rise Relative to MHHW (Map 3)

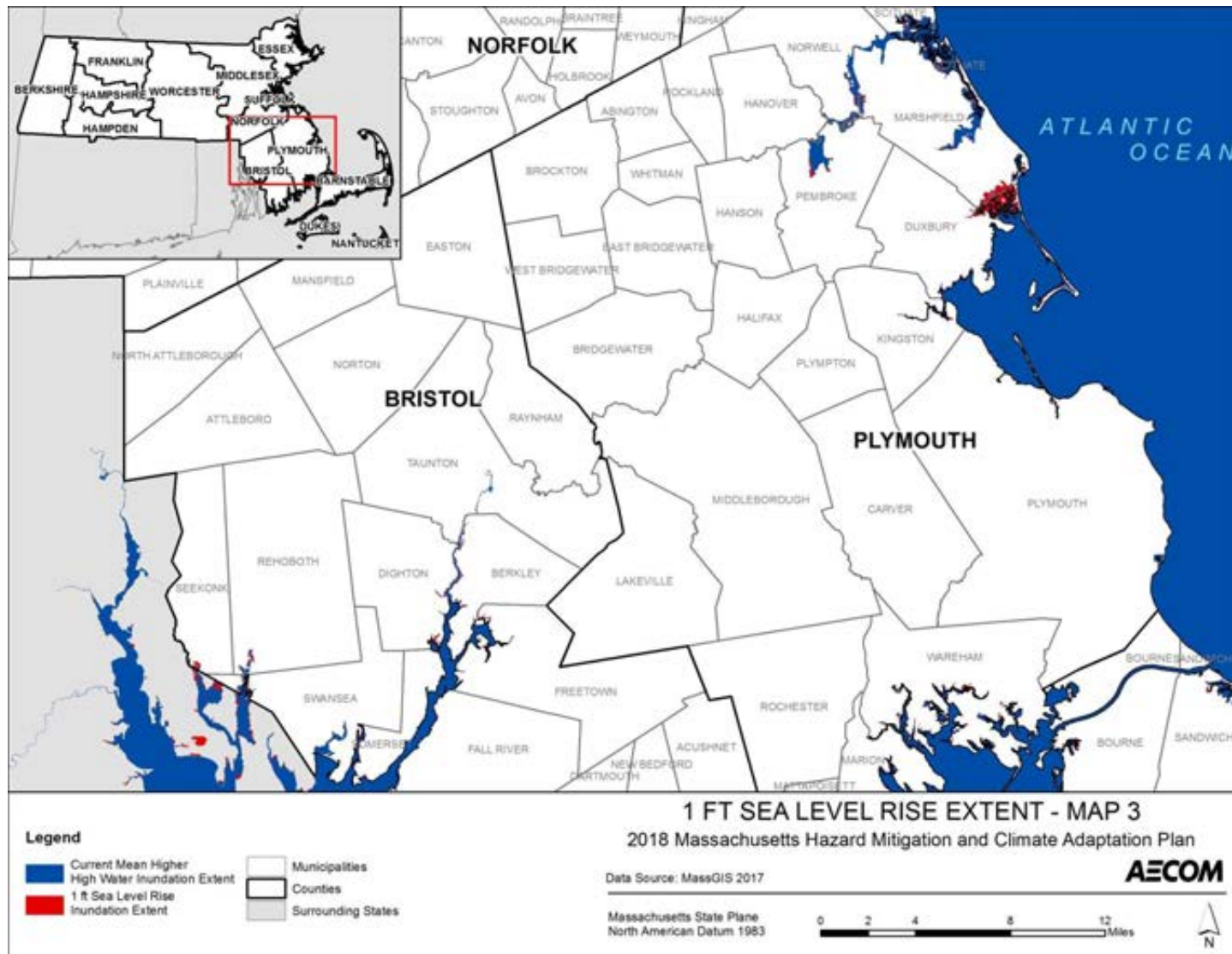


Figure 4-29: Inundation Extent of 3-Foot Sea Level Rise Relative to MHHW (Map 3)

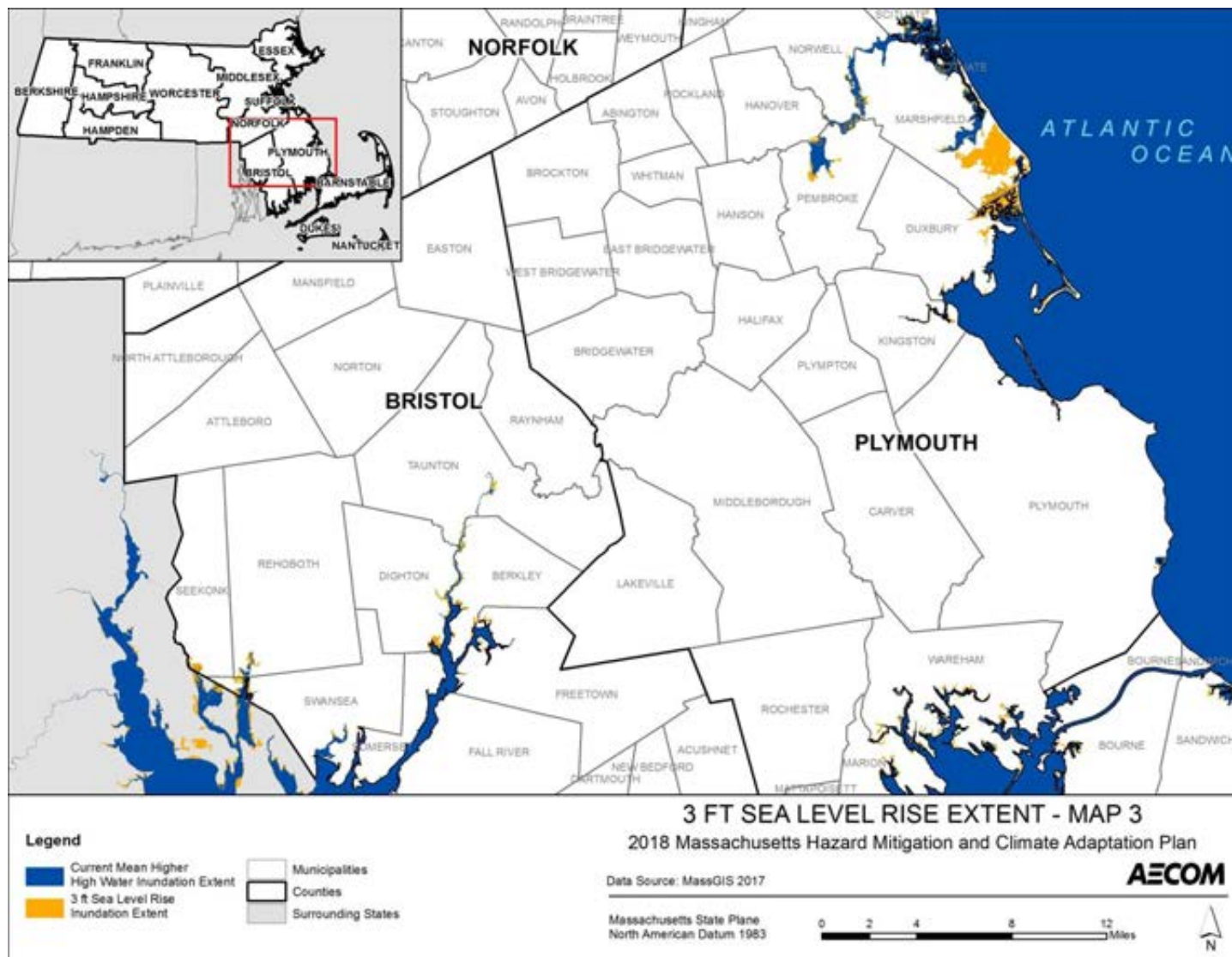


Figure 4-30: Inundation Extent of 1-Foot Sea Level Rise Relative to MHHW (Map 4)

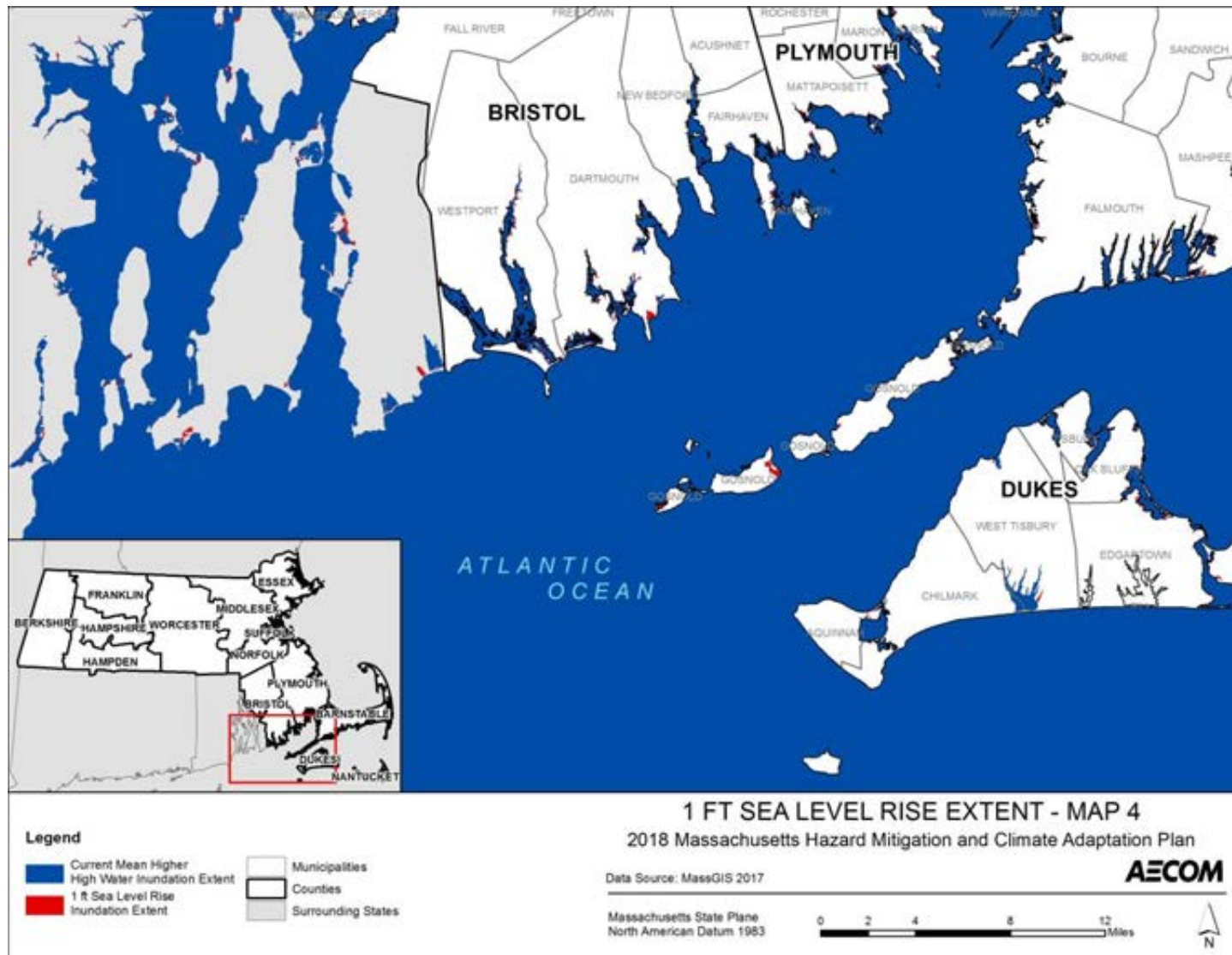


Figure 4-31: Inundation Extent of 3-Foot Sea Level Rise Relative to MHHW (Map 4)

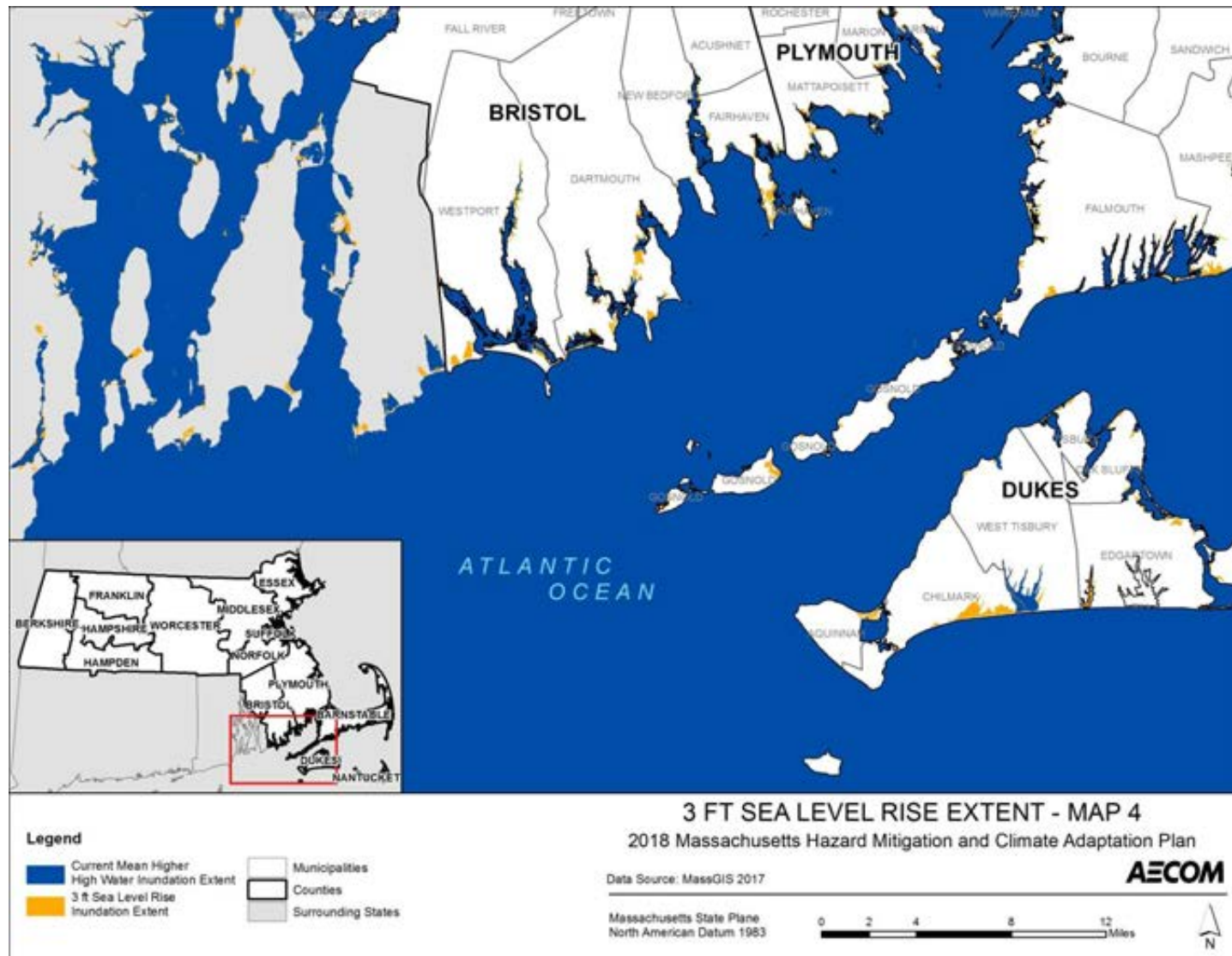


Figure 4-32: Inundation Extent of 1-Foot Sea Level Rise Relative to MHHW (Map 5)

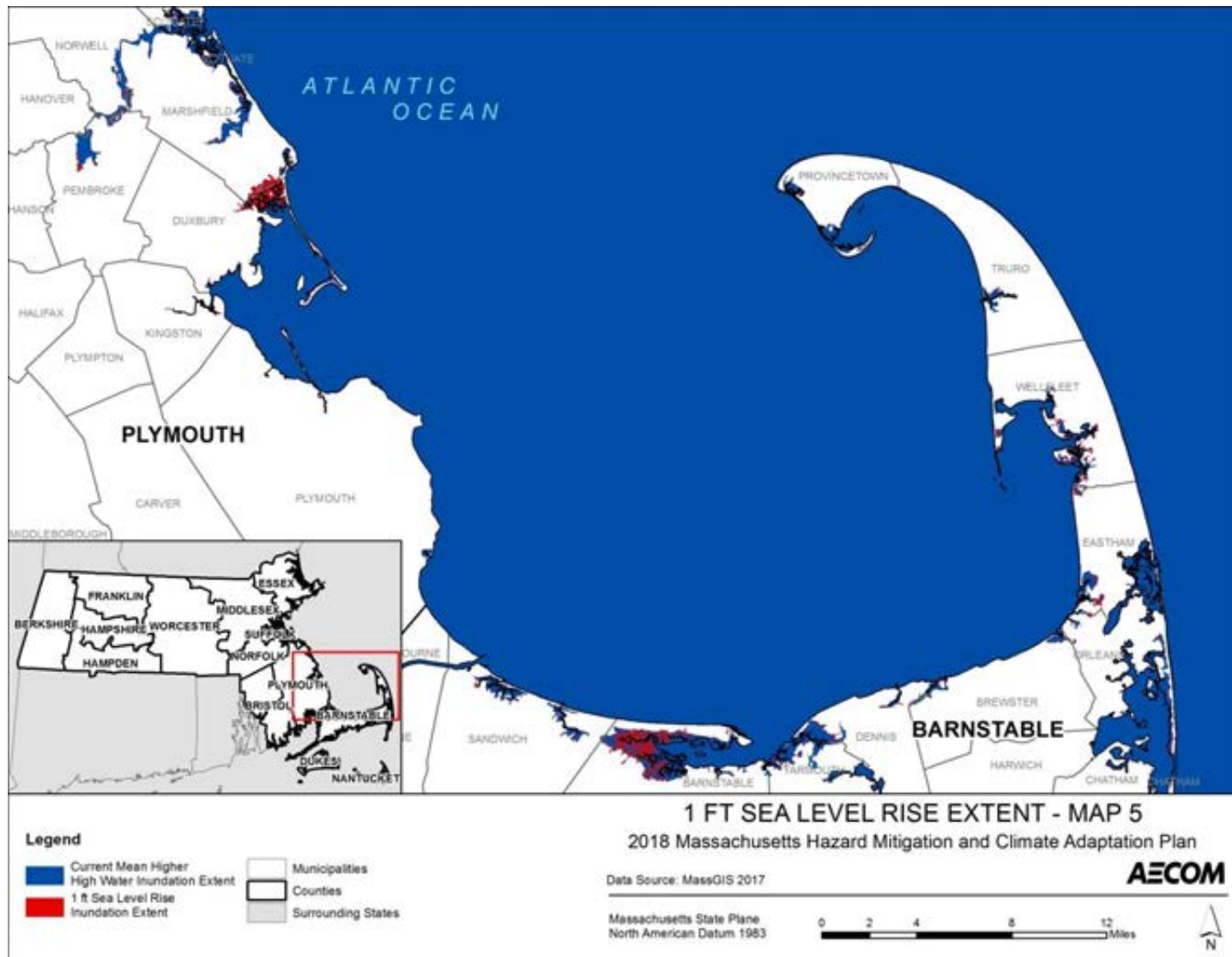


Figure 4-33: Inundation Extent of 3-Foot Sea Level Rise Relative to MHHW (Map 5)

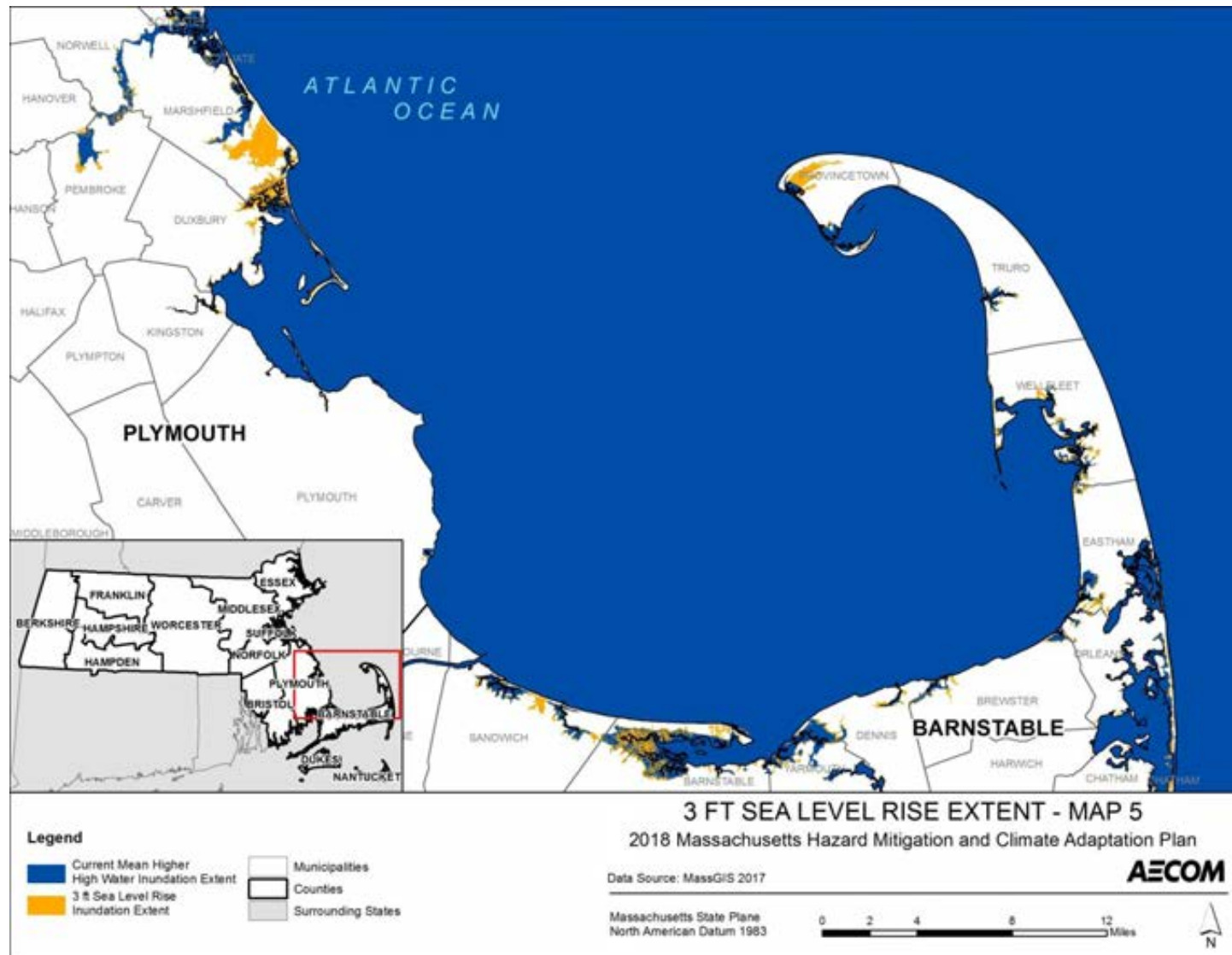


Figure 4-34: Inundation Extent of 1-Foot Sea Level Rise Relative to MHHW (Map 6)

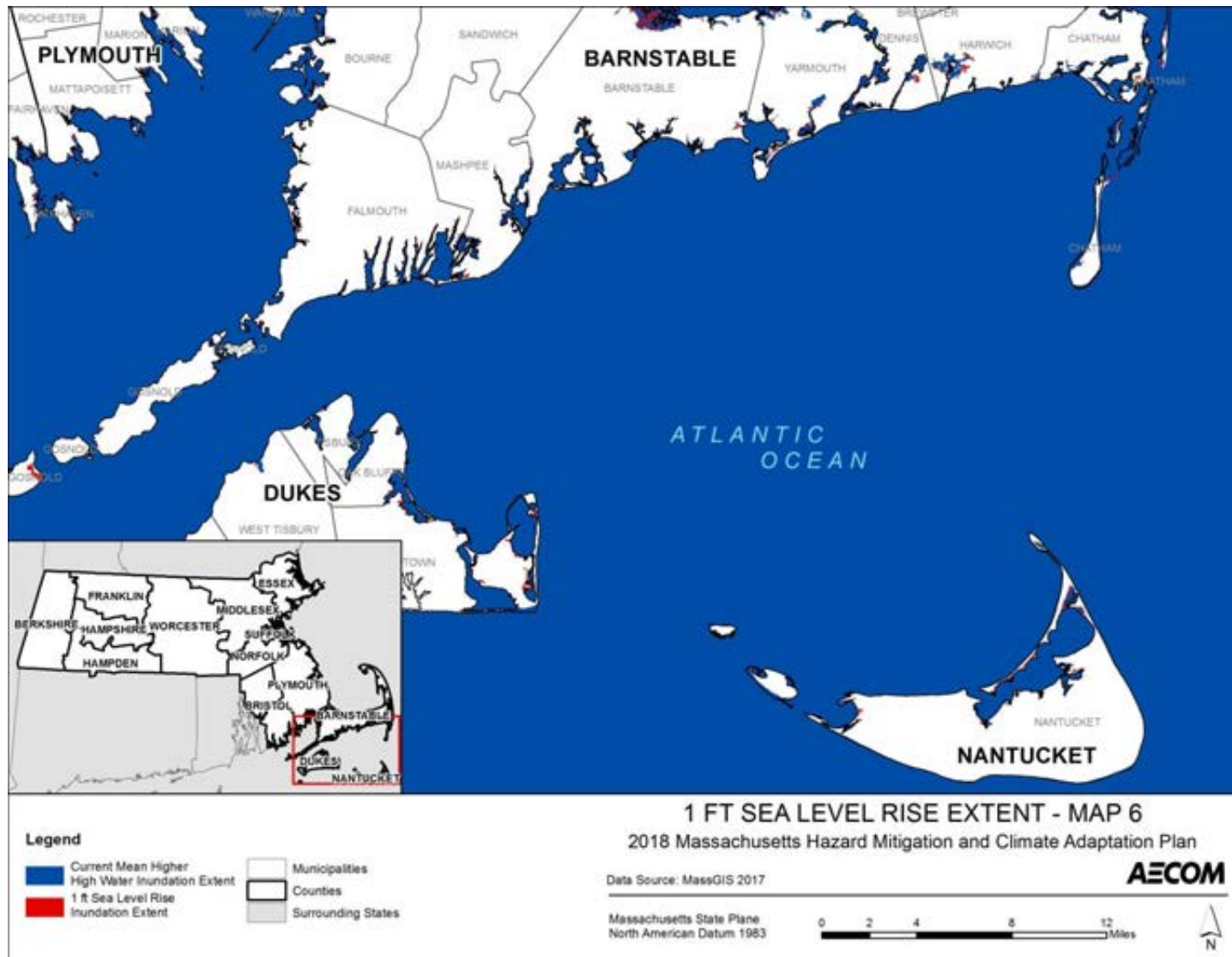
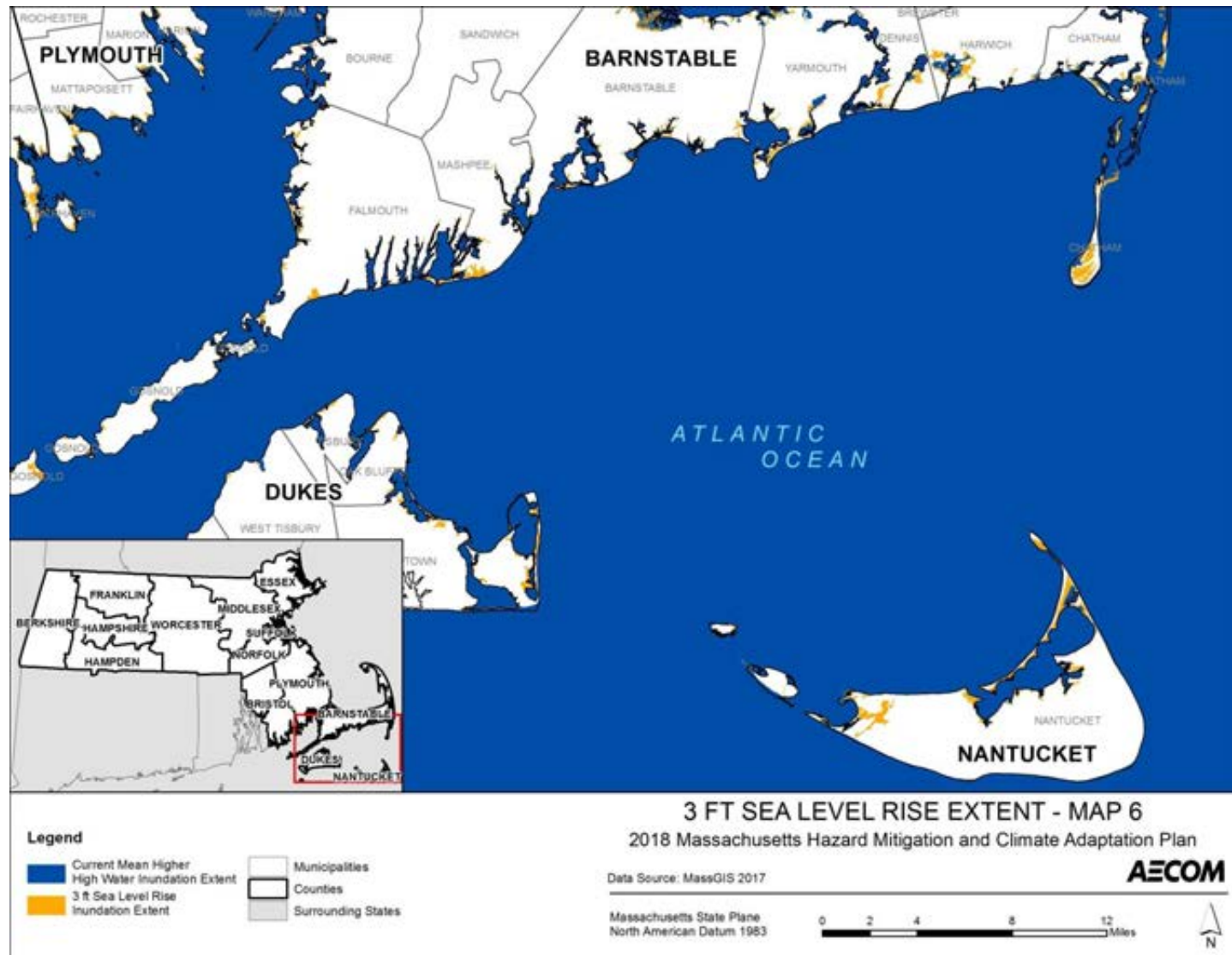


Figure 4-35: Inundation Extent of 3-Foot Sea Level Rise Relative to MHHW (Map 6)



However, mean sea level has been rising very gradually over the last century and will likely affect tidal levels and permanent inundation on a longer time scale. This affords communities the opportunity to plan infrastructure improvements in preparation for elevated water levels.

The NWS issues storm surge watches and warnings to highlight coastal areas with significant risk of life-threatening inundation from an ongoing or potential tropical cyclone, subtropical cyclone, or a post-tropical cyclone during an event. A storm surge *watch* is issued, generally within 48 hours, for the possibility of life-threatening inundation from rising water moving inland from the shoreline. The watch is issued earlier if other conditions such as wind may limit the time to take protective actions for surge, such as evacuations. A storm *warning* is issued, generally within 36 hours, if there is a danger of life-threatening inundation, (NWS, 2017).

Secondary Hazards

Many of the secondary hazards described for inland flooding can also occur as a result of coastal flooding if the necessary physical elements (rivers and slopes, respectively) are present within the impacted portion of the coastal zone. In addition, there are secondary hazards that are specific to coastal flooding. Foremost among these is coastal erosion, which is discussed in greater detail in Section 4.2.2. Although sea level rise does not result directly in coastal erosion, by increasing tidal datum heights, sea level rise can increase the impacts associated with storm surge and high tides and other erosive processes (e.g., currents and waves).

An additional secondary hazard associated with sea level rise is the possibility of saltwater intrusion into groundwater supplies, which provide potable water not only for residential uses but also for agriculture and industry. Sea level rise is also decreasing the separation distance between septic fields and the groundwater table, which compromises the septic systems' ability to treat bacteria and pathogens (CLF, 2017). Projected increased precipitation will exacerbate the effect of saltwater intrusion on groundwater, as groundwater levels are further elevated and the oxygen needed for microbial wastewater treatment is depleted (CLF, 2017).

EXPOSURE AND VULNERABILITY

To assess the Commonwealth's present-day exposure to the flood hazard, an analysis was conducted with the most current floodplain boundaries (as of July 25, 2017). These data include the locations of the FEMA flood zones: the 100-year flood zones or 1 percent annual chance event areas (A and V Zones) and the 500-year flood zones, or 0.2 percent annual chance event areas. Using ArcMap GIS software, these data were overlaid with data on the population, general building stock, state-owned facilities, and critical facilities, and the appropriate flood zone determination was assigned. The results of this analysis are shown in Figures 4-36 through 4-38.

Figure 4-36: FEMA Flood Hazard Areas in Coastal Massachusetts (Map 1)

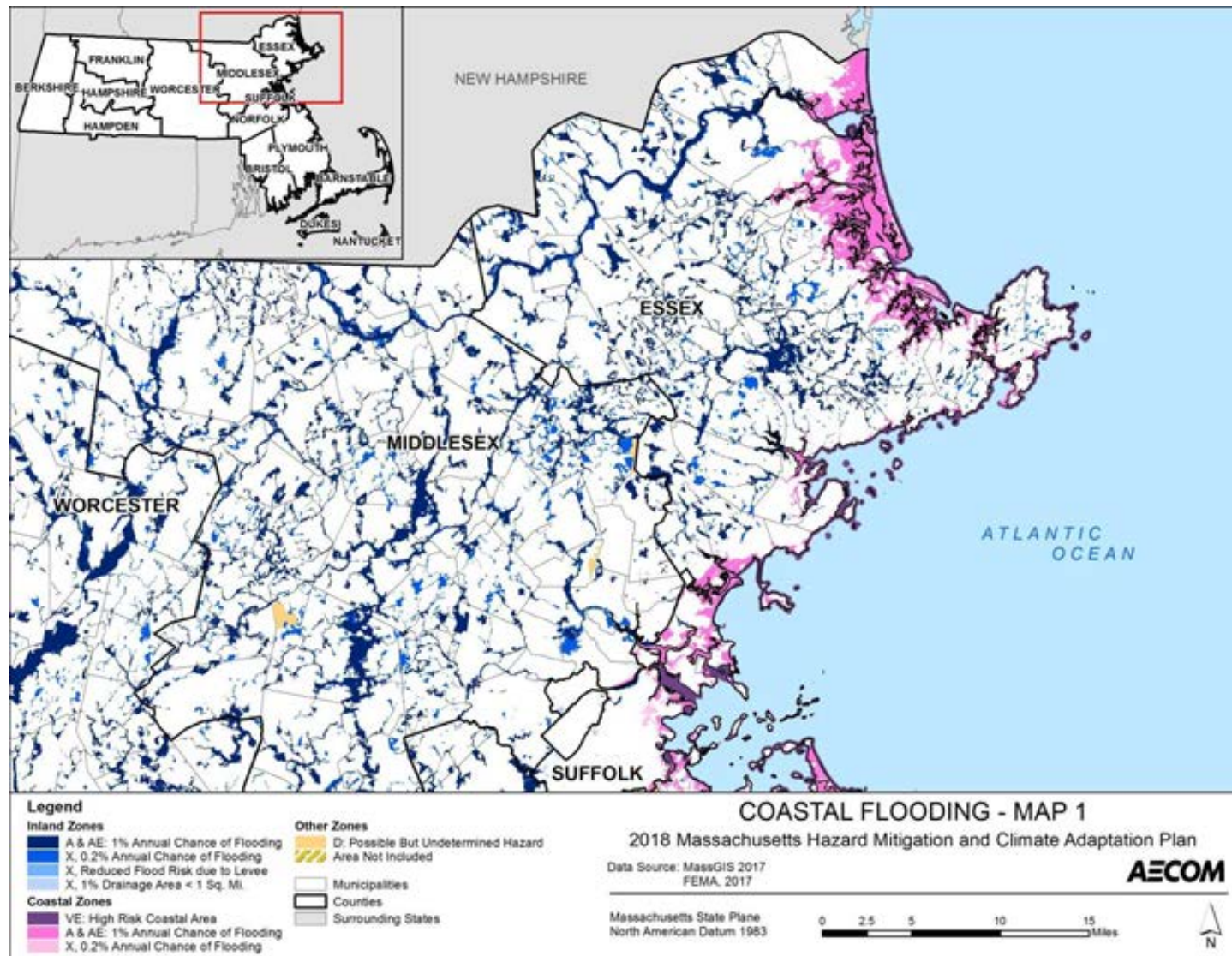


Figure 4-37: FEMA Flood Hazard Areas in Coastal Massachusetts (Map 2)

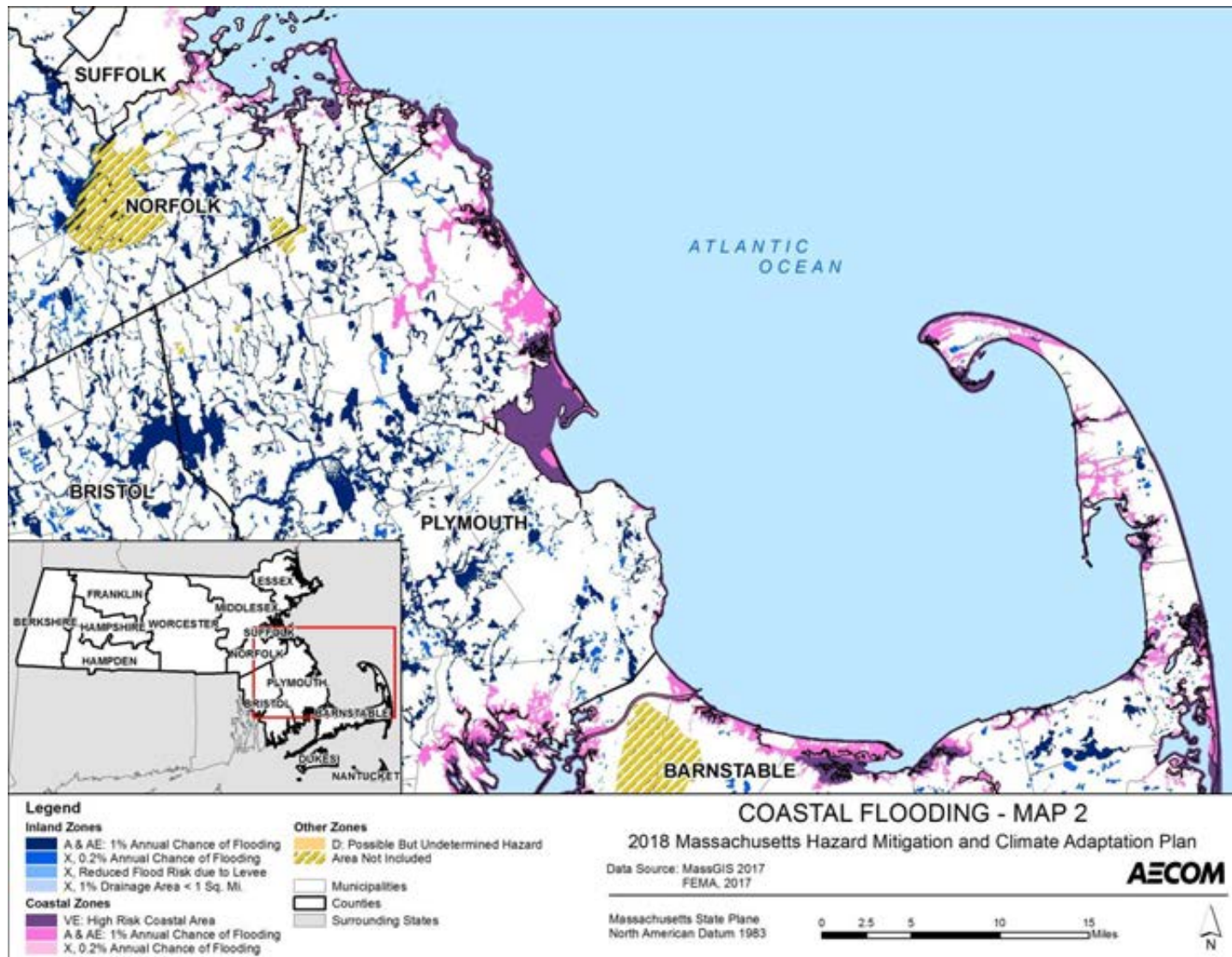
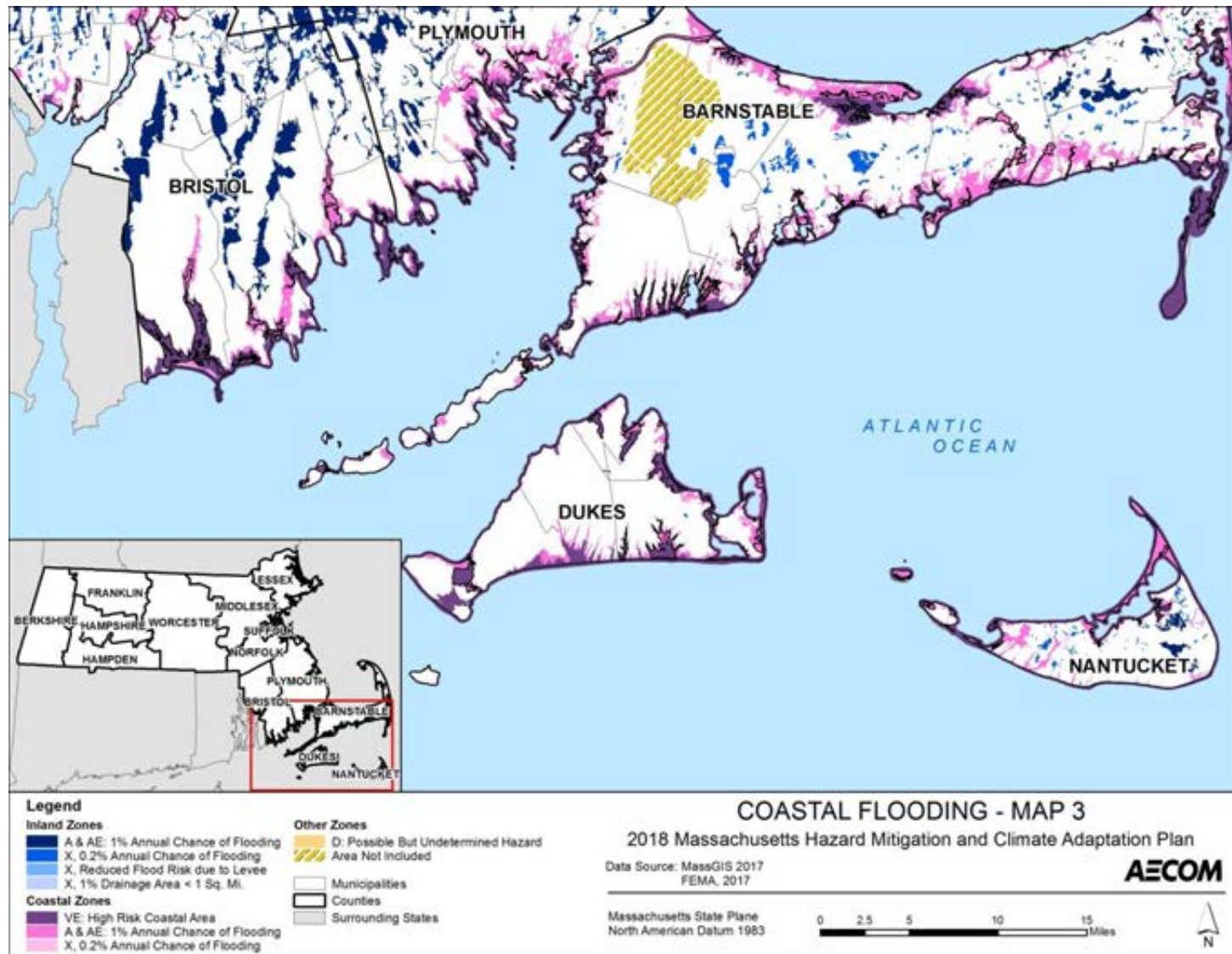


Figure 4-38: FEMA Flood Hazard Areas in Coastal Massachusetts (Map 3)



Populations



Between 2000 and 2010, the population in coastal counties in the Commonwealth increased by 3.1 percent, from 3.3 to 3.4 million people. The population in Dukes County grew by more than 10 percent during this time period, while Barnstable County experienced a 3 percent decline in population (U.S. Census, 2000, 2010). Due to increasing population in the coastal zones, additional pressure has been placed on coastal systems by construction of infrastructure and housing in previously undeveloped areas. This increase in impervious surfaces can exacerbate flooding impacts. In addition, as more individuals move to the coast, both that population and the development that supports them may be at risk due to the coastal flooding hazard. The estimated population exposed to coastal flooding in each county is shown in Table 4-25.

Table 4-25: Estimated Population Exposed to the 1 Percent and 0.2 Percent Annual Chance Flood Events

County	Total 2010 Population	1 Percent Annual Chance Flood Event				0.2 Percent Annual Chance Flood Event	
		A Zone		V Zone		X500 Zone	
		Population	% of Total	Population	% of Total	Population ⁽¹⁾	% of Total
Barnstable	215,888	15,207	7.0	1,873	0.9	5,813	2.7
Bristol	548,285	7,211	1.3	3,358	0.6	3,392	0.6
Dukes	16,535	528	3.2	136	0.8	126	0.8
Essex	743,159	20,150	2.7	2,620	0.4	511	0.1
Nantucket	10,172	197	1.9	44	0.4	63	0.6
Norfolk	670,850	12,682	1.9	1,311	0.2	1,069	0.2
Plymouth	494,919	20,683	4.2	3,984	0.8	3,452	0.7
Suffolk	722,023	32,246	4.5	1,172	0.2	9,424	1.3
Total	3,421,831	108,904	3.2	14,498	0.4	23,850	0.7

Note: (1) Represents population within the X500 Zone. Population in the A Zone and V Zone would also be exposed to a 0.2 percent annual chance flood event.

Sources: 2010 U.S. Census, MassGIS 2017

Vulnerable Populations

Of the population exposed, the most vulnerable include the people with low socioeconomic status, people over the age of 65, renters, people with compromised immune systems, children under the age of 5, and people with low English language fluency. The population over the age of 65 is vulnerable because these individuals are more likely to seek or need medical attention, which may not be available due to isolation during a flood event, and they may have more

difficulty evacuating. People with mobility limitations are similarly vulnerable. Young children are vulnerable due to their dependence on adults to make decisions about their safety. People with low socioeconomic status are vulnerable because they are likely less able to bear the additional expense of evacuating and/or may lack transportation to evacuate. They are also less likely to have the resources needed to recover from damage to homes and businesses.

Populations that live or work in proximity to facilities that use or store toxic substances are at greater risk of exposure to these substances during a coastal flood event. The [Massachusetts Toxic Users and Climate Vulnerability Factors](#) map displays wastewater treatment plants; major facilities that treat, use, or store hazardous waste; and classified oil and/or hazardous material sites within the FEMA flood zones, including high-risk coastal areas (EOEEA, n.d.).

During and after an event, rescue workers and utility workers are vulnerable to impacts, including high water, swift currents, rescues, and submerged debris.

NFIP data are a useful for determining the location of areas vulnerable to flood and severe storm hazards. Data on NFIP policies, properties, and claims associated with all flood events (inland and coastal flooding) are discussed in detail in Section 4.1.1.

Health Impacts

Flood waters from coastal flooding events may contain infectious organisms, such as bacteria, and viruses from untreated wastewater that is released to surface waters (OSHA, 2005). For example, coastal flooding may directly damage or flood wastewater treatment facilities, causing the floodwater to carry untreated wastewater to other locations. Flooding that causes power outages at wastewater treatment facilities could impact treatment prior to discharge if the facility lacks sufficient backup power. To a lesser degree, coastal floodwaters could inundate streets that drain to combined sewers, causing activation of the combined sewage overflows, which normally discharge a combination of stormwater and untreated wastewater to the harbor or nearby rivers during periods of heavy rainfall.

Coastal storm flooding can also result in direct mortality in the flood zone. Even a relatively low-level flood can be more hazardous than many residents realize. For example, only 6 inches of moving water can cause adults to fall, and 1 foot to 2 feet of water can sweep cars away. Immediate danger is also presented by downed powerlines, sharp objects in the water, or fast-moving debris that may be moving in or near the water.

Coastal floodwaters may also contain agricultural or industrial chemicals, hazardous materials swept away from containment areas, or electrical hazards if downed power lines are present. Individuals with pre-existing health conditions may also experience medical emergencies, and they are at risk if flood events (or related evacuations) render them unable to access medical support. Flooded streets and roadblocks may make it difficult for emergency vehicles to respond to calls for service, particularly in rural areas.

Coastal storm flooding events can have significant impacts after the initial event has passed. For example, flooded areas that do not drain properly can become breeding grounds for mosquitos, which can transmit vector-borne diseases. Exposure to mosquitos may also increase if individuals are outside of their homes for longer than usual as a result of power outages or other flood-related conditions. The growth of mold inside buildings is often widespread after a flood. Investigations following Hurricane Katrina and Superstorm Sandy found mold in the walls of many water-damaged homes and buildings. Mold can result in allergic reactions and can exacerbate existing respiratory diseases, including asthma (CDC, 2014). Property damage and displacement of homes and businesses can lead to loss of livelihood and long-term mental stress for those facing relocation. Individuals may develop post-traumatic stress, anxiety, and depression following major flooding events. Events that cause loss of electricity and heating systems increase the risk of carbon monoxide poisoning. Carbon monoxide is present in emissions from combustion appliances, such as cooking and heating devices (grills and stoves), damaged chimneys, or generators. Improper location and operation of combustion appliances in indoor or poorly ventilated areas leads to increased risks of carbon monoxide poisoning.

Tidal flooding of coastal areas, apart from a storm, can also damage infrastructure and property and lead to health impacts. Salinization of drinking water supplies as rising sea levels erode shorelines and salt water intrudes into sources of fresh water can impact both private wells and municipal water supplies, leading to increases in water-borne illnesses, excessive salt intake, loss of drinking water supplies, and drinking water system outages. Frequent tidal flooding from sea level rise may also lead to increases in respiratory diseases due to mold from dampness in homes. The burden of the long-term impacts of rising sea levels can also affect mental health.

Government



To assess the exposure of state-owned facilities identified by DCAMM and the Office of Leasing, an analysis was conducted with the most current floodplain boundaries (as of July 25, 2017). Using ArcMap GIS software, the flood hazard area data were overlaid with the state facility data, and the appropriate flood zone determination was assigned to each facility. Table 4-26 summarizes the number of state buildings located in the 1 percent and 0.2 percent annual chance flood zones by county.

Table 4-26: Government Facilities in the Flood Zones by County

County	1 Percent Annual Chance Flood Event				0.2 Percent Annual Chance Flood Event	
	In A Zone		In V Zone		In X500 Zone	
	Count	Replacement Value	Count	Replacement Value	Count	Replacement Value
Barnstable	18	\$98,487,484	17	\$31,052,700	—	—
Bristol	14	\$15,311,153	28	\$17,676,463	—	—
Dukes	2	\$2,072,371	—	—	—	—
Essex	25	\$101,555,701	9	\$7,783,228	—	—
Middlesex	1	\$71,395	—	—	—	—
Nantucket	—	—	—	—	—	—
Norfolk	3	\$1,303,793	2	\$1,044,719	—	—
Plymouth	10	\$7,432,926	14	\$13,370,385	10	\$2,247,037
Suffolk	32	\$220,566,080	13	\$12,582,944	3	\$737,909
Total	105	\$446,800,903	83	\$83,510,439	13	\$2,984,946

Sources: MassGIS, 2017; DCAMM, 2017 (facility inventory)

As shown in Table 4-26, Suffolk and Bristol Counties have the greatest number of government buildings in areas that have a 1 percent and a 0.2 percent chance of flooding in a given year. In addition, there is an increased risk to state-owned beaches, marshes, and wetlands due to increased rates of coastal flooding. The nature of the coastal hazard is inherently geographically limited to areas in proximity to the coast; however, sea level rise will expand the amount of coastal and near-coastal areas that are impacted by coastal flooding, increasing the exposure and thereby expanding the exposure to the hazard.

The Built Environment



Coastal flooding could hamper or disable operations for a wide range of facilities, including commercial establishments such as ports, natural gas terminals, and chemical storage facilities, as well as services such as the Coast Guard.

To estimate the critical facilities exposed to the coastal flood hazard, the flood hazard boundaries were overlaid upon the police stations, fire stations, hospitals, schools (pre-kindergarten through grade 12), colleges, and state emergency operation centers. Table 4-27 summarizes the number of facilities in each zone by county, and Table 4-28 summarizes the facilities by facility type.

Table 4-27: Critical Facilities in Flood Zones by County

County	1 Percent Annual Chance Flood Event		0.2 Percent Annual Chance Flood Event
	In A Zone	In V Zone	In X500 Zone
Barnstable	1	1	—
Bristol	1	1	—
Dukes	—	—	—
Essex	2	1	—
Middlesex	—	—	—
Nantucket	—	—	—
Norfolk	—	—	—
Plymouth	—	—	—
Suffolk	3	2	1
Total	7	5	1

Sources: MassGIS 2017; DCAMM, 2017 (facility inventory)

Table 4-28: Critical Facilities in Flood Zones by Facility Type

Facility Type	1 Percent Annual Chance Flood Event		0.2 Percent Annual Chance Flood Event
	In A Zone	In V Zone	In X500 Zone
Police Stations	2	—	1
Fire Stations	—	1	—
Hospitals	—	—	—
Schools (pre-kindergarten through grade 12)	—	—	—
Colleges	5	4	—
Emergency Operations Centers	—	—	—
Total	7	5	1

Sources: MassGIS 2017; DCAMM, 2017 (facility inventory)

Historic and archeological sites that are within current and future coastal flood zones are vulnerable to sea level rise. Colonial and Native American cemeteries located on the Boston Harbor Islands are already being impacted by erosion. Revolutionary War and other historic sites in Boston, such as the Charleston Navy Yard and Faneuil Hall, are vulnerable to flooding.

Sea level rise, extreme precipitation, and other weather impacts may disrupt the storage of toxic chemicals or otherwise expose them. The State's [online map tool for assessing climate](#)

[vulnerability and toxics](#) can be used to evaluate the vulnerability of a toxic chemical storage facility's location to severe weather events and the potential for chemicals used or stored at a site to impact the surrounding neighborhood. Additional impacts to sectors of the built environment are described in the following subsections.

[Agriculture](#)

Increasing tidal range and tidal inundation is likely to cause more saltwater intrusion into aquifers in agricultural areas (resilient MA, 2018).

[Energy](#)

Facilities that are located in proximity to the coast are vulnerable to sea level rise, flooding, and storm surge. Intense storms can disrupt generation, transmission, distribution, and oil and gas operations. High water levels on roads can restrict transportation. Sea level rise may also impact the accessibility of ports.

[Public Health](#)

Coastal flooding may increase the vulnerability of commercial and residential buildings to toxic mold buildup, leading to the health risks described in the *Populations* section of the coastal flooding hazard profile. Road closures due to coastal flooding may impact the accessibility of hospitals and medical providers. Coastal flooding may also lead to contamination of well water and contamination from septic systems (DPH, 2014).

[Public Safety](#)

Increased coastal flooding may result in more frequent emergency evacuations and the need to relocate critical assets and facilities. Similar to inland flooding, coastal flooding can have a significant impact on public safety. Fast-moving water can sweep up debris, hazardous objects, and vehicles and carry them toward people and property. Coastal flooding can impact the ability of emergency response personnel to reach stranded or injured people. Drownings may also occur as people attempt to drive through streets that are flooded or impacted by storm surge.

[Transportation](#)

As sea level rise progresses, roadways, subway and highway tunnels, Logan International Airport, and other critical elements in our transportation network could be inundated (resilient MA, 2018). Other waterfront areas, including the Massachusetts Port Authority's port and maritime facilities, and the highway and public transit tunnels are vulnerable to sea level rise (EOEEA, 2011).

MassDOT conducted a [pilot transportation infrastructure vulnerability analysis](#) that incorporated sea level rise scenarios and a high-resolution, physically based, coupled hydrodynamic-wave numerical model to quantify the magnitude and extent of flooding along the highly urbanized

Boston coastline (MassDOT, FHWA, 2015). The pilot assessed the vulnerability of the Central Artery/Tunnel Project, which consists of more than 160 lane-miles (more than half of which are in tunnels), six interchanges, and 200 bridges, to sea level rise and storm events. The study found that six non-boat section structures were found to experience flooding under current conditions and that 19 additional non-boat section structures would experience flooding by 2030.

Depending on the actual rate of sea level rise, an additional 26 structures may become vulnerable and the number of vulnerable boat sections with portals (a type of tunnel section) increases dramatically by the end of this century. Under current conditions and by 2030, 12 portals are vulnerable to flooding. By 2070 or 2100, an additional 42 portals become vulnerable (MassDOT, FHWA, 2015).

Many coastal bridges and culverts are, and will be, subjected to coastal flooding, particularly those that are hydraulically undersized or tidally restricted. Table 4-29 lists the bridges that are exposed to the coastal flooding hazard. Damage or destruction to these crossings will result in road closures, isolation of communities, as well as impacts to emergency services. Additionally, tidally restricted crossings cause damage to critical coastal wetlands that help offset the impact of sea level rise.

Other types of existing coastal infrastructure with long life spans, such as roads and bridges, were not designed to accommodate increasing rates of sea level rise. Consequently, over time, more frequent overtopping of roads and bridges may be expected in coastal areas during storms and non-storm high-tide events. The increase in overtopping will impact transportation and emergency services, and cause isolation of residents.

Table 4-29: Number of Bridges in Coastal Flood Zones

County	1 Percent Annual Chance Flood Event						0.2 Percent Annual Chance Flood Event
	In A Zone			In VE Zone			In X500 Zone
	Federal	State	Local	Federal	State	Local	State
Barnstable	1	13	19	—	1	9	—
Berkshire	—	—	—	—	—	—	—
Bristol	—	19	12	—	4	6	1
Dukes	—	2	1	—	2	—	—
Essex	—	15	16	—	1	—	3
Franklin	—	—	—	—	—	—	—
Hampden	—	—	—	—	—	—	—
Hampshire	—	—	—	—	—	—	—
Middlesex	—	6	—	—	—	—	—
Nantucket	—	—	2	—	—	—	—

County	1 Percent Annual Chance Flood Event						0.2 Percent Annual Chance Flood Event
	In A Zone			In VE Zone			In X500 Zone
	Federal	State	Local	Federal	State	Local	State
Norfolk	—	8	1	—	—	—	—
Plymouth	—	25	15	—	3	2	—
Suffolk	—	75	18	—	—	—	26
Worcester	—	—	—	—	—	—	—
Total	1	163	84	0	12	17	30

Source: MassGIS, 2017; National Bridge Inventory

Water Infrastructure

Saltwater intrusion may make infrastructure more vulnerable to corrosion and may threaten coastal aquifers and the drinking water they supply. Larger coastal storm surges may put critical water and wastewater infrastructure at risk. Some municipal stormwater and wastewater collection systems, outfalls, and wastewater treatment plants may eventually need relocation (resilient MA, 2018). The Massachusetts Water Resources Authority's Deer Island Sewage Treatment Plant is vulnerable to sea level rise (EOEEA, 2011).

Natural Resources and Environment



Coastal flooding is a natural component of the environmental process. However, populations that become established in coastal areas, and the development that occurs as a result, can often exacerbate both the severity of flooding and its impacts due to the loss of flood buffering from the environment. For example, an increase in impervious ground cover can cause runoff to drain into water bodies more quickly, overwhelming the damage-mitigating and water-filtering benefits of estuarine systems commonly found at the junction between river and ocean. Flood waters can become extremely contaminated, bringing that contamination into sensitive coastal ecosystems as they recede, which will impact that environment. Coastal flooding will increase naturally occurring erosion along beaches and bluffs, impacting habitat and bank stability (U.S. Climate Resilience Toolkit, 2016). Many of the impacts described in Section 4.1.1, such as soil erosion and impacts to wildlife and livestock industries, can also occur in the coastal zone (for example, in the lower Mystic River) if those industries are present.

Many of the unique impacts of coastal flooding are associated with sea level rise and the expanded reach of flood-inducing events such as storm surge. As noted in the State Wildlife Action Plan, transition from one ecosystem or population to another ecological state is likely along the coast. Factors including land use will dictate the ability of certain ecosystems, such as marshes, to migrate inland as the sea level rises (DFW, 2015). In estuarine habitats where subtle

differences in elevation provide diverse habitat, changing water levels may significantly impact species who inhabit low and high marshes, subtidal and intertidal flats, and tidal creeks, Increasing storms and storm intensity are also likely to cause physical damage to habitat (NHESP, 2010).

Tables 4-30, 4-31, and 4-32 display the acreage in key natural habitat areas that is vulnerable to 1 percent and 0.2 percent annual flooding by county. The natural habitat areas include Areas of Critical Environmental Concern (ACEC) and BioMap2 Core Habitat and Critical Natural Landscapes that have been identified for land protection and stewardship purposes. ACEC are places in Massachusetts that have been designated by the EOEEA and that receive special recognition because of the quality, uniqueness, and significance of their natural and cultural resources. As shown in Table 4-30, for example, more than 87 percent of the Great Marsh in Essex County lies within the A Zone, which has a 1 percent chance of flooding annually (MassGIS, 2009).

BioMap2 was developed by the Natural Heritage and Endangered Species Program and The Nature Conservancy's Massachusetts Program to protect the state's biodiversity in the context of the projected effects of climate change (DFW, 2015). The state's BioMap 2 Core Habitat data identify the specific areas needed to promote long-term persistence of Species of Concern, including species listed under the Massachusetts Endangered Species Act, and additional species identified in the State Wildlife Action Plan; exemplary natural communities; and intact ecosystems. BioMap2 Critical Natural Landscape data were developed in order to identify and prioritize intact landscapes in the state that are better able to support ecological processes and disturbance regimes and a wide array of species and habitats over a long time frame (MassGIS 2011). Buffering uplands around coastal, wetland, and aquatic core habitats, maintaining connectivity among habitats, and enhancing ecological resilience are among the functions of areas identified as Critical Natural Landscapes (DFW, 2010). The BioMap2 data sets incorporate adaptation strategies that "promote resistance and resilience of plant and animal populations and ecosystems" and that have the potential to assist with "transformations caused by climate change and other stressors" (DFW, 2015). The ACEC, Core Habitat, and Critical Natural Landscape designations signify the presence of valuable ecological and cultural resources. The data sets provide a framework for prioritizing conservation and stewardship activities.

Table 4-30: Natural Resources Exposure – Areas of Critical Environmental Concern

Name	County	Total Acreage	1 Percent Annual Chance Flood Event				0.2 Percent Annual Chance Flood Event	
			A Zone		V Zone		X500 Zone	
			Acres	% of Total	Acres	% of Total	Acres	% of Total
Bourne Back River	Barnstable	1,608.8	482.9	30.0	83.6	5.2	36.67	2.3
Ellisville Harbor	Plymouth	573.0	97.6	17.0	81.6	14.2	—	—
Great Marsh	Essex	19,529.7	17,054.9	87.3	848.3	4.3	27.33	0.1
Inner Cape Cod Bay	Barnstable	1,206.6	572.9	47.5	607.8	50.4	—	—
Neponset River Estuary	Norfolk	584.4	328.7	56.2	3.4	0.6	6.26	1.1
Neponset River Estuary	Suffolk	232.8	148.2	63.7	8.8	3.8	—	—
Pleasant Bay	Barnstable	3,757.1	1,416.5	37.7	856.6	22.8	78.39	2.1
Pocasset River	Barnstable	144.8	89.5	61.8	—	—	2.82	1.9
Rumney Marshes	Essex	1,217.9	956.2	78.5	—	—	—	—
Rumney Marshes	Suffolk	1,037.2	884.0	85.2	62.0	6.0	7.1	0.7
Sandy Neck Barrier Beach System	Barnstable	6,099.9	3,445.6	56.5	2,248.7	36.9	—	—
Three Mile River Watershed	Bristol	14,273.2	44.1	0.3	—	—	7.25	0.1
Waquoit Bay	Barnstable	1,622.4	552.7	34.1	912.3	56.2	57.41	3.5
Weir River	Norfolk	26.7	26.6	99.9	—	—	—	—
Weir River	Plymouth	400.7	322.1	80.4	5.1	1.3	—	—
Wellfleet Harbor	Barnstable	4,550.9	2,031.6	44.6	715.3	15.7	—	—
Weymouth Back River	Norfolk	178.0	99.0	55.6	—	—	0.31	0.2
Weymouth Back River	Plymouth	576.9	83.9	14.5	—	—	14.51	2.5

Table 4-31: Natural Resources Exposure—BioMap2 Core Habitats

Name	County	Total Acreage	1 Percent Annual Chance Flood Event				0.2 Percent Annual Chance Flood Event	
			A Zone		V Zone		X500 Zone	
			Acres	% of Total	Acres	% of Total	Acres	% of Total
Aquatic Core	Barnstable	10,760.0	1,935.8	18.0	345.6	3.2	73.8	0.7
Aquatic Core	Bristol	11,266.0	1,130.9	10.0	1,008.5	9.0	29.3	0.3
Aquatic Core	Dukes	2,002.3	445.9	22.3	978.1	48.8	3.5	0.2
Aquatic Core	Essex	13,397.8	13,484.6	100.6	295.6	2.2	20.9	0.2
Aquatic Core	Middlesex	11,699.1	315.7	2.7	—	—	—	—
Aquatic Core	Nantucket	626.3	260.8	41.6	6.2	1.0	28.3	4.5
Aquatic Core	Norfolk	6,992.3	176.9	2.5	72.0	1.0	0.6	0.0
Aquatic Core	Plymouth	27,564.3	5,257.5	19.1	764.0	2.8	117.6	0.4
Aquatic Core	Suffolk	567.0	98.1	17.3	7.3	1.3	—	—
Forest Core	Barnstable	9,358.2	23.7	0.3	0.1	0.0	—	—
Forest Core	Dukes	1,395.7	6.3	0.5	—	—	—	—
Forest Core	Essex	11,085.6	1.9	0.0	—	—	1.1	0.0
Forest Core	Plymouth	20,647.7	3.7	0.0	—	—	111.7	0.5
Priority Natural Communities	Barnstable	10,944.0	3,436.9	31.4	5,116.2	46.7	90.8	0.8
Priority Natural Communities	Bristol	3,906.4	253.9	6.5	342.7	8.8	3.3	0.1
Priority Natural Communities	Dukes	2,481.9	371.8	15.0	1,812.4	73.0	18.1	0.7
Priority Natural Communities	Essex	18,759.2	16,881.6	90.0	877.7	4.7	6.4	0.0
Priority Natural Communities	Nantucket	4,630.3	521.0	11.3	175.9	3.8	8.5	0.2
Priority Natural Communities	Norfolk	921.8	—	—	1.2	0.1	—	—
Priority Natural Communities	Plymouth	23,473.0	1,011.3	4.3	962.4	4.1	1.8	0.0
Priority Natural Communities	Suffolk	31.3	24.1	77.1	2.5	8.0	—	—
Species of Conservation Concern	Barnstable	88,027.0	10,667.6	12.1	11,392.8	12.9	275.4	0.3
Species of Conservation Concern	Bristol	46,019.3	1,753.7	3.8	2,156.4	4.7	211.6	0.5
Species of Conservation Concern	Dukes	43,315.5	3,236.4	7.5	3,607.2	8.3	213.1	0.5
Species of Conservation Concern	Essex	61,417.7	14,696.8	23.9	1,241.0	2.0	48.6	0.1
Species of Conservation Concern	Nantucket	22,933.2	2,649.9	11.6	1,656.3	7.2	389.1	1.7

Name	County	Total Acreage	1 Percent Annual Chance Flood Event				0.2 Percent Annual Chance Flood Event	
			A Zone		V Zone		X500 Zone	
			Acres	% of Total	Acres	% of Total	Acres	% of Total
Species of Conservation Concern	Norfolk	22,990.7	122.0	0.5	87.8	0.4	0.1	0.0
Species of Conservation Concern	Plymouth	98,328.1	3,438.3	3.5	2,206.7	2.2	413.9	0.4
Species of Conservation Concern	Suffolk	2,334.1	239.7	10.3	160.5	6.9	0.0	0.0
Vernal Pool	Bristol	7,363.4	101.0	1.4	—	—	51.3	0.7
Vernal Pool	Dukes	300.6	25.1	8.4	—	—	5.5	1.8
Wetlands	Barnstable	2,595.9	1,897.0	73.1	249.6	9.6	33.1	1.3
Wetlands	Bristol	15,440.9	443.5	2.9	62.1	0.4	18.8	0.1
Wetlands	Dukes	307.2	180.6	58.8	24.1	7.8	2.3	0.7
Wetlands	Essex	8,429.7	917.5	10.9	26.0	0.3	6.5	0.1
Wetlands	Nantucket	972.3	398.4	41.0	0.2	0.0	29.4	3.0
Wetlands	Plymouth	23,776.4	2,401.6	10.1	73.5	0.3	77.1	0.3

Table 4-32: Natural Resources Exposure—BioMap2 Critical Natural Lands

Name	County	Total Acreage	1 Percent Annual Chance Flood Event				0.2 Percent Annual Chance Flood Event	
			A Zone		V Zone		X500 Zone	
			Acres	% of Total	Acres	% of Total	Acres	% of Total
Aquatic Buffer	Barnstable	15,910.8	2,405.7	15.1	843.2	5.3	120.3	0.8
Aquatic Buffer	Bristol	20,468.8	1,807.4	8.8	1,237.6	6.0	137.8	0.7
Aquatic Buffer	Dukes	4,308.7	719.7	16.7	1,791.7	41.6	8.5	0.2
Aquatic Buffer	Essex	32,046.2	15,240.6	47.6	410.5	1.3	45.7	0.1
Aquatic Buffer	Middlesex	16,657.9	315.7	1.9	—	—	—	—
Aquatic Buffer	Nantucket	1,578.7	407.9	25.8	15.0	0.9	49.4	3.1
Aquatic Buffer	Norfolk	10,263.4	245.1	2.4	103.5	1.0	1.9	0.0
Aquatic Buffer	Plymouth	41,381.2	6,240.5	15.1	1,012.7	2.4	265.3	0.6
Aquatic Buffer	Suffolk	626.3	123.8	19.8	8.5	1.4	—	—
Coastal Adaptation Analysis	Barnstable	20,054.7	12,178.3	60.7	6,985.2	34.8	218.4	1.1
Coastal Adaptation Analysis	Bristol	8,612.7	4,192.2	48.7	3,640.0	42.3	111.4	1.3
Coastal Adaptation Analysis	Dukes	6,649.1	3,531.6	53.1	2,345.5	35.3	94.2	1.4
Coastal Adaptation Analysis	Essex	22,326.2	20,405.5	91.4	332.5	1.5	82.5	0.4

Name	County	Total Acreage	1 Percent Annual Chance Flood Event				0.2 Percent Annual Chance Flood Event	
			A Zone		V Zone		X500 Zone	
			Acres	% of Total	Acres	% of Total	Acres	% of Total
Coastal Adaptation Analysis	Nantucket	4,365.8	1,692.3	38.8	403.9	9.3	275.7	6.3
Coastal Adaptation Analysis	Norfolk	787.1	493.2	62.7	179.0	22.7	0.5	0.1
Coastal Adaptation Analysis	Plymouth	12,732.9	8,666.3	68.1	3,326.7	26.1	93.5	0.7
Coastal Adaptation Analysis	Suffolk	738.3	671.4	90.9	60.4	8.2	0.2	0.0
Landscape Blocks	Barnstable	82,481.2	6,936.4	8.4	6,897.9	8.4	179.8	0.2
Landscape Blocks	Bristol	85,667.1	1,913.5	2.2	1,981.5	2.3	234.3	0.3
Landscape Blocks	Dukes	37,813.2	3,537.4	9.4	4,132.5	10.9	180.3	0.5
Landscape Blocks	Essex	41,937.3	16,307.9	38.9	848.2	2.0	13.0	0.0
Landscape Blocks	Nantucket	11,571.3	1,237.9	10.7	287.7	2.5	180.0	1.6
Landscape Blocks	Plymouth	124,678.0	1,460.7	1.2	674.1	0.5	441.5	0.4
Tern Foraging	Barnstable	17,852.0	7,203.4	40.4	10,395.3	58.2	4.9	0.0
Tern Foraging	Bristol	3,542.6	770.0	21.7	2,756.9	77.8	0.9	0.0
Tern Foraging	Dukes	6,197.1	1,210.4	19.5	4,913.9	79.3	6.0	0.1
Tern Foraging	Essex	15,025.3	14,438.1	96.1	515.1	3.4	0.8	0.0
Tern Foraging	Nantucket	2,703.2	1,170.7	43.3	1,203.3	44.5	14.5	0.5
Tern Foraging	Norfolk	12.3	7.1	57.7	5.2	42.0	—	—
Tern Foraging	Plymouth	5,482.2	2,381.3	43.4	3,076.9	56.1	1.3	0.0
Tern Foraging	Suffolk	28.2	—	—	24.2	85.9	—	—
Wetland Buffer	Barnstable	6,021.9	3,106.9	51.6	478.0	7.9	66.6	1.1
Wetland Buffer	Bristol	29,531.6	898.4	3.0	183.1	0.6	100.3	0.3
Wetland Buffer	Dukes	926.7	402.3	43.4	105.0	11.3	7.1	0.8
Wetland Buffer	Essex	17,056.9	1,343.7	7.9	139.4	0.8	12.6	0.1
Wetland Buffer	Nantucket	3,088.1	832.6	27.0	4.7	0.2	122.2	4.0
Wetland Buffer	Plymouth	45,543.6	3,683.3	8.1	100.9	0.2	261.3	0.6

Economy



Economic losses due to coastal flooding will include damage to buildings and infrastructure, agricultural losses, interruption of business activity with minor flooding of roads and parking areas, impacts on tourism, and tax base impacts. The extent of economic impacts from coastal flooding and sea level rise may be greater than inland flooding because of the concentration of populations, infrastructure, and economic activity in the Massachusetts coastal zone. The U.S. National

Assessment's coastal sector assessment (Boesch et al., 2000) estimated the total cost of 18 inches of sea level rise by 2100 at between \$20 billion and \$200 billion, and the economic cost of 36 inches of sea level rise at approximately double that value. Those costs could be incurred even as the result of one storm. Some research has found that under sea level rise conditions in the future, evacuation costs alone for a storm in the Northeast region of the U.S. could range between \$2 billion and \$6.5 billion (Ruth et al., 2007). These costs may now be underestimates, considering newly projected sea level rise rates.

In order to estimate the economic assets exposed to this hazard, the boundaries of the V-Zone were overlaid upon the Hazus default general building stock inventory. The estimated building replacement cost value within this zone is displayed by county in Table 4-33.

Sea level rise is expected to have gradual but severe impacts on coastal habitats. The impacts of sea level rise on wetlands and shorelines are extensively detailed in the Sea Level Affecting Marshes Model (SLAMM) available on NOAA Digital Coast. As sea level rises, habitats that are contingent on specific inundation frequencies may move further and further landward as inundation becomes more frequent, and eventually permanent, in seaward areas. These impacts are reduced in large wetland areas surrounded by undeveloped transitional and upland habitat. In areas where development or unsuitable upland conditions prevent upward habitat migrations, these estuarine systems will gradually disappear. Fisheries and oyster cultivators are dependent on these ecosystems, so their loss would likely have a significant commercial effect. In addition, a number of species would suffer if these ecosystems disappear, including the following:

- Saltmarsh sparrow
- Piping plover
- Diamondback terrapin
- Northeastern beach tiger beetle
- Oyster leaf
- Sea-beach knotweed
- Eelgrass
- Sea-beach amaranth
- Fish species, such as Atlantic sturgeon, winter flounder, bluefish and other species that rely on estuaries for nursery habitat

Table 4-33: General Building Stock Current Exposure by Coastal County (\$1,000s)

County	1 Percent Annual Chance Flood Event		0.2 Percent Annual Chance Flood Event
	In A Zone	In V Zone	In X500 Zone
Barnstable	\$7,580,776	\$1,180,063	\$2,443,839
Bristol	—	—	\$895,108
Dukes	\$558,511	\$157,356	\$104,125
Essex	\$5,860,923	\$959,763	\$186,002
Middlesex	\$190,953	—	—
Nantucket	\$470,724	\$93,483	\$55,506
Norfolk	\$2,618,544	\$30,3950	\$260,365
Plymouth	\$5,491,833	\$1,515,001	\$767,372
Suffolk	\$11,026,551	\$501,274	\$2,470,164
Total	\$33,798,815	\$4,710,890	\$7,182,481

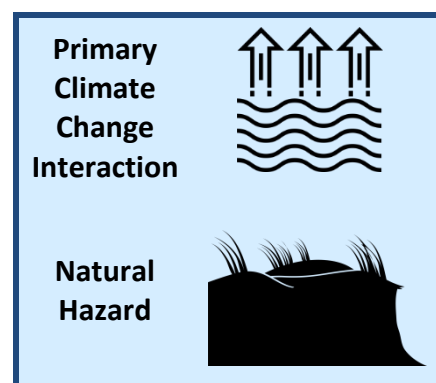
Sources: MassGIS 2017, FEMA Hazus loss estimation methodology

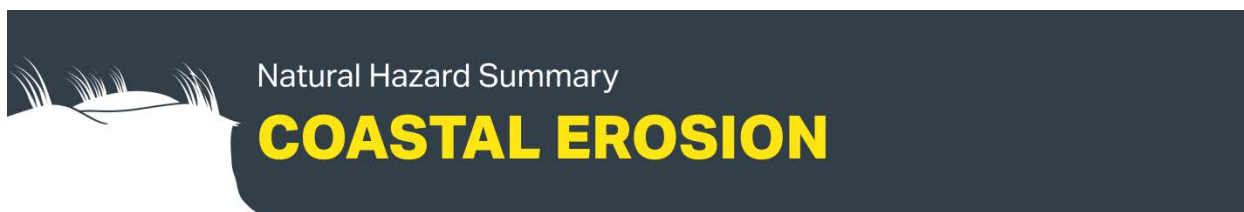
Although value estimates are beyond the scope of this plan, sea level rise will also cause the loss of beach ecosystems and the buffering services they provide. In addition to losing the intrinsic value of these ecosystems and exposing sea-level development to flooding impacts, beach loss will also expose any cliffs or uplands along the back beach to more frequent erosive wave energy. Homes and infrastructure located above these cliffs will be destabilized and possibly lost to bluff erosion or cliff collapse as a result.

4.2.2 Coastal Erosion

GENERAL BACKGROUND

Coastal shorelines change constantly in response to wind, waves, tides, sea level fluctuation, seasonal and climatic variations, human alteration, and other factors that influence the movement of sand and material within a shoreline system. Storms, including hurricanes and nor'easters (discussed in detail in Sections 4.4.1 and 4.4.2, respectively), decrease sediment supplies, and sea-level rise contributes to these coastal hazards.













Natural Hazard Summary

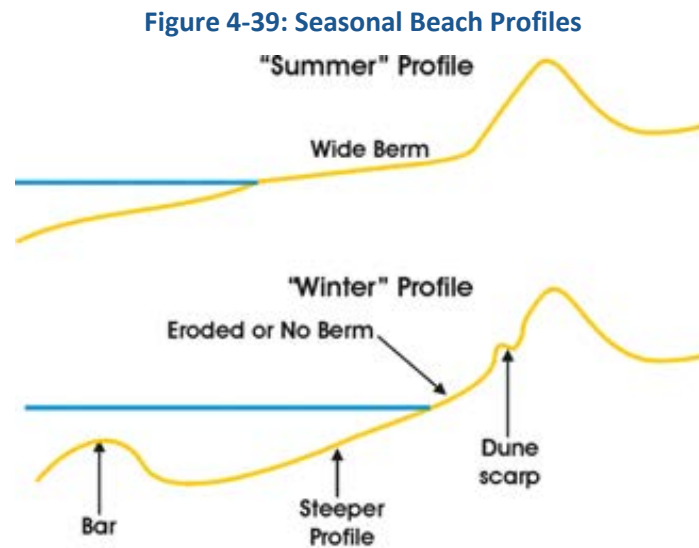
COASTAL EROSION

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
Coastal shorelines change constantly in response to wind, waves, tides, sea level fluctuation, seasonal and climatic variations, human alteration, and other factors that influence the movement of sand and material within a shoreline system.	A report by the Massachusetts Coastal Erosion Commission reported that the highest erosion rates occur in Eastham, Orleans, and Yarmouth.	Coastal erosion is measured as the rate of change of a shoreline over a specific period of time, measured in feet or meters per year. Although discrete events may exacerbate shoreline change, the frequency of erosion cannot be measured.

Potential Effects of Climate Change		
	SEA LEVEL RISE ➔ RISING WAVE ACTION	As the sea level rises, wave action moves higher onto the beach. The surf washes sand and dunes out to sea or makes the sand migrate parallel to the shoreline. As a rule-of-thumb, a sandy shoreline retreats landward about 100 feet for every 1-foot rise in sea level.
	SEA LEVEL RISE ➔ LOSS OF BUFFER SYSTEMS	Rising waves, tides, and currents erode beaches, dunes, and banks, resulting in landward retreat of these landforms and reducing the buffer they provide to existing development. More sediment is washed out to sea, rather than settling on the shore.

Exposure and Vulnerability by Key Sector 		
	POPULATIONS	General At-Risk Population: Populations who reside in the coastal high hazard area. Vulnerable Populations: Waterfront residents whose properties are not sufficiently protected from the threat of coastal erosion.
	GOVERNMENT	There are relatively few state-owned properties immediately adjacent to the coastline. Many coastal infrastructure elements such as roads however, are likely to be severely impacted by coastal erosion.
	BUILT ENVIRONMENT	All structures adjacent to the coast, especially those located in high-wave energy areas or those atop coastal bluffs, are exposed to the coastal erosion hazard. Coastal erosion exposes coastal elements such as roads and bridges to additional impacts from other hazards. Shoreline management techniques to protect structures and roads include adapting existing buildings and infrastructure via elevating roads or relocating buildings; enhancing natural systems through beach nourishment, bioengineering, cobble berm, etc.; installing nearshore coastal engineered structures; or in certain situations, armoring the shoreline.
	NATURAL RESOURCES AND ENVIRONMENT	Coastal erosion is a natural process, but under increasing rates of sea level rise, coastal erosion has numerous direct and indirect impacts on the local environment, including direct loss of habitat (including coastal wetlands and salt marsh) and mortality for animals that are not able to relocate. Remaining animals may suffer from crowding, increased competition, or increased predation. Shoreline accretion can also change the shoreline and habitat.
	ECONOMY	The beaches, parks, and natural resources along the Massachusetts coast contribute greatly to the local economy, especially during the summer season where the population in coastal areas can more than double. Beach loss, if not mitigated, will likely result in significant economic impacts to these communities.

Loss (erosion) and gain (accretion) of coastal land are visible results of the way these conditions reshape shorelines. Shorelines naturally change seasonally, accreting slowly during summer when sediments are deposited by relatively low energy waves and eroding dramatically during winter when sediments are moved offshore by high-energy storm waves, such as those generated by nor'easters. This process is depicted in Figure 4-39.



Source: Maine Geological Survey, 2005

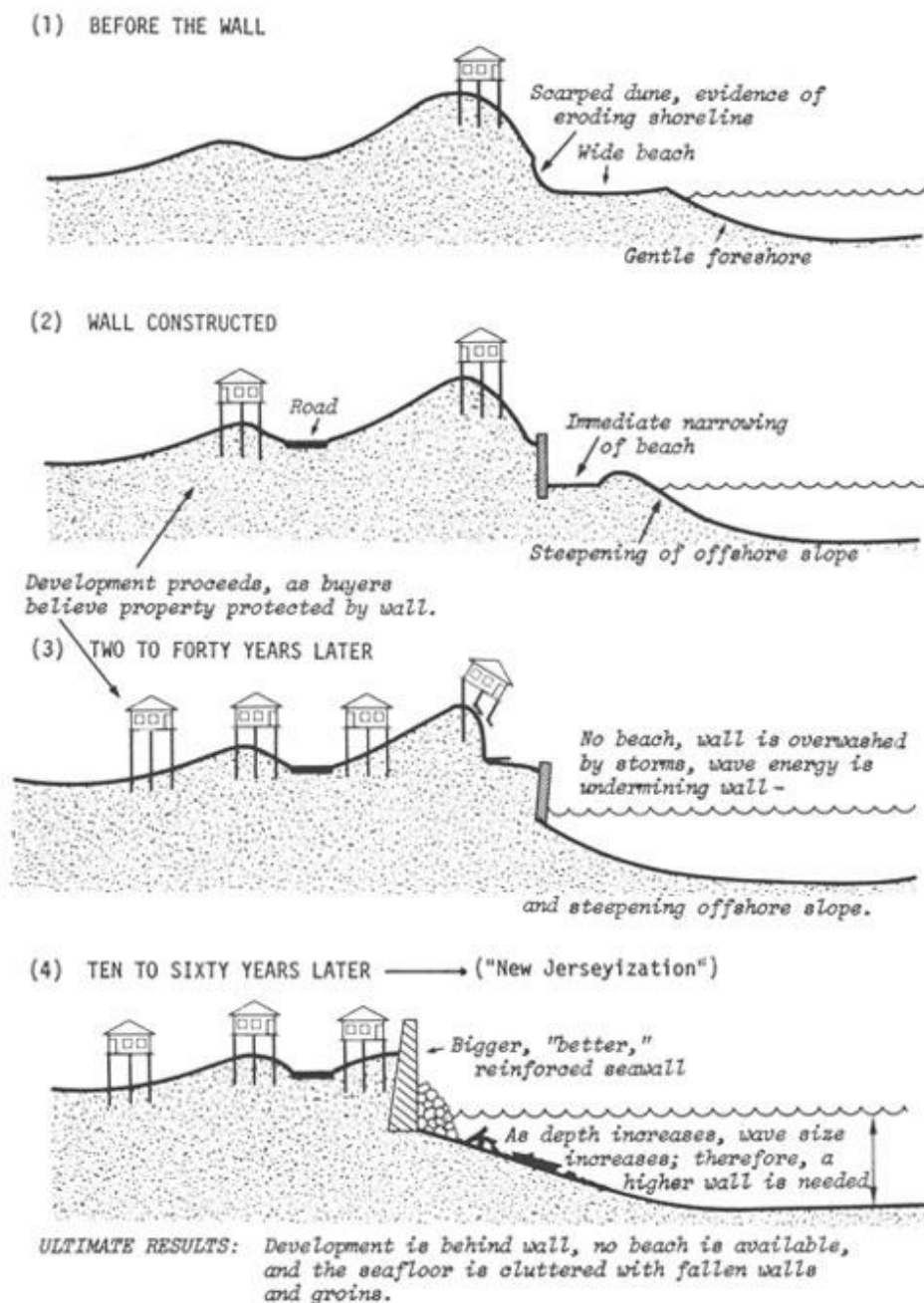
HAZARD PROFILE

Decreased Sediment Supply

Some of the methods used by property owners to stop or slow down coastal erosion or shoreline change can actually exacerbate the problem. Coastal landforms such as coastal banks are essential to maintaining a supply of sediment to beaches and dunes. Where engineered structures are used to stabilize shorelines, the natural process of sediment transport is interrupted, decreasing the amount of sediment available for beaches and dunes. Under conditions of reduced sediment, the ability of coastal resource areas such as dunes and beaches to provide storm damage prevention and flood control benefits is continually reduced.

In addition to preventing the addition of sediment to the beach system, attempting to halt the natural process of erosion with seawalls and other hard structures can actually worsen erosion in a number of ways. Seawalls can increase the rate of erosion on the seaward side of the wall, as shown in Figure 4-40, and shore-perpendicular structures like groins and jetties can interrupt the longshore flow of sediment, causing downstream erosion.

Figure 4-40: Long-Term Impacts of Shoreline Armoring



Source: CoastalCare.org, n.d.

As in many other highly developed coastlines, a large proportion of the Massachusetts coast is armored. The Massachusetts Coastal Erosion Commission 2015 report found that 27 percent of the exposed coastal shoreline is armored by some form of coastal protection. Broken down by regions, the percentage of coastline protected by coastal engineered structures can be summarized as follows: Boston Harbor—58 percent, North Shore—46 percent, South Shore—44

percent, South Coastal—36 percent, and Cape Cod and Islands—13 percent. As shown in Figure 4-40, shoreline armoring can protect adjacent structures effectively, but can also have long-term negative impacts. In 2013, the Massachusetts Legislature established a Coastal Erosion Commission (CEC) to investigate and document the levels and impacts of coastal erosion in the Commonwealth and to develop strategies and recommendations to reduce or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, beaches, and dunes. The Erosion Impacts Working Group of the CEC had several goals, including evaluating past erosion, estimating future impacts, and examining practices that could reduce the impacts of this hazard.

The CEC report found that, “of the assessed shoreline, 71 percent is comprised of coastal beach resource areas, while mapped coastal dunes, banks and salt marshes account for 35 percent, 22 percent, and 23 percent respectively” (2015). Because the ability of a coastal system to adapt to coastal erosion and sea level rise varies based on a number of local characteristics, these data allow for more precise modeling of projected future impacts. This report also revealed the concentration of residential development in the coastal zone, finding that “Residential development accounts for 40 percent of the shoreline, with natural upland areas, maintained open space, and non-residential developed accounting for 32 percent, 23 percent, and 7 percent respectively” (CEC, 2015).

Location

The CEC report analyzed data from the Massachusetts Shoreline Change Project. Launched in 1989, this project mapped the local high waterline and shoreline change rates over the long-term (150-year) and short-term (30-year) periods. The project provides data on the net distance of shoreline movement and shoreline change rates for more than 26,000 transects. The CEC report combined this data with information from other, more recent sources and identified “hot spots”, where the combination of erosion, storm surge, flooding, and waves have caused significant damage to buildings and/or infrastructure over the past 5 years. These locations are identified in Table 4-34.

Table 4-34: Coastal Erosion Hot Spots, from North to South

Location	Beach Name
Salisbury	Salisbury Beach
Newburyport	Plum Island
Newbury	Plum Island
Hull	Nantasket Beach
Hull	Crescent Beach
Scituate	Glades
Scituate	Oceanside Drive
Scituate	Lighthouse Point
Scituate	Humarock Beach (northern half)
Marshfield	Fieldstone to Brant Rock
Marshfield	Bay Ave.
Plymouth	Saquist
Plymouth	Long Beach (southern end)
Plymouth	White Horse Beach
Plymouth	Nameloc Heights
Sandwich	Town Neck Beach
Dennis	Chapin Beach
Nantucket	Siasconset
Edgartown	Wasque Point
Oak Bluffs	Inkwell Beach
Gosnold	Barges Beach
Westport	East Beach

Source: Massachusetts Coastal Erosion Commission, 2015

The detailed data of the Massachusetts Shoreline Change Project are available through the Massachusetts Ocean Resource Information System (MORIS). Parties interested in the vulnerability of specific locations to coastal erosion are encouraged to explore this resource at <http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change/>. Because of the detailed nature of coastal erosion data, the risk assessment focuses on generalized state-level trends.

Previous Occurrences

Coastal erosion rates, as previously described, vary significantly along the coast. Average short-term (~30-year) erosion rates for the most vulnerable communities range from 8.70 feet per year in Yarmouth along the Cape Cod Bay shoreline to 0.99 feet per year in West Tisbury. Historic

trends in coastal erosion are described in further detail in the following section. Both human activity and natural processes impact erosion and accretion rates. It is important to consider that there can be significant short-term variability and instability of the shoreline that is masked by local fluctuation between eroding and accreting shorelines over time.

Frequency of Occurrences

Coastal erosion is measured as the rate of change in the position or horizontal displacement of a shoreline over a specific period of time, measured in units of feet or meters per year. Erosion rates vary as a function of shoreline type and are influenced primarily by episodic events. Among other physical factors such as sea level rise, the location of the shoreline, its geomorphology, its proximity to development, and the natural and man-made alterations to it, and both long- and short-term rates of change can play important roles in the analysis of the future shoreline configuration. The long-term patterns of coastal erosion are difficult to detect because of substantial and rapid changes in coastlines in the short term (that is, over days or weeks from storms and natural tidal processes). For example, prior to the construction of groins and jetties in the 1930s and 1940s, long-term changes were frequently relied upon to predict future conditions. On the other hand, as sea level continues to rise and the intensity of storms increases, short-term erosion events can become greater indicators of future shoreline conditions than data averaged over the past century and a half. Analysis of both long- and short-term shoreline changes, therefore, is required to determine which is more reflective of the potential future shoreline configuration.

The most frequently used measure of coastal erosion is the average annual erosion rate. Erosion rates can be used in land use and hazard management to define areas in which development should be limited or where special

Climatic trends can change a beach from naturally accreting to eroding due to an increase in the frequency or severity of storms and high tides, or from the long-term effects of fluctuations in sea level. Sea level rise will increase coastal erosion in several ways. First, as the sea level rises, wave action moves higher onto the beach. The surf washes sand and dunes out to sea or makes the sand migrate parallel to the shoreline. The loss of the beach equals a loss in a buffer zone between the land and the sea, and this can lead to erosion of inland areas. As a rule-of-thumb, a sandy shoreline retreats about 100 feet for every 1-foot rise in sea level. These impacts, however, can vary widely based on local variables, including the slope of the shoreline, the composition of the beach, and the presence and height of beach dunes at a given location.

The loss of coastal wetlands also contributes to coastal erosion. Some Intergovernmental Panel on Climate Change models suggest that 33 percent of the global coastal wetlands will be under water by the year 2080. Areas that have small tidal ranges, especially sandy beaches with small tidal ranges, will see the greatest effect. Rising waves, tides, and currents erode beaches, dunes, and banks, resulting in landward retreat of these landforms and reducing the buffer they provide to existing development. More sediment is washed out to sea, rather than settling on the shore. The Massachusetts Wetlands Protection Act and associated regulations protect the ability of sand dunes and wetlands to migrate naturally, without human inference. The goal of this approach is to allow nature to take its course, which will result in less coastal loss over time.

construction measures should be used. The average annual erosion rate is based on analysis of historical shorelines derived from maps, charts, surveys, and aerial photography obtained over a period of record.

Severity/Extent

Coastal erosion is measured as the rate of change in the position or horizontal displacement of a shoreline over a period of time. A number of factors determine whether a community exhibits greater long-term erosion or accretion, including the following:

- Exposure to high-energy storm waves
- Sediment size and composition of eroding coastal landforms feeding adjacent beaches
- Near-shore bathymetric variations, which direct wave approach
- Alongshore variations in wave energy and sediment transport rates
- Relative sea level rise
- Frequency and severity of storm events
- Human interference with the sediment supply (e.g., revetments, seawalls, and jetties)

Additional impacts from this hazard that may occur as a result of climate change (and municipal responses to climate change) include:

- Increased armoring of shorelines, resulting in decreases in the sediment supply to beaches and the prevented migration of coastal landforms
- A decrease in sediment, which contributes to flattening of the adjacent profile and increases wave effects
- More intense, longer-duration coastal storms
- Increases in erosion rates

Natural recovery after erosive episodes can take months or years. If a dune or beach does not recover quickly enough via natural processes, coastal and upland property may be exposed to further damage in subsequent events. Coastal erosion can cause the destruction of buildings and infrastructure.

The 2015 CEC report found that the total costs from NFIP claims for all coastal events since 1978 was nearly \$370 million. Although the specific economic impact of coastal erosion cannot be separated from that of other coastal hazards, erosion can both cause direct economic damage and exacerbate other hazards. The severity of coastal erosion is expected to worsen and costs are expected to rise as a result of climate change and sea level rise.

Warning Time

Meteorologists can often predict the likelihood of weather events that can impact shoreline communities and ultimately, the shoreline. NOAA's NWS monitors potential events and provides forecasts and information in advance of a storm through multiple means, which vary in system characteristics and time issued. The NWS provides early notification through its Hazardous Weather Outlook, which is a narrative statement produced and issued on a routine basis to provide information regarding the potential of significant weather expected during the next 1 to 5 days (NWS, 2018). Additionally, for nor'easters, the NWS issues Coastal Flood Advisories when minor flooding is possible; Coastal Flood Watches when flooding with significant impacts is possible; or Coastal Flood Warnings when flooding that will pose a serious threat to life and property is occurring, imminent, or highly likely (NWS, 2018). For tropical, subtropical, or post-tropical systems, the NWS will issue a Hurricane or Tropical Storm Warning 36 hours in advance of the anticipated onset of tropical-storm-force winds or a Hurricane or Tropical Storm Watch 48 hours in advance of the anticipated onset of tropical-storm-force winds (NWS, 2018).

SECONDARY HAZARDS

Windstorm events can blow beach and dune sand overland into adjacent low-lying marshes, upland habitats, inland bays, and communities. Flooding from extreme rainfall events can scour and erode dunes as inland floodwaters return through the dunes and beach face into the ocean. Additionally, by removing the buffering effects of coastal ecosystems, such as beaches, dunes, and salt marshes, coastal erosion leaves adjacent properties, infrastructure, and ecosystems increasingly vulnerable to natural hazards, including coastal flooding and storm surge.

EXPOSURE AND VULNERABILITY

Coastal erosion is a significant concern to the Commonwealth because of the large number of communities and cultural resources located along the coast. Healthy beaches, dunes, and banks serve as a buffer and protect the built environment and other natural resources on the mainland from coastal storm events such as hurricanes, tropical storms, and nor'easters, which can cause shoreline erosion or accretion.

As previously described, coastal erosion in Massachusetts is currently the subject of a great deal of research. The Coastal Erosion Commission has identified coastal erosion hot spots and is currently working on developing projected erosion rates for areas all along the Massachusetts coastline. Although a comprehensive geospatial representation of areas at risk for coastal erosion is not yet available, average shoreline change rates for a number of coastal communities have been identified. The communities with the highest rates of erosion are shown in Table 4-34. However, given the lack of geospatial data, a quantified analysis of the population and structures

considered to be exposed to this hazard was not conducted. Instead, the exposure and vulnerability of each of these categories are discussed qualitatively in the subsections that follow.

Populations



The coastal high hazard area (described further in Section 4.2.1) is the most hazardous part of the coastal floodplain due to its exposure to wave effects. Storm surge inundation can exceed regulatory floodplain boundaries (V Zones and A Zones), which also can contribute to coastal erosion. Individuals whose homes are located in this area are considered exposed to this hazard. However, the risk a property faces from this hazard varies dramatically based on a number of factors, including the type of coastline in front of the property and whether the property is located atop a cliff, the proximity of the building or infrastructure to the shoreline, as well as any reinforcements the property itself may have.

Vulnerable Populations

Coastal erosion is considered an imminent significant threat to public health, safety, and welfare. Coastal erosion not only occurs as a result of the impacts of high-intensity single storm events but also when changes are gradual over many years. Waterfront property owners whose properties are not sufficiently protected from the threat of coastal erosion are considered particularly vulnerable to this hazard.

Health Impacts

Coastal erosion is both a chronic and an episodic hazard. An eroded coastline has less capacity to act as a buffer against the storm surge associated with hurricanes, nor'easters, or other coastal storms. As coastlines erode, septic systems and sanitary sewer systems may be damaged, resulting in the discharge of wastewater to the surrounding environment. Underground tanks containing a variety of contaminants can also be compromised. Damage to both types of structures can contaminate surface and subsurface drinking water supplies (including public and private wells), resulting in potential adverse health impacts. Coastal erosion combined with sea level rise may also cause the intrusion of seawater into supplies of fresh water that serve both private wells and municipal water systems. Finally, where coastal erosion progresses to the point that coastal residents are forced to relocate or lose their homes, the stress of this process could cause or exacerbate mental health issues, including anxiety and depression.

Government



A spatial exposure analysis was not conducted for this hazard. According to the DCAMM property inventory, there are relatively few state-owned properties immediately adjacent to the coastline. There are 38 structures located within 50 feet of the coast, only one of which—the Massachusetts Maritime Academy—would be defined as “critical.” Therefore, structures owned by the Commonwealth of Massachusetts are not severely

exposed to this hazard directly. Instead, impacts to government could come from increased vulnerability to other coastal hazards and impacts to nonstructural government parcels such as beaches and other waterfront natural systems, including species that the government is responsible for protecting. Additionally, the state government could suffer economically as a result of coastal erosion—either because of the substantial cost of defensive measures against this hazard or because of reduced tourism revenues if beaches are diminished.

The Built Environment



Most structures within the coastal zone are exposed to the coastal erosion hazard. The Commonwealth of Massachusetts has two coastal structures inventories (public and privately owned Coastal Shoreline Engineered Structures) that together provide a comprehensive assessment of shoreline armoring coast-wide. These reports indicate that 27 percent of the exposed coastal shoreline is armored with some form of public or private coastal protection, as summarized in Table 4-35. The detailed reports from both of the coastal structures inventories are available at www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/seawall-inventory/. Geodatabases containing the coastal structures data are available in the online MORIS, which can be accessed at the Office of Coastal Zone Management's (CZM) website. In addition, CZM and DEP have mapped other public and private structures (e.g., piers and stairs) along the coastline, and these data are available for shoreline characterization and erosion impact analyses.

Table 4-35: Summary of the Miles of Coastline Protected by Shore-Parallel Coastal Engineered Structures by Coastal Region and State Total

Region	Shoreline Length (miles)	Private Structure Length (miles)	Public Structure Length (miles)	Percent Shoreline with Structure
North Shore	160	50	24	46.3
Boston Harbor	57	12	21	57.9
South Shore	129	28	29	44.2
Cape Cod and Islands	615	66	11	12.5
South Coastal	154	49	7	36.4
Total	1,115	205	92	26.6

Source: Massachusetts Coastal Erosion Commission Report, 2015

Agriculture

Rising sea levels and extreme storms may accelerate erosion of coastal agricultural land (resilient MA, 2018).

Public Safety

As discussed in the coastal erosion hazard profile, eroded coastlines have a lower capacity to buffer against the storm surge associated with hurricanes, nor'easters or other coastal storms, resulting in the greater vulnerability of populations living on the coast. Damaged roadways also limit the ability of fire, police, and emergency medical technicians to respond to emergencies.

Transportation

As described earlier in this section, continuous coastal erosion exposes coastal elements such as roads and bridges to additional impacts from other coastal hazards. This hazard could also impact these infrastructure elements directly if the underlying sediment beneath the road or the bridge supports becomes unstable or disappears entirely.

Water Infrastructure

Coastal erosion can damage septic systems, drinking water, and wastewater pipes.

Natural Resources and Environment



Coastal erosion has numerous direct and indirect impacts on the local environment. When storms or sea level rise erodes the coast, it inundates valuable coastal habitat as well as any benthic organisms in the soil or other animals that could not escape the eroding portion of the beach. Remaining beach-dwelling organisms may suffer from crowding, increased competition, or increased predation, and the size of their habitat shrinks. Direct impacts from the loss of wetland habitats include the loss of nursery habitat for ecologically and economically important fish species as well as the loss of ecosystem services, such as water filtration and buffering against sea level rise and storm surge. As the high carbon content of salt marsh peat erodes and disintegrates, salt marshes lose their carbon storage capacity and can become a source of GHG emissions (Theuerkauf et al., 2015). Additionally, as coastal erosion progresses further and further inward, the nature of shoreline habitats may change as their inundation frequency increases. Areas that were previously vegetated upland could be converted to estuarine habitat if sea level rise and coastal erosion reduce the area's elevation and increase its inundation frequency. An estuarine habitat requires a source of freshwater input. Estuaries are the highly productive and nutrient-rich mixing zones where freshwater and seawater meet. This scenario would more likely result in open water marine habitat over time. Without the buffer of a robust coastline, coastal environments and adjacent areas also become more susceptible to the impacts of storm events, as described elsewhere in this section.

Preliminary models based on SLAMM (Sea Level Affecting Marshes Model) of the North and South Rivers in Marshfield and Norwell, for example, display significant loss of irregularly flooded marsh and an increase in regularly flooded marsh adjacent to the river under intermediate high sea level rise scenarios by 2070 (Carullo, 2016).

Coastal environments and adjacent areas also become more susceptible to the impacts of storm events without the buffer of a robust coastline, as described elsewhere in this section.

Economy



Because of the concentration of economic activity in the coastal zone, coastal erosion exposes a great deal of public and private property to potential damage. Direct impacts of coastal erosion are likely to include the following:

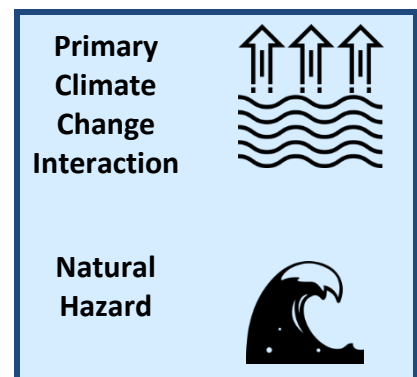
- Loss of and/or damage to homes
- Loss of upland property
- Loss of the contribution of high-value property to the local tax base
- Loss of roads and emergency access routes
- Loss of and damage to cultural and historic structures
- Structural damage from one property damaging adjacent properties
- Contamination of water supplies by salt water and toxic discharges from brownfield erosion and industrial sites

In addition, the beaches, parks, and natural resources along the Massachusetts coast greatly contribute to the local economy, especially during the summer season when the population in these areas can more than double. Many natural coastal resources serve the dual purposes of protecting the shoreline and bringing enormous ecological and economic value. The Massachusetts coastline and state ocean waters support 152,000 jobs and generate \$4.3 billion in income each year, in addition to providing recreational opportunities (Durrant, 2008). As a result, beach loss (if not mitigated by beach nourishment efforts) will likely result in significant economic impacts to local communities. The loss of salt marshes and other coastal estuarine systems as a result of coastal erosion will also result in significant economic damage, both directly and indirectly, as previously discussed. Indirect economic impacts will be realized when this reduced buffer capacity causes an increase in coastal flooding or wind-related damage to public and private property.

4.2.3 Tsunami

GENERAL BACKGROUND

A tsunami is a devastating onshore surge of water or a string of waves created by the displacement of a large volume of water. This displacement can be caused by a number of triggers, including earthquakes, volcanic eruptions, landslides, glacier calving, and meteorite impacts. Tsunamis can move hundreds of miles per hour (mph) in the open ocean and can come ashore with waves as high as 100 feet or





Natural Hazard Summary

TSUNAMI

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
A tsunami is caused by the displacement of water. This can be caused by a number of triggers, including earthquakes, volcanic eruptions, landslides, glacier calving and meteorite impacts.	All of the coastal areas of Massachusetts are exposed to the threat of tsunamis; however, that probability is relatively low compared to the Pacific Coast of the U.S.	The historical frequency of tsunami or run-up events on the East Coast of the U.S. is approximately 1 event every 39 years. A significant tsunami has never struck the Massachusetts coast.

Potential Effects of Climate Change

	SEA LEVEL RISE AND RISING TEMPERATURES → ISOSTATIC REBOUND	As ice melts across the world, the earth's crust is expected to rise under the reduced weight. This will cause earthquakes and submarine landslides, potentially triggering tsunamis.
	RISING TEMPERATURES → GLACIAL EARTHQUAKES	As glaciers collapse in a warming climate, the impact may trigger massive landslides. Research suggests that these events would generate far more powerful tsunamis than underwater earthquakes.

Exposure and Vulnerability by Key Sector

	POPULATIONS	General At-Risk Population: Populations who live within a 1-mile buffer of the coast in the tsunami exposure zone. Vulnerable Populations: Populations who would have difficulty receiving tsunami warnings or evacuating, including populations over 65, the disabled, families with young children, car-free households, and communication-impaired individuals.
	GOVERNMENT	Because of the ambiguity surrounding potential tsunami impacts, a 1-mile buffer from the coast was used to simulate potential exposure. 694 state-owned buildings are located in this area, with the highest number in Suffolk County (173), followed by Essex (140) and Barnstable (139) Counties.
	BUILT ENVIRONMENT	Roads are the primary resource for evacuation before and during a tsunami event. Bridges, utilities, and power generation facilities would also be exposed. Widespread impacts could occur if salt water were to inundate drinking water supplies or overburden stormwater and wastewater systems. Fifty-three critical facilities in the tsunami hazard area were identified, with 12 in Suffolk County and 11 in Essex County.
	NATURAL RESOURCES AND ENVIRONMENT	The inundation of typically dry areas from a tsunami can reshape the topography both by scouring existing sediment and by depositing sediment from other locations. In addition to these physical impacts, tsunamis can also uproot trees and other plants in its path, causing habitat loss in addition to direct mortality to animals in the area.
	ECONOMY	A tsunami's negative impact on the economy is difficult to quantify. Losses would likely include general building stock damage, business interruption/closures, port closures, utility and transportation damage, and impacts on tourism and tax base to the Commonwealth.

more. The height of a tsunami wave that comes ashore is related to the strength of the event that generated the tsunami and to the configuration of the ocean bottom along the tsunami's path.

According to the NOAA, tsunamis are most commonly generated by earthquakes in marine and coastal regions. Major tsunamis are produced by large, shallow earthquakes associated with the movement of oceanic and continental plates. Tsunamis occur more often along the Pacific Coast; however, a tsunami could potentially impact other U.S. coastlines as well.

HAZARD PROFILE

Location

All of the coastal areas of Massachusetts are exposed to the threat of tsunamis; however, that probability is relatively low compared to the Pacific Coast of the U.S. According to *U.S. States and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves* (Dunbar and Weaver, 2015), the Atlantic Coast and the Gulf Coast states have experienced very few tsunamis in the last 200 years. The states of Louisiana, Mississippi, Alabama, Florida (the Florida Gulf Coast), Georgia, Virginia, North Carolina, Pennsylvania, and Delaware have no known historical tsunami records. Only six tsunamis have been recorded in the Gulf and East Coast states. Three of these tsunamis were generated in the Caribbean—two were related to a magnitude 7+ earthquake along the Atlantic Coast and one that was reported in the Mid-Atlantic states may have been related to an underwater explosion or landslide.

Tsunamis could potentially travel to New England from the Caribbean, the Mid-Atlantic Ridge, the Canary Islands, or the continental shelf located offshore of North Carolina and Virginia (least likely). Each of these areas is described in more detail below.

Mid-Atlantic Ridge

The closest tectonic boundary to the U.S. East Coast is the spreading (divergent) Mid-Atlantic Ridge, which is relatively tectonically active. However, according to the Maine Geological Survey, tsunamis are more likely to occur at convergent margins.

Caribbean Islands

The Caribbean is home to some of the most geologically active areas outside of the Pacific Ocean. There is a subduction zone, called the Puerto Rico trench, located just north of Puerto Rico. In this area, the American plate is being subducted beneath the Caribbean Plate, which has produced numerous earthquakes, submarine landslides, and volcanic eruptions, with resulting tsunami activity.

Canary Islands

The Canary Islands are a chain of volcanic islands located in the eastern Atlantic Ocean, just west of the Moroccan coastline. La Palma is the westernmost and the youngest of the Canary

Islands, and with three large volcanoes it is also the most volcanically active. Cumbre Vieja, located on La Palma, has erupted twice in the last century—once in 1949 and once in 1971. Some researchers point to this volcano as a potential driver of tsunamis in the Atlantic Ocean. It could also cause tsunamis in other ways. Based on a study of past landslide deposits and the existing geology of the volcano, the west flank of the Cumbre Vieja appears vulnerable to failure during a future eruption, which could result in a landslide into the depths of the Atlantic Ocean of a mass 9 to 12 miles wide and 9 to 16 miles long. Although this failure is likely, scientists believe there are several reasons it would not lead to a megatsunami. The International Tsunami Information Center has released the following information on the probability of this event:

- While the active volcano of Cumbre Vieja on Las Palma is expected to erupt again, it will not send a large part of the island into the ocean, though small landslides could occur.
- No megatsunamis have occurred in the Atlantic or Pacific Oceans in recorded history.
- The colossal collapses of Krakatau and Santorin generated catastrophic waves in the immediate area, but hazardous waves did not propagate to distant shores. Numerical and experimental models of such events and of the Las Palma event verify that the relatively short waves from these small occurrences do not travel as tsunami waves from a major earthquake (ITIC, n.d.).

[North Carolina / Virginia Continental Shelf](#)

Evidence has been found of a large submarine landslide called the Albemarle-Currituck Slide, which occurred 18,000 years ago off the coasts of Virginia and North Carolina. In this event, more than 33 cubic miles of material slid seaward from the edge of the continental shelf, most likely causing a tsunami. It is possible that a similar event could occur in the future.

Previous Occurrences

Very few significant tsunami events have occurred in Massachusetts history. The events in the historical record are described in Appendix B.

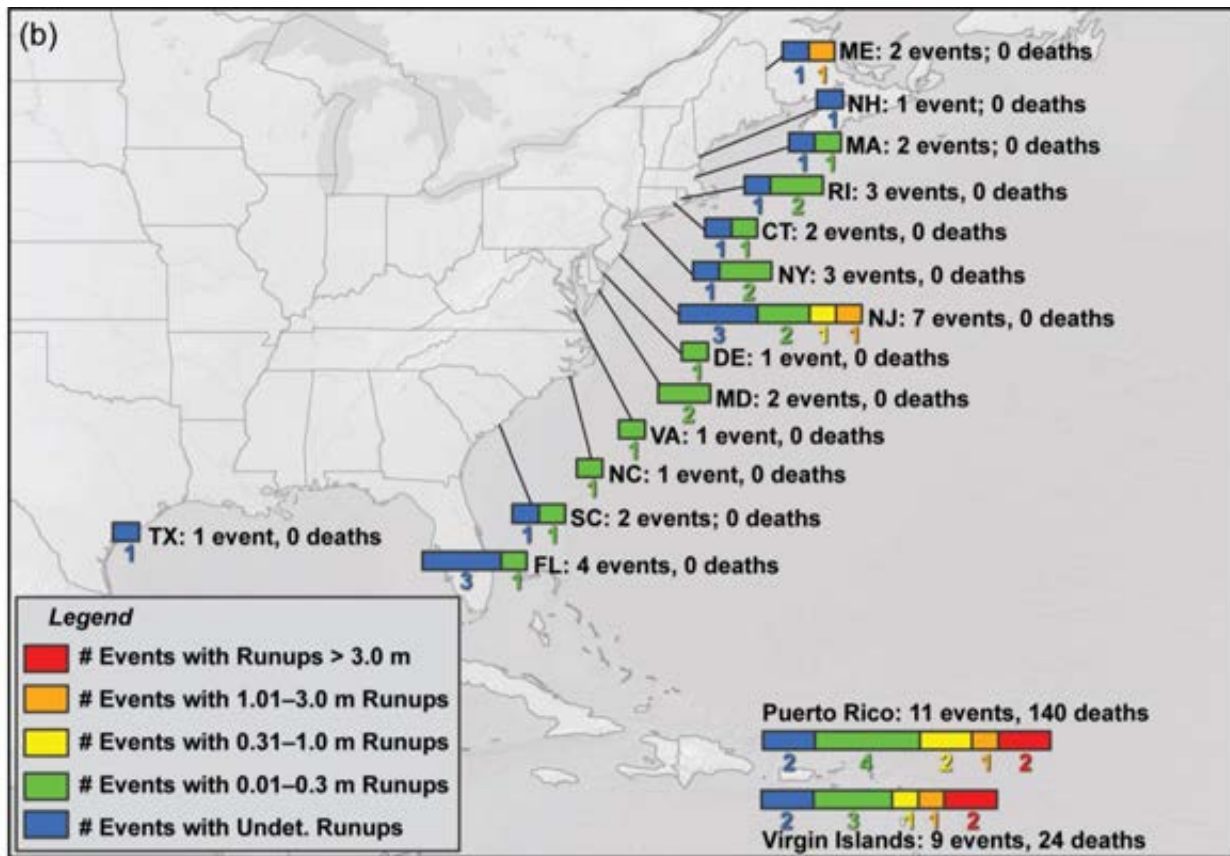
Table 4-36 summarizes the findings of NOAA and USGS research on historic tsunami events and losses in the Atlantic region (Dunbar and Weaver, 2015). Figure 4-41 shows the number of tsunami events and the total number of events causing run-up heights from 0.3 foot to greater than 9.8 feet for the U.S. and its territories in the Atlantic, Gulf Coast, Puerto Rico, and the Virgin Islands.

Table 4-36: Summary of Tsunami Events and Losses in the Atlantic Region

Location (and year of first confirmed report)	Total number of tsunami events with any observed runup						Total number of runups for all tsunami events	Reported deaths	Million dollars damage reported
	Events with undetermined runup heights	Events with runups 0.01 to 0.5 m	Events with runups 0.51 to 1.0 m	Events with runups 1.01 to 3.0 m	Events with runups >3.0 m				
U.S. Atlantic Coast									
Maine (1929)	1	1					3		
New Hampshire (1929)	1	1					1		
Massachusetts (1929)	1	1					2		
Rhode Island (1929)	2	1	1				3		
Connecticut (1964)	1	1					1		
New York (1895)	2	1	1				7		
New Jersey (1918)	6	3	2	1			8		
Pennsylvania									
Delaware									
Maryland (1929)	1		1				1		
Virginia									
North Carolina									
South Carolina (1886)	2	1	1				2		
Georgia									
Florida (1886)	4	3	1				5		
Atlantic Coast Totals	21	13	7	1	0	0	33	0	\$0

Source: Dunbar and Weaver, 2015

Figure 4-41: Total Number of Tsunami Events for the U.S. and Its Territories



Source: Dunbar and Weaver, 2015

Frequency of Occurrences

The frequency of tsunamis is related to the frequency of the events that cause them, so it is similar to the frequency of seismic or volcanic activities or landslides. In the U.S. coastal areas, while the frequency of damaging tsunamis is low compared to many other natural hazards, the impacts can be extremely high.

The NOAA's National Geophysical Data Center (NGDC) compiled a list of all tsunamis and tsunami-like waves of the eastern U.S. and Canada. Fifty-two potential tsunami events have been identified as possibly impacting the East Coast of the U.S. between 1668 and 2017. Of these events, nine were categorized as definite or probable tsunamis (NGDC, 2017). As a result, the historical frequency of tsunamis on the East Coast is approximately one event every 39 years. However, no tsunamis have hit the Massachusetts coastline since 1950. The probability of future tsunami events is low based on historical data and the low frequency of activities that cause them (i.e., seismic, volcanic, or landslide events).

Severity/Extent

Tsunamis are typically measured by their height at the shore and the maximum run-up of the tsunami waves on the land (NOAA, 1998).

A 1-mile buffer from the coastline was developed during the preparation of the 2013 SHMP in order to define the geographic extent of the tsunami hazard until modeling and inundation mapping were completed. This buffer was also used for the purpose of this update. Portions of Barnstable, Bristol, Dukes, Essex, Middlesex, Nantucket, Norfolk, Plymouth, and Suffolk Counties fall within this buffer.

The effect that climate change and sea level rise will have on the frequency of tsunami events is unclear; however, initial research efforts suggest that warming global temperatures may result in an increase in tsunamis. The primary driver for this increase, according to a 2009 paper from University College London, will be the loss of ice cover, causing the earth's crust to rise as less mass presses it down. As the crust rises, earthquakes and submarine landslides will occur, causing tsunamis (McGuire, 2010). The paper found that this impact will likely be most noticeable in high-latitude areas with significant ice cover. An additional hazard known as "glacial earthquakes," in which collapsing glaciers trigger massive landslides, may also occur. Research suggests that these events would generate far more powerful tsunamis than underwater earthquakes and would likely pose a threat to high-latitude regions such as Chile, New Zealand, and Newfoundland.

Warning Time

The National Tsunami Hazard Mitigation Program was formed in 1995 by Congressional action, which directed the NOAA to form and lead a federal/state working group. The program is a partnership between the NOAA, the USGS, FEMA, the National Science Foundation, and the 28 U.S. coastal states, territories, and commonwealths.

One of the actions outlined by the plan was the development of a tsunami monitoring system to monitor the ocean's activity and make citizens aware of a possible tsunami approaching land. In response, the NOAA developed Deep-ocean Assessment and Reporting of Tsunami (DART) monitoring buoys. To ensure early detection of tsunamis and to acquire data critical to real-time forecasts, the NOAA has placed DART stations at sites in regions with a history of generating destructive tsunamis. The NOAA completed the original 6-buoy operational array in 2001 and expanded to a full network of 39 stations in March 2008. The information collected by a network of DART buoys positioned at strategic locations throughout the ocean plays a critical role in tsunami forecasting.

When a tsunami event occurs, the first information available about the source of the tsunami is the seismic information for the earthquake. As the tsunami wave propagates across the ocean and successively reaches the DART systems, the systems report sea level measurements to the Tsunami Warning Centers, where the information is processed to produce a new and more

refined estimate of the tsunami. The result is an increasingly accurate forecast of the tsunami that can be used to issue watches, warnings, or evacuations.

SECONDARY HAZARDS

Aside from the tremendous hydraulic force of the tsunami waves themselves, floating debris carried by a tsunami can endanger human lives and batter inland structures. Ships moored at piers and in harbors often are swamped and sunk or are left battered and stranded high on the shore. Breakwaters and piers collapse, sometimes because of scouring actions that sweep away their foundation material and sometimes because of the sheer impact of the waves. Railroad yards and oil tanks situated near the waterfront are particularly vulnerable. Oil fires frequently result and are spread by the waves.

Port facilities, naval facilities, fishing fleets, and public utilities are often the backbone of the economy of the affected areas, and these resources generally receive the most severe damage. Until debris can be cleared, wharves and piers rebuilt, utilities restored, and fishing fleets reconstituted, communities may find themselves without fuel, food, and employment. Wherever water transport is a vital means of supply, disruption of coastal systems caused by tsunamis can have far-reaching social effects.

EXPOSURE AND VULNERABILITY

The University of Delaware has prepared draft inundation mapping for portions of the Massachusetts coastline in coordination with the National Tsunami Hazard Mitigation Program. These maps cover the extent of the NGDC Nantucket Digital Elevation Model and encompass coastlines in the following areas:

- East Nantucket
- West Nantucket
- Martha's Vineyard
- Falmouth
- Hyannis
- Dennis
- Chatham

These maps are considered more accurate than buffer-based exposure; however, they are not available for the entire coastline. Therefore, the methodology used in the 2013 SHMP, in which a 1-mile buffer from the coast was used to approximate the exposure area from a major tsunami, was repeated in this update. If NGDC mapping is available for the entire coastline at the time of

the next plan update, this data source would provide more detailed and accurate exposure information.

Populations



A 1-mile buffer was used for this exposure analysis. Table 4-37 shows the population in each county located within this buffer.

Table 4-37: 2010 U.S. Census Population Exposed to Tsunami Hazard

County	Population Exposed to Tsunami
Barnstable	140,853
Bristol	197,511
Dukes	12,947
Essex	304,924
Middlesex	124,145
Nantucket	6,433
Norfolk	157,233
Plymouth	124,346
Suffolk	466,475
Total	1,534,867

Source: 2010 U.S. Census

Vulnerable Populations

The populations most vulnerable to the tsunami hazard include people over the age of 65 and children under the age of 5 who reside near beaches, low-lying coastal areas, tidal flats, and river deltas that empty into ocean-going waters. In the event of a local tsunami generated in or near the Commonwealth, there would be little warning time, so more of the population would be vulnerable. The degree of vulnerability of the population exposed to the tsunami hazard event is based on a number of factors:

- Is there a warning system?
- What is the lead time of the warning?
- What is the method of warning dissemination?
- Will the people evacuate when warned?

For this assessment, the population vulnerable to possible tsunami inundation is considered to be the same as the exposed population.

Health Impacts

Tsunamis have resulted in massive casualties and health impacts (both direct and indirect) throughout the world. When a tsunami is occurring, direct mortality can occur as individuals drown in the floodwaters or are struck by fast-moving debris. According to the CDC, as tsunamis recede, the strong suction of debris being pulled into densely populated coastal areas can cause additional deaths and injuries (CDC, 2013). Following a tsunami, health concerns include contaminated food and water supplies (discussed later in this section) and exposure-related impacts such as exposure to insects, temperatures, and other environmental hazards.

Government



The impact of the waves and the scouring associated with debris that may be carried in the water could be very damaging to structures located in the tsunami's path. Structures that would be most vulnerable are those located in the front line of tsunami impact and those that are structurally unsound. Similar to the exposed population, all state buildings within 1-mile of the coastline are considered exposed to the tsunami hazard for the purposes of this SHMCAP. Table 4-38 summarizes the number and estimated replacement cost value (structure and contents) of state-owned buildings in these coastal counties.

Table 4-38: State-Owned Buildings in the Tsunami Hazard Zone by County

County	Number of Buildings	Replacement Cost Value (Structure and Contents)
Barnstable	139	\$324,986,220
Bristol	81	\$355,261,393
Dukes	5	\$10,269,171
Essex	140	\$782,088,889
Middlesex	20	\$378,943,236
Nantucket	3	\$3,168,858
Norfolk	25	\$75,952,463
Plymouth	108	\$206,061,112
Suffolk	173	\$5,599,769,083
Total	694	\$7,736,500,425

Source: DCAMM, 2017 (facility inventory)

Impacts to government structures and operations due to a tsunami may cause:

- Delays in spill clean-up response, in emergency response, and in assessment of potential hazardous conditions;

- Delays in technical assistance to affected drinking water, which may cause delayed public health orders (e.g., boil water, do not drink, and/or do not use orders);
- Lack of environmental laboratory testing services for environmental assessment;
- Delays in providing background environmental information to assess and respond to a critical concern;
- Delays in technical assistance to affected wastewater facilities, which may cause severe environmental hazards due to overflows and potential public health issues from raw sewage releases;
- Delayed approvals for clean-up work in wetlands (when needed);
- Potential delays in accessing and providing assistance for debris management (including asbestos and construction and demolition debris disposal); and
- Potential delays in responding to solid waste disposal and recycling capacity issues.

The Built Environment



All elements of the built environment within a buffer zone of 1 mile from the coastline are considered exposed to the tsunami hazard at this time. Tables 4-39 and 4-40 summarize the number of state-owned critical facilities per county and by type.

Agriculture

Tsunamis that flood farmland could have a devastating and long-term impact on cropland and livestock.

Energy

The forces of tsunami waves can also impact aboveground utilities by knocking down power lines and radio/cellular communication towers. Power generation facilities can be severely impacted by both the velocity impact of the wave action and the inundation of floodwaters.

Public Health

Similar to inland and coastal flood events, tsunamis impact public health by increasing the potential exposure to mold and toxic substances following a flood event. Hospitals and medical provider facilities that are impacted by a tsunami may have limited capacity to care for patients due to flooding, loss of power, or physical damage.

Public Safety

Flooding caused by a tsunami will greatly impact public safety, which is an important component in the management of tsunami-related emergencies. As shown in Table 4-40, 13

state-owned police facilities and two fire departments are exposed to the tsunami hazard. Municipally owned facilities within the tsunami hazard zone are also vulnerable.

Transportation

Roads are the primary resource for evacuation to higher ground before and during the course of a tsunami event. Flooding may impact the structural integrity and the drivability of roads. Bridges exposed to tsunami events can be extremely vulnerable due to the forces transmitted by the wave run-up and by the impact of debris carried by the wave action. Table 4-41 shows the bridges located within the tsunami zone.

Table 4-39: Number of Critical Facilities Exposed to the Tsunami Hazard by County

County	Tsunami Exposure Area
Barnstable	9
Bristol	9
Dukes	2
Essex	11
Middlesex	2
Nantucket	2
Norfolk	3
Plymouth	3
Suffolk	12
Total	53

Source: DCAMM facility inventory 2017

Table 4-40: Number of Critical Facilities Exposed to the Tsunami Hazard by Type

Type	Tsunami Exposure Area
Military	9
Police Facilities	13
Fire Departments	2
Hospitals	—
Colleges	11
Social Services	18
Total	53

Source: DCAMM facility inventory 2017

Table 4-41: Number of Bridges Exposed to the Tsunami Hazard

County	Federal	State	Local
Barnstable	2	37	17
Bristol	—	63	15
Dukes	—	1	1
Essex	—	76	21
Middlesex	—	34	—
Nantucket	—	—	1
Norfolk	—	24	7
Plymouth	—	59	11
Suffolk	—	388	19
Total	2	682	92

Source: National Bridge Inventory

The replacement cost values for critical facilities were not available for this planning effort. A total risk exposure would equal the full replacement value of each critical facility exposed. As these data become available, the Commonwealth will update this section of the plan with new information. The functional downtime to restore elements of the built environments to 100 percent of their functionality will be dependent upon the severity of the damage. The total estimated replacement cost value of the 850 bridges within 1 mile of the coastline is \$24 billion.

Water Infrastructure

Water infrastructure (such as water treatment plants located within the 1-mile tsunami hazard zone) is vulnerable to this hazard. It is possible that more widespread regional impacts could occur if salt water were to inundate drinking water supplies or overburden stormwater or wastewater systems.

Natural Resources and Environment



The environmental impact of tsunamis can be widespread and devastating. The inundation of typically dry areas can reshape the topography of an area, both by scouring existing sediment and by depositing sediment from other locations. In addition to these physical impacts, a tsunami can also uproot trees and other plants in its path, causing habitat loss in addition to direct mortality to animals in the area. Animals in the area could die as a result of drowning, and marine animals often die as a result of chemicals or contaminants swept into the ocean. These chemicals and contaminants, as well as salt water, can remain in aquifers or can percolate into groundwater supplies after the tsunami recedes, causing extensive and prolonged environmental devastation.

Economy

\$ A tsunami's negative impact on the economy is difficult to quantify. Losses include, but are not limited to, general building stock damage, business interruption/closures, port closures, utility and transportation damage, and impacts on tourism and the tax base that affect the Commonwealth. However, because there have not been any major tsunami events in Massachusetts history, it is difficult to calculate the probable cost of such an event. An exposure analysis of the general building stock was conducted to approximate losses in the tsunami hazard zone, and the results are summarized in Table 4-42; however, this method is considered extremely conservative.

Table 4-42: Economic Exposure to Tsunami

County	Building Stock within Tsunami Exposure Area
Barnstable	\$52,384,982
Bristol	\$39,919,295
Dukes	\$6,091,471
Essex	\$65,396,417
Middlesex	\$32,238,859
Nantucket	\$5,305,922
Norfolk	\$31,697,431
Plymouth	\$30,005,713
Suffolk	\$128,546,252
Total	\$391,586,342

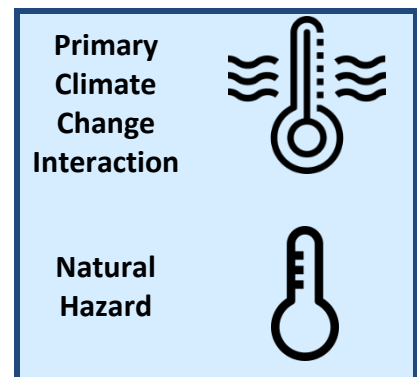
Source: FEMA Hazus loss estimation methodology

4.3 Primary Climate Change Interaction: Rising Temperatures

4.3.1 Average/Extreme Temperature

GENERAL BACKGROUND

There is no universal definition for extreme temperatures. The term is relative to the usual weather in the region based on climatic averages. Extreme heat for Massachusetts is usually defined as a period of 3 or more consecutive days above 90 degrees





Natural Hazard Summary

AVERAGE AND EXTREME TEMPERATURE

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
Temperature variations occur due to a number of atmospheric phenomena. Notable heat for Massachusetts is defined as 3+ days above 90°F, while Wind Chill Advisories are issued if wind chill is forecast to dip below -15 °F for at least 3 hours.	Extreme temperature events occur more frequently and with greater severity in inland portions of the Commonwealth than in coastal areas.	Over the last two decades, an average of 1.5 extreme cold weather events, and an average of 2 extreme hot weather events have occurred in Massachusetts annually.

Potential Effects of Climate Change

	RISING TEMPERATURES ➔ HIGHER EXTREME TEMPERATURES	The average summer across the Massachusetts during the years between 1971 and 2000 included 4 days over 90°F (i.e. extreme heat days). Climate scientists project that by mid-century, the state could have a climate that resembles that of southern states today, with an additional 10-28 days over 90°F during summer. By the end of the century, extreme heat could occur between 13-56 days during summer.
	RISING TEMPERATURES ➔ HIGHER AVERAGE TEMPERATURES	Compared to an annual 1971-2000 average temperature baseline of 47.6°F, annual average temperatures in Massachusetts are projected to increase by 3.8 to 10.8 degrees (likely range) by the end of the 21st century; slightly higher in western Massachusetts.

Exposure and Vulnerability by Key Sector

	POPULATIONS	General At-Risk Population: State-wide exposure; populations in urban areas may face greater risk. Vulnerable Populations: Populations over age 65; infants and young children; Individuals who are physically ill; low-income individuals who cannot afford proper heating and cooling; populations whose jobs involve exposure to extreme temperatures.
	GOVERNMENT	Extreme heat generally does not impact buildings, although losses may occur as the result of overheated HVAC systems. Extreme cold temperature events can damage buildings through freezing/bursting pipes and freeze/thaw cycles.
	BUILT ENVIRONMENT	Extreme heat events can sometimes cause short periods of utility failure due to increased usage from air conditioners and other appliances. Heavy snowfall and ice storms, associated with extreme cold temperature events, can also cause power interruption. Periods of both hot and cold weather can stress energy infrastructure. Above average, below average, and extreme temperatures are likely to impact crops – such as apples, cranberries, and maple syrup – that rely on specific temperature regimes.
	NATURAL RESOURCES AND ENVIRONMENT	Because the species that exist in a given area are designed to survive within a specific temperature range, extreme temperatures events can place significant stress both on individual species and ecosystems. Warming temperature across the globe force species poleward, or upward in elevation, while species that cannot relocate fast enough or find suitable habitat face local extinction.
	ECONOMY	Extreme temperature events can have significant economic impacts, including loss of business function and damage/loss of inventory. The agricultural industry is the industry most at risk in terms of economic impact and damage due to extreme temperature and drought events.

Fahrenheit (°F), but more generally as a prolonged period of excessively hot weather, which may be accompanied by high humidity. Extreme cold is also considered relative to the normal climatic lows in a region.

Massachusetts has four seasons with several defining factors, and temperature is one of the most significant. Extreme temperatures can be defined as those that are far outside the normal ranges. The average highs and lows of the hottest and coldest months in Massachusetts are provided in Table 4-43.

Table 4-43: Annual Average High and Low Temperatures

	July (Hottest Month)	January (Coldest Month)
Average High (°F)	81°	36°
Average Low (°F)	65°	22°

Source: U.S. Climate Data, 2017

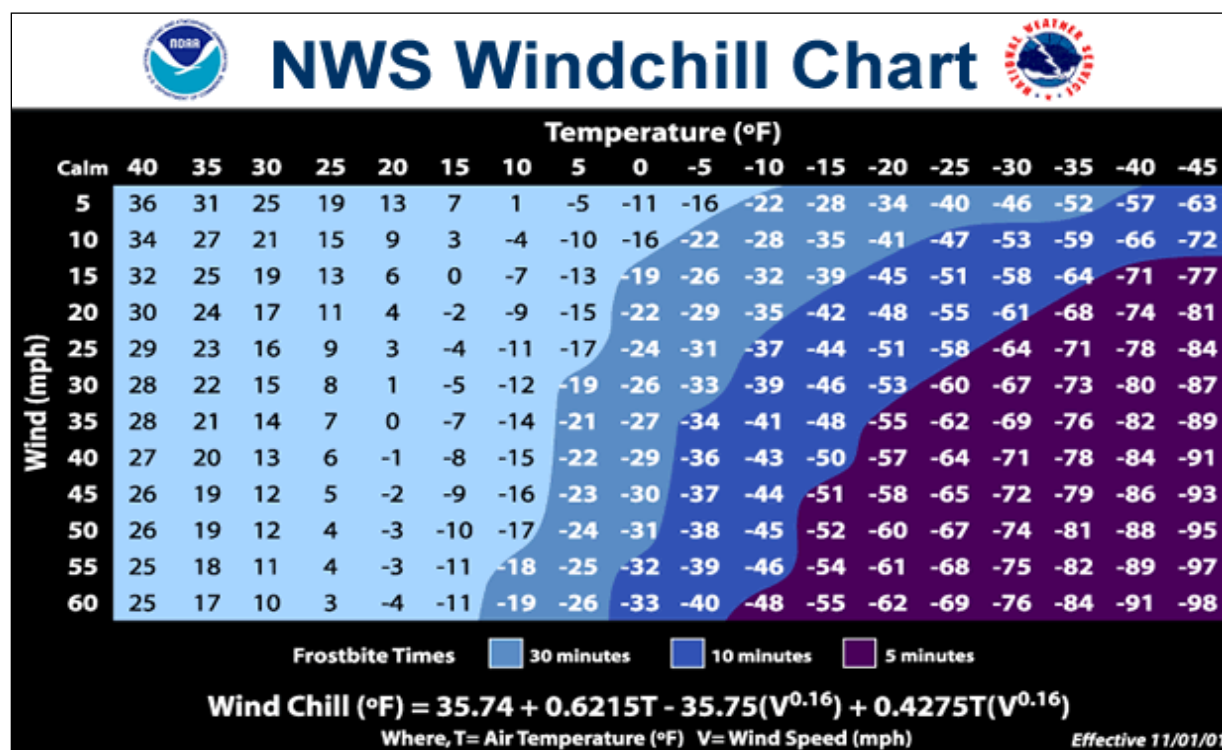
HAZARD PROFILE

Extreme Cold

The extent (severity or magnitude) of extreme cold temperatures is generally measured through the Wind Chill Temperature Index. Wind Chill Temperature is the temperature that people and animals feel when they are outside, and it is based on the rate of heat loss from exposed skin by the effects of wind and cold. As the wind increases, the body loses heat at a faster rate, causing the skin's temperature to drop.

The NWS issues a Wind Chill Advisory if the Wind Chill Index is forecast to dip to –15°F to –24°F for at least 3 hours, based on sustained winds (not gusts). The NWS issues a Wind Chill Warning if the Wind Chill Index is forecast to fall to –25°F or colder for at least 3 hours. On November 1, 2001, the NWS implemented a Wind Chill Temperature Index designed to more accurately calculate how cold air feels on human skin. Figure 4-42 shows the Wind Chill Temperature Index.

Figure 4-42: Wind Chill Temperature Index and Frostbite Risk



Source: National Weather Service (NWS), Wind Chill Chart, 2018

Extreme cold is a dangerous situation that can result in health emergencies for susceptible people, such as those without shelter or who are stranded or who live in homes that are poorly insulated or without heat. Extreme cold events are events when temperatures drop well below normal in an area. Extreme cold temperatures are characterized by the ambient air temperature dropping to approximately 0°F or below.

When winter temperatures drop significantly below normal, staying warm and safe can become a challenge. Extremely cold temperatures often accompany a winter storm, which may also cause power failures and icy roads. During cold months, carbon monoxide may be high in some areas because the colder weather makes it difficult for car emission control systems to operate effectively, and temperature inversions can trap the resulting pollutants closer to the ground. Another hazard of extended cold temperatures in Massachusetts is saltwater freezing in coastal bays and harbors. Coastal freezing can interfere with the transportation of goods and people, and can also inhibit fishing and other industries that rely on boats.

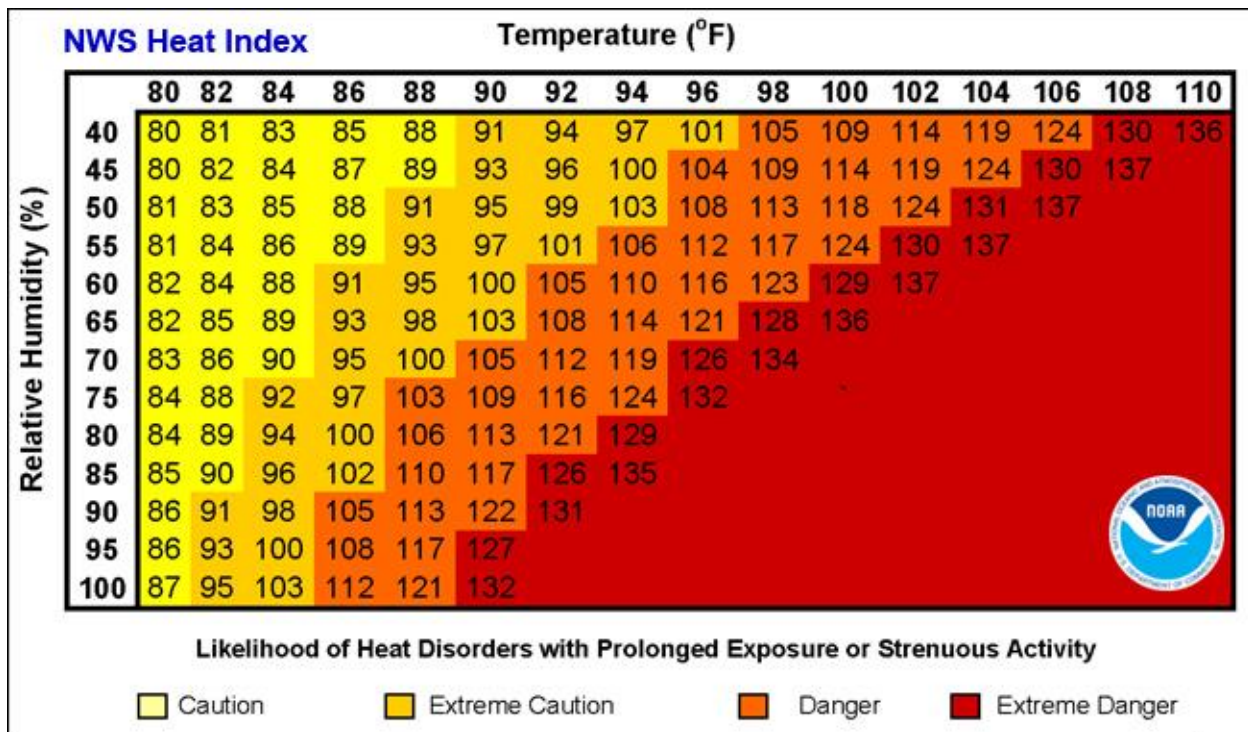
Staying indoors as much as possible can help reduce the risk of car crashes and falls on the ice, but cold weather also can present hazards indoors. Many homes will be too cold, either due to a power failure or because the heating system is not adequate for the weather. Exposure to cold temperatures, whether indoors or outside, can cause other serious or life-threatening health problems. Power outages may also result in inappropriate use of combustion heaters, cooking

appliances, and generators in indoor or poorly ventilated areas, leading to increased risk of carbon monoxide poisoning.

Extreme Heat

The NWS issues a Heat Advisory when the NWS Heat Index is forecast to reach 100 to 104°F for 2 or more hours. The NWS issues an Excessive Heat Warning if the Heat Index is forecast to reach 105°F or higher for 2 or more hours. The NWS Heat Index is based both on temperature and relative humidity, and describes a temperature equivalent to what a person would feel at a baseline humidity level. It is scaled to the ability of a person to lose heat to their environment. The relationship between these variables and the levels at which the NWS considers various health hazards to become relevant are shown in Figure 4-43. It is important to know that the heat index values are devised for shady, light wind conditions. Exposure to full sunshine can increase heat index values by up to 15°F. Also, strong winds, particularly with very hot, dry air, can increase the risk of heat-related impacts.

Figure 4-43: Heat Index



Source: National Weather Service (NWS), Heat Index, 2018

A heat wave is defined as 3 or more days of temperatures of 90°F or above. A basic definition of a heat wave implies that it is an extended period of unusually high atmosphere-related heat stress, which causes temporary modifications in lifestyle and which may have adverse health consequences for the affected population.

Heat waves cause more fatalities in the U.S. than the total of all other meteorological events combined. Since 1979, more than 9,000 Americans have died from heat-related ailments (EPA, 2016).

Heat impacts can be particularly significant in urban areas. Approximately half of the world's population lives in these heavily developed areas, with that number increasing to 74 percent in developed nations. As these urban areas develop and change, so does the landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist are now impermeable and dry. Dark-colored asphalt and roofs also absorb more of the sun's energy. These changes cause urban areas to become warmer than the surrounding areas. This forms "islands" of higher temperatures, often referred to as "heat islands."

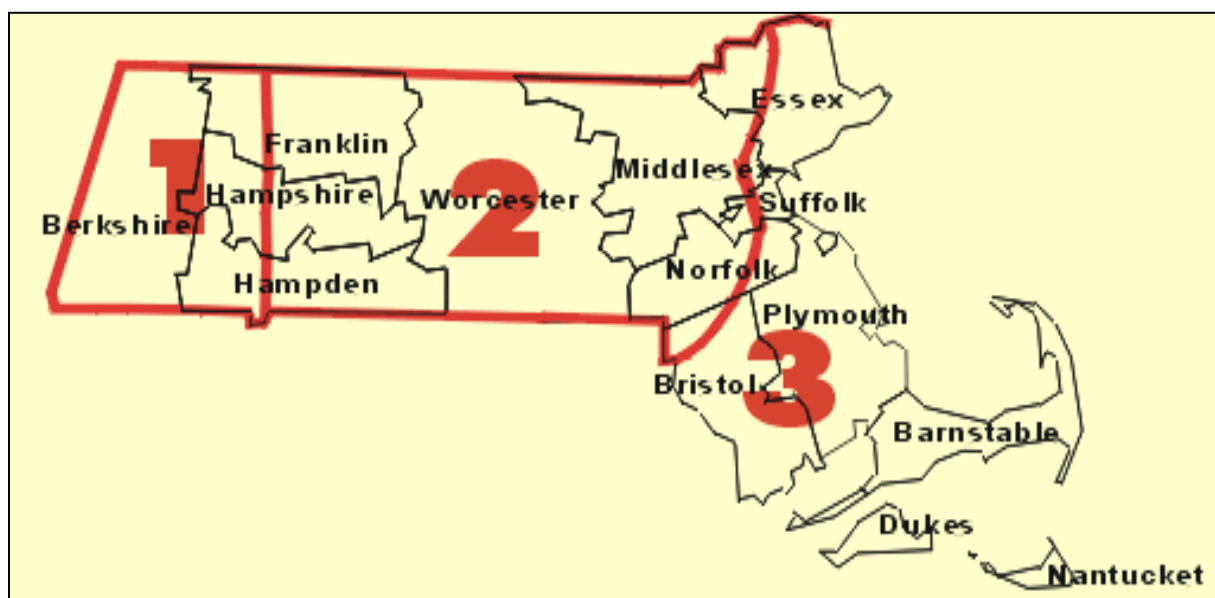
The term "heat island" describes built-up areas that are hotter than nearby rural or shaded areas. The annual mean air temperature of a city with more than 1 million people can be between 1.8°F and 5.4°F warmer than its surrounding areas. In the evening, the difference in air temperatures can be as high as 22°F. Heat islands occur on the surface and in the atmosphere. On a hot, sunny day, the sun can heat dry, exposed urban surfaces to temperatures 50°F to 90°F hotter than the air. Heat islands can affect communities by increasing peak energy demand during the summer, air conditioning costs, air pollution and GHG emissions, heat-related illness and death, and water quality degradation (EPA, n.d).

Extreme heat events can also have impacts on air quality. Many conditions associated with heat waves or more severe events—including high temperatures, low precipitation, strong sunlight and low wind speeds—contribute to a worsening of air quality in several ways. High temperatures can increase the production of ozone from volatile organic compounds and other aerosols. Weather patterns that bring high temperatures can also transport particulate matter air pollutants from other areas of the continent. Additionally, atmospheric inversions and low wind speeds allow polluted air to remain in one location for a prolonged period of time (UCI, 2017).

Location

According to the NOAA, Massachusetts is made up of three climate divisions: Western, Central, and Coastal, as shown in Figure 4-44 (NOAA, n.d.). Average annual temperatures vary slightly over the divisions, with annual average temperatures of around 46°F in the Western division (area labeled "1" in the figure), 49°F in the Central division (area labeled "2" in the figure) and 50°F in the Coastal division (area labeled "3" in the figure).

Figure 4-44: Climate Divisions of Massachusetts



Source: NOAA, n.d.

Extreme temperature events occur more frequently and vary more in the inland regions where temperatures are not moderated by the Atlantic Ocean. The severity of extreme heat impacts is greater in densely developed urban areas like Boston than in suburban and rural areas.

Previous Occurrences

Extreme Cold

Since 1994, there have been 33 cold weather events within the Commonwealth, ranging from Cold/Wind Chill to Extreme Cold/Wind Chill events. Detailed information regarding most of these extreme temperature events was not available; however, additional detail on recent extreme events is provided below.

In February 2015, a series of snowstorms piled nearly 60 inches on the city of Boston in 3 weeks and caused recurrent blizzards across eastern Massachusetts. Temperature gauges across the Commonwealth measured extreme cold, with wind chills as low as -31°F. Four indirect fatalities occurred as a result of this event: two adults died shoveling snow and two adults were hit by snowplows.

In February 2016, one cold weather event broke records throughout the state. Wind chill in Worcester was measured at -44°F, and the measured temperature in Boston (-9°F) broke a record previously set in 1957. Extreme cold/wind chill events were declared in 16 climate zones across the Commonwealth. A more comprehensive list of historic cold weather events is provided in Appendix B.

Extreme Heat

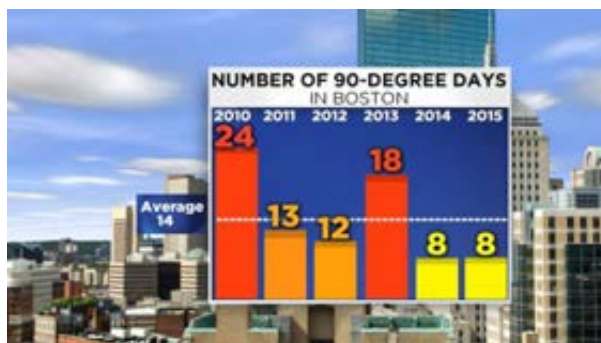
According to the NOAA's Storm Events Database, accessed in March 2018, there have been 43 warm weather events (ranging from Record Warmth/Heat to Excessive Heat events) since 1995. The most current event in the database occurred in July 2013. Excessive heat results from a combination of temperatures well above normal and high humidity. Whenever the heat index values meet or exceed locally or regionally established heat or excessive heat warning thresholds, an event is reported in the database.

In 2012, Massachusetts temperatures broke 27 heat records. Most of these records were broken between June 20 and June 22, 2012, during the first major heat wave of the summer to hit Massachusetts and the East Coast. In July 2013, a long period of hot and humid weather occurred throughout New England. One fatality occurred on July 6, when a postal worker collapsed as the Heat Index reached 100°F. A more comprehensive list of historic warm weather events is provided in Appendix B.

Frequency of Occurrences

Massachusetts has averaged 2.4 declared cold weather events and 0.8 extreme cold weather events annually between January 2013 and October 2017. The year 2015 was a particularly notable one, with seven cold weather events, including three extreme cold/wind chill events, as compared to no cold weather events in 2012 and one in 2013. Although hot weather events are declared less often in Massachusetts, Figure 4-45 shows the frequency of 90-degree days (the criteria for a heat wave) since 2010. Considering that three of these days comprise a heat wave, it would be assumed that an average of between four and five heat waves occur annually in Massachusetts.

Figure 4-45: Historical Number of 90-Degree Days.



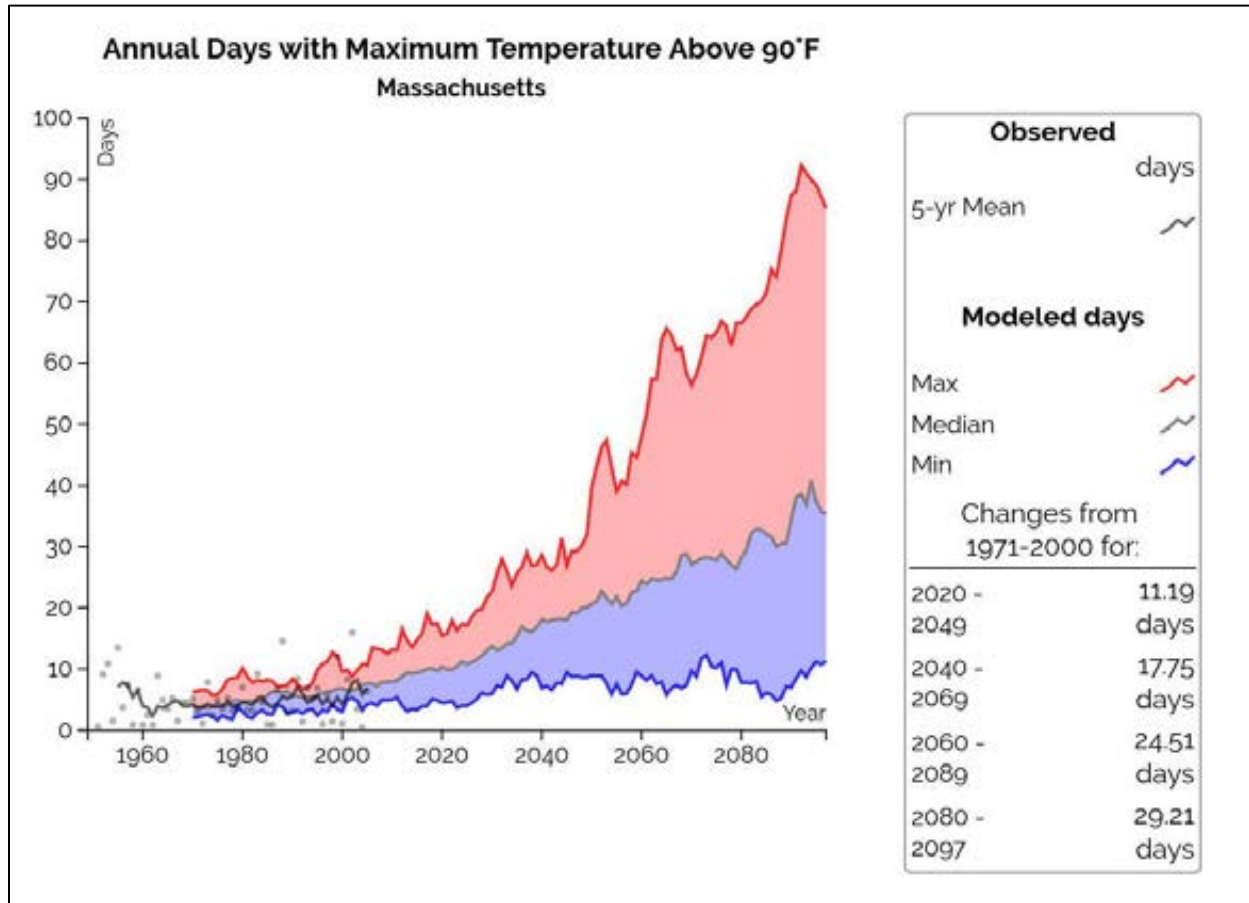
Source: CBS Boston, 2016

There are a number of climatic phenomena that determine the number of extreme weather events in a specific year. However, there are significant long-term trends in the frequency of extreme hot and cold events. In the last decade, U.S. daily record high temperatures have occurred twice as often as record lows (as compared to a nearly 1:1 ratio in the 1950s). Models suggest that this

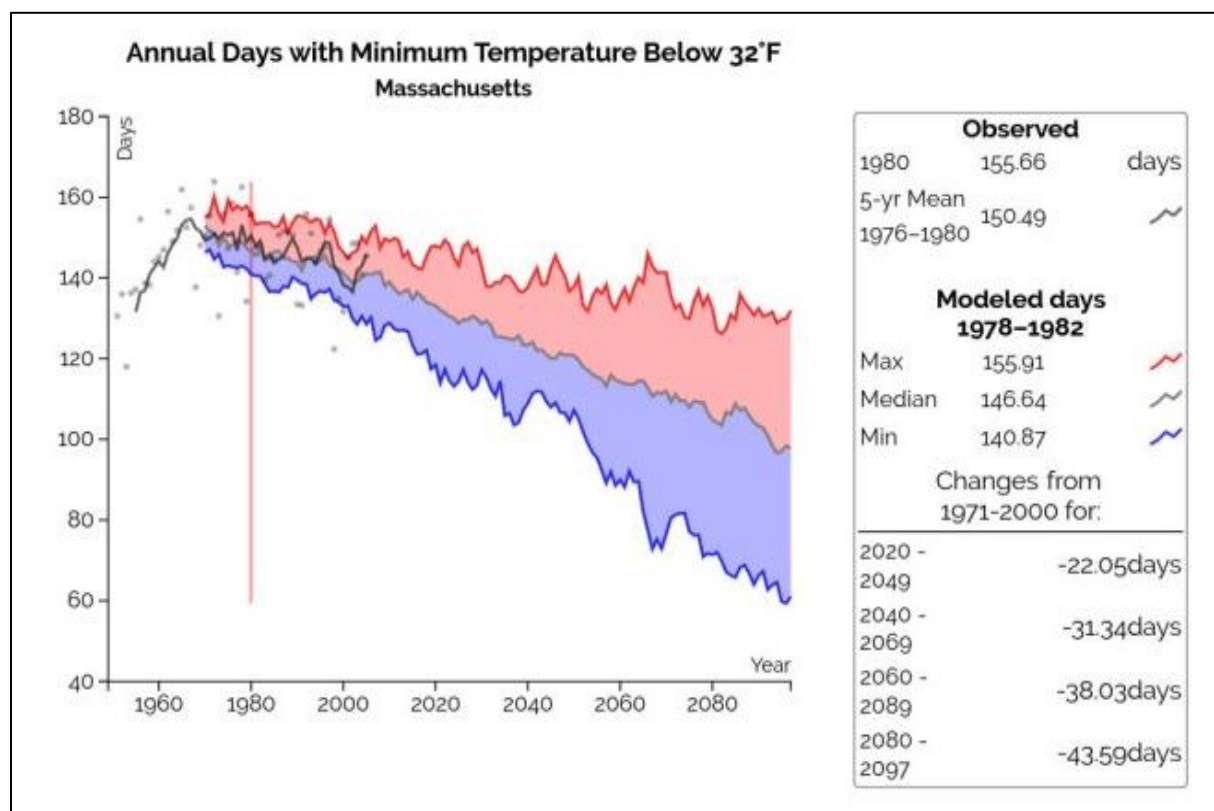
ratio could climb to 20:1 by midcentury, if GHG emissions are not significantly reduced (C2ES, n.d.).

The NE CASC data support the trends of an increased frequency of extreme hot weather events and a decreased frequency of extreme cold weather events. Figures 4-46 and 4-47 show the projected changes in these variables between 2020 and the end of this century.

Figure 4-46: Projected Annual Days with Temperature Above 90°F



Source: resilient MA, 2018

Figure 4-47: Projected Annual Days with Temperature Below 32°F

Source: resilient MA, 2018

Severity/Extent

The severity of extreme cold temperatures is generally measured through the Wind Chill Temperature Index. Wind Chill Temperature is the temperature that people and animals feel when outside based on the rate of heat loss from exposed skin by the effects of wind and cold. As the wind increases, the body is cooled at a faster rate, causing the skin's temperature to drop. The severity of extreme heat temperatures is generally measured through the Heat Index. The Heat Index can be used to determine what effects the temperature and humidity can have on the population. Detailed information regarding the Wind Chill Temperature Index and Heat Index is found in the previous Hazard Profile section for average and extreme temperature.

High, low, and average temperatures in Massachusetts are all likely to increase significantly over the next century as a result of climate change. Table 4-44 shows the change in average, maximum, and minimum temperatures through the end of this century, as determined by the downscaled climate projections for Massachusetts (resilient MA, 2018). This gradual change will put long-term stress on a variety of social and natural systems, and will exacerbate the influence of discrete events. Figure 4-48 shows the range of annual temperature increases predicted by the NE CASC. Statewide average temperature ranges for the SHMCAP's planning horizons are

provided in Table 4-44, and the distribution of temperatures throughout the Commonwealth is shown in Figures 4-49 through 4-52.

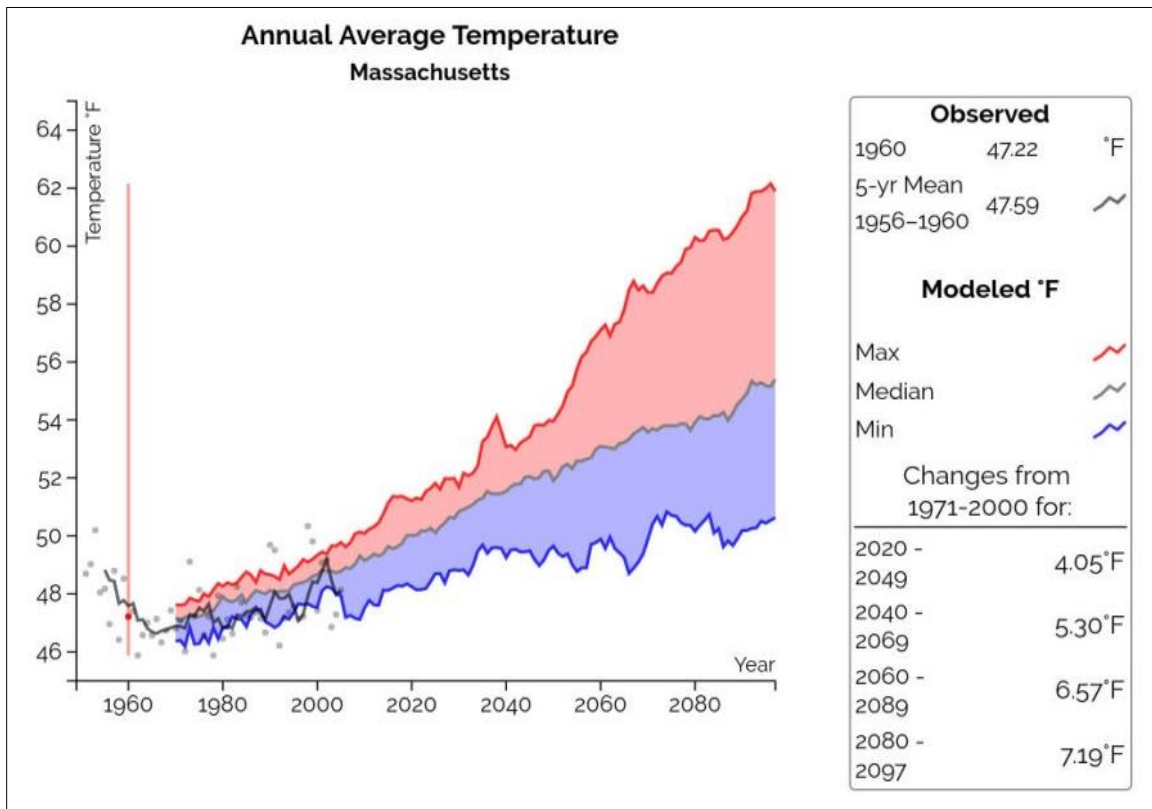
Table 4-44: Maximum Daily Projected Temperature Changes Through 2100

Climate Indicator		Observed Value 1971-2000 Average	Mid-Century Projected and Percent Change in 2050s (2040-2069)	End of Century Projected and Percent Change in 2090s (2080-2099)*
Average Temperature	Annual	47.6 °F	Increase by 2.8 to 6.2 °F Increase by 6 to 13 %	Increase by 3.8 to 10.8 °F Increase by 8 to 23 %
	Winter	26.6 °F	Increase by 2.9 to 7.4 °F Increase by 11 to 28 %	Increase by 4.1 to 10.6 °F Increase by 15 to 40 %
	Spring	45.4 °F	Increase by 2.5 to 5.5 °F Increase by 6 to 12 %	Increase by 3.2 to 9.3 °F Increase by 7 to 20 %
	Summer	67.9 °F	Increase by 2.8 to 6.7 °F Increase by 4 to 10 %	Increase by 3.7 to 12.2 °F Increase by 6 to 18 %
	Fall	50 °F	Increase by 3.6 to 6.6 °F Increase by 7 to 13 %	Increase by 3.9 to 11.5 °F Increase by 8 to 23 %
Maximum Temperature	Annual	58.0 °F	Increase by 2.6 to 6.1 °F Increase by 4 to 11 %	Increase by 3.4 to 10.7 °F Increase by 6 to 18 %
	Winter	36.2 °F	Increase by 2.5 to 6.8 °F Increase by 7 to 19 %	Increase by 3.5 to 9.6 °F Increase by 10 to 27 %
	Spring	56.1 °F	Increase by 2.3 to 5.4 °F Increase by 4 to 10 %	Increase by 3.1 to 9.4 °F Increase by 6 to 17 %
	Summer	78.9 °F	Increase by 2.6 to 6.7 °F Increase by 3 to 8 %	Increase by 3.6 to 12.5 °F Increase by 4 to 16 %
	Fall	60.6 °F	Increase by 3.4 to 6.8 °F Increase by 6 to 11 %	Increase by 3.8 to 11.9 °F Increase by 6 to 20 %
Minimum Temperature	Annual	37.1 °F	Increase 3.2 to 6.4 °F Increase by 9 to 17 %	Increase by 4.1 to 10.9 °F Increase by 11 to 29 %
	Winter	17.1 °F	Increase by 3.3 to 8.0 °F Increase by 19 to 47 %	Increase by 4.6 to 11.4 °F Increase by 27 to 66 %
	Spring	34.6 °F	Increase by 2.6 to 5.9 °F Increase by 8 to 17 %	Increase by 3.3 to 9.2 °F Increase by 9 to 26 %
	Summer	56.8 °F	Increase by 3 to 6.9 °F Increase by 5 to 12 %	Increase by 3.9 to 12 °F Increase by 7 to 21 %
	Fall	39.4 °F	Increase by 3.5 to 6.5 °F Increase by 9 to 16 %	Increase by 4.0 to 11.4 °F Increase by 10 to 29 %

* A 20-yr mean is used for the 2090s because the climate models end at 2100.

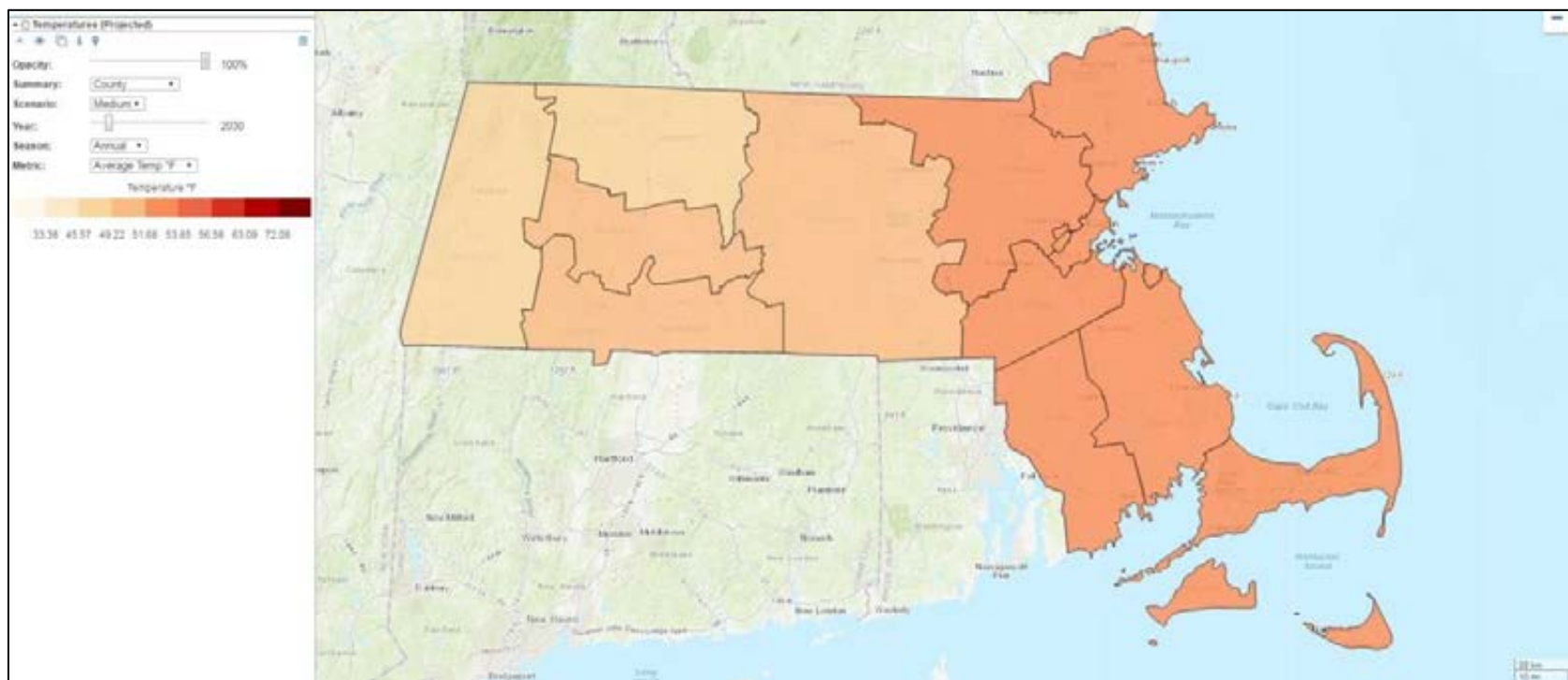
Source: resilient MA, 2018

Figure 4-48: Projected Annual Average Temperature



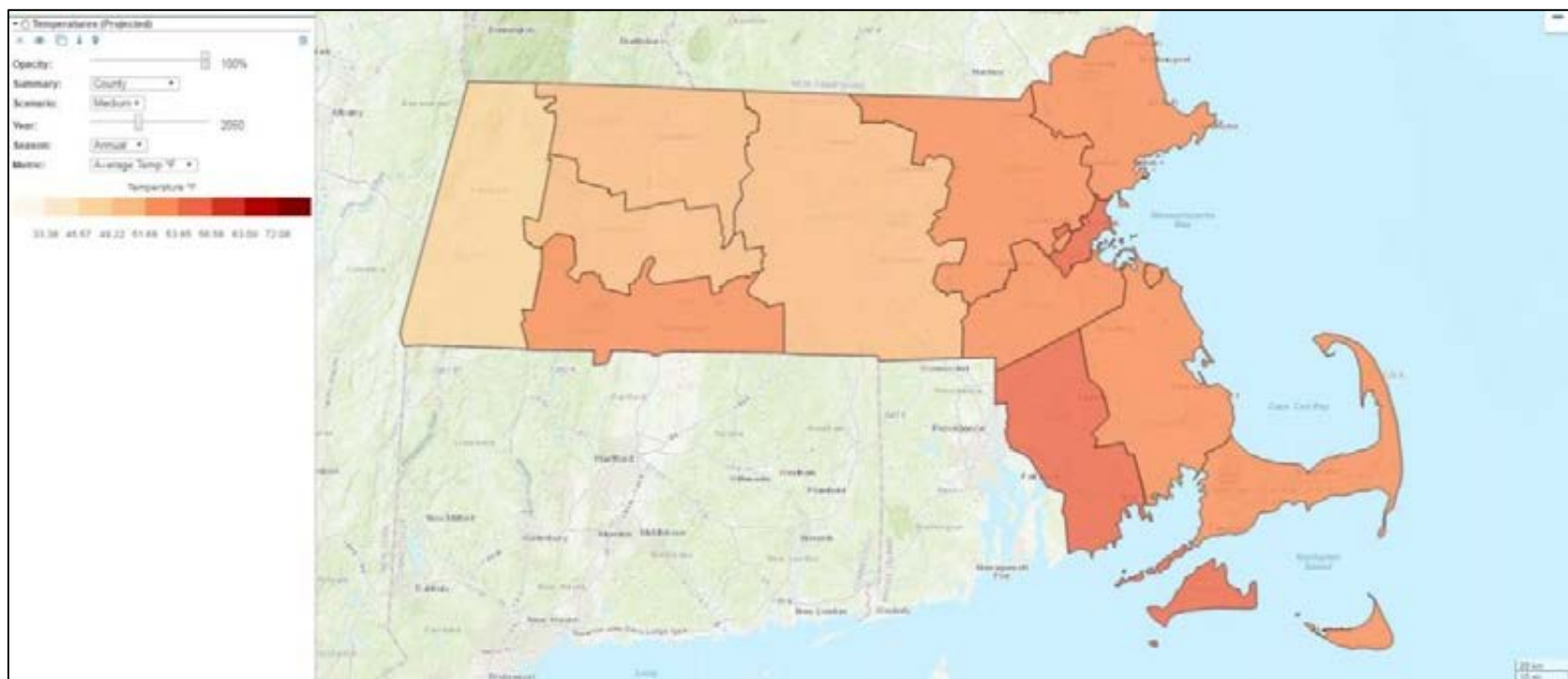
Source:resilient MA, 2018

Figure 4-49: Geospatial Distribution of Projected Annual Temperature – 2030



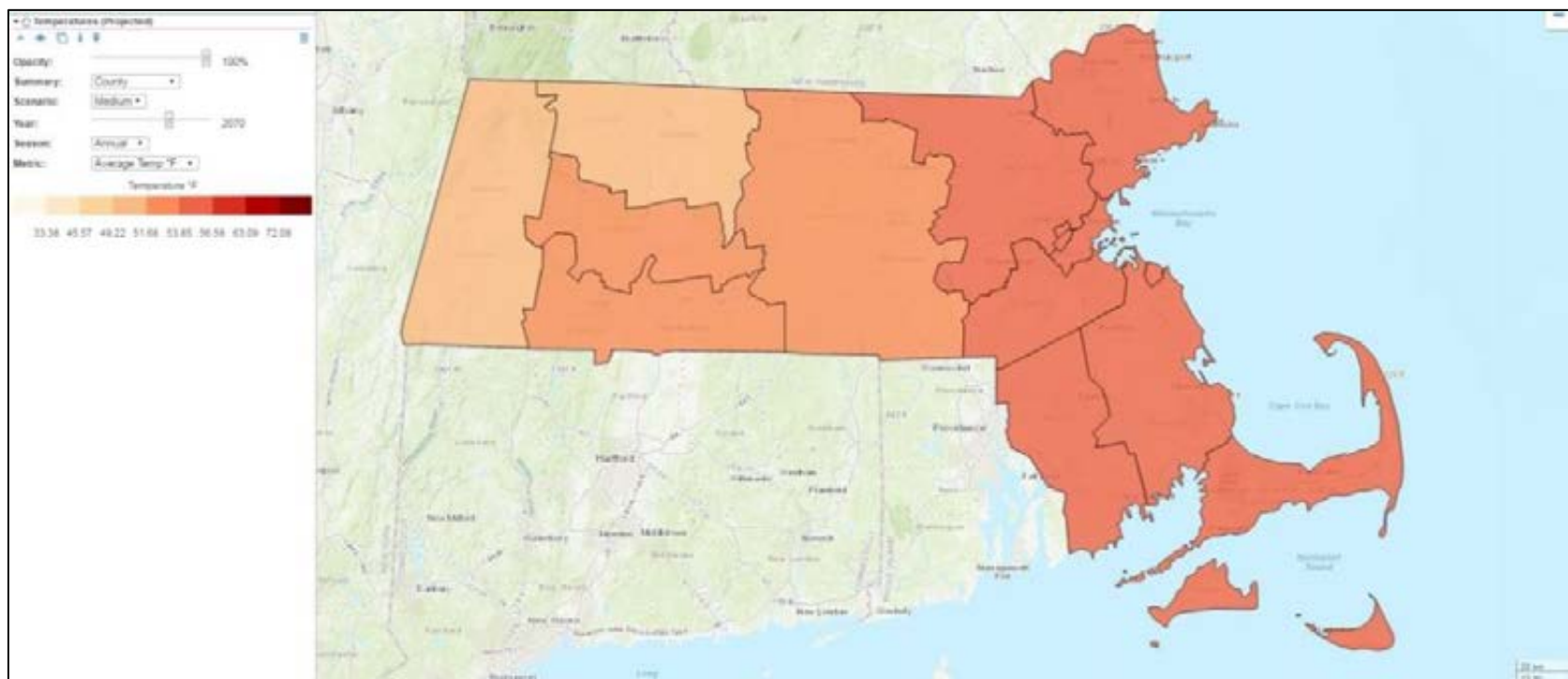
Source: resilient MA, 2018

Figure 4-50: Geospatial Distribution of Projected Annual Temperature – 2050



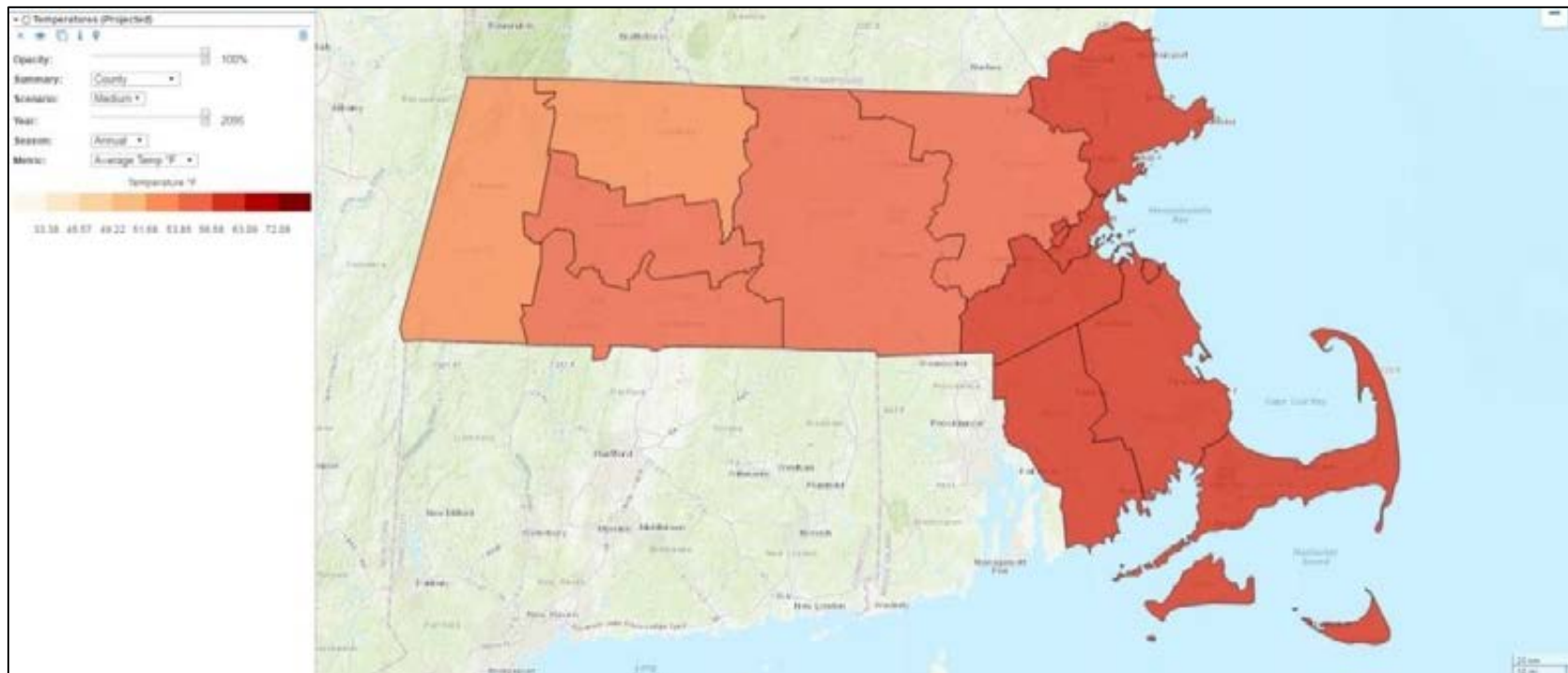
Source: resilient MA, 2018

Figure 4-51: Geospatial Distribution of Projected Annual Temperature – 2070



Source: resilient MA, 2018

Figure 4-52: Geospatial Distribution of Projected Annual Temperature – 2100



Warning Time

Temperature changes will be gradual over the years. However, for the extremes, meteorologists can accurately forecast event development and the severity of the associated conditions with several days lead time. These forecasts provide an opportunity for public health and other officials to notify vulnerable populations. For heat events, the NWS issues excessive heat outlooks when the potential exists for an excessive heat event in the next 3 to 7 days. Notifications such as “watches” are issued when conditions are favorable for an excessive heat event in the next 24 to 72 hours. Excessive heat warning/advisories are issued when an excessive heat event is expected in the next 36 hours. Winter temperatures may fall to extreme cold readings with no wind occurring. Currently, the only way to headline very cold temperatures is either through the issuance of a Wind Chill Advisory or Warning, or the issuance of a winter weather-related Warning, Watch, or Advisory if the cold temperatures are occurring in conjunction with a winter storm event.

SECONDARY HAZARDS

The most significant secondary hazard associated with extreme temperatures is a severe weather event. Hot weather events are often associated with drought, as evaporation increases with temperature, and with wildfire, as high temperatures can cause vegetation to dry out and become more flammable. Warmer weather will also have an impact on invasive species (see Section 4.3.3 for additional detail). More commonly, heat events contribute to the formation of ground-level ozone, a respiratory irritant that can exacerbate asthma and result in an increase in emergency department visits.

Cold weather events are primarily associated with severe winter storms. The combination of cold weather with severe winter storm events is particularly dangerous because winter weather can knock out heat and power, increasing the vulnerability of populations sheltering from the cold. Loss of heat and power may also lead to carbon monoxide poisoning from inappropriate use of combustion-powered generators, heaters, and cooking appliances, and heavy snowfall may block vents for gas dryers and heaters. Similarly, prolonged extreme heat can cause power infrastructure to overheat or catch fire, leaving customers without power or the ability to operate air conditioning. Power failure leads to increased use of diesel generators for power and more wood stoves are used in extreme cold; in both situations, air pollution and health impacts increase.

EXPOSURE AND VULNERABILITY

Populations



For the purposes of the SHMCAP, the entire population of the Commonwealth of Massachusetts is considered to be exposed to extreme temperatures. While extreme

temperatures are historically more common in the inland portions of the Commonwealth, the impacts to people may be more severe in densely developed urban areas around the state.

Vulnerable Populations

According to the Centers for Disease Control and Prevention, populations most at risk to extreme cold and heat events include the following: (1) people over the age of 65, who are less able to withstand temperatures extremes due to their age, health conditions, and limited mobility to access shelters; (2) infants and children under 5 years of age; (3) individuals with pre-existing medical conditions that impair heat tolerance (e.g., heart disease or kidney disease); (4) low-income individuals who cannot afford proper heating and cooling; (5) people with respiratory conditions, such as asthma or chronic obstructive pulmonary disease; and (6) the general public who may overexert themselves when working or exercising during extreme heat events or who may experience hypothermia during extreme cold events. Additionally, people who live alone—particularly the elderly and individuals with disabilities—are at higher risk of heat-related illness due to their isolation and reluctance to relocate to cooler environments. The distribution of these variables by county is shown in Table 4-45, along with the median predicted increase in temperature for each county (from NE CASC) by the end of this century.

The urban heat island effect can exacerbate vulnerability to extreme heat in urban areas. Other research, including a study of the spatial variability of heat-related mortality in Massachusetts, found that sociodemographic variables, including percent African-American and percent elderly, may be more important to heat-related mortality than the level of urbanization (Hattis et al., 2012).

An additional element of vulnerability to extreme temperature events is homelessness, as homeless individuals have a limited capacity to shelter from dangerous temperatures. According to data from the U.S. Department of Housing and Urban Development, 17,565 people experienced homelessness during a point-in-time count conducted in January 2017 (US HUD, 2017). On January 25, 2017, a total of 6,327 homeless individuals was recorded during the 37th Annual Homeless Census in Boston; this represents a 5 percent decline in homelessness from the City of Boston's count in 2016 (DND, 2017).

Health Impacts

When people are exposed to extreme heat, they can suffer from potentially deadly illnesses, such as heat exhaustion and heat stroke. Heat is the leading weather-related killer in the U.S., even though most heat-related deaths are preventable through outreach and intervention (EPA, 2016). A study of heat-related deaths across Massachusetts estimated that when the temperature rises above the 85th percentile (hot: 85-86°F), 90th percentile (very hot: 87-89°F) and 95th percentile (extremely hot: 89-92°F) there are between five and seven excess deaths per day in Massachusetts. These estimates were higher for communities with high percentages of African

American residents and elderly residents on days exceeding the 85th percentile (Hattis et al., 2011). A 2013 study of heart disease patients in Worcester, MA, found that extreme heat (high temperature greater than the 95th percentile) in the 2 days before a heart attack resulted in an estimated 44 percent increase in mortality. Living in poverty appeared to increase this effect (Madrigano et al., 2013). In 2015, researchers analyzed Medicare records for adults over the age of 65 who were living in New England from 2000 to 2008. They found that a rise in summer mean temperatures of 1°C resulted in a 1 percent rise in the mortality rate due to an increase in the number and intensity of heat events (Shi et al., 2015).

Hot temperatures can also contribute to deaths from respiratory conditions (including asthma), heart attacks, strokes, other forms of cardiovascular disease, renal disease, and respiratory diseases such as asthma and chronic obstructive pulmonary disorder. Human bodies cool themselves primarily through sweating and through increasing blood flow to body surfaces. Heat events thus increase stress on cardiovascular, renal, and respiratory systems, and may lead to hospitalization or death in the elderly and those with pre-existing diseases.

Massachusetts has a very high prevalence of asthma: approximately 1 out of every 11 people in the state currently has asthma (Mass.gov, n.d.). In Massachusetts, poor air quality often accompanies heat events, as increased heat increases the conversion of ozone precursors in fossil fuel combustion emissions to ozone. Particulate pollution may also accompany hot weather, as the weather patterns that bring heat waves to the region may carry pollution from other areas of the continent. Poor air quality can negatively affect respiratory and cardiovascular systems, and can exacerbate asthma and trigger heart attacks.

The interaction of heat and cardiovascular disease caused approximately 25 percent of the heat-related deaths since 1999 (EPA, 2016). The rate of hospital admissions for heat stress under existing conditions is shown in Table 4-45 and Figure 4-53. Between 2002 and 2012, the annual average age-adjusted rate of hospital admission for heat stress was highest in Plymouth and Suffolk Counties (0.14 to 0.16 admissions per 10,000 people) (see Figure 4-53). As displayed in Figure 4-54, Plymouth, Bristol, Franklin, and Berkshire Counties experienced the highest annual average age-adjusted hospital admissions for heart attacks (4.29 to 4.17 per 10,000 people) during this period. Hamden County had the highest annual average age emergency department visits due to asthma (110.1 to 125.6 visits per 10,000 people) (see Figure 4-55).

Some behaviors increase the risks of temperature-related impacts. These behaviors include voluntary actions, such as drinking alcohol or taking part in strenuous outdoor physical activities in extreme weather, but may also include necessary actions, such as taking prescribed medications that impair the body's ability to regulate its temperature or that inhibit perspiration.

Table 4-45: Heat Vulnerability Indicators

County	Estimated Increase in Average Temperature by 2100 (°F)	General Vulnerability Indicators			Heat Vulnerability Indicators			
		Proportion of Population Aged 65 or Older	Proportion of Population Aged Younger than 5 Years	Proportion of the Population Living Below Poverty Level	Rate of Emergency Room Visits for Heat Stress (per 10,000 residents)	Rate of Hospital Admissions for Heart Attacks (per 10,000 residents)	Rate of Emergency Department Visits for Asthma per 10,000 Residents	Rate of Emergency Department visits for Asthma for Children under age 15 per 10,000 Residents
Barnstable	+6.6°	25%	4%	9%	0.07	3.51	89.1	82.8
Berkshire	+8.3°	19%	5%	13%	0.07	4.39	90.7	82.5
Bristol	+6.5°	14%	6%	13%	0.12	4.41	88.1	97.6
Dukes	+6.9°	16%	5%	12%	NS	3.08	118.9	151.3
Essex	+6.6°	14%	6%	11%	0.10	3.76	76.0	107.7
Franklin	+5.6°	17%	5%	15%	0.13	4.29	68.5	83.7
Hampden	+6.4°	6%	6%	17%	0.11	4.25	120.3	164.8
Hampshire	+7.5°	5%	4%	15%	0.12	3.96	48.0	69.1
Middlesex	+6.2°	13%	6%	8%	0.11	3.56	49.6	76.9
Nantucket	+7°	12%	7%	12%	—	2.84	125.6	155.2
Norfolk	+6. 7°	15%	6%	7%	0.10	3.85	48.6	79.0
Plymouth	+6.2°	14%	6%	8%	0.14	4.71	70.8	87.1
Suffolk	+6°	10%	5%	21%	0.16	3.38	122.3	241.7
Worcester	+6. 6°	13%	6%	12%	0.09	4.13	76.7	120.4

Sources: U.S. Census Fact Finder n.d.; Massachusetts Environmental Public Health Tracking n.d.; NS = suppressed (number of cases or rate is below reporting threshold)

Figure 4-53: Rates of Heat Stress-Related Hospitalization by County

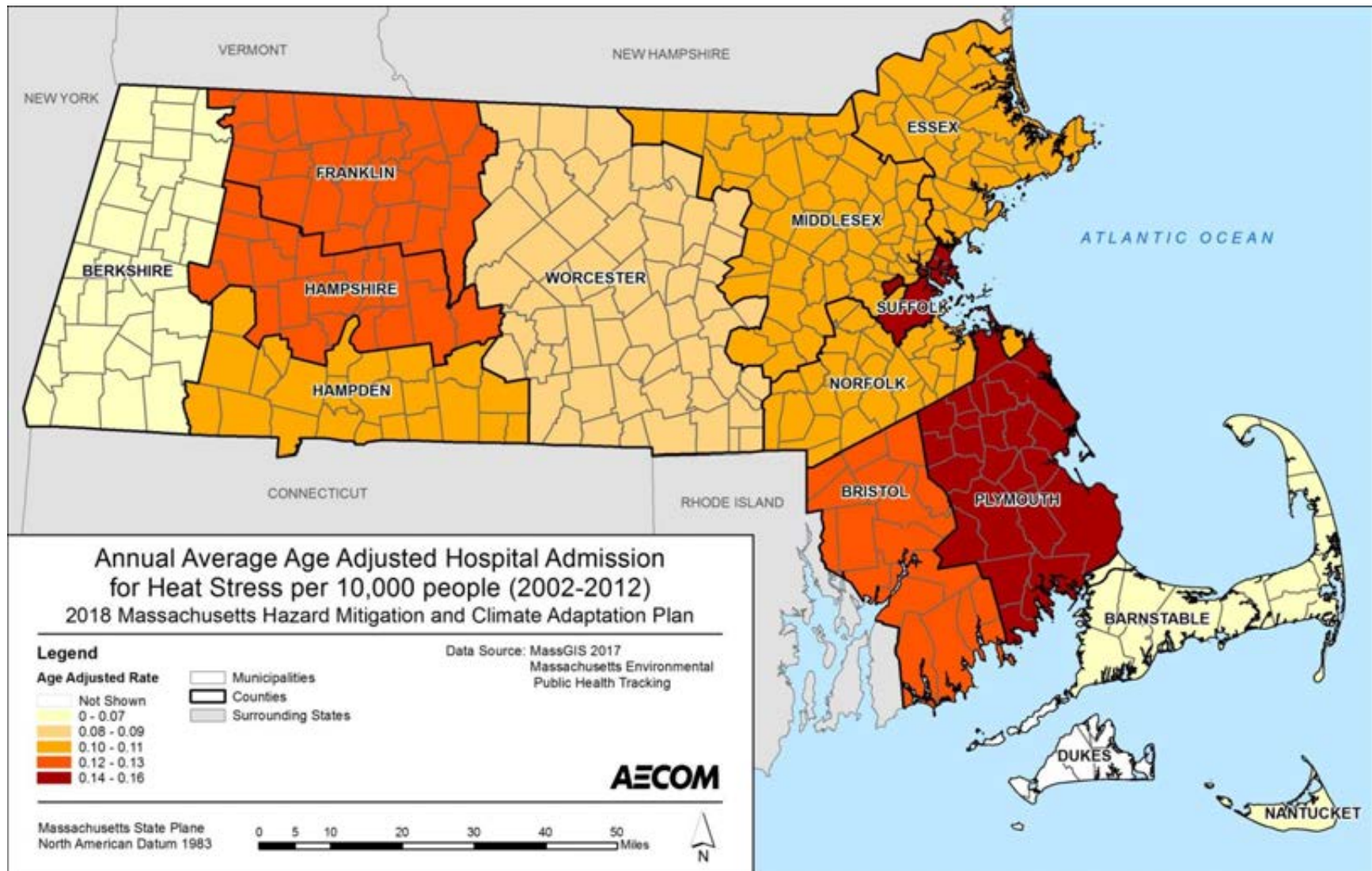


Figure 4-54: Rates of Hospital Admissions for Heart Attacks by County

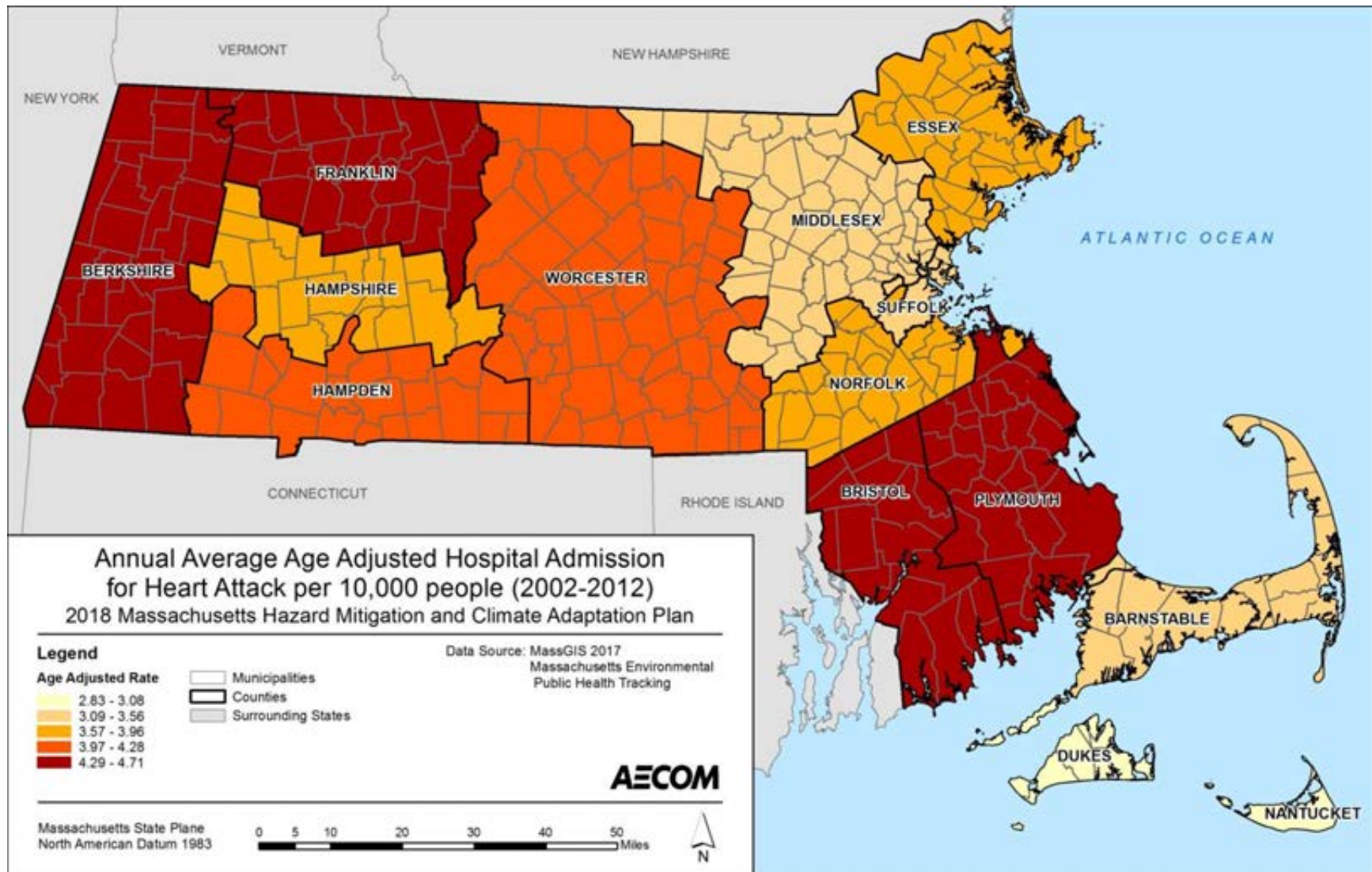
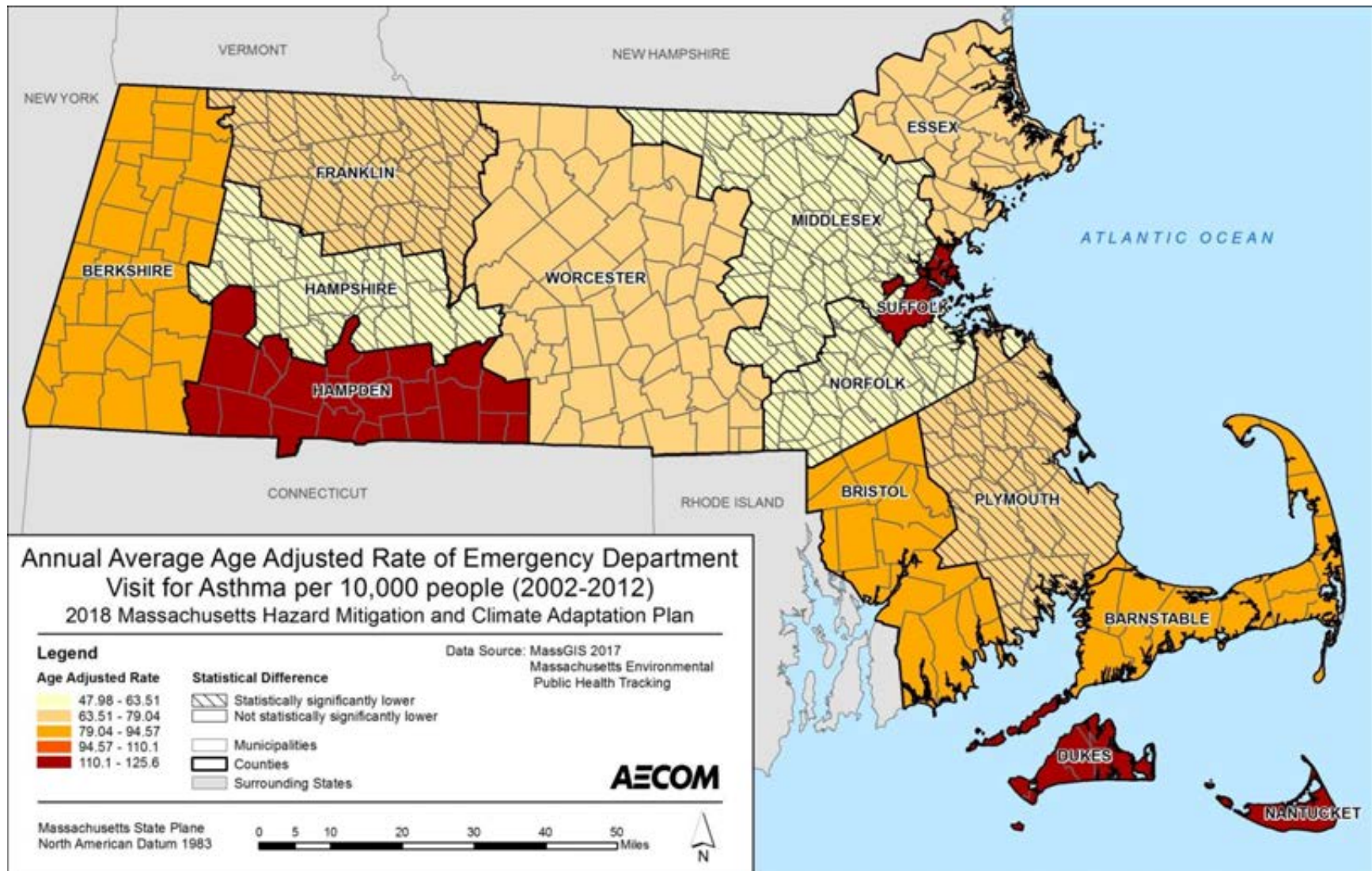


Figure 4-55: Rates of Emergency Department Visits Due to Asthma by County



Cold-weather events can also have significant health impacts. The most immediate of these impacts are cold-related injuries, such as frostbite and hypothermia, which can become fatal if exposure to cold temperatures is prolonged. Similar to the impacts of hot weather that have already been described, cold weather can exacerbate pre-existing respiratory and cardiovascular conditions. Additionally, power outages that occur as a result of extreme temperature events can be immediately life-threatening to those dependent on electricity for life support or other medical needs. Isolation of these populations is a significant concern if extreme temperatures preclude their mobility or the functionality of systems they depend on. Power outages during cold weather may also result in inappropriate use of combustion heaters, cooking appliances, and generators in indoor or poorly ventilated areas, leading to increased risk of carbon monoxide poisoning.

Government



All state-owned buildings are exposed to the extreme temperature hazard. Extreme heat will result in an increased demand for cooling centers and air conditioning. Extreme heat events can sometimes cause short periods of utility failure, commonly referred to as brownouts, due to increased usage of air conditioners, appliances, and other items requiring power.

Extreme cold temperature events can damage buildings through freezing or bursting pipes and freeze and thaw cycles. Additionally, manufactured buildings (trailers and mobile homes) and antiquated or poorly constructed facilities may not be able to withstand extreme temperatures. The heavy snowfall and ice storms associated with extreme cold temperature events can also cause power interruptions. Backup power is recommended for critical facilities and infrastructure.

The Built Environment



All elements of the built environment are exposed to the extreme temperature hazard, including state-owned critical facilities. The impacts of extreme heat on buildings include: increased thermal stresses on building materials, which leads to greater wear and tear and reduces a building's useful lifespan; increased air-conditioning demand to maintain a comfortable temperature; overheated heating, ventilation, and air-conditioning systems; and disruptions in service associated with power outages (resilient MA, 2018). Extreme cold can cause materials such as plastic to become less pliable, increasing the potential for these materials to break down during extreme cold events (resilient MA, 2018). In addition to the facility-specific impacts, extreme temperatures can impact critical infrastructure sectors of the built environment in a number of ways, which are summarized in the subsections that follow.

Agriculture

Above average, below average, and extreme temperatures are likely to impact crops—such as apples, cranberries, and maple syrup—that rely on specific temperature regimes (resilient MA,

2018). Unseasonably warm temperatures in early spring that are followed by freezing temperatures can result in crop loss of fruit-bearing trees. Farmers may have the opportunity to introduce new crops that are viable under warmer conditions and longer growing seasons; however, a transition such as this may be costly (resilient MA, 2018).

Energy

In addition to increasing demand for heating and cooling, periods of both hot and cold weather can stress energy infrastructure (resilient MA, 2018). Heat waves caused 2 of the 24 electric transmission outages (16 percent) reported by the North American Electric Reliability Corporation (NERC) between 1992 and 2009 (DOE, n.d.). Electricity consumption during summer may reach three times the average consumption rate of the period between 1960 and 2000; more than 25 percent of this consumption may be attributable to climate change (EOEEA, 2011). In addition to affecting consumption rates, high temperatures can also reduce the thermal efficiency of electricity generation (EOEEA, 2011).

Extended-duration extreme cold can lead to energy supply concerns, as the heating sector then demands a higher percentage of the natural gas pipeline capacity. When this occurs, New England transitions electricity generation from natural gas to oil and liquid natural gas. Limited on-site oil and liquid natural gas storage as well refueling challenges may cause energy supply concerns if the events are colder and longer in duration.

While extreme heat has not resulted in property loss in Massachusetts, winter storms and extreme cold have resulted in \$5.8 million in property damage per year, according to NOAA records for the period from 1996 to 2014 (DOE, n.d.).

Transportation

Extreme heat has potential impacts on the design and operation of the transportation system. Impacts on the design include the instability of materials, particularly pavement, exposed to high temperatures over longer periods of time, which can cause buckling and lead to increased failures (MassDOT, 2017). High heat can cause pavement to soften and expand, creating ruts, potholes, and jarring, and placing additional stress on bridge joints. Extreme heat may cause heat stress in materials such as asphalt and increase the frequency of repairs and replacements (resilient MA, 2018). Railroad tracks can expand in extreme heat, causing the track to “kink” and derail trains. Higher temperatures inside the enclosure-encased equipment, such as traffic control devices and signal control systems for rail service, may result in equipment failure.

Operations are vulnerable to heat waves and associated power outages that affect electrical power supply to rail operations and to supporting ancillary assets for highway operations, such as electronic signing. Peaks in power demand during hotter summer days could cause outages that affect electrified public transit (resilient MA, 2018). Increased heat also impacts transportation workers, the viability of vegetation in rights-of-way, and vehicle washing or maintenance

schedules (MassDOT, 2017). Hot weather increases the likelihood that cars may overheat during hot weather, and also increases the deterioration rate of tires.

High temperatures may also impact airplane operations. If the length of existing runways is not sufficient under higher temperature conditions, planes may not be able to take off when there is less lift available (MassDOT, 2017). High temperatures and dense air conditions could lead to increased runway length requirements for aircraft due to diminished performance in such conditions (resilient MA, 2018). Moreover, heat can soften the asphalt of airport runways, impairing airplane movement.

Rail operations will also be impacted when mandatory speed reductions are issued in areas where tracks have been exposed to high temperatures over many days, resulting in increased transit travel time and operating costs as well as a reduction in track capacity (MassDOT, 2017). Commuter tracks are also vulnerable to extreme heat. The impact of commuter rail failure due to high temperatures would require the use of long-distance bus bridges, with higher operating costs and increase transit times. Finally, extreme temperatures also discourage active modes of transportation, such as bicycling and walking (MassDOT, 2017). This will have a secondary impact on sustainable transportation objectives and public health.

Roads are also vulnerable to rapid freeze and thaw cycles, which may cause damage to road surfaces (resilient MA, 2018). An increase in freeze and thaw cycles can also damage bridge expansion joints.

Water Infrastructure

Extreme temperatures do not pose as great a threat to water infrastructure as flood-related hazards, but changes in temperature can impact water infrastructure. For example, extreme heat that drives increases in air-conditioning demand can trigger power outages that disrupt water and wastewater treatment (resilient MA, 2018). Hotter temperatures will also likely result in increased outdoor water consumption. Combined with other climate impacts such as an increase in surface water evapotranspiration, changing precipitation patterns, and groundwater recharge rates, increased water demand may challenge the capacity of water supplies and providers. Extreme heat can damage aboveground infrastructure such as tanks, reservoirs, and pump stations. Warmer temperatures can also lead to corrosion, water main breaks, and inflow and infiltration into water supplies (Jha and Pathak, 2016). Extreme heat is likely to result in increased drought conditions, and this has significant implications for water infrastructure, as discussed in Section 4.1.2.

Extreme cold can freeze pipes, causing them to burst. This can then lead to flooding and mold inside buildings when frozen pipes thaw.

Natural Resources and Environment



There are numerous ways in which changing temperatures will impact the natural environment. Because the species that exist in a given area have adapted to survive within a specific temperature range, extreme temperature events can place significant stress both on individual species and the ecosystems in which they function. High-elevation spruce-fir forests, forested boreal swamp, and higher-elevation northern hardwoods are likely to be highly vulnerable to climate change (MCCS and DFW, 2010). Higher summer temperatures will disrupt wetland hydrology. Paired with a higher incidence and severity of droughts, high temperatures and evapotranspiration rates could lead to habitat loss and wetlands drying out (MCCS and DFW, 2010). Individual extreme weather events usually have a limited long-term impact on natural systems, although unusual frost events occurring after plants begin to bloom in the spring can cause significant damage. However, the impact on natural resources of changing average temperatures and the changing frequency of extreme climate events is likely to be massive and widespread. Climate change is anticipated to be the second-greatest contributor to this biodiversity crisis, which is predicted to change global land use.

One significant impact of increasing temperatures may be the northern migration of plants and animals. Over time, shifting habitat may result in a geographic mismatch between the location of conservation land and the location of critical habitats and

Vegetation models predict that between 5% and 20% of the land area of the U.S. will experience a change in biome by 2100 (USGRP, 2014). One specific way in which average temperatures influence plant behavior is through changes in phenology, the pattern of seasonal life events in plants and animals. A recent study by the National Park Service found that of 276 parks studied, three-quarters are experiencing earlier spring conditions, as defined by the first greening of trees and first bloom of flowers, and half are experiencing an “extreme” early spring that exceeds 95% of historical conditions (NPS, 2016). These changing seasonal cues can lead to ecological mismatches, as plants and animals that rely on each other for ecosystem services become “out of sync.” For example, migratory birds that rely on specific food sources at specific times may reach their destinations before or after the species they feed on arrive or are in season. Additionally, invasive species tend to have more flexible phenologies than their native counterparts; therefore, shifting seasons may increase the competitiveness of present and introduced invasive species.

Wild plants and animals are also migrating away from their current habitats in search of the cooler temperatures to which they are accustomed. For example, species across the world have moved to higher elevations at a median rate of 36 feet per decade, and to higher latitudes at a rate of 10.5 miles per decade. This is particularly pertinent for ecosystems that (like many in the northeastern U.S.) lie on the border between two biome types. For example, an examination of the Green Mountains of Vermont found a 299- to 390-foot upslope shift in the boundary between northern hardwoods and boreal forests between 1964 and 2004 (USGRP, 2014). Such a shift is hugely significant for the species that live in this ecosystem as well as for forestry companies or others who rely on the continued presence of these natural resources. Massachusetts ecosystems that are expected to be particularly vulnerable to warming temperatures include:

- Coldwater streams and fisheries
- Vernal pools
- Spruce-fir forests
- Northern hardwood (Maple-Beech-Birch) forests, which are economically important due to their role in sugar production
- Hemlock forests, particularly those with the hemlock wooly adelgid
- Urban forests, which will experience extra impacts due to the urban heat island effect

species the conserved land was designed to protect. Between 1999 and 2018 (fiscal years), the Commonwealth spent more than \$395 million on the acquisition of more than 143,033 acres of land and has managed this land under the assumption of a stable climate. As species respond to climate change, they will likely continue to shift their ranges or change their phenologies to track optimal conditions (MCCS and DFW, 2010). As a result, climate change will have significant impacts on traditional methods of wildlife and habitat management, including land conservation and mitigation of non-climate stressors (MCCS and DFW, 2010). Changing temperatures, particularly increasing temperatures, will also have a major impact on the sustainability of our waterways and the connectivity of aquatic habitats (i.e., entire portions of major rivers will dry up, limiting fish passage down the rivers).

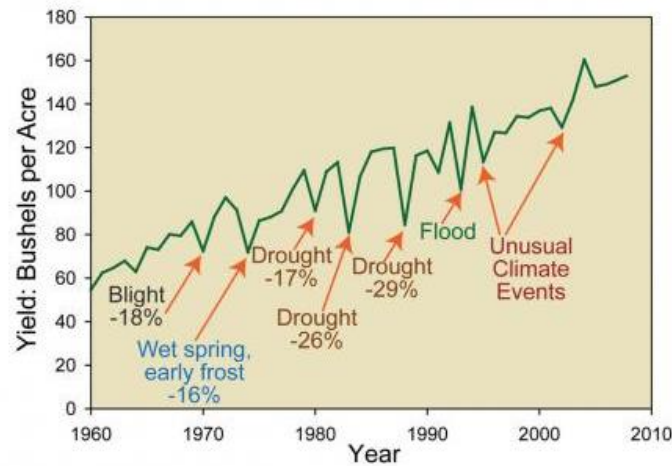
Additional impacts of warming temperatures include the increased survival and grazing damage of white-tailed deer, increased invasion rates of invasive plants, and increased survival and productivity of insect pests, which cause damage to forests (MCCS and DFW, 2010). As temperature increases, the length of the growing season will also increase. Since the 1960s, the growing season in Massachusetts increased by approximately 10 days (CAT, n.d.).

Economy

\$ Extreme temperature events also have impacts on the economy, including loss of business function and damage to and loss of inventory. Business owners may be faced with increased financial burdens due to unexpected building repairs (e.g., repairs for burst pipes), higher than normal utility bills, or business interruptions due to power failure (i.e., loss of electricity and telecommunications). Increased demand for water and electricity may result in shortages and a higher cost for these resources. Industries that rely on water for business (e.g., landscaping businesses) will also face significant impacts. There is a loss of productivity and income when the transportation sector is impacted and people and commodities cannot get to their intended destination. Even though most businesses will still be operational, they may be impacted aesthetically if extreme temperatures damage landscaping around their buildings. Businesses with employees that work outdoors (such as agricultural and construction companies) may have to reduce employees' exposure to the elements by reducing or shifting their hours to cooler or warmer periods of the day.

The agricultural industry is most directly at risk in terms of economic impact and damage due to extreme temperature and drought events. Extreme heat can result in drought and dry conditions, which directly impact livestock and crop production. Increasing average temperatures may make crops more susceptible to invasive species (see Section 4.3.3 for additional information). Higher temperatures that result in greater concentrations of ozone negatively impact plants that are sensitive to ozone (USGCRP, 2009). Additionally, as previously described, changing temperatures can impact the phenology. The impact of temperature anomalies and associated climate events on crop yields is shown in Figure 4-56.

Figure 4-56: Impact of Extreme Weather Events on U.S. Corn Yields, 1960 to 2008; Drought and Climate Events on Crop Yields



Source: USGCRP, 2009

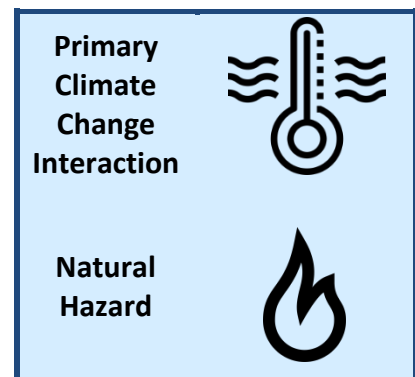
Livestock are also impacted, as heat stress can make animals more vulnerable to disease, reduce their fertility, and decrease the rate of milk production. Additionally, scientists believe the use of parasiticides and other animal treatments may increase as the threat of invasive species grows. Increased use of these treatments increases the risk of pesticides entering the food chain and could result in pesticide resistance, which could result in additional economic impacts on the agricultural industry.

4.3.2 Wildfires

GENERAL BACKGROUND

A wildfire can be defined as any non-structure fire that occurs in vegetative wildland that contains grass, shrub, leaf litter, and forested tree fuels. Wildfires in Massachusetts are caused by natural events, human activity, or prescribed fire. Wildfires often begin unnoticed but spread quickly, igniting brush, trees, and potentially homes.

The wildfire season in Massachusetts usually begins in late March and typically culminates in early June, corresponding with the driest live fuel moisture periods of the year. April is historically the month in which wildfire danger is the highest. Drought, snowpack level, and local weather conditions can impact the length of the fire season.







Natural Hazard Summary






WILDFIRE

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
A wildfire can be defined as any non-structure fire that occurs in the vegetative wildland, including grass, shrub, leaf litter, and forested tree fuels. Wildfires in Massachusetts are caused by natural events, human activity, or prescribed fire.	The ecosystems most susceptible to fire are pitch pine, scrub oak, and oak forests. According to a U.S. Forest Service study, Barnstable and Plymouth Counties are the most fire-prone due to their vegetation, sandy soil, and the presence of a drying wind.	Based on the frequency of past occurrences, the Commonwealth is likely to experience at least one wildfire with noteworthy damages each year.

Potential Effects of Climate Change

	RISING TEMPERATURES AND CHANGES IN PRECIPITATION ➔ PROLONGED DROUGHT	Seasonal drought risk is projected to increase during summer and fall in the Northeast as higher temperatures lead to greater evaporation and earlier winter and spring snowmelt, coupled with more variable precipitation patterns. Drought and warmer temperatures may also heighten the risk of wildfire, by causing forested areas to dry out and become more flammable.
	RISING TEMPERATURES ➔ MORE FREQUENT LIGHTNING	Research has found that the frequency of lightning strikes – an occasional cause of wildfires – could increase by approximately 12 percent for every degree Celsius of warming.

Exposure and Vulnerability by Key Sector 

	POPULATIONS	General At-Risk Population: Populations whose homes are located in wildfire hazard areas. Vulnerable Populations: Populations who are sensitive to smoke and poor air quality, including children, the elderly, and those with respiratory and cardiovascular diseases.
	GOVERNMENT	According to the DCAMM facility inventory, 1,143 state-owned buildings are located in identified wildfire hazard areas. The highest concentration of these facilities occurs in Middlesex (185) and Worcester (157) Counties.
	BUILT ENVIRONMENT	Fires can create conditions that block or prevent access and can isolate residents and emergency service providers. Power lines are the most at risk to wildfire because most poles are made of wood and susceptible to burning. In addition to potential direct losses to water infrastructure, wildfires may result in significant withdrawal of water supplies. They can also damage infrastructure elements such as power and communication lines. The DCAMM facility inventory revealed 176 critical facilities located in wildfire hazard areas, primarily in Worcester, Hampshire and Plymouth Counties.
	NATURAL RESOURCES AND ENVIRONMENT	Fire serves important ecological purposes; however, it can also cause environmental impacts. In addition to direct mortality, wildfires and the ash they generate can distort the flow of nutrients through an ecosystem, reducing the biodiversity that can be supported.
	ECONOMY	Wildfire events can have major economic impacts on a community, both from the initial loss of structures and the subsequent loss of revenue from destroyed business and decrease in tourism. Additionally, wildfires can require thousands of taxpayer dollars in fire response efforts.

Fire Ecology and Wildfire Behavior

The “wildfire behavior triangle” reflects how three primary factors influence wildfire behavior: fuel, topography, and weather. Each point of the triangle represents one of the three factors, and arrows along the sides represent the interplay between the factors. For example, drier and warmer weather with low relative humidity combined with dense fuel loads and steeper slopes can result in dangerous to extreme fire behavior.

How a fire behaves primarily depends on the characteristics of available fuel, weather conditions, and terrain, as described below.

- Fuel:
 - Lighter fuels such as grasses, leaves, and needles quickly expel moisture and burn rapidly, while heavier fuels such as tree branches, logs, and trunks take longer to warm and ignite.
 - Snags and hazard trees, especially those that are diseased or dying, become receptive to ignition when influenced by environmental factors such as drought, low humidity, and warm temperatures.
- Weather:
 - Strong winds, especially wind events that persist for long periods or ones with significant sustained wind speeds, can exacerbate extreme fire conditions or accelerate the spread of wildfire.
 - Dry spring and summer conditions, or drought at any point of the year, increases fire risk. Similarly, the passage of a dry, cold front through the region can result in sudden wind speed increases and changes in wind direction.
 - Thunderstorms in Massachusetts are usually accompanied by rainfall; however, during periods of drought, lightning from thunderstorm cells can result in fire ignition. Thunderstorms with little or no rainfall are rare in New England but have occurred.
- Terrain
 - Topography of a region or a local area influences the amount and moisture of fuel.
 - Barriers such as highways and lakes can affect the spread of fire.
 - Elevation and slope of landforms can influence fire behavior because fire spreads more easily uphill compared to downhill.

The wildland-urban interface is the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels. There are a number of reasons that the wildland-urban interface experiences an increased risk of wildfire

damage. Access and fire suppression issues on private property in the wildland-urban interface can make protecting structures from wildfires difficult. This zone also faces increased risk because structures are built in densely wooded areas, so fires started on someone's property are more easily spread to the surrounding forest.

Fire is also used extensively as a land management tool to replicate natural fire cycles, and it has been used to accomplish both fire-dependent ecosystem restoration and hazard fuel mitigation objectives on federal, state, municipal, and private lands in Massachusetts since the 1980s. Between 2009 and 2012, more than 1,300 acres of state and private partnership lands in the southeastern Massachusetts pitch pine and scrub oak forests were treated with prescribed fire. This project was designed to mitigate high-hazard fuel-loading in and around wildland-urban interface zones. Controlled burns continue to be conducted throughout the Commonwealth. For example, Westover Air Reserve Base uses this technique on several hundred acres each year to maintain healthy grasslands, reduce fuel for future fires, and remove weeds and invasive vegetation.

In Massachusetts, the DCR Bureau of Forest Fire Control is the state agency responsible for protecting 3.5 million acres of state, public, and private wooded land and for providing aid, assistance, and advice to the Commonwealth's cities and towns. The Bureau coordinates efforts with a number of entities, including fire departments, local law enforcement agencies, the Commonwealth's county and statewide civil defense agencies, and mutual aid assistance organizations.

Bureau units respond to all fires that occur on state-owned forestland and are available to municipal fire departments for mutual assistance. Bureau firefighters are trained in the use of forestry tools, water pumps, brush breakers, and other motorized equipment, as well as in fire behavior and fire safety. Massachusetts also benefits from mutual aid agreements with other state and federal agencies. The Bureau is a member of the Northeastern Forest Fire Protection Commission, a commission organized in 1949 by the New England states, New York, and four eastern Canadian Provinces to provide resources and assistance in the event of large wildfires. Massachusetts DCR also has a long-standing cooperative agreement with the U.S. Department of Agriculture's Forest Service both for providing qualified wildfire-fighters for assistance throughout the U.S. and for receiving federal assistance within the Commonwealth. Improved coordination and management efforts seem to be reducing the average damage from wildfire events. According to the Bureau's website, in 1911, more than 34 acres were burned on average during each wildfire. As of 2017, that figure has been reduced to 1.17 acres.

HAZARD PROFILE

Location

The ecosystems that are most susceptible to the wildfire hazard are pitch pine, scrub oak, and oak forests, as these areas contain the most flammable vegetative fuels. Other portions of the Commonwealth are also susceptible to wildfire, particularly at the urban-wildland interface, shown in Figure 4-57. The SILVIS Lab at the University of Wisconsin-Madison Department of Forest Ecology and Management classifies exposure to wildfire hazard as “interface” or “intermix.” Intermix communities are those where housing and vegetation intermingle and where the area includes more than 50 percent vegetation and has a housing density greater than one house per 16 hectares (approximately 6.5 acres). Interface communities are defined as those in the vicinity of contiguous vegetation, with more than one house per 40 acres and less than 50 percent vegetation, and within 1.5 miles of an area of more than 500 hectares (approximately 202 acres) that is more than 75 percent vegetated. These areas are shown in Figure 4-57. Inventoried assets (population, building stock, and critical facilities) were overlaid with these data to determine potential exposure and impacts related to this hazard.

The Northeast Wildfire Risk Assessment Geospatial Work Group completed a geospatial analysis of fire risk in the 20-state U.S. Forest Service Northeastern Area. The assessment is comprised of three components—fuels, wildland-urban interface, and topography (slope and aspect)—that are combined using a weighted overlay to identify wildfire-prone areas where hazard mitigation practices would be most effective. Figure 4-58 illustrates the areas identified for the Commonwealth. This spatial data set was not made available in time for inclusion in the 2018 SHMCAP. However, it is noted as data to be used to enhance the exposure and vulnerability assessment for further plan updates.

Figure 4-57: Wildland-Urban Interface and Intermix for the Commonwealth of Massachusetts

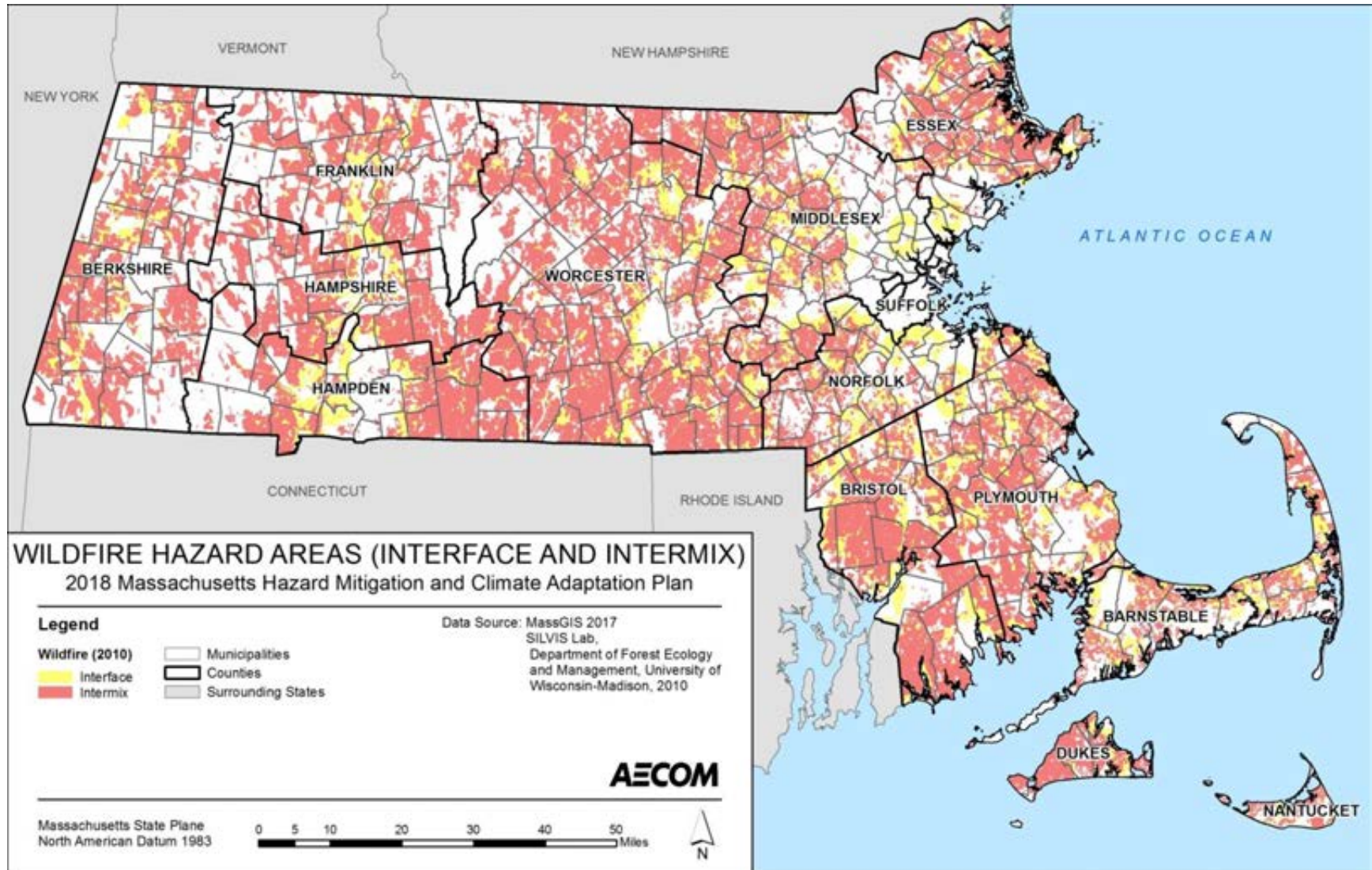
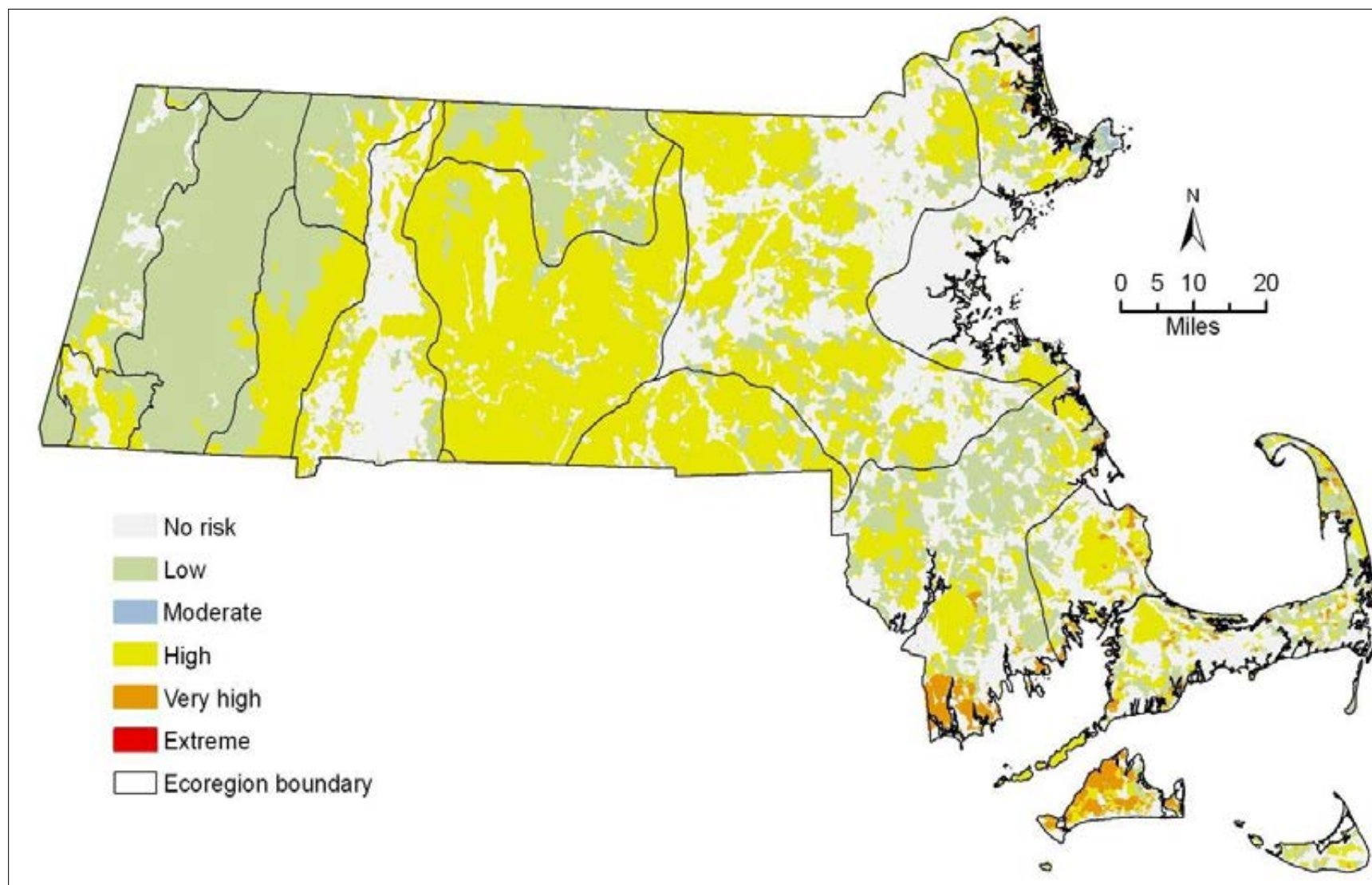


Figure 4-58: Wildfire Risk Areas for the Commonwealth of Massachusetts



Source: Northeast Wildfire Risk Assessment Geospatial Work Group, 2009

Previous Occurrences

Several notable wildfires have occurred in Massachusetts history, although none has ever resulted in a FEMA disaster declaration. Details on these historical events are provided in Appendix B.

Frequency of Occurrences

It is difficult to predict the likelihood of wildfires in a probabilistic manner because a number of factors affect fire potential and because some conditions (e.g., ongoing land use development patterns, location, and fuel sources) exert changing pressure on the wildland-urban interface zone. However, based on the frequency of past occurrences, interested parties should anticipate at least one notable wildfire in the Commonwealth each year.

Climate change has the potential to affect multiple elements of the wildfire system: fire behavior, ignitions, fire management, and vegetation fuels. Periods of hot, dry weather create the highest fire risk. Therefore, the predicted increase in average and extreme temperatures in the Commonwealth may intensify wildfire danger by warming and drying out vegetation. A recent study published in the *Proceedings of the National Academy of Sciences* found that climate change has likely been a significant contributor to the expansion of wildfires in the western U.S., which have nearly doubled in extent in the past 3 decades (Abatzoglou and Williams, 2016). Another study found that the frequency of lightning strikes—an occasional cause of wildfires—could increase by approximately 12 percent for every degree Celsius of warming (Romps et al., 2014). Finally, the year-round increase in temperatures is likely to expand the duration of the fire season.

Severity/Extent

The National Wildfire Coordinating Group defines seven classes of wildfires:

- Class A: 0.25 acre or less
- Class B: more than 0.25 acre, but less than 10 acres
- Class C: 10 acres or more, but less than 100 acres
- Class D: 100 acres or more, but less than 300 acres
- Class E: 300 acres or more, but less than 1,000 acres
- Class F: 1,000 acres or more, but less than 5,000 acres
- Class G: 5,000 acres or more.

Unfragmented and heavily forested areas of the state are vulnerable to wildfires, particularly during droughts. The greatest potential for significant damage to life and property from fire exists in areas designated as wildland-urban interface areas. A wildland-urban interface area defines the conditions where highly flammable vegetation is adjacent to developed areas.

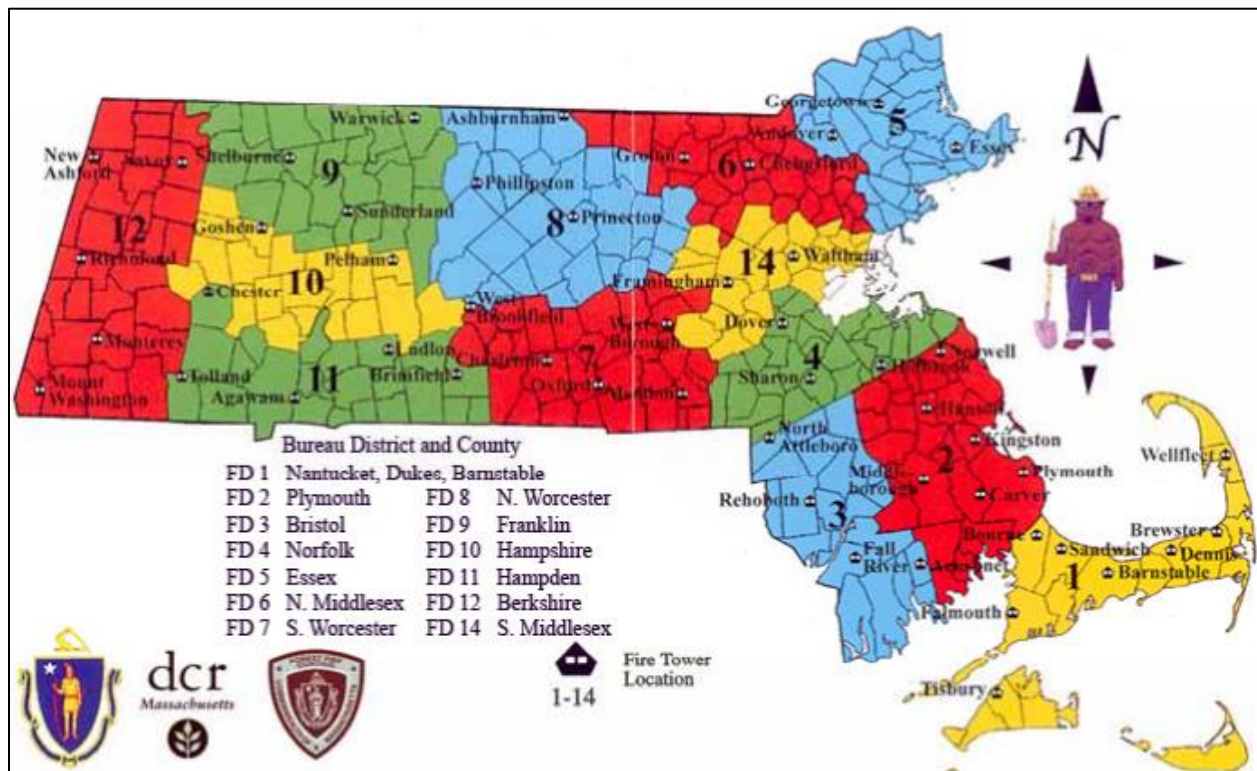
Fires can be classified by physical parameters such as their fireline intensity, or Byram's intensity, which is the rate of energy per unit length of the fire front (BTU [British thermal unit] per foot of fireline per second) (NPS, n.d.). Wildfires are also measured by their behavior,

including total heat release during burnout of fuels (BTU per square foot) and whether they are crown-, ground-, or surface-burning fires. Following a fire event, the severity of the fire can be measured by the extent of mortality and survival of plant and animal life aboveground and belowground and by the loss of organic matter (NPS, n.d.).

Warning Time

Early detection of wildfires is a key part of the Bureau's overall effort. Early detection is achieved by trained Bureau observers who staff the statewide network of 42 operating fire towers. During periods of high fire danger, the Bureau conducts county-based fire patrols in forested areas. These patrols assist cities and towns in prevention efforts and allow for the quick deployment of mobile equipment for suppression of fires during their initial stage. Figure 4-59 displays the Bureau's fire control districts and fire towers in Massachusetts.

Figure 4-59: Massachusetts Bureau of Forest Fire Control Districts and Tower Network



Source: Massachusetts Department of Conservation and Recreation, Bureau of Forest Fire Control, 2018

If a fire breaks out and spreads rapidly, residents may need to evacuate within days or hours. A fire's peak burning period generally is between 1 p.m. and 6 p.m. Once a fire has started, fire alerting is reasonably rapid in most cases. The rapid spread of cellular and two-way radio communications in recent years has further contributed to a significant improvement in warning time.

SECONDARY HAZARDS

Wildfires can generate a range of secondary effects, which in some cases may cause more widespread and prolonged damage than the fire itself. Wildfires cause the contamination of reservoirs; destroy power, gas, water, broadband, and oil transmission lines; and contribute to flooding. They strip slopes of vegetation, exposing them to greater amounts of runoff. This in turn can weaken soils and cause failures on slopes as well as water quality impacts in downstream water bodies. Major landslides can occur several years after a wildfire. Most wildfires burn hot, and they can bake soils for long periods of time, thus increasing the imperviousness of the ground. This increases the runoff generated by storm events and, as a result, the chance of flooding.

EXPOSURE AND VULNERABILITY

Populations



As demonstrated by historical wildfire events, potential losses from wildfire include human health and the lives of residents and responders. The most vulnerable populations include emergency responders and those within a short distance of the interface between the built environment and the wildland environment.

To estimate the population vulnerable to the wildfire hazard, the interface and intermix hazard areas were overlaid upon the 2010 U.S. Census population data. The Census blocks identified as interface or intermix were used to calculate the estimated population exposed to the wildfire hazard. In total, approximately 2.5 million people (or nearly 40 percent of the Commonwealth's total population) live within these zones. Table 4-46 summarizes the estimated population within the defined hazard areas by county.

Vulnerable Populations

All individuals whose homes or workplaces are located in wildfire hazard zones are exposed to this hazard, as wildfire behavior can be unpredictable and dynamic. However, the most vulnerable members of this population are those who would be unable to evacuate quickly, including those over the age of 65, households with young children under the age of 5, people with mobility limitations, and people with low socioeconomic status. Landowners with pets or livestock may face additional challenges in evacuating if they cannot easily transport their animals. Outside of the area of immediate impact, sensitive populations, such as those with compromised immune systems or cardiovascular or respiratory diseases, can suffer health impacts from smoke inhalation. Individuals with asthma are more vulnerable to the poor air quality associated with wildfire. Finally, firefighters and first responders are vulnerable to this hazard if they are deployed to fight a fire in an area they would not otherwise be in.

Table 4-46: 2010 Population in Wildfire Hazard Areas

County	Total Population	Interface	% Total	Intermix	% Total
Barnstable	215,888	62,190	28.8	48,289	22.4
Berkshire	131,219	55,486	42.3	39,171	29.9
Bristol	548,285	150,890	27.5	116,462	21.2
Dukes	16,535	6,007	36.3	7,453	45.1
Essex	743,159	174,121	23.4	84,446	11.4
Franklin	71,372	31,267	43.8	27,093	38.0
Hampden	463,490	76,147	16.4	61,462	13.3
Hampshire	158,080	59,161	37.4	52,177	33.0
Middlesex	1,503,085	314,100	20.9	132,353	8.8
Nantucket	10,172	6,161	60.6	2,552	25.1
Norfolk	670,850	164,684	24.5	73,965	11.0
Plymouth	494,919	145,314	29.4	130,761	26.4
Suffolk	722,023	16,035	2.2	211	0.0
Worcester	798,552	294,657	36.9	233,872	29.3
Total	6,547,629	1,556,220	23.8	1,010,267	15.4

Sources: 2010 U.S. Census; Radeloff et al., 2005

Health Impacts

Smoke and air pollution from wildfires can be a severe health hazard. Smoke generated by wildfire consists of visible and invisible emissions containing particulate matter (soot, tar, and minerals), gases (water vapor, carbon monoxide, carbon dioxide (CO₂), and nitrogen oxides), and toxics (formaldehyde and benzene). Emissions from wildfires depend on the type of fuel, the moisture content of the fuel, the efficiency (or temperature) of combustion, and the weather. Other public health impacts associated with wildfire include difficulty in breathing, reactions to odor, and reduction in visibility. Due to the high prevalence of asthma in Massachusetts, there is a high incidence of emergency department visits when respiratory irritants like smoke envelop an area. Wildfires may also threaten the health and safety of those fighting the fires. First responders are exposed to dangers from the initial incident and the aftereffects of smoke inhalation and heat-related illness.

Government



Wildfires may impact government structures and operations, including telecommunications. Table 4-47 summarizes the number of state-owned and state-leased buildings located in wildfire hazard areas (interface and intermix) within each

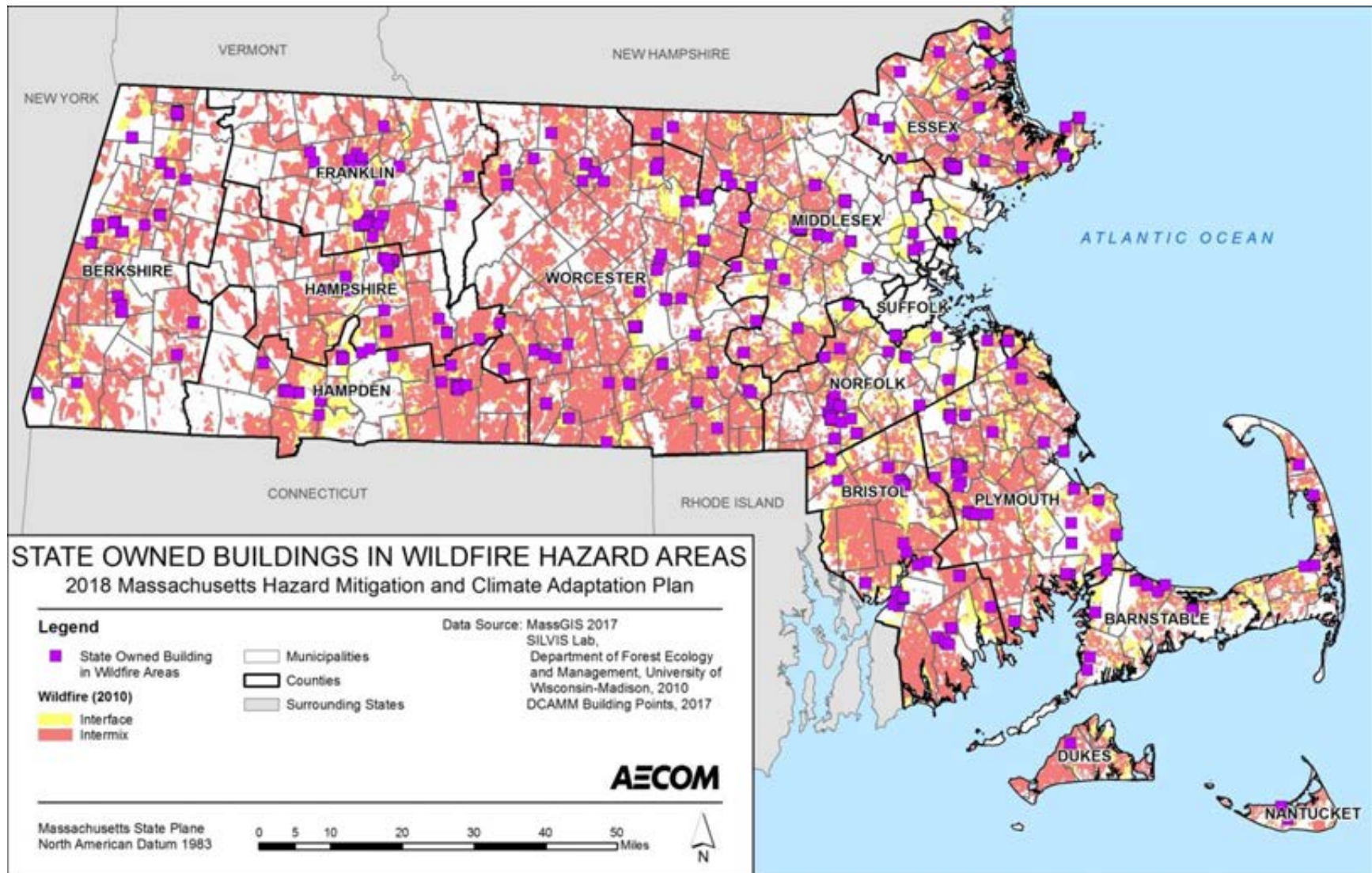
county and provides the total replacement value per DCAMM. This figure assumes 100 percent loss to each structure and its contents. This estimate is considered high because structure and content losses generally do not occur to the entire inventory exposed. Figure 4-60 illustrates the location of state-owned buildings in wildfire hazard areas.

Table 4-47: State-Owned Buildings in Wildfire Hazard Areas by County

County	Interface		Intermix		Total
	Count	Replacement Value	Count	Replacement Value	
Barnstable	6	\$15,875,021.92	26	\$25,127,350.51	32
Berkshire	62	\$303,781,234.77	52	\$54,777,558.66	114
Bristol	46	\$209,891,183.51	35	\$7,965,709.24	81
Dukes	—	N/A	1	Unknown	1
Essex	71	\$296,556,424.22	39	\$24,872,247.16	110
Franklin	39	\$132,474,036.21	21	\$17,331,124.34	60
Hampden	26	\$210,844,834.40	68	\$133,224,724.08	94
Hampshire	24	\$56,895,845.33	48	\$37,677,876.92	72
Middlesex	94	\$433,046,098.55	91	\$151,239,825.93	185
Nantucket	3	\$3,168,857.63	—	—	3
Norfolk	24	\$11,370,343.12	61	\$52,264,786.55	85
Plymouth	93	\$361,263,802.83	49	\$41,591,772.02	142
Suffolk	7	\$20,281,994.98	—	—	7
Worcester	56	\$508,109,234.46	101	\$158,111,672.22	157
Total	551	\$2,563,558,911.93	592	\$704,184,647.63	1143

Sources: DCAMM, 2017 (facility inventory); Radeloff et al., 2005

Figure 4-60: State-Owned Buildings in Wildfire Hazard Areas



Source: DCAMM, 2017 (facility inventory)

Given the limitations of this methodology, the mitigation strategy identifies activities that could advance the accuracy of the wildfire potential loss estimates. This includes state agency review and validation of the government structure data in terms of location as well as the replacement cost value of structures and their contents.

The Built Environment



For the purposes of this planning effort, all elements of the built environment located in the wildland interface and intermix areas are considered exposed to the wildfire hazard. Table 4-48 summarizes the number of critical facilities exposed to the wildfire hazard in the Commonwealth by type. Table 4-49 summarizes the number of critical facilities exposed to wildfire by county.

Table 4-48: Number of Critical Facilities Exposed to Wildfire by Facility Type

Type of Facility	Total	Interface	Intermix
Police Facilities	52	14	19
Military	19	7	6
Fire Department Facilities	12	—	6
Hospitals	1	1	—
Schools (K-12)	—	—	—
College Facilities	48	16	19
Social Services	44	14	18
Total	176	52	68

Sources: DCAMM, 2017 (facility inventory); Radeloff et al. 2005

Table 4-49: Number of Critical Facilities in Massachusetts Exposed to Wildfire by County

County	Total	Interface	Intermix
Barnstable	4	1	3
Berkshire	8	4	4
Bristol	3	1	2
Dukes	1	—	1
Essex	12	7	5
Franklin	7	4	3
Hampden	11	4	7
Hampshire	12	3	9
Middlesex	16	10	6
Nantucket	3	3	—

County	Total	Interface	Intermix
Norfolk	11	4	7
Plymouth	15	6	9
Suffolk	—	—	—
Worcester	17	5	12
Total	120	52	68

Sources: DCAMM, 2017 (facility inventory); Radeloff et al. 2005

Agriculture

While Massachusetts does not experience wildfires at the same magnitude as those in western states, wildfires do occur and are a threat to the agriculture sector. The forestry industry is especially vulnerable to wildfires. Barns, other wooden structures, and animals and equipment in these facilities are susceptible to wildfires.

Energy

Distribution lines are subject to wildfire risk because most poles are made of wood and susceptible to burning. Transmission lines are at risk to faulting during wildfires, which can result in a broad area outage. In the event of a wildfire, pipelines could provide a source of fuel and lead to a catastrophic explosion.

Public Health

As discussed in the *Populations* section of the wildfire hazard profile, wildfires impact air quality and public health. Widespread air quality impairment can lead to overburdened hospitals.

Public Safety

Wildfire is a threat to emergency responders and all infrastructure within the vicinity of a wildfire.

Transportation

Most road and railroads would be without damage except in the worst scenarios. However, fires can create conditions that block or prevent access, and they can isolate residents and emergency service providers.

The wildfire hazard typically does not have a major direct impact on bridges, but wildfires can create conditions in which bridges are obstructed. The default Hazus highway bridge inventory developed from the 2001 NBI database was used for this analysis. Table 4-50 identifies the number of highway bridges in the Hazus default highway bridge inventory exposed to the wildland interface and intermix areas; 1,298 bridges are located within the hazard areas, or 27 percent of the total Massachusetts inventory in Hazus (4,832 bridges).

Table 4-50: Number of Bridges in Massachusetts Exposed to Wildfire by County

County	Total	Interface	Intermix
Barnstable	25	11	14
Berkshire	209	84	125
Bristol	76	35	41
Dukes	2	—	2
Essex	41	18	23
Franklin	126	49	77
Hampden	127	46	81
Hampshire	128	38	90
Middlesex	80	36	44
Nantucket	1	—	1
Norfolk	52	36	16
Plymouth	82	28	54
Suffolk	7	6	1
Worcester	342	138	204
Total	1,298	525	773

Source: National Bridge Inventory

Water Infrastructure

In addition to potential direct losses to water infrastructure, wildfires may result in significant withdrawal of water supplies. Coupled with the increased likelihood that drought and wildfire will coincide under the future warmer temperatures associated with climate change, this withdrawal may result in regional water shortages and the need to identify new water sources.

Natural Resources and Environment



Fire is a natural part of many ecosystems and serves important ecological purposes, including facilitating the nutrient cycling from dead and decaying matter, removing diseased plants and pests, and regenerating seeds or stimulating germination of certain plants. However, many wildfires, particularly man-made wildfires, can also have significant negative impacts on the environment. In addition to direct mortality, wildfires and the ash they generate can distort the flow of nutrients through an ecosystem, reducing the biodiversity that can be supported.

Frequent wildfires can eradicate native plant species and encourage the growth of fire-resistant invasive species. Some of these invasive species are highly flammable; therefore, their establishment in an area increases the risk of future wildfires. There are other possible feedback loops associated with this hazard. For example, every wildfire contributes to atmospheric CO₂

accumulation, thereby contributing to global warming and increasing the probability of future wildfires (as well as other hazards). There are also risks related to hazardous material releases during a wildfire. During wildfires, containers storing hazardous materials could rupture due to excessive heat and act as fuel for the fire, causing rapid spreading of the wildfire and escalating it to unmanageable levels. In addition, these materials could leak into surrounding areas, saturating soils and seeping into surface waters to cause severe and lasting environmental damage.

Economy

\$ Wildfire events can have major economic impacts on a community, both from the initial loss of structures and the subsequent loss of revenue from destroyed businesses and a decrease in tourism. Individuals and families also face economic risk if their home is impacted by wildfire. The exposure of homes to this hazard is widespread. According to the characterization of wildland hazard areas by Radeloff et al., the Massachusetts intermix hazard area contains 476,934 housing units (or approximately 17 percent of the total housing units in the Commonwealth). The interface hazard area contains 715,209 housing units (or approximately 26 percent of the total housing units in the Commonwealth). Additionally, wildfires can require thousands of taxpayer dollars in fire response efforts and can involve hundreds of operating hours on fire apparatus and thousands of man-hours from volunteer firefighters. There are also many direct and indirect costs to local businesses that excuse volunteers from work to fight these fires.

To estimate the total potential loss of buildings in the Commonwealth, the wildfire hazard areas were overlaid upon the default general building stock in Hazus. Table 4-51 summarizes the estimated replacement cost value of the Commonwealth's general building stock located in the interface and intermix hazard areas, summarized by county.

Table 4-51: Estimated Potential Building Loss (Structure and Content) in the Wildland Interface and Intermix

County	Total	Interface	% of Total	Intermix	% of Total
Barnstable	\$47,450,250,000	\$21,304,885,000	44.9	\$24,558,487,000	51.8
Berkshire	\$20,566,219,000	\$15,329,205,000	74.5	\$12,350,966,000	60.1
Bristol	\$74,946,506,000	\$36,068,531,000	48.1	\$30,293,572,000	40.4
Dukes	\$4,894,499,000	\$3,100,639,000	63.3	\$3,219,756,000	65.8
Essex	\$100,099,771,000	\$38,480,980,000	38.4	\$28,948,292,000	28.9
Franklin	\$10,130,548,000	\$8,464,330,000	83.6	\$7,054,574,000	69.6
Hampden	\$67,212,508,000	\$19,614,174,000	29.2	\$18,883,677,000	28.1
Hampshire	\$20,961,384,000	\$15,678,408,000	74.8	\$11,679,123,000	55.7
Middlesex	\$244,161,008,000	\$79,306,788,000	32.5	\$57,977,573,000	23.7

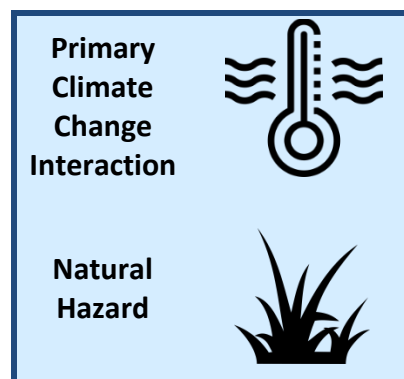
County	Total	Interface	% of Total	Intermix	% of Total
Nantucket	\$3,610,072,000	\$3,364,579,000	93.2	\$1,627,659,000	45.1
Norfolk	\$111,344,832,000	\$42,949,345,000	38.6	\$34,254,477,000	30.8
Plymouth	\$70,614,087,000	\$40,612,784,000	57.5	\$40,616,831,000	57.5
Suffolk	\$115,439,212,000	\$2,307,078,000	2.0	\$519,563,000	0.5
Worcester	\$112,858,251,000	\$69,937,235,000	62.0	\$55,933,034,000	49.6
Total	\$1,004,289,147,000	\$396,518,961,000	39.5	\$327,917,584,000	32.7

Source: FEMA Hazus loss estimation methodology

4.3.3 Invasive Species

GENERAL BACKGROUND

Invasive species are defined as non-native species that cause or are likely to cause harm to ecosystems, economies, and/or public health (NISC 2006). The focus of this section is on invasive terrestrial plants, as this is the most studied and managed type of invasive; information for invasive aquatic flora and fauna (including marine species) is also provided when relevant.



The Massachusetts Invasive Plant Advisory Group (MIPAG), a collaborative representing organizations and professionals concerned with the conservation of the Massachusetts landscape, is charged by EOEEA to provide recommendations to the Commonwealth to manage invasive species. MIPAG defines invasive plants as "non-native species that have spread into native or minimally managed plant systems in Massachusetts, causing economic or environmental harm by developing self-sustaining populations and becoming dominant and/or disruptive to those systems" (MIPAG, n.d.). These species have biological traits that provide them with competitive advantages over native species, particularly because in a new habitat they are not restricted by the biological controls of their native habitat. As a result, these invasive species can monopolize natural communities, displacing many native species and causing widespread economic and environmental damage.



Natural Hazard Summary

INVASIVE SPECIES

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
Invasive species are intentionally or non-intentionally introduced into local ecosystems.	Invasive species represent a threat to native or minimally managed ecosystems throughout Massachusetts.	Increased rates of global trade and travel have created new pathways for the dispersion of exotic species, increasing the frequency with which these species are introduced.

Potential Effects of Climate Change

	RISING TEMPERATURES ➔ WARMING CLIMATE	A warming climate may place stress on colder-weather species, while allowing non-native species accustomed to warmer climates to spread northward.
	RISING TEMPERATURES AND CHANGES IN PRECIPITATION ➔ ECOSYSTEM STRESS	Changes in precipitation and temperature combine to create new stresses for Massachusetts' unique ecosystems. For example, intense rainfall in urbanized areas can cause pollutants on roads and parking lots to get washed into nearby rivers and lakes, reducing habitat quality. As rainfall and snowfall patterns change, certain habitats and species that have specific physiological requirements may be affected. The stresses experienced by native ecosystems as a result of these changes may increase the chances of a successful invasion of non-native species.

Exposure and Vulnerability by Key Sector

	POPULATIONS	General At-Risk Population: State-wide exposure. Vulnerable Populations: Populations who depend on the Commonwealth's existing ecosystems for their economic success.
	GOVERNMENT	State-managed water bodies and reservoirs could be exposed to the zebra mussel if knowingly or unknowingly introduced from other areas. This prolific invasive species can clog water infrastructure and cause extensive ecological, economic, and social impacts. Invasive species also impacting state wildlife management areas.
	BUILT ENVIRONMENT	As described above, water bodies such as reservoirs could be exposed to the zebra mussel if it is introduced. Invasive species can pose a threat along roadways by impeding sight lines if left unchecked. More pest pressure from insects, diseases, and weeds may harm crops and cause farms to increase pesticide use. Species like zebra mussels can damage aquatic infrastructure and vessels. Invasive species may cause impacts to water quality, which would have implications for the drinking water supplies and the cost of treatment.
	NATURAL RESOURCES AND ENVIRONMENT	Invasive species present a significant threat to the environment and natural resources present in the Commonwealth. Research has found that competition or predation by alien species is the second most significant threat to biodiversity, only surpassed by direct habitat destruction or degradation.
	ECONOMY	Invasive species are widely considered to be one of the most costly natural hazards in the United States, as invasive control efforts can be quite extensive and these species can damage crops, recreational amenities, and public goods such as water quality.

MIPAG recognized 69 plant species as "Invasive," "Likely Invasive," or "Potentially Invasive." The criteria for an "Invasive" species are listed below; the other assigned categories are associated with lower scores on the criteria checklist. The criteria for invasive animal species are less well-defined, but many of the same characteristics (including a non-Massachusetts origin and the ability to out-compete native species) are similar. In order to be considered "Invasive" by MIPAG, a plant species must meet the following criteria:

- Be nonindigenous to Massachusetts.
- Have the biologic potential for rapid and widespread dispersion and establishment in minimally managed habitats.
- Have the biologic potential for dispersing over spatial gaps away from the site of introduction.
- Have the biologic potential for existing in high numbers away from intensively managed artificial habitats.
- Be naturalized in Massachusetts (persists without cultivation in Massachusetts).
- Be widespread in Massachusetts or at least common in a region or habitat in the state.
- Have many occurrences of numerous individuals in Massachusetts that have high numbers of individuals forming dense stands in minimally managed habitats.
- Be able to outcompete other species in the same natural plant community.
- Have the potential for rapid growth, for high seed or propagule production and dissemination, and for establishment in natural plant communities (MIPAG, 2016)

Regulation on Invasive Species

Massachusetts has a variety of laws and regulations in place that attempt to mitigate the impacts of these species. The Department of Agricultural Resources (DAR) maintains a list of prohibited plants for the state, which includes federally noxious weeds as well as invasive plants recommended by MIPAG and approved for listing by DAR. Species on the DAR list are regulated with prohibitions on importation, propagation, purchase, and sale in the Commonwealth. Additionally, the Massachusetts Wetlands Protection Act (310 CMR 10.00) includes language requiring all activities covered by the Act to account for, and take steps to prevent, the introduction or propagation of invasive species. More about this can be found in the state capability and adaptive capacity section of this plan (Chapter 6).

In 2000, Massachusetts passed an Aquatic Invasive Species Management Plan, making the Commonwealth eligible for federal funds to support and implement the plan through the federal Aquatic Nuisance Prevention and Control Act. MassDEP and CZM are part of the Northeast

Aquatic Nuisance Species Panel, which was established under the federal Aquatic Nuisance Species Task Force. This panel allows managers and researchers to exchange information and coordinate efforts on the management of aquatic invasive species. The Commonwealth also has several resources pertaining to terrestrial invasive species, such as the Massachusetts Introduced Pest Outreach Project, although a strategic management plan has not yet been prepared for these species. More specific regulations are discussed below.

Code of Massachusetts Regulation (CMR) 330 CMR 6.0(d) requires any seed mix containing restricted noxious weeds to specify the name and number per pound on the seed label. Regulation 339 CMR 9.0 restricts the transport of currant or gooseberry species in an attempt to prevent the spread of white pine blister rust.

There are also a number of state laws pertaining to invasive species. Chapters 128, 130, and 132 of Part I of the General Laws of the state include language addressing water chestnuts, green crabs, the Asian longhorn beetle, and a number of other species. These laws also include language allowing orchards and gardens to be surveyed for invasive species and for quarantines to be put into effect at any time.

HAZARD PROFILE

Location

The damage rendered by invasive species is significant. Experts estimate that about 3 million acres within the U.S. (an area twice the size of Delaware) are lost each year to invasive plants (Pulling Together, 1997, from Mass.gov “Invasive Plant Facts”). The massive scope of this hazard means that the entire Commonwealth experiences impacts from these species.

Furthermore, the ability of invasive species to travel far distances (either via natural mechanisms or accidental human interference) allows these species to propagate rapidly over a large geographic area. Similarly, in open freshwater and marine ecosystems, invasive species can quickly spread once introduced, as there are generally no physical barriers to prevent establishment, outside of physiological tolerances, and multiple opportunities for transport to new locations (by boats, for example).

Previous Occurrences

The terrestrial, freshwater, and marine species listed on the MIPAG website as “Invasive” (last updated April 2016) are listed in Table 4-52. The table also includes details on the nature of the ecological and economic challenges presented by each species as well as information on when and where the species was first detected in Massachusetts.

Table 4-52: Invasive Species (Flora) in Massachusetts

Species	Common name	Notes
Terrestrial/Freshwater		
<i>Acer platanoides</i>	Norway maple	A tree occurring in all regions of the state in upland and wetland habitats, and especially common in woodlands with colluvial soils. It grows in full sun to full shade. Escapes from cultivation; can form dense stands; outcompetes native vegetation, including sugar maples; dispersed by wind, water, and vehicles.
<i>Acer pseudoplatanus</i>	Sycamore maple	A tree occurring mostly in southeastern counties of Massachusetts, primarily in woodlands and especially near the coast. It grows in full sun to partial shade. Escapes from cultivation inland as well as along the coast; salt-spray tolerant; dispersed by wind, water, and vehicles.
<i>Aegopodium podagraria</i>	Bishop's goutweed, bishop's weed; goutweed	A perennial herb occurring in all regions of the state in uplands and wetlands. Grows in full sun to full shade. Escapes from cultivation; spreads aggressively by roots; forms dense colonies in floodplains.
<i>Ailanthus altissima</i>	Tree of Heaven	This tree occurs in all regions of the state in upland, wetland, and coastal habitats. Grows in full sun to full shade. Spreads aggressively from root suckers, especially in disturbed areas.
<i>Alliaria petiolata</i>	Garlic mustard	A biennial herb occurring in all regions of the state in uplands. Grows in full sun to full shade. Spreads aggressively by seed, especially in wooded areas.
<i>Berberis thunbergii</i>	Japanese barberry	A shrub occurring in all regions of the state in open and wooded uplands and wetlands. Grows in full sun to full shade. Escapes from cultivation; spread by birds; forms dense stands.
<i>Cabomba caroliniana</i>	Carolina fanwort; fanwort	A perennial herb occurring in all regions of the state in aquatic habitats. Common in the aquarium trade; chokes waterways.
<i>Celastrus orbiculatus</i>	Oriental bittersweet; Asian or Asiatic bittersweet	A perennial vine occurring in all regions of the state in uplands. Grows in full sun to partial shade. Escapes from cultivation; berries spread by birds and humans; overwhelms and kills vegetation.
<i>Cynanchum louiseae</i>	Black swallow-wort; Louise's swallow-wort	A perennial vine occurring in all regions of the state in upland, wetland, and coastal habitats. Grows in full sun to partial shade. Forms dense stands, outcompeting native species: deadly to Monarch butterflies.
<i>Elaeagnus umbellata</i>	Autumn olive	A shrub occurring in uplands in all regions of the state. Grows in full sun. Escapes from cultivation; berries spread by birds; aggressive in open areas; has the ability to change soil.
<i>Euonymus alatus</i>	Winged euonymus, burning bush	A shrub occurring in all regions of the state and capable of germinating prolifically in many different habitats. It grows in full sun to full shade. Escapes from cultivation and can form dense thickets and dominate the understory; seeds are dispersed by birds.
<i>Euphorbia esula</i>	Leafy spurge; wolf's milk	A perennial herb occurring in all regions of the state in grasslands and coastal habitats. Grows in full sun. An aggressive herbaceous perennial and a notable problem in the western U.S..

Species	Common name	Notes
<i>Frangula alnus</i>	European buckthorn, glossy buckthorn	Shrub or tree occurring in all regions of the state in upland, wetland, and coastal habitats. Grows in full sun to full shade. Produces fruit throughout the growing season; grows in multiple habitats; forms thickets.
<i>Glaucium flavum</i>	Sea or horned poppy, yellow hornpoppy	A biennial and perennial herb occurring in southeastern MA in coastal habitats. Grows in full sun. Seeds float; spreads along rocky beaches; primarily Cape Cod and Islands.
<i>Hesperis matronalis</i>	Dame's rocket	A biennial and perennial herb occurring in all regions of the state in upland and wetland habitats. Grows in full sun to full shade. Spreads by seed; can form dense stands, particularly in floodplains.
<i>Iris pseudacorus</i>	Yellow iris	A perennial herb occurring in all regions of the state in wetland habitats, primarily in floodplains. Grows in full sun to partial shade. Outcompetes native plant communities.
<i>Lepidium latifolium</i>	Broad-leaved pepperweed, tall pepperweed	A perennial herb occurring in eastern and southeastern regions of the state in coastal habitats. Grows in full sun. Primarily coastal at upper edge of wetlands; also found in disturbed areas; salt tolerant.
<i>Lonicera japonica</i>	Japanese honeysuckle	A perennial vine occurring in all regions of the state in upland, wetland, and coastal habitats. Grows in full sun to full shade. Rapidly growing, dense stands climb and overwhelm native vegetation; produces many seeds that are dispersed by birds; more common in southeastern Massachusetts.
<i>Lonicera morrowii</i>	Morrow's honeysuckle	A shrub occurring in all regions of the state in upland, wetland, and coastal habitats. Grows in full sun to full shade. Part of a confusing hybrid complex of non-native honeysuckles commonly planted and escaping from cultivation via bird dispersal.
<i>Lonicera x bella</i> [<i>morrowii</i> x <i>tatarica</i>]	Bell's honeysuckle	This shrub occurs in all regions of the state in upland, wetland, and coastal habitats. Grows in full sun to full shade. Part of a confusing hybrid complex of non-native honeysuckles commonly planted and escaping from cultivation via bird dispersal.
<i>Lysimachia nummularia</i>	Creeping jenny, moneywort	A perennial herb occurring in all regions of the state in upland and wetland habitats. Grows in full sun to full shade. Escaping from cultivation; problematic in floodplains, forests and wetlands; forms dense mats.
<i>Lythrum salicaria</i>	Purple loosestrife	A perennial herb or subshrub occurring in all regions of the state in upland and wetland habitats. Grows in full sun to partial shade. Escaping from cultivation; overtakes wetlands; high seed production and longevity.
<i>Myriophyllum heterophyllum</i>	Variable water-milfoil; two-leaved water-milfoil	A perennial herb occurring in all regions of the state in aquatic habitats. Chokes waterways, spread by humans and possibly birds.
<i>Myriophyllum spicatum</i>	Eurasian or European water-milfoil; spike water-milfoil	A perennial herb found in all regions of the state in aquatic habitats. Chokes waterways, spread by humans and possibly birds.
<i>Phalaris arundinacea</i>	Reed canary-grass	This perennial grass occurs in all regions of the state in wetlands and open uplands. Grows in full sun to partial shade. Can form huge colonies and overwhelm wetlands; flourishes in disturbed areas; native and introduced strains; common in agricultural settings and in forage crops.

Species	Common name	Notes
<i>Phragmites australis</i>	Common reed	A perennial grass (USDA lists as subshrub, shrub) found in all regions of the state. Grows in upland and wetland habitats in full sun to full shade. Overwhelms wetlands forming huge, dense stands; flourishes in disturbed areas; native and introduced strains.
<i>Polygonum cuspidatum</i> / <i>Fallopia japonica</i>	Japanese knotweed; Japanese or Mexican bamboo	A perennial herbaceous subshrub or shrub occurring in all regions of the state in upland, wetland, and coastal habitats. Grows in full sun to full shade, but hardier in full sun. Spreads vegetatively and by seed; forms dense thickets.
<i>Polygonum perfoliatum</i>	Mile-a-minute vine or weed; Asiatic tearthumb	This annual herbaceous vine is currently known to exist in several counties in MA, and has also has been found in RI and CT. Habitats include streamsides, fields, and road edges in full sun to partial shade. Highly aggressive; bird and human dispersed.
<i>Potamogeton crispus</i>	Crisped pondweed, curly pondweed	A perennial herb occurring in all regions of the state in aquatic habitats. Forms dense mats in the spring and persists vegetatively.
<i>Ranunculus ficaria</i>	Lesser celandine; fig buttercup	A perennial herb occurring on stream banks, and in lowland and uplands woods in all regions of the state. Grows in full sun to full shade. Propagates vegetatively and by seed; forms dense stands, especially in riparian woodlands; an ephemeral that outcompetes native spring wildflowers.
<i>Rhamnus cathartica</i>	Common buckthorn	A shrub or tree occurring in all regions of the state in upland and wetland habitats. Grows in full sun to full shade. Produces fruit in fall; grows in multiple habitats; forms dense thickets.
<i>Robinia pseudoacacia</i>	Black locust	A tree that occurs in all regions of the state in upland habitats. Grows in full sun to full shade. While the species is native to central portions of Eastern North America, it is not indigenous to MA. It has been planted throughout the state since the 1700s and is now widely naturalized. It behaves as an invasive species in areas with sandy soils.
<i>Rosa multiflora</i>	Multiflora rose	A perennial vine or shrub occurring in all regions of the state in upland, wetland, and coastal habitats. Grows in full sun to full shade. Forms impenetrable thorny thickets that can overwhelm other vegetation; bird dispersed.
<i>Salix atrocinerea</i> / <i>Salix cinerea</i>	Rusty Willow/Large Gray Willow complex	A large shrub or small tree most commonly found in the eastern and southeastern areas of the state, with new occurrences being reported further west. Primarily found on pond shores but is also known from other wetland types and rarely uplands. Forms dense stands and can outcompete native species along the shores of coastal plain ponds.
<i>Trapa natans</i>	Water chestnut	An annual herb occurring in the western, central, and eastern regions of the state in aquatic habitats. Forms dense floating mats on water.

Species	Common name	Notes
Marine		
<i>Codium fragile ssp. fragile</i>	Codium	This alga is distributed along nearly the entire coastline of the eastern United States. It was most likely introduced to Massachusetts waters with oysters transplanted from Long Island Sound in the mid-20th century. It now covers a region from the Gulf of St. Lawrence, Canada, to North Carolina. It attaches to nearly any hard surface, increasing maintenance labor for aquaculturists and reducing the productivity of cultured species. It can also cause its host shellfish to detach. This species outcompetes many native species, such as kelp, that serve as shelters for fish and invertebrate species.
<i>Colpomenia peregrina</i>	Sea potato (brown seaweed)	<i>C. peregrina</i> was first reported in Massachusetts waters in 2011. It looks similar to the native <i>Leathesia marina</i> and forms a bubble as it grows, often attaching to other seaweeds. First observed in Nova Scotia in 1960, it has made its way south into Maine, New Hampshire, and Massachusetts. The impacts to Massachusetts waters are unclear at this time, but its tendency to grow on native seaweeds, shellfish, and other species could lead to shading and other competitive impacts.
<i>Grateloupia turuturu</i>	Red algae	This red alga, native to Asia, was first observed in Rhode Island in 1994. Since then it has expanded northward and was first recorded in Massachusetts in 2007; is continuing to spread northward at this time. This species can grow rapidly, producing large blades capable of covering other seaweed species in the intertidal and subtidal environments.
<i>Dasyatispongia japonica</i>	Red filamentous algae	This red filamentous alga, native to Asia, is widespread across Europe, likely introduced there as a hitchhiker on oysters for aquaculture. It was first observed on the coast of Rhode Island in 2009, then found in Massachusetts in 2010. In the spring and summer of 2012, this species in particular received much attention and press reports of masses washing up on beaches. As it is difficult to identify, these reports have not been substantiated. This species is likely expanding its distribution along the coast of Massachusetts, and research on the impacts to native species is ongoing.
<i>Neosiphonia harveyi</i>	Red filamentous algae	This invasive red filamentous alga was misidentified as a native species for nearly 150 years, highlighting the difficulty in identifying many non-native seaweed species. The increase in the invasive green algae <i>Codium</i> has helped pave the way for this red filamentous alga, which grows attached to other seaweeds. It has increased six-fold since 1966 and is now one of the most widely distributed seaweed species in the Gulf of Maine and the Northeast. It was documented at 100% of monitored sites during CZM's 2013 Rapid Assessment Survey.

Source: Massachusetts DNR, CZM 2013, CZM 2015

Massachusetts has also implemented biological control programs aimed at controlling these invasive species: purple loosestrife (*Lythrum salicaria*), mile-a-minute vine (*Persicaria perfoliata*), hemlock woolly adelgid (*Adelges tsugae*), and winter moth (*Operophtera brumata*). Although there are less clear-cut criteria for invasive fauna, there are a number of animals that have disrupted natural systems and inflicted economic damage on the Commonwealth, as summarized in Table 4-53. Invasive fungi are also included in this table. In marine systems, management of invasives is extremely difficult once a species has become established; therefore the focus is on monitoring established populations and surveying marine habitats for early detection and rapid response. Because of the rapidly evolving nature of the invasive species hazard, this list is not considered exhaustive.

Table 4-53: Invasive Species (Fauna and Fungi) in Massachusetts

Species	Common name	Notes
Terrestrial Species		
<i>Lymantria dispar dispar</i>	Gypsy moth (insect)	This species was imported to Massachusetts for silk production, but escaped captivity in the 1860s. It is now found throughout the Commonwealth and has spread to parts of the Midwest. This species is considered a serious defoliator of oaks and other forest and urban trees; however, biological controls have been fairly successful against it.
<i>Ophiostoma ulmi</i> , <i>Ophiostoma himal-ulmi</i> , <i>Ophiostoma novo-ulmi</i>	Dutch elm disease (fungus)	In the 1930s, this disease arrived in Cleveland, Ohio, on infected elm logs imported from Europe. A more virulent strain arrived in the 1940s. The American elm originally ranged in all states east of Rockies, and elms were once the nation's most popular urban street tree. However, the trees have now largely disappeared from both urban and forested landscapes. It is estimated that "Dutch" elm disease has killed more than 100 million trees.
<i>Adelges tsugae</i>	Hemlock woolly adelgid (insect)	This species was introduced accidentally around 1924 and is now found from Maine to Georgia, including all of Massachusetts. It has caused up to 90% mortality in eastern hemlock species, which are important for shading trout streams and provide habitat for about 90 species of birds and mammals. It has been documented in about one-third of Massachusetts cities and towns and threatens the state's extensive Eastern Hemlock groves.
<i>Cryphonectria parasitica</i>	Chestnut blight (fungus)	This fungus was first detected in New York City in 1904. By 1926, the disease had devastated chestnuts from Maine to Alabama. Chestnuts once made up one-fourth to one-half of eastern U.S. forests, and the tree was prized for its durable wood and as a food for humans, livestock, and wildlife. Today, only stump sprouts from killed trees remain.
<i>Anoplophora glabripennis</i>	Asian long-horned beetle	This species was discovered in Worcester in 2008. The beetle rapidly infested trees in the area, resulting in the removal of nearly 30,000 infected or high-risk trees in just 3 years.

Species	Common name	Notes
<i>Cronartium ribicola</i>	White pine blister rust (fungus)	This fungus is an aggressive and non-native pathogen that was introduced into eastern North America in 1909. Both the pine and plants in the <i>Ribes</i> genus (gooseberries and currants) must be present in order for the disease to complete its life cycle. The rust threatens any pines within a quarter-mile radius from infected <i>Ribes</i> .
Aquatic Species		
<i>Carcinus maenas</i>	European green crab (crab)	This crab was probably introduced accidentally via ballast water in the 1800s. It is now the most prolific crab in Massachusetts. It is a voracious predator on native shore organisms; some blame the crab for the collapse of the New England soft-shell clam fishery. A 1999 study estimated that predation of shellfish by the European green crab has resulted in a loss of \$44 million per year in New England and the Canadian Maritimes.
<i>Didemnum vexillum</i>	Tunicate	The tunicate <i>Didemnum vexillum</i> was first observed in Damariscotta River area in Maine in the 1970s and has recently expanded its range. Unlike other invasive tunicates, <i>D. vexillum</i> is able to utilize open coast and deep water habitats, including Georges Bank. It can overgrow and displace most species and established communities, forming a barrier to prey, modifying habitat, and leading to the death of bivalves by overgrowing their siphons.
<i>Hemigrapsis sanguineus</i>	Asian shore crab	The Asian shore crab was likely introduced to the Massachusetts area in the late 1990s or early 2000s. It competes with the European green crab; as a result, it is anticipated that the arrival of this species may reduce the long-existing predominance of the green crab in the Commonwealth in some habitats where they overlap.
<i>Membranipora membranacea</i>	Lace Bryozoan	This species encrusts seaweed fronds, including kelp, leading to breakage and losses that can disrupt the function of the surrounding ecosystem.
<i>Dreissena polymorpha</i>	Zebra mussel	The first documented occurrence of zebra mussels in a Massachusetts water body occurred in Laurel Lake in July 2009. Zebra mussels can significantly alter the ecology of a water body and attach themselves to boats hulls and propellers, dock pilings, water intake pipes and aquatic animals. They are voracious eaters that can filter up to a liter of water a day per individual. This consumption can deprive young fish of crucial nutrients.
<i>Ostrea edulis</i>	European Oyster	The European oyster was first imported to Maine in the 1950s for aquaculture. A 1997 Salem Sound survey revealed dense concentrations of <i>O. edulis</i> in Salem Harbor, Danvers River, and Manchester Bay, Massachusetts. Lower densities were observed north to Cape Ann and south to Boston Harbor. It has continued to expand its range and is now found throughout Massachusetts.

Species	Common name	Notes
<i>Palaemon elegans</i>	European Shrimp	<i>Palaemon elegans</i> was first documented in New England during the 2010 Rapid Assessment Survey and has since rapidly expanded its range from Maine to Connecticut. <i>P. elegans</i> can grow to more than 2 inches in length and is able to consume a number of smaller marine organisms.
<i>Styela clava</i>	Club tunicate	Abundant in sheltered, subtidal waters attached to hard surfaces, this solitary tunicate first appeared in Long Island Sound, Connecticut, in 1973 and rapidly spread north to Prince Edward Island and south to New Jersey. This species is a strong competitor for space and is a fouling organism on ship hulls, mussels, and oyster beds, impacting native species and the aquaculture industry.

Sources: Chase et al., 1997; Pederson et al., 2005, CZM, 2013, 2014; Defenders of Wildlife; Gulf of Maine; EOEEA, 2013a, 2013b

Frequency of Occurrences

Because the presence of invasive species is ongoing rather than a series of discrete events, it is difficult to quantify the frequency of these occurrences. However, increased rates of global trade and travel have created many new pathways for the dispersion of exotic species. As a result, the frequency with which these threats have been introduced has increased significantly. Increased international trade in ornamental plants is particularly concerning because many of the invasive plants species in the U.S. were originally imported as ornamentals.

More generally, a warming climate may place stress on colder-weather species while allowing non-native species accustomed to warmer climates to spread northward. This pole-ward trend is already well documented, and is expected to accelerate in the future. A recent study found that the studied array of species have already moved 10.5 miles toward the poles or 36 feet upward in elevation per decade. Marine species also moved to colder waters over the course of the last century (Schwartz, 2014).

Another way in which climate change may increase the frequency of natural species threat is through the possibility of climate refugees. As populations move to escape increasingly inhospitable climates, they are likely to bring along products, food, and livestock that could introduce novel (and potentially invasive) species to the areas in which they settle (Szyniszewska, n.d.).

Severity/Extent

Invasive species are a widespread problem in Massachusetts and throughout the country. The geographic extent of invasive species varies greatly depending on the species in question and other factors, including habitat and the range of the species. In marine environments, for example, the majority of invasive species are found on artificial substrates such as docks, oceanic platforms, boats, and ships (Mineur et al., 2012). Some (such as the gypsy moth) are nearly controlled, whereas others, such as the zebra mussel, are currently adversely impacting ecosystems throughout the Commonwealth. Invasive species can be measured through monitoring and recording observances.

The MIPAG has developed a list of Early Detection plant species that lists species according to an established set of criteria that includes MIPAG classification as an invasive, likely invasive, or potentially invasive ecological threat and one of these three criteria—limited prevalence in Massachusetts, partial containment potential, or public health threat. The Early Detection table includes the documented distribution of a species by county. Twelve Category 1 plants are listed (MIPAG, 2011).

Temperature, concentration of CO₂ in the atmosphere and oceans, frequency and intensity of coastal storm events, atmospheric concentration of CO₂, and available nutrients are key factors in determining species survival. It is likely that climate change will alter all of these variables. As a result, climate change is likely to stress native ecosystems and increase the chances of a successful invasion.

Additionally, some research suggests that elevated atmospheric CO₂ concentrations could reduce the ability of ecosystems to recover after a major disturbance, such as a flood or fire event. As a result, invasive species—which are often able to establish more rapidly following a disturbance—could have an increased probability of successful establishment or expansion. Other climate change impacts that could increase the severity of the invasive species hazard include the following (Bryan and Bradley, 2016; Mineur et al., 2012; Schwartz, 2014; Sorte, 2014; Stachowicz et al., 2002):

- Elevated atmospheric CO₂ levels could increase some organisms' photosynthetic rates, improving the competitive advantage of those species.
- Changes in atmospheric conditions could decrease the transpiration rates of some plants, increasing the amount of moisture in the underlying soil. Species that could most effectively capitalize on this increase in available water would become more competitive.
- Fossil fuel combustion can result in widespread nitrogen deposition, which tends to favor fast-growing plant species. In some regions, these species are primarily invasive, so continued use of fossil fuels could make conditions more favorable for these species.
- As the growing season shifts to earlier in the year, several invasive species (including garlic mustard, barberry, buckthorn, and honeysuckle) have proven more able to capitalize by beginning to flower earlier, which allows them to outcompete later-blooming plants for available resources. Species whose flowering times do not respond to elevated temperatures have decreased in abundance.
- Some research has found that forest pests (which tend to be ectotherms, drawing their body heat from environmental sources) will flourish under warming temperatures. As a result, the population sizes of defoliating insects and bark beetles are likely to increase.

- Warmer winter temperatures also mean that fewer pests will be killed off over the winter season, allowing populations to grow beyond previous limits.
- There are many environmental changes possible in the marine environment that can impact the introduction, spread, and establishment of marine species, including increased water temperature, decreased oxygen concentration, decreased ocean pH (ocean acidification), and longer shipping seasons and new travel routes from reduced ice. For example, increases in winter water temperatures in particular could facilitate year-round establishment of species that currently cannot overwinter in New England (i.e., Lionfish *Pterois* spp.)(Sorte, 2014).
- The success of marine invasives on hard substrate is often linked with spring temperatures. During warmer years, marine invasives are able to start growing earlier and therefore outcompete native species that are not able to switch their growth timing. In addition these temperature increases are exacerbated in shallow, estuarine environments that heat up more than surrounding, deeper waters and that are also centers of activity for major introduction pathways, such as shipping and recreational boating (Stachowicz et al., 2002).

Warning Time

Once established, invasive species often escape notice for years or decades. Introduced species that initially escaped many decades ago are only now being recognized as invasives. Because these species can occur anywhere (on public or private property), new invasive species often escape notice until they are widespread and eradication is impractical. As a result, early and coordinated action between public and private landholders is critical to preventing widespread damage from an invasive species.

SECONDARY HAZARDS

Invasive species can trigger a wide-ranging cascade of lost ecosystem services. Additionally, they can reduce the resilience of ecosystems to future hazards by placing a constant stress on the system.

EXPOSURE AND VULNERABILITY

Because plant and animal life is so abundant throughout the Commonwealth, the entire area is considered to be exposed to the invasive species hazard. Areas with high amounts of plant or animal life may be at higher risk of exposure to invasive species than less vegetated urban areas; however, invasive species can disrupt ecosystems of all kinds.

Populations



Because this hazard is present throughout the Commonwealth, the entire population is considered exposed. The majority of invasive species do not have direct impacts on human well-being; however, as described in the following subsections, there are some health impacts associated with invasive species.

Vulnerable Populations

Invasive species rarely result in direct impacts on humans, but sensitive people may be vulnerable to specific species that may be present in the state in the future. These include people with compromised immune systems, children under the age of 5, people over the age of 65, and pregnant women. Those who rely on natural systems for their livelihood or mental and emotional well-being are more likely to experience negative repercussions from the expansion of invasive species.

Health Impacts

Some research suggests that “unnatural” green space that appears to fall outside the expected appearance of a natural area can cause psychological stress in visitors to that area (Fuller et al., 2007). When an invasive species causes an area to appear overrun and unmanaged, the area is also more likely to be perceived as unsafe, reducing the likelihood that residents and visitors will reap the health benefits associated with outdoor recreation.

Additionally, specific species have been found to have negative impacts on human health. The Tree of Heaven (*Ailanthus altissima*) produces powerful allelochemicals that prevent the reproduction of other species and can cause allergic reactions in humans (Bardsley and Edward-Jones, 2007). Similarly, due to its voracious consumption, the zebra mussel accumulates aquatic toxins, such as polychlorinated biphenyls or polyaromatic hydrocarbons, in their tissues at a rapid rate. When other organisms consume these mussels, the toxins can accumulate, resulting in potential human health impacts if any of these animals are ever eaten by humans.

Government



No structures are anticipated to be directly affected by invasive species, although water storage facilities, reservoirs, and other state-managed water bodies are vulnerable to invasive species such as zebra mussels. Because these species are present throughout the Commonwealth, all state facilities are considered exposed to this hazard. State facilities that rely on or cultivate specific species, such as a greenhouse that is propagating endangered plant species, are more vulnerable to this hazard than other state facilities.

The Built Environment



Because invasive species are present throughout the Commonwealth, all elements are considered exposed to this hazard; however, the built environment is not expected to be impacted by invasive species to the degree that the natural environment is. Buildings are not likely to be directly impacted by invasive species. Amenities such as outdoor recreational areas that depend on biodiversity and ecosystem health may be impacted by invasive species. Facilities that rely on biodiversity or the health of surrounding ecosystems, such as outdoor recreation areas or agricultural/forestry operations, could be more vulnerable to impacts from invasive species.

Agriculture

The agricultural sector is vulnerable to increased invasive species associated with increased temperatures. More pest pressure from insects, diseases, and weeds may harm crops and cause farms to increase pesticide use. In addition, floodwaters may spread invasive plants that are detrimental to crop yield and health. Agricultural and forestry operations that rely on the health of the ecosystem and specific species are likely to be vulnerable to invasive species.

Public Health

An increase in species not typically found in Massachusetts could expose populations to vector-borne disease. A major outbreak could exceed the capacity of hospitals and medical providers to care for patients.

Transportation

Water transportation may be subject to increased inspections, cleanings, and costs that result from the threat and spread of invasive species. Species such as zebra mussels can damage aquatic infrastructure and vessels.

Water Infrastructure

Water storage facilities may be impacted by zebra mussels. Invasive species may lead to reduced water quality, which has implications for the drinking water supplies and the cost of treatment.

Natural Resources and Environment



An analysis of threats to endangered and threatened species in the U.S. indicates that invasives are implicated in the decline of 42 percent of the endangered and threatened species. In 18 percent of the cases, invasive species were listed as the primary cause of the species being threatened, whereas in 24 percent of the cases they were identified as a contributing factor (Somers, 2016). A 1998 study found that competition or predation by alien species is the second most significant threat to biodiversity, only surpassed by direct habitat

destruction or degradation (Wilcove et al., 1998). This indicates that invasive species present a significant threat to the environment and natural resources in the Commonwealth.

Aquatic invasive species pose a particular threat to water bodies. In addition to threatening native species, they can degrade water quality and wildlife habitat. Impacts of aquatic invasive species include:

- Reduced diversity of native plants and animals
- Impairment of recreational uses, such as swimming, boating, and fishing
- Degradation of water quality
- Degradation of wildlife habitat
- Increased threats to public health and safety
- Diminished property values
- Declines in fin and shellfish populations
- Loss of coastal infrastructure due to the habits of fouling and boring organisms
- Local and complete extinction of rare and endangered species (EOEEA, 2002)

Economy

\$ Invasive species are widely considered to be one of the most costly natural hazards in the U.S. A widely cited paper (Pimental et al., 2005) found that invasive species cost the U.S. more than \$120 billion in damages every year. One study found that in 1 year alone, Massachusetts agencies spent more than \$500,000 on the control of invasive aquatic species through direct efforts and cost-share assistance. This figure does not include the extensive control efforts undertaken by municipalities and private landowners, lost revenue due to decreased recreational opportunities, or decreases in property value due to infestations (Hsu, 2000).

Individuals who are particularly vulnerable to the economic impacts of this hazard would include all groups who depend on existing ecosystems in the Commonwealth for their economic success. This includes all individuals working in agriculture-related fields, as well as those whose livelihoods depend on outdoor recreation activities such as hunting, hiking, or aquatic sports. Additionally, homeowners whose properties are adjacent to vegetated areas could experience property damage in a number of ways. For example, the roots of the Tree of Heaven (*Ailanthus altissima*) plant are aggressive enough that they can damage both sewer systems and house foundations up to 50 to 90 feet from the parent tree. According to the Charles River Watershed Association, homeowners along the Charles River are concerned about the influence of invasive species on property values as well.

4.4 Primary Climate Change Interaction: Extreme Weather

4.4.1 Hurricanes/Tropical Storms

GENERAL BACKGROUND

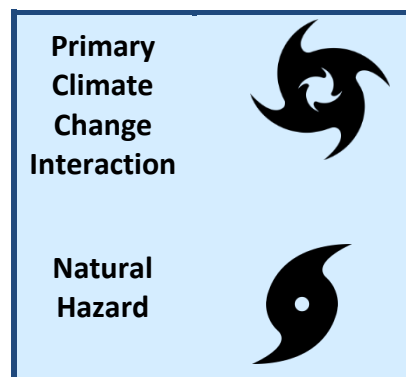
Hurricanes


Hurricanes begin as tropical storms over the warm moist waters of the Atlantic Ocean, off the coast of West Africa, and over the Pacific Ocean near the equator. As the moisture evaporates, it rises until enormous amounts of heated, moist air are twisted high in the atmosphere. The winds begin to circle counterclockwise north of the equator or clockwise south of the equator. The center of the hurricane is called the eye.

Tropical cyclones (tropical depressions, tropical storms, and hurricanes) form over the warm, moist waters of the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico:

- A tropical depression is declared when there is a low-pressure center in the tropics with sustained winds of 25 to 33 mph.
- A tropical storm is a named event defined as having sustained winds from 34 to 73 mph.
- If sustained winds reach 74 mph or greater, the storm becomes a hurricane. The Saffir-Simpson scale ranks hurricanes based on sustained wind speeds—from Category 1 (74 to 95 mph) to Category 5 (156 mph or more). Category 3, 4, and 5 hurricanes are considered “major” hurricanes. Hurricanes are categorized based on sustained winds; wind gusts associated with hurricanes may exceed the sustained winds and cause more severe localized damage (NOAA, n.d.[b]).

When water temperatures are at least 80°F, hurricanes can grow and thrive, generating enormous amounts of energy, which is released in the form of numerous thunderstorms, flooding, rainfall, and very damaging winds. The damaging winds help create a dangerous storm surge in which the water rises above the normal astronomical tide. In the lower latitudes, hurricanes tend to move from east to west. However, when a storm drifts further north, the westerly flow at the mid-latitudes tends to cause the storm to curve toward the north and east. When this occurs, the storm may accelerate its forward speed. This is one of the reasons why some of the strongest hurricanes of record have reached New England.







Natural Hazard Summary






HURRICANES/TROPICAL STORMS

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
Hurricanes begin as tropical storms near the equator. As the moisture evaporates, it rises until enormous amounts of heated, moist air are twisted high in the atmosphere.	The entire Commonwealth is vulnerable to hurricanes and tropical storms, dependent on the storm's track. The coastal areas are more susceptible to damage due to the combination of both high winds and tidal surge, as depicted on the SLOSH maps.	The average number of hurricane or tropical storm events is 1 every 2 years. Storms severe enough to receive FEMA disaster declarations, however, only occur every 9 years on average.

Potential Effects of Climate Change

	EXTREME WEATHER AND RISING TEMPERATURES → LARGER, STRONGER STORMS	As warmer oceans provide more energy for storms, both past events and models of future conditions suggest that the intensity of tropical storms and hurricanes will increase.
	CHANGES IN PRECIPITATION → INCREASED RAINFALL RATES	Warmer air can hold more water vapor, which means the rate of rainfall will increase. One study found that hurricane rainfall rates were projected to rise 7 percent for every degree Celsius increase in tropical sea surface temperature.

Exposure and Vulnerability by Key Sector

	POPULATIONS	General At-Risk Population: State-wide exposure. Vulnerable Populations: Economically disadvantaged population, which is more likely to evaluate the economic impact of evacuating; individuals over age 65, who are more likely to face physical challenges or to require medical care while evacuating; individuals with low English language fluency who may not receive or understand warnings to evacuate.
	GOVERNMENT	According to the DCAMM inventory, a total of 1,030 government buildings are located within the Category 1-4 SLOSH zones. The highest concentrations of these facilities are in Suffolk County (445), Bristol County (132) and Essex County (132).
	BUILT ENVIRONMENT	A total of 74 critical facilities, including military installations, police stations, fire stations, college facilities and social service providers, are located within the Category 1-4 SLOSH zones. The majority of these facilities are located in Suffolk County (34) and Essex County (16). Hurricanes and tropical storms can result in power outages and road closures that impact emergency response. Heavy rains can lead to contamination of well water, septic system failure, and overburden stormwater systems.
	NATURAL RESOURCES AND ENVIRONMENT	As the storm is occurring, flooding, or wind/water-borne detritus can cause mortality to animals if it strikes them or transports them to a non-suitable habitat. In the longer term, environmental impacts can occur as a result of riverbed scour, fallen trees, storm surge, or contamination of ecosystems by transported pollutants.
	ECONOMY	Hurricanes are among the most costly natural disasters in terms of damage inflicted and recovery costs required. Using general building stock as a proxy for overall economic exposure, Suffolk and Middlesex Counties are the most at-risk to economic damage from the hurricane hazard. This damage will likely include loss of building function, relocation costs, wage loss, road repair and rental loss.

Hurricanes can range from as small as 50 miles across to as much as 500 miles across; Hurricane Allen in 1980 took up the entire Gulf of Mexico. There are generally two source regions for storms that have the potential to strike New England: (1) off the Cape Verde Islands near the west coast of Africa, and (2) in the Bahamas. The Cape Verde storms tend to be very large in diameter, since they have a week or more to traverse the Atlantic Ocean and grow. The Bahamas storms tend to be smaller, but they can also be just as powerful, and their effects can reach New England in only a day or two.

Tropical systems customarily come from a southerly direction and when they accelerate up the East Coast of the U.S., most take on a distinct appearance that is different from a typical hurricane. Instead of having a perfectly concentric storm with heavy rain blowing from one direction, then the calm eye, then the heavy rain blowing from the opposite direction, our storms (as viewed from satellite and radar) take on an almost winter-storm-like appearance. Although rain is often limited in the areas south and east of the track of the storm, these areas can incur the worst winds and storm surge. Dangerous flooding occurs most often to the north and west of the track of the storm. An additional threat associated with a tropical system making landfall is the possibility of tornado generation. Tornadoes would generally occur in the outer bands to the north and east of the storm, a few hours to as much as 15 hours prior to landfall.

The official hurricane season runs from June 1 to November 30. In New England, these storms are most likely to occur in August, September, and the first half of October. This is due in large part to the fact that it takes a considerable amount of time for the waters south of Long Island to warm to the temperature necessary to sustain the storms this far north. Also, as the region progresses into the fall months, the upper-level jet stream has more dips, meaning that the steering winds might flow from the Great Lakes southward to the Gulf States and then back northward up the eastern seaboard. This pattern would be conducive for capturing a tropical system over the Bahamas and accelerating it northward.

Tropical Storms

A tropical storm system is characterized by a low-pressure center and numerous thunderstorms that produce strong winds and heavy rain (winds are at a lower speed than hurricane-force winds, thus gaining its status as a tropical storm versus a hurricane). Tropical storms strengthen when water evaporated from the ocean is released as the saturated air rises, resulting in condensation of water vapor contained in the moist air. They are fueled by a different heat mechanism than other cyclonic windstorms, such as nor'easters and polar lows. The characteristic that separates tropical cyclones from other cyclonic systems is that at any height in the atmosphere, the center of a tropical cyclone will be warmer than its surroundings—a phenomenon called “warm core” storm systems.

The term “tropical” refers both to the geographical origin of these systems, which usually form in tropical regions of the globe, and to their formation in maritime tropical air masses. The term “cyclone” refers to such storms’ cyclonic nature, with counterclockwise wind flow in the Northern Hemisphere and clockwise wind flow in the Southern Hemisphere.

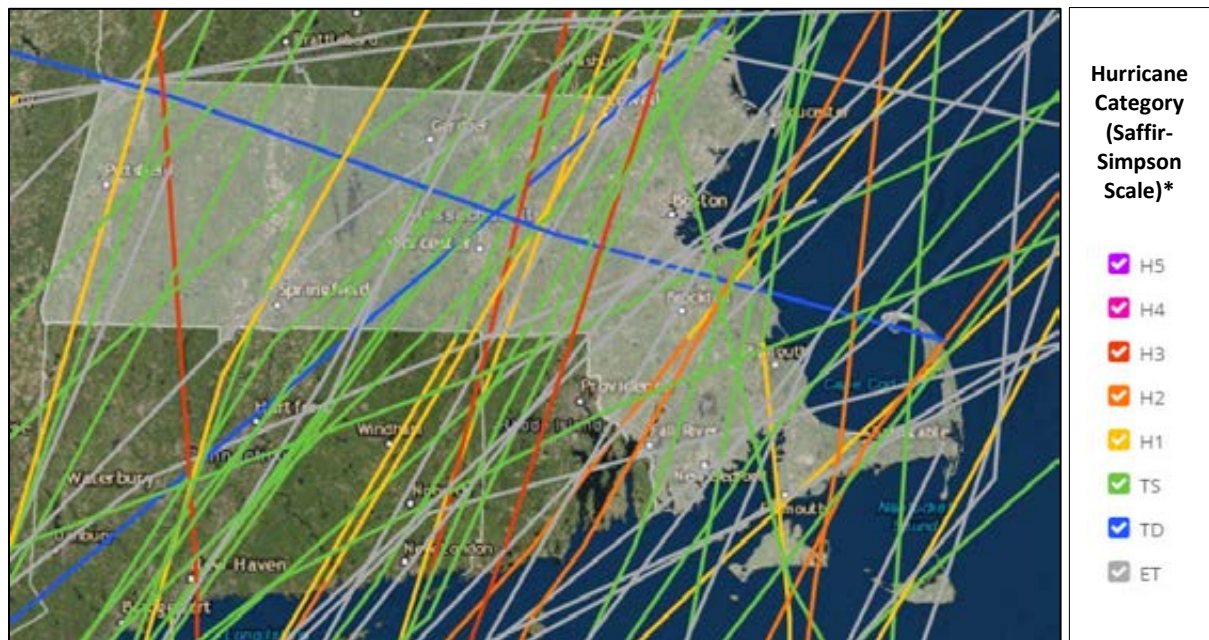
HAZARD PROFILE

Location

The entire Commonwealth is vulnerable to hurricanes and tropical storms, depending on each storm’s track. The coastal areas are more susceptible to damage due to the combination of both high winds and tidal surge, as depicted on the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) maps. Thus, the 78 coastal communities in Massachusetts are most vulnerable to the damaging impacts of major storms. As coastal development increases, the amount of property and infrastructure exposed to this hazard will increase. Inland areas, especially those in floodplains, are also at risk for flooding from heavy rain and wind damage. The majority of the damage following hurricanes and tropical storms often results from residual wind damage and inland flooding, as was demonstrated during recent tropical storms.

NOAA’s Historical Hurricane Tracks tool is a public interactive mapping application that displays Atlantic Basin and East-Central Pacific Basin tropical cyclone data. This interactive tool tracks tropical cyclones from 1842 to 2017. According to this resource, over the time frame tracked, 63 events categorized as an extra-tropical storm or higher occurred within 65 nautical miles of Massachusetts. The tracks of these storms are shown in Figure 4-61. As this figure shows, the paths of these storms vary across the Commonwealth but are more likely to occur toward the coast.

The location and path of a system can also be a major factor in the severity of storm impacts, especially when it comes to storm surge. Most storm surge happens when the force of the wind (called wind stress) pushes water toward the shore. For hurricanes in the northern hemisphere, this occurs most intensely in the right-front quadrant of the storm. The winds are strongest there due to the combination of a storm’s counter-clockwise rotation and forward motion (NOAA, n.d.). For Massachusetts, a particularly serious scenario would be if the eye of a major hurricane tracked west of Buzzards Bay. This would produce a potential storm surge of 25 feet or more at the upper part of Buzzards Bay. According to the NWS, this was most likely the scenario that occurred in the Colonial Hurricane of 1635, which produced a storm surge of 20 feet at the upper part of Buzzards Bay. More recent hurricanes that went west or up Buzzards Bay also may be good examples—the New England Hurricane (1938), Hurricanes Edna and Carol (1954), and Hurricane Bob (1991). More information on previous occurrences is provided in Appendix B.

Figure 4-61: Historical Hurricane Paths within 65 miles of Massachusetts

Source: NOAA, n.d. (*TS= Tropical Storm, TD = Tropical Depression)

Previous Occurrences

Hurricanes and related events occur somewhat regularly in Massachusetts. Notable events since the publication of the previous iteration of this plan include Tropical Depression Hermine (2016) and Tropical Storm Andrea (2013). All historical events are listed in Appendix B.

The Commonwealth has not been impacted by any Category 4 or 5 hurricanes; however, Category 3 storms have historically caused widespread flooding. Winds have caused sufficient damage to impair the ability of individuals to remain in their homes.

Frequency of Occurrences

According to NOAA's Historical Hurricane Tracker tool, 63 hurricane or tropical storm events have occurred in the vicinity of Massachusetts between 1842 and 2016. The Commonwealth was impacted by tropical storms Jose and Phillipe in 2017. Therefore, there is an average of one storm every other year or 0.5 storms per year. Storms severe enough to receive FEMA disaster declarations, however, are far rarer, occurring every 9 years on average.

Severity/Extent

Hurricanes are measured according to the Saffir-Simpson scale, which categorizes or rates hurricanes from 1 (minimal) to 5 (catastrophic) based on their intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline in the landfall

region. All winds are assessed using the U.S. 1-minute average, meaning the highest wind that is sustained for 1 minute. The Saffir-Simpson Scale described in Table 4-54 gives an overview of the wind speeds and range of damage caused by different hurricane categories.

Table 4-54: Saffir-Simpson Scale

Scale No. (Category)	Winds (mph)	Potential Damage
1	74 – 95	Minimal: Damage is primarily to shrubbery and trees, mobile homes, and some signs. No real damage is done to structures.
2	96 – 110	Moderate: Some trees topple; some roof coverings are damaged; and major damage is done to mobile homes.
3	111 – 130	Extensive: Large trees topple; some structural damage is done to roofs; mobile homes are destroyed; and structural damage is done to small homes and utility buildings.
4	131 – 155	Extreme: Extensive damage is done to roofs, windows, and doors; roof systems on small buildings completely fail; and some curtain walls fail.
5	> 155	Catastrophic: Roof damage is considerable and widespread; window and door damage is severe; there are extensive glass failures; and entire buildings could fail.
Additional Classifications		
Tropical Storm	39-73	NA
Tropical Depression	< 38	NA

mph = miles per hour; NA = not applicable
Source: NOAA, n.d.

Although no one storm can be directly attributed to climate change, both past events and models of future conditions suggest that the intensity of tropical storms and hurricanes will increase as a result of climate change. Trends in the frequency of these storms are less clear. Research from Florida State University found that since 1981, the maximum wind speed of the most powerful hurricanes has increased markedly because a warmer ocean provides more energy for storms (Kang and Elsner, 2015). These higher ocean temperatures may cause storm systems to become larger and longer in duration. Warmer global oceans could also expand the portions of the ocean in which conditions conducive to hurricane formation occur, potentially expanding the parts of the world susceptible to this hazard. Additionally, warmer air can hold more water vapor, which means the rate of rainfall will increase. One study found that hurricane rainfall rates were projected to rise 7 percent for every degree Celsius increase in tropical sea surface temperature (Wang et al., 2017). Finally, as described for other hazards, sea level rise will exacerbate the impact of storm surge from storms of all severities.

Tropical storms and tropical depressions, while generally less dangerous than hurricanes, can be deadly. The winds of tropical depressions and tropical storms are usually not the greatest threat; rather, the rains, flooding, and severe weather associated with the tropical storms are what customarily cause more significant problems. Serious power outages can also be associated with

these types of events. After Hurricane Irene passed through the region as a tropical storm in late August 2011, many areas of the Commonwealth were without power for more than 5 days.

While tropical storms can produce extremely powerful winds and torrential rain, they are also able to produce high waves, damaging storm surge, and tornadoes. They develop over large bodies of warm water and lose their strength if they move over land due to increased surface friction and loss of the warm ocean as an energy source. Heavy rains associated with a tropical storm, however, can produce significant flooding inland, and storm surges can produce extensive coastal flooding up to 25 miles from the coastline.

One measure of the size of a tropical cyclone is determined by measuring the distance from its center of circulation to its outermost closed isobar. If the radius is less than 2 degrees of latitude, or 138 miles, then the cyclone is “very small.” A radius between 3 and 6 degrees of latitude, or 207 to 420 miles, is considered “average-sized.” “Very large” tropical cyclones have a radius of greater than 8 degrees, or 552 miles.

The location and path of a system can also be a major factor in the severity of storm impacts, especially when it comes to storm surge. Most storm surge happens when the force of the wind (called wind stress) pushes water toward the shore. For hurricanes in the northern hemisphere, this occurs most intensely in the right-front quadrant of the storm. For Massachusetts, a particularly serious scenario would be if the eye of a major hurricane tracked west of Buzzards Bay. This would produce a potential storm surge of 25 feet or more at the upper part of Buzzards Bay. According to the NWS, this was most likely the scenario that occurred in the Colonial Hurricane of 1635, which produced a storm surge of 20 feet at the upper part of Buzzards Bay.

Warning Time

The NWS issues a hurricane warning when sustained winds of 74 mph or higher are *expected* in a specified area in association with a tropical, subtropical, or post-tropical cyclone. A warning is issued 36 hours in advance of the anticipated onset of tropical-storm-force winds. A hurricane watch is announced when sustained winds of 74 mph or higher are *possible* within the specified area in association with a tropical, subtropical, or post-tropical cyclone. A watch is issued 48 hours in advance of the anticipated onset of tropical-storm-force winds (NWS, 2013).

Preparations should be complete by the time the storm is at the latitude of North Carolina. Outer bands containing squalls with heavy showers and wind gusts to tropical storm force can occur as much as 12 to 14 hours in advance of the eye, which can cause coastal flooding and may cut off exposed coastal roadways. The 1938 hurricane raced from Cape Hatteras to the Connecticut coast in 8 hours.

SECONDARY HAZARDS

Precursor events or hazards that may exacerbate hurricane damage include heavy rains, winds, tornadoes, storm surge, insufficient flood preparedness, subsea infrastructure, and levee or dam breach or failure. Potential cascading events include health issues (mold and mildew); increased risk of fire hazards; hazardous materials, including waste byproducts; coastal erosion; compromise of levees or dams; isolated islands of humanity; increased risk of landslides or other types of land movement; disruptions to transportation; disruption of power transmission and infrastructure; structural and property damage; debris distribution; and environmental impacts.

EXPOSURE AND VULNERABILITY

To understand risk, the assets exposed to the hazard areas are identified. For the hurricane and tropical storm hazard, the entire Commonwealth of Massachusetts is exposed; more specifically, the Commonwealth is exposed to the wind and rains associated with these events. However, certain areas, types of building, and infrastructure are at greater risk than others, based on their proximity to the coast and/or manner of construction. Storm surge from a hurricane/tropical storm poses one of the greatest risks to residents and property.

A FEMA Risk Analysis Team developed storm surge inundation grids for the Commonwealth in GIS format from the “maximum of maximums” outputs from the SLOSH model. These represent the worst-case storm surge scenarios for each hurricane category (Categories 1 through 4). To assess the Commonwealth’s exposure to storm surge from hurricanes and tropical storms, a spatial analysis was conducted using the SLOSH model. The SLOSH boundaries do not account for any inland flash flooding.

Populations



As shown in Table 4-55, the population of Suffolk County is the most exposed to the hurricane-related storm surge hazard. Barnstable and Middlesex Counties also have relatively high exposure to this hazard. It should be noted, however, that impacts from individual hurricane events vary widely; therefore, all coastal counties should evaluate the potential impacts of storm surge on vulnerable residents.

Table 4-55: Population Exposed to Hurricane-Related Storm Surge

County	Population	Category 1		Category 2		Category 3		Category 4	
		Number	% Total	Number	% Total	Number	% Total	Number	% Total
Barnstable	215,888	5,537	2.6	8,393	3.9	10,543	4.9	11,528	5.3
Bristol	548,285	2,975	0.5	4,134	0.8	4,773	0.9	29,679	5.4
Dukes	16,535	310	1.9	301	1.8	475	2.9	562	3.4
Essex	743,159	13,390	1.8	16,324	2.2	18,091	2.4	18,835	2.5

County	Population	Category 1		Category 2		Category 3		Category 4	
		Number	% Total	Number	% Total	Number	% Total	Number	% Total
Middlesex	1,503,085	27,589	1.8	80,390	5.3	43,427	2.9	44,816	3.0
Nantucket	10,172	99	1.0	117	1.2	104	1.0	187	1.8
Norfolk	670,850	13,275	2.0	14,150	2.1	12,744	1.9	12,720	1.9
Plymouth	494,919	10,563	2.1	13,137	2.7	10,098	2.0	8,912	1.8
Suffolk	722,023	76,395	10.6	119,445	16.5	42,807	5.9	30,930	4.3
Total	4,924,916	150,133	3.0	256,391	5.2	143,062	2.9	158,169	3.2

Vulnerable Populations

Populations that live or work in proximity to facilities that use or store toxic substances are at greater risk of exposure to these substances during a flood event. The [Massachusetts Toxic Users and Climate Vulnerability Factors](#) map displays wastewater treatment plants; major facilities that treat, use, or store hazardous waste; and classified oil and/or hazardous material sites within the FEMA flood and storm surge zones (EOEEA, n.d.). Among the exposed populations, the most vulnerable include people with low socioeconomic status, people over the age of 65, people with medical needs, and those with low English language fluency. For example, people with low socioeconomic status are likely to consider the economic impacts of evacuation when deciding whether or not to evacuate.

Individuals with medical needs may have trouble evacuating and accessing needed medical care while displaced. Those who have low English language fluency may not receive or understand the warnings to evacuate. Findings reveal that human behavior contributes to flood fatality occurrences. For example, people between the ages of 10 and 29 and over 60 years of age are found to be more vulnerable to floods. During and after an event, rescue workers and utility workers are vulnerable to impacts from high water, swift currents, rescues, and submerged debris. Vulnerable populations may also be less likely to have adequate resources to recover from the loss of their homes and jobs or to relocate from a damaged neighborhood.

Health Impacts

The health impacts from hurricanes and tropical storms can generally be separated into impacts from flooding and impacts from wind. The potential health impacts of flooding are extensive, and are discussed in detail in Section 4.1.1. In general, some of the most serious flooding-related health threats include floodwaters sweeping away individuals or cars, downed power lines, and exposure to hazards in the water, including dangerous animals or infectious organisms. Contact with contaminated floodwaters can cause gastrointestinal illness. Individuals who are housed in public shelters during or after hurricane events also have an increased risk of becoming infected by contagious diseases (CDC, 2017).

Wind-related health threats associated with hurricanes are most commonly caused by projectiles propelled by the storm's winds. Wind- and water-caused damage to residential structures can also increase the risk of threat impacts by leaving residents more exposed to the elements. Hurricanes that occur later in the year also increase the risk of hypothermia.

After a hurricane or tropical storm subsides, substantial health risks remain. For example, flooded areas that do not drain properly can become breeding grounds for mosquitos, which can transmit vector-borne diseases. Exposure to mosquitos may also increase if individuals are outside of their homes for longer than usual as a result of power outages or other flood-related conditions. The growth of mold inside buildings is often widespread after a flood. Investigations following Hurricane Katrina and Superstorm Sandy found mold in the walls of many water-damaged homes and buildings. Mold can result in allergic reactions and can exacerbate existing respiratory diseases, including asthma (CDC, 2014). Extended loss of electricity and heating systems increases the risk of carbon monoxide poisoning. Carbon monoxide is present in emissions from combustion appliances such as cooking and heating devices (grills, stoves, etc.), damaged chimneys, or generators, and improper location and operation of combustion appliances in indoor or poorly ventilated areas leads to increased risks (Chen et al., 2015). Severe flooding that can occur as a result of hurricanes and tropical storms may damage transportation networks and prevent individuals in need from reaching health services for long periods of time after the storm has passed. Finally, property damage and displacement of homes and businesses can lead to loss of livelihood and long-term mental stress for those facing relocation. Individuals may develop post-traumatic stress, anxiety, and depression following major flooding events.

Government



To assess the exposure of the government facilities to the surge inundation from a hurricane event, the digital SLOSH zones were overlaid upon the state facility data. Table 4-56 summarizes the results of the analysis by county.

Table 4-56: State-Owned Building Exposure in SLOSH Zones by County

County	Category 1		Category 2		Category 3		Category 4	
	Count	Replacement Value	Count	Replacement Value	Count	Replacement Value	Count	Replacement Value
Barnstable	8	\$19,624,813	16	\$126,127,306	19	\$126,404,699	30	\$159,811,208
Bristol	12	\$2,783,088	31	\$14,063,355	41	\$20,117,369	48	\$36,944,954
Dukes	—	—	2	\$2,072,371	2	\$2,072,371	4	\$10,269,171
Essex	4	\$13,931,127	25	\$129,572,381	48	\$168,166,125	55	\$308,814,312
Middlesex	11	\$27,161,467	23	\$51,873,303	28	\$72,025,894	32	\$375,527,271
Norfolk	4	\$1,823,150	14	\$20,097,094	16	\$31,578,270	18	\$31,721,471
Plymouth	1	\$206,027	16	\$18,750,966	32	\$25,767,411	45	\$40,300,644
Suffolk	46	\$559,642,502	112	\$1,517,378,501	139	\$2,562,326,814	148	\$2,982,176,208
Total	86	\$625,172,174	239	\$1,879,935,277	325	\$3,008,458,953	380	\$3,945,565,239

Sources: DCAMM, 2017 (facility inventory);, MassGIS, 2017

The Built Environment



Tables 4-57 and 4-58 summarize critical facility exposure to the SLOSH Category 1 through four storm surge inundation categories by facility type and county, respectively.

Table 4-57: Critical Facility Exposure to SLOSH Hazard Zones by Facility Type

County	Category 1	Category 2	Category 3	Category 4
Military	—	2	3	4
Police Stations	3	6	6	10
Fire Stations	—	—	1	1
Hospitals	—	—	—	—
Schools (pre-K-12)	—	—	—	—
Colleges	1	6	9	9
Social Services	1	2	5	5
Total	5	16	24	29

Sources: DCAMM, 2017 (facility inventory); MassGIS, 2017

Table 4-58: Critical Facility Exposure to SLOSH Hazard Zones by County

County	Category 1	Category 2	Category 3	Category 4
Barnstable	1	1	1	3
Bristol	—	—	1	2
Dukes	—	—	—	1
Essex	1	4	6	5
Middlesex	1	2	2	3
Norfolk	—	—	2	2
Plymouth	—	—	1	1
Suffolk	2	9	11	12
Total	5	16	24	29

Sources: DCAMM, 2017 (facility inventory); MassGIS, 2017

Energy

Hurricanes and tropical storms often result in power outages and contact with damaged power lines during and after a storm, which may result in electrocution. Hurricanes and tropical storms resulted in 80,000 electric customers disrupted by NERC-reported electrical transmission between 1992 and 2009 (DOE, n.d.).

Public Health

Combined sewer overflows associated with heavy rainfall can release contaminants, chemicals, and pathogens directly into the environment and into water systems. If a mass outbreak of waterborne illness were to occur, hospitals and medical providers may lack the capacity to treat patients.

Public Safety

As discussed above, critical infrastructure, including local and state-owned police and fire stations, other public safety buildings, and facilities that serve as emergency operation centers may experience direct loss (damage) during a hurricane or tropical storm. Emergency responders may also be exposed to hazardous situations when responding to calls. Road blockages caused by downed trees may impair travel.

Transportation

Some roads and bridges are also considered critical infrastructure, particularly those providing ingress and egress and allowing emergency vehicles access to those in need. Costly damage to roads, bridges, and rail networks may occur as a result of hurricanes (resilient MA, 2018).

The default Hazus highway bridge inventory developed from the 2001 NBI database was used to conduct an exposure analysis for the bridges in the Commonwealth. Table 4-59 identifies the number of highway bridges in the Hazus default highway bridge inventory exposed to Category 1 through Category 4 hurricanes, summarized by county.

Table 4-59: Number of Bridges in SLOSH Hazard Zones by County

County	Category 1	Category 2	Category 3	Category 4
Barnstable	6	10	11	14
Bristol	11	20	30	49
Dukes	1	1	1	1
Essex	22	24	35	46
Middlesex	27	50	59	72
Nantucket	2	2	2	2
Norfolk	6	9	12	17
Plymouth	12	16	24	35
Suffolk	149	318	347	371
Total	236	450	521	607

Source: National Bridge Inventory

Water Infrastructure

Wastewater treatment centers may face elevated risks of damage and destruction from hurricanes (resilient MA, 2018). Heavy rains can lead to contamination of well water and can release contaminants from septic systems (DPH, 2014). Heavy rainfall can also overburden stormwater systems, drinking water supplies, and sewage systems.

Natural Resources and Environment



The environmental impacts of hurricanes and tropical storms are similar to those described for other hazards, including inland flooding (Section 4.1.1), severe winter storms (Section 4.4.2) and other severe weather events (Section 4.4.5). As described for human health, environmental impacts can generally be divided into short-term direct impacts and long-term impacts. As the storm is occurring, flooding may disrupt normal ecosystem function and wind may fell trees and other vegetation. Additionally, wind-borne or waterborne detritus can cause mortality to animals if they are struck or transported to a non-suitable habitat. Estuarine habitats are particularly susceptible to hurricanes and tropical storms, both because they also experience coastal storm surge and because altering the salinity of these systems can cause widespread effects to the many inhabitant species.

In the longer term, impacts to natural resources and the environment as a result of hurricanes and tropical storms are generally related to changes in the physical structure of ecosystems. For example, flooding may cause scour in riverbeds, modifying the river ecosystem and depositing the scoured sediment in another location. Similarly, trees that fall during the storm may represent lost habitat for local species, or they may decompose and provide nutrients for the growth of new vegetation. If the storm spreads pollutants into natural ecosystems, contamination can disrupt food and water supplies, causing widespread and long-term population impacts on species in the area.

Tables 4-60 through 4-62 document the exposure of ACEC, BioMap2 Core Habitat, and BioMap2 Critical Natural Landscape to hurricane categories based on GIS analysis.

Table 4-60: Natural Resources Exposure—Areas of Critical Environmental Concern

Name	County	Total Acreage	Category 1		Category 2		Category 3		Category 4	
			Acres	% of Total	Acres	% of Total	Acres	% of Total	Acres	% of Total
Bourne Back River	Barnstable	1,608.8	344.0	21.4	199.2	12.4	116.1	7.2	140.9	8.8
Ellisville Harbor	Plymouth	573.0	89.9	15.7	22.2	3.9	53.8	9.4	14.7	2.6
Great Marsh	Essex	19,529.7	14,119.5	72.3	1,629.2	8.3	895.2	4.6	565.2	2.9
Herring River Watershed	Barnstable	1,233.2	—	—	—	—	14.2	1.1	11.1	0.9
Inner Cape Cod Bay	Barnstable	1,206.6	626.8	51.9	255.6	21.2	182.0	15.1	102.6	8.5
Neponset River Estuary	Norfolk	584.4	458.9	78.5	28.4	4.9	6.6	1.1	10.7	1.8
Neponset River Estuary	Suffolk	232.8	139.5	59.9	26.2	11.2	10.8	4.6	16.6	7.1
Pleasant Bay	—	12.7	0.3	2.3	0.0	0.2	0.0	0.3	0.0	0.2
Pleasant Bay	Barnstable	3,757.1	1,031.9	27.5	151.3	4.0	535.8	14.3	301.0	8.0
Pocasset River	Barnstable	144.8	61.6	42.6	18.8	13.0	9.6	6.6	15.3	10.6
Rumney Marshes	—	1.9	0.2	9.1	0.0	0.0	—	—	—	—
Rumney Marshes	Essex	1,217.9	891.4	73.2	89.2	7.3	36.9	3.0	31.9	2.6
Rumney Marshes	Suffolk	1,037.2	810.4	78.1	62.4	6.0	12.6	1.2	3.1	0.3
Sandy Neck Barrier Beach System	Barnstable	6,099.9	1,186.7	19.5	2,686.7	44.0	867.3	14.2	613.5	10.1
Three Mile River Watershed	Bristol	14,273.2	28.3	0.2	20.5	0.1	20.8	0.1	8.5	0.1
Waquoit Bay	Barnstable	1,622.4	907.1	55.9	231.8	14.3	139.4	8.6	55.0	3.4
Weir River	Norfolk	26.7	0.3	1.2	0.0	0.1	0.1	0.2	0.0	0.0
Weir River	Plymouth	400.7	145.7	36.4	56.1	14.0	61.2	15.3	12.9	3.2
Wellfleet Harbor	Barnstable	4,550.9	1,436.1	31.6	800.6	17.6	338.0	7.4	157.3	3.5
Weymouth Back River	Norfolk	178.0	96.2	54.1	9.2	5.2	8.3	4.7	6.6	3.7
Weymouth Back River	Plymouth	576.9	68.0	11.8	23.0	4.0	61.0	10.6	18.3	3.2

Table 4-61: Natural Resources Exposure—BioMap2 Core Habitat

Name	County	Total Acreage	Category 1		Category 2		Category 3		Category 4	
			Acres	% of Total	Acres	% of Total	Acres	% of Total	Acres	% of Total
Aquatic Core	Barnstable	10,760.03	1,022.19	9.50	399.78	3.72	633.44	5.89	539.52	5.01
Aquatic Core	Bristol	11,265.95	1,593.72	47.48	382.35	3.39	258.63	2.30	661.63	5.87
Aquatic Core	Dukes	2,002.34	417.72	20.86	228.39	11.41	149.69	7.48	49.25	2.46
Aquatic Core	Essex	23,397.79	14,366.82	61.40	766.42	3.28	573.70	2.45	648.76	2.77
Aquatic Core	Middlesex	10,760.0	1,022.2	9.5	399.8	3.7	633.4	5.9	539.5	5.0
Aquatic Core	Nantucket	11,266.0	1,593.7	14.1	382.4	3.4	258.6	2.3	661.6	5.9
Aquatic Core	Norfolk	2,002.3	417.7	20.9	228.4	11.4	149.7	7.5	49.3	2.5
Aquatic Core	Plymouth	23,397.8	14,366.8	61.4	766.4	3.3	573.7	2.5	648.8	2.8
Aquatic Core	Suffolk	11,699.1	87.0	0.7	182.3	1.6	27.5	0.2	64.1	0.5
Forest Core	Barnstable	626.3	138.9	22.2	119.2	19.0	35.8	5.7	91.0	14.5
Forest Core	Dukes	6,992.3	292.0	4.2	19.2	0.3	6.8	0.1	29.0	0.4
Forest Core	Essex	27,564.3	5,149.2	18.7	544.3	2.0	481.1	1.7	293.1	1.1
Forest Core	Plymouth	567.0	76.6	13.5	10.4	1.8	0.7	0.1	0.4	0.1
Priority Natural Communities	Barnstable	9,358.2	3.2	0.0	8.7	0.1	6.4	0.1	5.4	0.1
Priority Natural Communities	Bristol	1,395.7	0.8	0.1	4.3	0.3	6.4	0.5	18.5	1.3
Priority Natural Communities	Dukes	11,085.6	0.6	0.0	3.5	0.0	11.3	0.1	12.5	0.1
Priority Natural Communities	Essex	20,647.7	—	—	51.0	0.2	48.6	0.2	272.7	1.3
Priority Natural Communities	Nantucket	10,944.0	2,350.9	21.5	2,806.2	25.6	970.2	8.9	828.1	7.6
Priority Natural Communities	Norfolk	3,906.4	348.9	8.9	95.6	2.4	21.4	0.5	46.7	1.2
Priority Natural Communities	Plymouth	2,481.9	208.8	8.4	139.9	5.6	181.8	7.3	104.8	4.2
Priority Natural Communities	Suffolk	18,759.2	16,670.3	88.9	589.6	3.1	391.3	2.1	268.5	1.4
Species of Conservation Concern	Barnstable	1,630.3	224.6	13.8	238.9	14.7	366.0	22.4	43.3	2.7

Name	County	Total Acreage	Category 1		Category 2		Category 3		Category 4	
			Acres	% of Total	Acres	% of Total	Acres	% of Total	Acres	% of Total
Species of Conservation Concern	Bristol	921.8	0.4	0.0	0.3	0.0	0.3	0.0	0.5	0.1
Species of Conservation Concern	Dukes	23,473.0	1,927.2	8.2	43.1	0.2	139.2	0.6	71.7	0.3
Species of Conservation Concern	Essex	31.3	28.1	89.7	0.4	1.2	0.4	1.3	0.5	1.5
Species of Conservation Concern	Middlesex	88,027.0	7,309.3	8.3	4,691.5	5.3	4,425.7	5.0	2,751.2	3.1
Species of Conservation Concern	Nantucket	46,019.3	1,736.1	3.8	727.3	1.6	608.9	1.3	657.9	1.4
Species of Conservation Concern	Norfolk	43,315.5	2,215.1	5.1	2,144.0	4.9	2,171.2	5.0	1,738.0	4.0
Species of Conservation Concern	Plymouth	61,417.7	15,113.2	24.6	1,372.6	2.2	996.6	1.6	1,241.5	2.0
Species of Conservation Concern	Suffolk	80,649.1	27.4	0.0	0.6	0.0	0.4	0.0	1,329.4	1.6
Vernal Pool	Bristol	22,933.2	1,821.9	7.9	1,074.6	4.7	1,238.3	5.4	11.1	0.0
Vernal Pool	Dukes	22,990.7	209.8	0.9	9.9	0.0	1.5	0.0	864.7	3.8
Wetlands	Barnstable	98,328.1	4,065.5	4.1	1,329.1	1.4	1,023.1	1.0	63.6	0.1
Wetlands	Bristol	2,334.1	317.6	13.6	920.5	39.4	160.3	6.9	138.4	5.9
Wetlands	Dukes	7,363.4	98.9	1.3	157.7	2.1	250.4	3.4	18.5	0.3
Wetlands	Essex	300.6	14.6	4.8	11.1	3.7	15.1	5.0	248.4	82.6
Wetlands	Nantucket	2,595.9	965.7	37.2	32.2	1.2	819.5	31.6	248.4	9.6
Wetlands	Plymouth	15,440.9	496.8	3.2	75.1	0.5	135.7	0.9	194.5	1.3

Table 4-62: Natural Resources Exposure—BioMap2 Critical Landscape

Name	County	Total Acreage	Category 1		Category 2		Category 3		Category 4	
			Acres	% of Total	Acres	% of Total	Acres	% of Total	Acres	% of Total
Aquatic Buffer	Barnstable	15,910.8	1,427.1	9.0	627.7	3.9	880.5	5.5	780.8	4.9
Aquatic Buffer	Bristol	20,468.8	2,103.1	10.3	776.1	3.8	562.6	2.7	1,266.8	6.2
Aquatic Buffer	Dukes	4,308.7	599.9	13.9	417.9	9.7	298.7	6.9	156.8	3.6
Aquatic Buffer	Essex	32,046.2	15,370.9	48.0	1,732.2	5.4	1,299.0	4.1	1,291.2	4.0
Aquatic Buffer	Middlesex	16,657.9	87.0	0.5	182.6	1.1	27.5	0.2	64.1	0.4
Aquatic Buffer	Nantucket	1,578.7	467.4	29.6	231.1	14.6	125.3	7.9	187.1	11.9
Aquatic Buffer	Norfolk	10,263.4	392.4	3.8	46.5	0.5	18.8	0.2	40.9	0.4
Aquatic Buffer	Plymouth	41,381.2	6,068.4	14.7	1,107.1	2.7	1,052.7	2.5	788.2	1.9
Aquatic Buffer	Suffolk	626.3	102.2	16.3	15.1	2.4	1.6	0.2	0.9	0.1
Coastal Adaptation Analysis	Barnstable	20,054.7	10,408.5	51.9	5,205.8	26.0	2,989.4	14.9	824.2	4.1
Coastal Adaptation Analysis	Bristol	8,612.7	6,190.3	71.9	1,795.9	20.9	249.3	2.9	194.3	2.3
Coastal Adaptation Analysis	Dukes	6,649.1	2,133.0	32.1	1,719.3	25.9	854.2	12.8	93.5	1.4
Coastal Adaptation Analysis	Essex	22,326.2	18,754.7	84.0	2,036.4	9.1	864.3	3.9	411.7	1.8
Coastal Adaptation Analysis	Nantucket	4,365.8	1,200.0	27.5	599.4	13.7	934.9	21.4	805.8	18.5
Coastal Adaptation Analysis	Norfolk	787.1	758.1	96.3	21.2	2.7	4.5	0.6	1.3	0.2
Coastal Adaptation Analysis	Plymouth	12,732.9	10,840.9	85.1	1,588.9	12.5	240.5	1.9	26.8	0.2
Coastal Adaptation Analysis	Suffolk	738.3	675.9	91.6	8.6	1.2	0.2	0.0	—	—
Landscape Blocks	Barnstable	82,481.2	4,032.9	4.9	3,202.4	3.9	2,910.3	3.5	1,596.8	1.9
Landscape Blocks	Bristol	85,667.1	2,587.5	3.0	684.2	0.8	614.3	0.7	822.5	1.0
Landscape Blocks	Dukes	37,813.2	2,085.5	5.5	1,858.1	4.9	1,636.1	4.3	1,375.2	3.6
Landscape Blocks	Essex	41,937.3	13,821.6	33.0	1,474.0	3.5	932.7	2.2	922.2	2.2
Landscape Blocks	Nantucket	11,571.2	659.9	5.7	544.0	4.7	863.5	7.5	673.8	5.8

Name	County	Total Acreage	Category 1		Category 2		Category 3		Category 4	
			Acres	% of Total	Acres	% of Total	Acres	% of Total	Acres	% of Total
Landscape Blocks	Plymouth	124,678.0	1,277.3	1.0	1,350.9	1.1	1,686.8	1.4	2,859.9	2.3
Tern Foraging	Barnstable	17,852.0	9,227.2	51.7	3,589.3	20.1	1,179.6	6.6	96.0	0.5
Tern Foraging	Bristol	3,542.6	2,772.8	78.3	28.3	0.8	5.6	0.2	24.2	0.7
Tern Foraging	Dukes	6,197.1	1,007.2	16.3	115.2	1.9	29.1	0.5	5.8	0.1
Tern Foraging	Essex	15,025.3	13,435.3	89.4	332.2	2.2	38.2	0.3	18.6	0.1
Tern Foraging	Nantucket	2,703.2	1,004.6	37.2	192.7	7.1	438.1	16.2	83.1	3.1
Tern Foraging	Norfolk	12.3	7.6	62.0	0.3	2.0	0.1	0.6	0.1	0.7
Tern Foraging	Plymouth	5,482.2	4,475.5	81.6	68.7	1.3	13.0	0.2	12.9	0.2
Tern Foraging	Suffolk	28.2	19.8	70.0	0.1	0.2	0.1	0.3	0.0	0.1
Wetland Buffer	Barnstable	6,021.8	1,249.8	20.8	153.0	2.5	1,525.7	25.3	561.9	9.3
Wetland Buffer	Bristol	29,531.6	899.6	3.0	296.4	1.0	350.9	1.2	382.7	1.3
Wetland Buffer	Dukes	926.7	207.4	22.4	146.5	15.8	50.0	5.4	31.9	3.4
Wetland Buffer	Essex	17,056.9	868.1	5.1	561.8	3.3	237.0	1.4	521.4	3.1
Wetland Buffer	Nantucket	3,088.1	433.1	14.0	365.3	11.8	328.9	10.7	421.1	13.6
Wetland Buffer	Plymouth	45,543.6	3,117.7	6.8	1,187.8	2.6	993.1	2.2	1,266.9	2.8

Economy

\$ Hurricanes are among the most costly natural disasters in terms of damage inflicted and recovery costs required. Although it is difficult to forecast the economic impact of any specific event, potential damage to buildings serves as a valuable proxy because damage to buildings can impact a community's economy and tax base. The exposure of the general building stock to the storm surge hazard is shown in Table 4-63. As shown in this table, Suffolk County has the largest economic exposure to this hazard, followed by Middlesex County.

Table 4-63: General Building Stock Exposure to Storm Surge

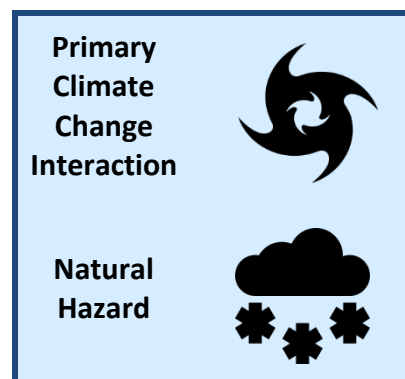
County	Category 1	Category 2	Category 3	Category 4
Barnstable	\$2,892,925	\$3,799,863	\$4,680,249	\$4,495,631
Bristol	\$817,827	\$1,151,586	\$1,323,099	\$6,680,399
Dukes	\$348,536	\$286,714	\$418,437	\$544,146
Essex	\$3,831,013	\$4,512,397	\$4,474,806	\$4,737,235
Middlesex	\$8,780,899	\$20,065,752	\$9,478,548	\$10,907,023
Nantucket	\$276,057	\$229,939	\$139,065	\$224,141
Norfolk	\$2,684,883	\$2,789,373	\$2,559,342	\$2,398,680
Plymouth	\$2,925,711	\$3,432,903	\$2,646,531	\$2,212,540
Suffolk	\$31,650,401	\$40,985,592	\$12,224,059	\$9,114,752
Total	\$54,208,252	\$77,254,119	\$37,944,136	\$41,314,547

4.4.2 Severe Winter Storm / Nor'easter

GENERAL BACKGROUND

Severe winter storms include ice storms, nor'easters, heavy snow, blowing snow, and other extreme forms of winter precipitation.

A blizzard is a winter snowstorm with sustained or frequent wind gusts to 35 mph or more, accompanied by falling or blowing snow that reduces visibility to or below a quarter of a mile (NWS, 2018). These conditions must be the predominant condition over a 3-hour period. Extremely cold temperatures are often associated with blizzard conditions, but are not a formal part of the definition. However, the hazard created by the combination of snow, wind, and low visibility increases significantly with temperatures below 20°F. A severe blizzard is categorized as having temperatures near or below 10°F, winds exceeding 45 mph, and visibility reduced by snow to near zero.






Natural Hazard Summary




SEVERE WINTER STORM / NOR'EASTER

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
Snow formation requires temperatures to be below freezing in most of the atmosphere from the surface up to cloud level. Ice storms occur when liquid rain freezes on contact with cold objects, creating ice build-up. Nor'easters are macro-scale cyclones that begin as strong areas of low pressure in the Gulf of Mexico or off the east coast in the Atlantic Ocean.	Higher snow accumulations are prevalent at higher elevations in Western and Central Massachusetts, and along the coast where snowfall can be enhanced by additional ocean moisture. East-facing coastal areas, including Salisbury Beach, Revere, Nahant, Scituate, and Marshfield, as well as parts of the Cape and Nantucket, experience nor'easters most strongly.	Although there is significant interannual variability in the frequency and severity of winter storms, a notable winter storm generally occurs at least once every winter. Nor'easters generally occur on at least an annual basis, with some years bringing up to four nor'easter events. This is currently the most frequently occurring natural hazard in the state.

Potential Effects of Climate Change

	EXTREME WEATHER AND RISING TEMPERATURES → INCREASED SNOWFALL	Increased sea surface temperature in the Atlantic Ocean will cause air moving north over the ocean to hold more moisture. As a result, when these fronts meet cold air systems moving from the north, an even greater amount of snow than normal can be anticipated to fall on Massachusetts.
	RISING TEMPERATURES → CHANGING CIRCULATION PATTERNS AND WARMING OCEANS	Research has found that increasing water temperatures and reduced sea ice extent in the Arctic are producing atmospheric circulation patterns that favor the development of winter storms in the eastern U.S. Global warming is increasing the severity of winter storms because warming ocean water allows additional moisture to flow into the storm, which fuels the storm to greater intensity.
	EXTREME WEATHER → INCREASE IN FREQUENCY AND INTENSITY	There is evidence suggesting that nor'easters along the Atlantic coast are increasing in frequency and intensity. Future nor'easters may become more concentrated in the coldest winter months when atmospheric temperatures are still low enough to result in snowfall rather than rain.

Exposure and Vulnerability by Key Sector

	POPULATIONS	General At-Risk Population: State-wide exposure. Vulnerable Populations: Elderly populations, who are susceptible due to their increased risk of injury and death from falls, overexertion, or hypothermia related to clearing snow or power failures; residents with low incomes who may lack access to housing or housing with sufficient insulation or heating supply; individuals who have difficulty evacuating for economic or physical reasons.
	GOVERNMENT	Using data from the Northeast States Emergency Consortium, 710 state-owned facilities are located in areas that typically experience more than 2.5 days with 5 or more inches of snow per year. Nearly half of these facilities are located in Worcester County. SLOSH Zones show that Suffolk, Bristol, and Essex Counties have highest number of government facilities exposed to nor'easters.
	BUILT ENVIRONMENT	All elements of the built environment in the Commonwealth are exposed to severe winter weather. According to the DCAMM facility inventory, 19 critical facilities are located in areas that typically experience more than 2.5 days with 5 or more inches of snow per year. SLOSH Zones show that Suffolk and Essex Counties have highest number of critical facilities exposed to nor'easters. Severe winter can result in downed power lines, extended power failures, and road blockages. It can also overwhelm the capacity of public safety providers.
	NATURAL RESOURCES AND ENVIRON.	Winter storms are a natural part of the Massachusetts climate, and native ecosystems and species are well-adapted to these events. However, more extreme winter storms can result in direct mortality, habitat modification, and flooding when snow and ice melt.
	ECONOMY	Potential impacts from winter storms and nor'easters include loss of utilities, interruption of transportation corridors, loss of business function and loss of income during business closures. The cost of snow and ice removal and repair of roads from the freeze/thaw process can also strain local financial resources.

Storm systems powerful enough to cause blizzards usually form when the jet stream dips far to the south, allowing cold air from the north to clash with warm air from the south. Blizzard conditions often develop on the northwest side of an intense storm system. The difference between the lower pressure in the storm and the higher pressure to the west creates a tight pressure gradient, resulting in strong winds and extreme conditions due to the blowing snow. Blowing snow is wind-driven snow that reduces visibility to 6 miles or less, causing significant drifting. Blowing snow may be snow that is falling and/or loose snow on the ground picked up by the wind.

Ice Storms

Ice storm conditions are defined by liquid rain falling and freezing on contact with cold objects, creating ice buildups of one-fourth of an inch or more. These can cause severe damage. An ice storm warning, which is now included in the criteria for a winter storm warning, is issued when a half inch or more of accretion of freezing rain is expected. This may lead to dangerous walking or driving conditions and the pulling down of power lines and trees.

Ice pellets are another form of freezing precipitation, formed when snowflakes melt into raindrops as they pass through a thin layer of warmer air. The raindrops then refreeze into particles of ice when they fall into a layer of subfreezing air near the surface of the earth. Finally, sleet occurs when raindrops fall into subfreezing air thick enough that the raindrops refreeze into ice before hitting the ground. The difference between sleet and hail is that sleet is a wintertime phenomenon whereas hail falls from convective clouds (usually thunderstorms), often during the warm spring and summer months.

Nor'easters

A nor'easter is a storm that occurs along the East Coast of North America with winds from the northeast (NWS, n.d.). A nor'easter is characterized by a large counter-clockwise wind circulation around a low-pressure center that often results in heavy snow, high winds, and rain. A nor'easter gets its name from its continuously strong northeasterly winds blowing in from the ocean ahead of the storm and over the coastal areas.

Nor'easters are among winter's most ferocious storms. These winter weather events are notorious for producing heavy snow, rain, and oversized waves that crash onto Atlantic beaches, often causing beach erosion and structural damage. These storms occur most often in late fall and early winter. The storm radius is often as much as 100 miles, and nor'easters often sit stationary for several days, affecting multiple tide cycles and causing extended heavy precipitation. Sustained wind speeds of 20 to 40 mph are common during a nor'easter, with short-term wind speeds gusting up to 50 to 60 mph. Nor'easters are commonly accompanied with a storm surge equal to or greater than 2.0 feet.

Nor'easters begin as strong areas of low pressure either in the Gulf of Mexico or off the East Coast in the Atlantic Ocean. The low will then either move up the East Coast into New England and the Atlantic provinces of Canada, or out to sea. The level of damage in a strong hurricane is often more severe than a nor'easter, but historically Massachusetts has suffered more damage from nor'easters because of the greater frequency of these coastal storms (one or two per year). The comparison of hurricanes to nor'easters reveals that the duration of high surge and winds in a hurricane is 6 to 12 hours, while a nor'easter's duration can be from 12 hours to 3 days.

HAZARD PROFILE

Location

Although the entire Commonwealth may be considered at risk to the hazard of severe winter storms, higher snow accumulations appear to be prevalent at higher elevations in Western and Central Massachusetts, and along the coast where snowfall can be enhanced by additional ocean moisture. Ice storms occur most frequently in the higher-elevation portions of Western and Central Massachusetts.

While nor'easters may impact the entire Commonwealth, the 78 coastal communities are especially vulnerable to the damaging impacts of nor'easters along more than 1,500 miles of varied coastline. As coastal development increases and sea level rise occurs, nor'easters will lead to more substantial damage. Similar to hurricane events, the coastal areas are more susceptible to damage than other areas of the Commonwealth due to the combination of high winds, waves, and tidal surge. Eastern-facing coastal areas are the most exposed and therefore often receive the most damage. These areas include Salisbury Beach, Revere, Nahant, Scituate and Marshfield, as well as parts of the Cape and Nantucket.

However, nor'easters can also bring heavy snow, which can paralyze inland cities or regions as well. Inland areas, especially those in floodplains, are also at risk for flooding and wind damage.

Previous Occurrences

Snow and other winter precipitation occur very frequently across the entire Commonwealth. The average annual snowfall for the snowiest city in each of four regions (Cape Cod/Islands, Eastern, Central, and Western) is as follows:

- Chatham (Cape Cod and Islands): 28.9 inches
- Milton (Eastern MA): 62.7 inches
- East Brimfield (Central MA): 59.0 inches
- Worthington (Western MA): 79.7 inches

Ice Storms

From 1998 to 2017, NCDC reported 28 ice storm events. All the storms within that period occurred between November and February, most frequently occurring in late December and early January. Ice storms of lesser magnitudes impact the Commonwealth on at least an annual basis.

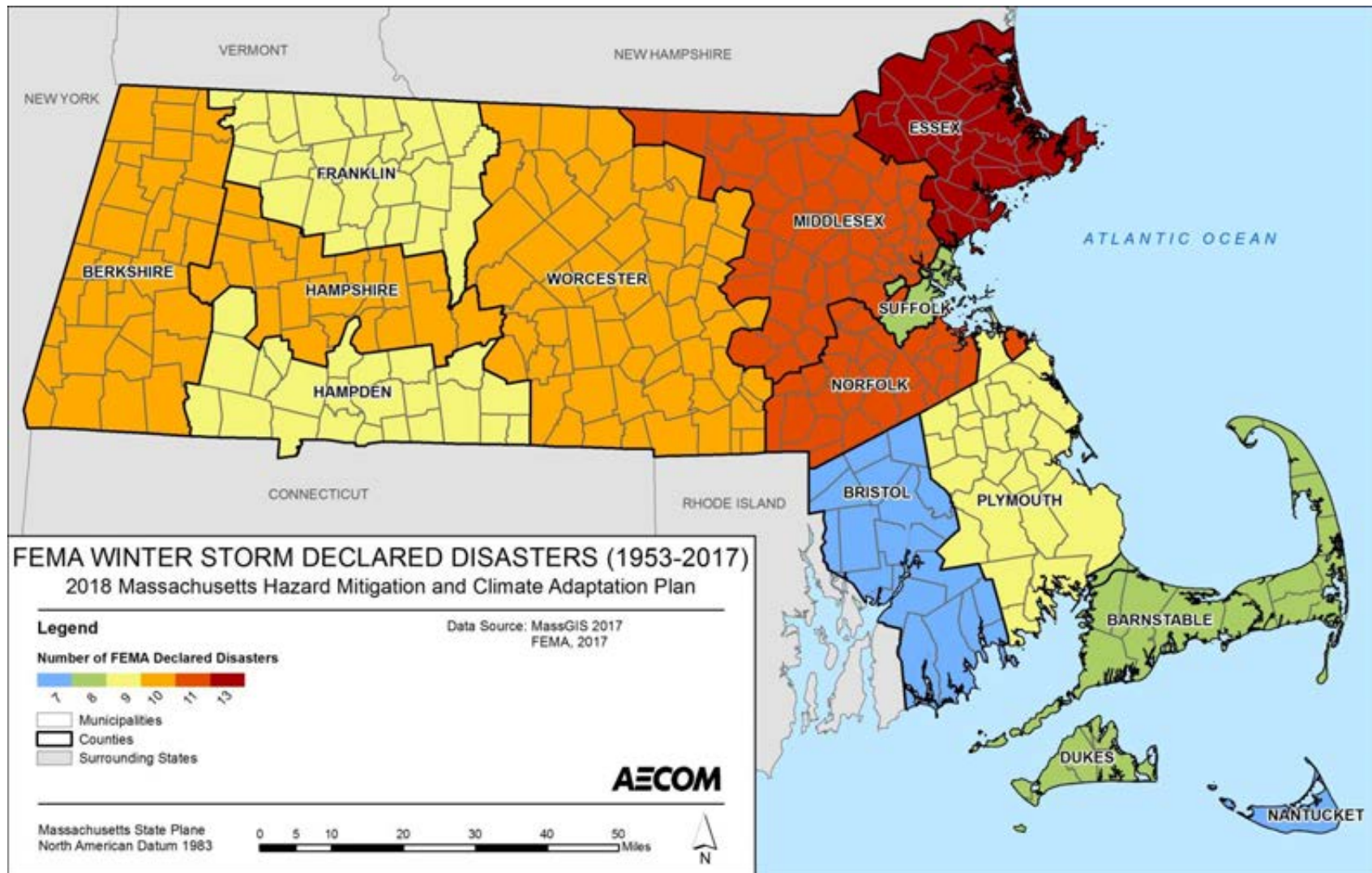
Nor'easters

Between 1953 and 2017, 59 significant winter storms occurred, 35 of which were classified as “major” or greater on the Northeast Snowfall Impact Scale (NESIS), and struck Massachusetts. These events are listed and described in Appendix B.

Severe Winter Weather Events

There is significant overlap between winter weather disasters and other types of disaster, such as flooding. In order to reduce redundancy, all FEMA declarations are listed in Appendix B. For an overview of the distribution of this hazard, Figure 4-62 depicts the number of winter storm disaster declarations by county between 1953 and 2017. On June 25, 2018, an additional severe winter storm and flooding was declared for a storm that occurred from March 2 to March 3, 2018 (FEMA-4372-DR). Public Assistance for emergency work and the repair or replacement of disaster-damaged facilities was available for the following counties under this declaration: Barnstable, Bristol, Essex, Nantucket, Norfolk, and Plymouth Counties. On July 19, 2018, an additional severe winter storm/snowstorm was declared for a storm that occurred from March 13 to March 14, 2018 (FEMA-4379-DR). Under this declaration, Public Assistance was available to five counties: Essex, Middlesex, Norfolk, Suffolk, and Worcester.

Figure 4-62: FEMA Winter Storm-Related Declared Disasters by County (1953 to 2017)



Note: FEMA-4372-DR and FEMA-4379-DR, both of which occurred in March 2018 and were declared in Summer 2018, are not included in the figure above.

Frequency of Occurrences

According to NESIS data, 59 winter storms rated as “notable” or higher affected the Northeast urban corridor, which includes Massachusetts. Based on this historical record, high-impact snowstorms occur at approximately the rate of one per year, although there is significant interannual variability in the frequency and severity of winter storms.

As discussed in other sections within this plan, extreme weather events—including extreme precipitation and snowfall levels—are anticipated to occur more frequently as climate change occurs. However, as temperatures throughout the year increase, it is possible that nor’easter events may become more concentrated in the coldest winter months when atmospheric temperatures are still low enough to result in snowfall rather than rain. Whether these events are classified as nor’easters or not, storm surge impacts from all storms are likely to increase significantly as a result of sea level rise and coastal erosion.

Severity/Extent

Snowfall is a component of multiple hazards, including nor’easters and severe winter storms. Two scores, the Regional Snowfall Index (RSI) and the NESIS, are described in this section.

Regional Snowfall Index

Since 2005, the RSI has become the descriptor of choice for measuring winter events that impact the eastern two-thirds of the U.S. The RSI ranks snowstorm impacts on a scale system from 1 to 5 as depicted in Table 4-64. The RSI is similar to the Fujita scale for tornadoes or the Saffir-Simpson scale for hurricanes, except that it includes an additional variable: population. The RSI is based on the spatial extent of the storm, the amount of snowfall, and population (NOAA, n.d.).

As described in Section 4.4.4, the amount of precipitation in Massachusetts is expected to increase over the next 80 years as a result of climate change. Additionally, the proportion of precipitation that falls during extreme events is predicted to increase. While rising temperatures mean that more of this precipitation is likely to fall as rain than snow, historical data show that the frequency of extreme snowstorms in the U.S. doubled between the first half of the 20th century and the second. NOAA analysis suggests that global warming is exacerbating the severity of winter storms because warming water in the Atlantic Ocean allows additional moisture to flow into the storm, which fuels the storm to greater intensity. Other research has found that increasing water temperatures and reduced sea ice extent in the Arctic are producing atmospheric circulation patterns that favor the development of winter storms in the eastern U.S. (Francis et al., 2012).

The RSI is a regional index. Each of the six climate regions (identified by the NOAA National Centers for Environmental Information) in the eastern two-thirds of the nation has a separate index. The RSI incorporated region-specific parameters and thresholds for calculating the index. The RSI is important because, with it, a storm event and its societal impacts can be assessed within the context of a region’s historical events. Snowfall thresholds in Massachusetts (in the Northeast region) are 4, 10, 20, and 30 inches of snowfall, while thresholds in the Southeast U.S. are 2, 5, 10, and 15 inches.

Table 4-64: Regional Snowfall Index Categories, Corresponding RSI Values, and Description

Category	RSI Value	Description
1	1-3	Notable
2	3-6	Significant
3	6-10	Major
4	10-18	Crippling
5	18.0+	Extreme

Source: NCDC, n.d.

Northeast Snowfall Impact Scale

Prior to the use of the RSI, the Northeast Snowfall Impact Scale, developed by Paul Kocin of The Weather Channel and Louis Uccellini of the NWS, was used to characterize and rank high-impact northeast snowstorms with large areas of 10-inch snowfall accumulations and greater. In contrast to the RSI, which is a regional index, NESIS is a quasi-national index that is calibrated to Northeast snowstorms. NESIS has five categories, as shown in Table 4-65.

Table 4-65: NESIS Categories, Corresponding NESIS Values, and Description

Category	NESIS	Value Description
1	1—2.499	Notable
2	2.5—3.99	Significant
3	4—5.99	Major
4	6—9.99	Crippling
5	10.0+	Extreme

Source: National Climate Data Center, n.d.
 NESIS = Northeast Snowfall Impact Scale

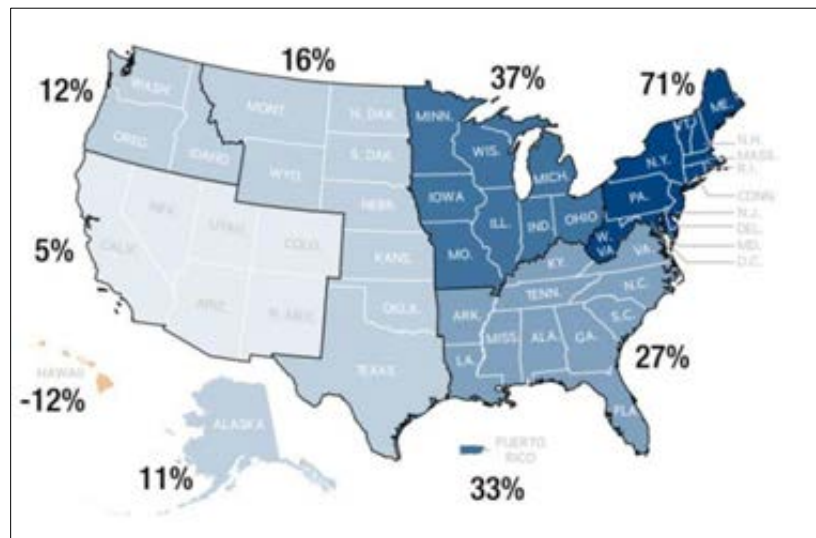
The magnitude or severity of a severe winter storm depends on several factors, including a region's climatological susceptibility to snowstorms, snowfall amounts, snowfall rates, wind speeds, temperatures, visibility, storm duration, topography, time of occurrence during the day (e.g., weekday versus weekend), and time of season. Depending on the scale used to describe a storm, severity may also be impacted based on its social impacts, such as the number of individuals or the extent of economic activity that will be affected.

The impacts of a nor'easter depends on several factors, including a region's climatological susceptibility to snowstorms, snowfall amounts, snowfall rates, wind speeds, temperatures, visibility, storm duration, topography, time of occurrence during the day (e.g., weekday versus weekend), and time of season. The severity of a nor'easter also depends on the time of occurrence relative to the lunar tide cycles (spring or neap tides) and during what tide stage the

maximum storm surge occurs at (high tide or low tide). Depending on the metric used to measure the storm, assigned severity may also take into account the storm's societal and economic impacts.

Increased sea surface temperature in the Atlantic Ocean will cause air moving north over this ocean to hold more moisture. As a result, when these fronts meet cold air systems moving from the north, an even greater amount of snow than normal can be anticipated to fall on Massachusetts. Although no one storm can be linked directly to climate change, the severity of rain and snow events has increased dramatically in recent years. As shown in Figure 4-63, the amount of precipitation released by storms in the Northeast has increased by 71 percent from the baseline level (recorded from 1901 to 1960) and present-day levels (measured from 2001 to 2012) (USGCRP, 2014).

Figure 4-63: Observed Changes in Heavy Precipitation



Source: NCA 2014

Sea level rise is also likely to exacerbate the impacts of nor'easters because as coastal erosion increases, beachfront homes will have less of a buffer against storm surge.

Warning Time

Meteorologists can often predict the likelihood of a severe storm or nor'easter. This can give several days of warning time. The NOAA's NWS monitors potential events and provides extensive forecasts and information several days in advance of the storm in order to help the state to prepare for the incident. However, meteorologists cannot predict the exact time of onset or severity of the storm. Some storms may come on more quickly and have only a few hours of warning time.

SECONDARY HAZARDS

The phrase “severe winter storm” encapsulates several types of natural hazards, including snowfall, wind, ice, sleet, and freezing rain hazards. Additional natural hazards that can occur as a result of winter storms include sudden and severe drops in temperature. Winter storms can also result in flooding and the destabilization of hillsides as snow or ice melts and begins to run off. The storms can also result in significant structural damage from wind and snow load as well as human injuries and economic and infrastructure impacts (described later in this section).

The secondary hazards associated with nor’easters are similar to those associated with hurricanes and severe winter storms. Natural hazards that could occur as a result of a nor’easter include coastal erosion, flooding, levee or dam failure, increased risk of landslides or other land movement, the release of hazardous materials, and environmental damage. Secondary social hazards could include health issues such as the growth of mold or mildew, isolation due to impacts on transportation, power loss, and structural and property damage. Power outages may also result in inappropriate use of combustion heaters, cooking appliances, and generators in indoor or poorly ventilated areas, which can lead to increased risks of carbon monoxide poisoning. Loss of power and refrigeration can also cause food contamination.

EXPOSURE AND VULNERABILITY

Nor’easters share many characteristics with hurricane events. Both types of events can bring high winds and surge inundation that results in similar impacts on the population, structures, and the economy. For the purposes of the SHMCAP, the Hazus wind/surge model was used to estimate potential losses attributed to the February 1978 nor’easter, the most extensive nor’easter on record, with current (2010) population and built environment. Additional detail on this model can be found in Section 4.4.1.

Populations



According to the NOAA National Severe Storms Laboratory, every year, winter weather indirectly and deceptively kills hundreds of people in the U.S., primarily from automobile accidents, overexertion, and exposure. Winter storms are often accompanied by strong winds creating blizzard conditions with blinding wind-driven snow, drifting snow, and extreme cold temperatures with dangerous wind chill. They are considered deceptive killers because most deaths and other impacts or losses are indirectly related to the storm. Injuries and deaths may occur due to traffic accidents on icy roads, heart attacks while shoveling snow, or hypothermia from prolonged exposure to cold.

Heavy snow can immobilize a region and paralyze a city, shutting down air and rail transportation, stopping the flow of supplies, and disrupting medical and emergency services. Accumulations of snow can cause buildings to collapse and knock down trees and power lines.

In rural areas, homes and farms may be isolated for days, and unprotected livestock may be lost. In the mountains, heavy snow can lead to avalanches. Storms near the coast can cause coastal flooding and beach erosion as well as sink ships at sea.

The impact of a nor'easter on life, health, and safety is dependent upon several factors, including the severity of the event and whether or not adequate warning time was provided to residents.

A nor'easter surge inundation zone does not exist to estimate the population exposed. However, the storm surge areas generated by SLOSH provide a useful proxy. Therefore, Table 4-55 depicts the populations exposed to storm surge by both hurricanes and nor'easters.

Residents may be displaced or require temporary to long-term sheltering. In addition, downed trees, damaged buildings, and debris carried by high winds can lead to injury or loss of life. The 1978 historical event was run in Hazus to estimate the sheltering needs should this event occur today. The estimated shelter needs due to wind-only impacts are summarized in Table 4-66.

Table 4-66: Estimated Shelter Needs for 1978 Nor'easter

County	Displaced Households	Short-Term Shelter Needs
Barnstable	68	12
Berkshire	—	—
Bristol	107	31
Dukes	1	—
Essex	4	1
Franklin	—	—
Hampden	—	—
Hampshire	—	—
Middlesex	22	1
Nantucket	2	—
Norfolk	65	10
Plymouth	51	11
Suffolk	99	22
Worcester	1	—
Total	420	88

Source: FEMA Hazus loss estimation methodology

For the purposes of the SHMCAP, the entire population of the Commonwealth is exposed to severe winter weather events. Additional information on areas of the Commonwealth that are more frequently exposed to high winds can be found in Section 4.4.4.

Vulnerable Populations

Vulnerable populations include the elderly living alone, who are susceptible to winter hazards due to their increased risk of injury and death from falls, overexertion, and/or hypothermia from attempts to clear snow and ice, or injury and death related to power failures. In addition, severe winter weather events can reduce the ability of these populations to access emergency services. People with low socioeconomic status are more vulnerable because they are likely to evaluate their risk and make decisions to evacuate based on the net economic impact on their families. Residents with low incomes may not have access to housing or their housing may be less able to withstand cold temperatures (e.g., homes with poor insulation and heating supply). The population over the age of 65, individuals with disabilities, and people with mobility limitations or who lack transportation are also more vulnerable because they are more likely to seek or need medical attention, which may not be available due to isolation during a flood event. These individuals are also more vulnerable because they may have more difficulty if evacuation becomes necessary. People with limited mobility risk becoming isolated or “snowbound” if they are unable to remove snow from their homes. Rural populations may become isolated by downed trees, blocked roadways, and power outages.

Health Impacts

Health impacts from severe winter storms are similar to those described for other hazards, particularly the extreme temperatures discussed in Section 4.3.1. Cold weather, which is a component of a severe winter storm, increases the risk of hypothermia and frostbite. Exposure to cold conditions can also exacerbate pre-existing respiratory and cardiovascular conditions. In addition to temperature-related dangers, however, severe winter storms also present other potential health impacts. For example, individuals may use generators in their homes if the power goes out or may use the heat system in their cars if they become trapped by snow. Without proper ventilation, both of these activities can result in carbon monoxide buildup that can be fatal. Loss of power can also lead to hypothermia. After Hurricane Sandy, the number of cases of cold exposure in New York City was three times greater than the same time period in previous years (Fink, 2012). Driving during severe snow and ice conditions can also be very dangerous, as roads become slick and cars can lose control. During and after winter storms, roads may be littered with debris, presenting a danger to drivers. Health impacts on people include the inability to travel to receive needed medical services and isolation in their homes. Additionally, natural gas-fueled furnaces, water heaters, and clothes driers, and even automobile exhaust pipes, may become blocked by snow and ice, which can lead to carbon monoxide poisoning.

Government



As part of a study funded by the FEMA Hazard Mitigation Grant Program, in 2010 the Northeast States Emergency Consortium developed regional hazard maps for snowfall for the Northeast. Using their GIS data, a map was created to show which areas experience high snow levels (defined as greater than 5 inches) with a given frequency. These data were overlaid with the DCAMM facility data, and the resulting map is shown in Figure 4-64. Table 4-67 summarizes the number of state-owned buildings in each of the four snow bands.

A nor'easter surge inundation zone does not exist to estimate the number of government facilities exposed. However, the storm surge areas generated by SLOSH provide a useful proxy; Table 4-56 depicts the government buildings exposed to storm surge by both hurricanes and nor'easters in SLOSH zones by county.

Figure 4-64: Number of Days with 5 Inches of Snow or More

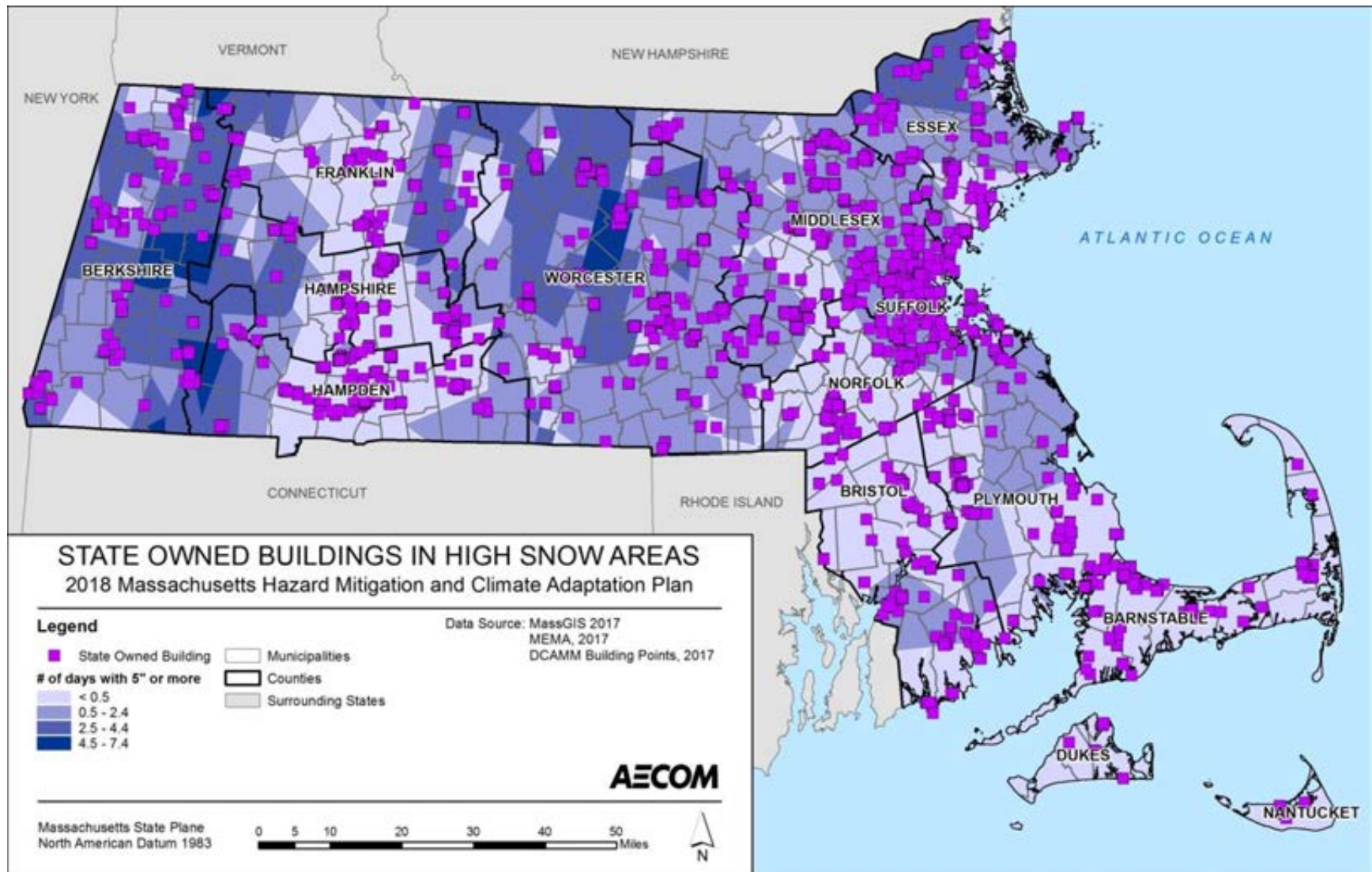


Table 4-67: State-Owned Buildings in High-Snow Areas

County	Number of Days of Storms Totaling More than 5 Inches of Snow							
	<0.5 days per year		0.5 – 2.4 days per year		2.5 – 4.4 days per year		4.5 – 7.4 days per year	
	Count	Replacement Value	Count	Replacement Value	Count	Replacement Value	Count	Replacement Value
Barnstable	283	\$387,520,413	—	—	—	—	—	—
Berkshire	23	\$225,978,032	120	\$441,564,695	134	\$53,267,992	34	\$ 3,040,655
Bristol	197	\$635,327,119	112	\$754,722,896	—	—	—	—
Dukes	9	\$11,109,395	—	—	—	—	—	—
Essex	189	\$1,232,718,479	169	\$363,209,369	63	\$163,667,402	—	—
Franklin	120	\$305,153,404	25	\$8,500,444	59	\$20,839,246	—	—
Hampden	361	\$2,378,445,047	49	\$103,042,029	16	\$1,371,482	1	Not provided
Hampshire	417	\$2,289,158,035	58	\$22,447,459	27	\$2,494,320	—	—
Middlesex	126	\$428,100,189	737	\$3,551,003,480	29	\$38,636,905	—	—
Nantucket	8	\$6,417,161	—	—	—	—	—	—
Norfolk	363	\$1,367,092,553	163	\$295,859,599	—	—	—	—
Plymouth	495	\$2,296,624,897	75	\$33,356,527	—	—	—	—
Suffolk	97	\$2,248,726,229	174	\$4,640,670,237	—	—	—	—
Worcester	32	\$113,889,724	483	\$3,059,546,065	310	\$819,537,336	37	\$22,998,037
Total	2,720	\$13,926,260,676	2,165	\$13,273,922,801	638	\$1,099,814,683	72	\$26,038,692

Sources: DCAMM, 2017 (facility inventory); MEMA, 2017

The Built Environment



All infrastructure and other elements of the built environment in the Commonwealth are exposed to the severe winter weather hazard. Potential structural damage to the facilities themselves may include damage to roofs and building frames. These facilities may not be fully operational if workers are unable to travel to ensure continuity of operations prior and after a severe winter event. Disruptions to key public services such as electricity, transportation, schools, and health care may become more common (resilient MA, 2018).

Table 4-68 summarizes the number of critical facilities in each of the four snow bands described earlier by county, and Table 4-69 describes the number of exposed state facilities by type.

Table 4-68: Number of Critical Facilities in High-Snow Areas by County

County	Number of Days of Storms Totaling More than 5 Inches of Snow			
	<0.5 days per year	0.5 – 2.4 days per year	2.5 – 4.4 days per year	4.5 – 7.4 days per year
Barnstable	10	—	—	—
Berkshire	1	7	1	—
Bristol	11	8	—	—
Dukes	2	—	—	—
Essex	16	13	2	—
Franklin	6	1	1	—
Hampden	19	4	—	—
Hampshire	10	3	1	—
Middlesex	9	35	1	—
Nantucket	3	—	—	—
Norfolk	14	8	—	—
Plymouth	20	3	—	—
Suffolk	7	14	—	—
Worcester	3	20	12	2
Total	131	116	18	2

Source: MEMA 2017

Table 4-69: Number of Critical Facilities in High-Snow Areas by Facility Type

Facility Type	<0.5 days per year	0.5 – 2.4 days per year	2.5 – 4.4 days per year	4.5 – 7.4 days per year
Military	18	19	3	—
Police Facilities	37	32	7	—
Fire Departments	8	5	2	1
Hospitals	2	5	—	—
Colleges	27	25	3	—
Social Services	40	30	2	1
Total	132	116	17	2

Sources: DCAMM, 2017 (facility inventory); MEMA, 2017

A nor'easter surge inundation zone does not exist to estimate the number of critical facilities exposed. However, the storm surge areas generated by SLOSH provide a useful proxy. Tables

4-56 through 4-59 depicts the elements of the built environment exposed to storm surge by both hurricanes and nor'easters in SLOSH zones.

Agriculture

Severe winter weather can lead to flooding in low-lying agricultural areas. Ice that accumulates on branches in orchards and forests can cause branches to break, while the combination of ice and wind can fell trees. Storms that occur in spring can delay planting schedules. Frost that occurs after warmer periods in spring can cause cold weather dieback and damage new growth.

Energy

Severe weather can cause power outages from trees that fall during heavy snow and strong wind events. Severe ice events can take down transmission and distribution lines. The severe weather can impair a utility's ability to rapidly repair and recover the system.

Public Health

Severe winter weather presents many health hazards, as previously described in the discussion of the severe winter storm/nor'easter hazard profile. Severe winter storms and events with extended power outages may overburden hospitals and emergency shelters.

Public Safety

Public safety buildings may experience direct loss (damage) from downed trees, heavy snowfall, and high winds. Full functionality of critical facilities, such as police, fire and medical facilities, is essential for response during and after a winter storm event. Because power interruptions can occur, backup power is recommended for critical facilities and infrastructure. The ability of emergency responders to respond to calls may be impaired by heavy snowfall, icy roads, and downed trees.

Transportation

Other infrastructure elements at risk for this hazard include roadways, which can be obstructed by snow and ice accumulation or by windblown debris. Additionally, over time, roadways can be damaged from the application of salt and the thermal expansion and contraction from alternating freezing and warming conditions. Other types of infrastructure, including rail, aviation, port, and waterway infrastructure (if temperatures are cold enough to cause widespread freezing), can be impacted by winter storm conditions.

Water Infrastructure

Water infrastructure that is exposed to winter conditions may freeze or be damaged by ice.

Natural Resources and Environment



Although winter storms are a natural part of the Massachusetts climate, and native ecosystems and species are well adapted to these events. However, changes in the frequency or severity of winter storms could increase their environmental impacts.

Environmental impacts of severe winter storms can include direct mortality of individuals and felling of trees, which can damage the physical structure of the ecosystem. Similarly, if large numbers of plants or animals die as the result of a storm, their lack of availability can impact the food supply for animals in the same food web. If many trees fall within a small area, they can release large amounts of carbon as they decay. This unexpected release can cause further imbalance in the local ecosystem. The flooding that results when snow and ice melt can also cause extensive environmental impacts, as discussed in Section 4.1.1. Nor'easters can cause impacts that are similar to those of hurricanes and tropical storms (Section 4.4.1), coastal flooding (Section 4.2.1), and inland flooding (Section 4.1.1). These impacts can include direct damage to species and ecosystems, habitat destruction, and the distribution of contaminants and hazardous materials throughout the environment.

Economy



The entire general building stock inventory in the Commonwealth is exposed to the severe winter weather hazard. In general, structural impacts include damage to roofs and building frames rather than building content. Heavy accumulations of ice can bring down trees, electrical wires, telephone poles and lines, and communication towers. Communications and power can be disrupted for days while utility companies work to repair the extensive damage. Even small accumulations of ice may cause extreme hazards to motorists and pedestrians. Bridges and overpasses are particularly dangerous because they freeze before other surfaces. A specific area that is vulnerable to the winter storm hazard is the floodplain. Snow and ice melt can cause both riverine and urban flooding. Estimated losses due to flooding in the Commonwealth are discussed in Section 4.1.1. The cost of snow and ice removal and repair of roads from the freeze/thaw process can drain local financial resources. The potential secondary impacts from winter storms, including loss of utilities, interruption of transportation corridors, loss of business functions, and loss of income for many individuals during business closures, also impact the local economy.

Similar to hurricanes and tropical storms, nor'easter events can greatly impact the economy, with impacts that include the loss of business functions (e.g., tourism and recreation), damage to inventories or infrastructure (the supply of fuel), relocation costs, wage losses, and rental losses due to the repair or replacement of buildings. Hazus estimates the total economic loss associated with each storm scenario (direct building losses and business interruption losses). Direct building losses are the estimated costs to repair or replace the damage caused to a building.

A Hazus analysis was conducted to determine the combination wind and surge impacts from the 1978 nor'easter event for the entire Commonwealth building stock. Because of differences in building construction, residential structures are generally more susceptible to wind damage than commercial and industrial structures. Wood and masonry buildings in general, regardless of their occupancy class, tend to experience more wind damage than concrete or steel buildings. Table 4-70 summarizes the estimated building loss (structure and contents). The total damage reflects the overall impact at an aggregate level.

Table 4-70: Estimated Building Loss from Hazus Wind and Storm Surge Analysis (Structure and Contents Replacement Cost Value) 1978 Nor'easter

County	Total (Wind and Surge)	Total Wind Only	Total Surge Only
Barnstable	\$590,093,258	\$194,949,258	\$395,144,000
Berkshire	\$0	\$0	\$0
Bristol	\$204,625,675	\$176,935,675	\$27,690,000
Dukes	\$53,040,437	\$13,157,437	\$39,883,000
Essex	\$732,222,926	\$64,446,927	\$667,775,999
Franklin	\$484,957	\$484,957	\$0
Hampden	\$5,963,018	\$5,963,018	\$0
Hampshire	\$1,897,908	\$1,897,908	\$0
Middlesex	\$462,591,150	\$221,504,150	\$241,087,000
Nantucket	\$24,544,131	\$17,829,131	\$6,715,000
Norfolk	\$427,367,579	\$231,024,579	\$196,343,000
Plymouth	\$555,012,866	\$242,940,866	\$312,072,000
Suffolk	\$1,317,085,107	\$134,302,106	\$1,182,783,001
Worcester	\$60,441,016	\$60,441,016	\$0
Total	\$4,435,370,028	\$1,365,877,028	\$3,069,493,000

Source: FEMA Hazus loss estimation methodology

Hazus also estimates the amount of debris that may be produced as a result of wind events. Table 4-71 summarizes the debris produced from the wind aspect of the storm hazard. Because the estimated debris production does not include flooding, this is likely a conservative estimate and may be higher if multiple impacts occur.

Table 4-71: Estimated Debris—1978 Nor'easter Wind-Only Analysis Based on the 2010 Built Environment

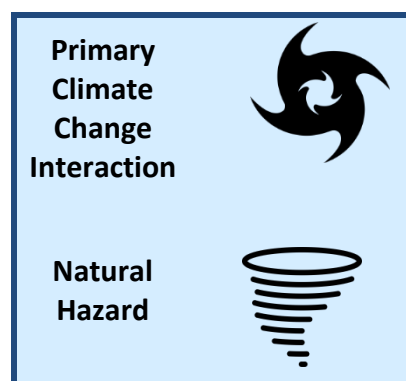
County	Brick/Wood (tons)	Concrete (tons)	Trees (tons)	Tree Volume (cubic yards)
Barnstable	24,660	9	117,205	1,172,065
Berkshire	—	—	—	—
Bristol	21,168	—	148,211	1,482,129
Dukes	1,501	—	20,208	202,087
Essex	7,521	—	30,721	307,241
Franklin	—	—	7,316	73,159
Hampden	54	—	8,360	83,580
Hampshire	6	—	6,361	63,607
Middlesex	20,497	—	55,718	557,140
Nantucket	2,321	2	5,969	59,686
Norfolk	19,269	—	81,312	813,137
Plymouth	16,779	—	237,870	2,378,770
Suffolk	26,011	—	5,458	54,584
Worcester	5,091	—	62,853	628,508
Total	144,878	11	787,562	7,875,693

Source: FEMA Hazus loss estimation methodology

4.4.3 Tornadoes

GENERAL BACKGROUND

A tornado is a narrow, violently rotating column of air that extends from the base of a cumulonimbus cloud to the ground. The observable aspect of a tornado is the rotating column of water droplets, with dust and debris caught in the column. Tornadoes are the most violent of all atmospheric storms.





Natural Hazard Summary

TORNADOES

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
Tornadoes require a number of elements in order to form: strong atmospheric winds, clockwise turning of the winds with height, increasing wind speed in the low atmosphere, a gradient of cooler, drier air at elevation and a forcing mechanism.	Historically, the most tornado-prone portions of Massachusetts are the central counties (Franklin, Hampshire, Hampden, and Worcester) as well as portions of Middlesex and Norfolk Counties.	Massachusetts experiences an average of 1.7 tornadoes per year.






Potential Effects of Climate Change



EXTREME WEATHER
→ INCREASE
IN FREQUENCY
AND INTENSITY
OF SEVERE
THUNDERSTORMS

Future environmental changes may result in an increase in the frequency and intensity of severe thunderstorms, which can include tornadoes. However, the resolution of current climate models is too coarse to accurately simulate tornado formation and the confidence on model details associated with this potential increase is low.

Exposure and Vulnerability by Key Sector 

	POPULATIONS	<p>General At-Risk Population: State-wide exposure; population in area having higher-than-average tornado frequency are at greater risk.</p> <p>Vulnerable Populations: Populations who may have difficulty evacuating, including car-free households, individuals over age 65, and households with young children; individuals with limited Internet or phone access or low English language fluency may not be aware of impending warning; people who reside in older or less stable housing.</p>
	GOVERNMENT	Using a tornado density approximation, as well as the DCAMM facility inventory, 4,511 state-owned facilities are located within tornado hazard areas. This method is conservative, and it is unlikely that even a fraction of these facilities will experience tornado impacts. The highest number of exposed facilities is in Middlesex County (663), followed by Worcester County (541).
	BUILT ENVIRONMENT	A total of 224 critical facilities were identified within tornado hazard areas, with the highest numbers in Middlesex (45) and Worcester (37) Counties. Tornadoes down power lines and damage transmission infrastructure. Shelters and other public safety facilities that provide services for people whose homes are damaged may be overburdened. Hail, wind, debris, and flash flooding associated with tornadoes can damage water infrastructure.
	NATURAL RESOURCES AND ENVIRONMENT	Direct impacts may occur to flora and fauna small enough to be transported by the tornado. Even if the winds are not sufficient to transport trees and other large plants, they may still uproot them. Material transported by tornadoes can also cause environmental havoc in surrounding areas, particularly if contaminating materials are introduced into the atmosphere or local water supplies.
	ECONOMY	Tornado events are typically localized; however, in those areas, economic impacts can be significant. Types of impacts may include loss of business function, water supply system damage, damage to inventory, relocation costs, wage loss, and rental loss due to the repair/replacement of buildings. Recovery and clean-up costs can also be costly.

The following are common factors in tornado formation:

- Very strong winds in the middle and upper levels of the atmosphere
- Clockwise turning of the wind with height (i.e., from southeast at the surface to west aloft)
- Increasing wind speed in the lowest 10,000 feet of the atmosphere (i.e., 20 mph at the surface and 50 mph at 7,000 feet)
- Very warm, moist air near the ground, with unusually cooler air aloft
- A forcing mechanism such as a cold front or leftover weather boundary from previous shower or thunderstorm activity

Tornadoes can form from individual cells within severe thunderstorm squall lines. They can also form from an isolated supercell thunderstorm. They can be spawned by tropical cyclones or the remnants thereof, and weak tornadoes can even occur from little more than a rain shower if air is converging and spinning upward.

Most tornadoes occur in the late afternoon and evening hours, when the heating is the greatest. The most common months for tornadoes to occur are June, July, and August, although the Great Barrington, Massachusetts, tornado (1995) occurred in May and the Windsor Locks, Connecticut, tornado (1979) occurred in October.

A tornadic waterspout is a rapidly rotating column of air extending from the cloud base (typically a cumulonimbus thunderstorm) to a water surface, such as a bay or the ocean. They can be formed in the same way as regular tornadoes, or can form on a clear day with the right amount of instability and wind shear. Tornadic waterspouts can have wind speeds of 60 to 100 mph, but since they do not move very far, they can often be navigated around. They can become a threat to land if they drift onshore.

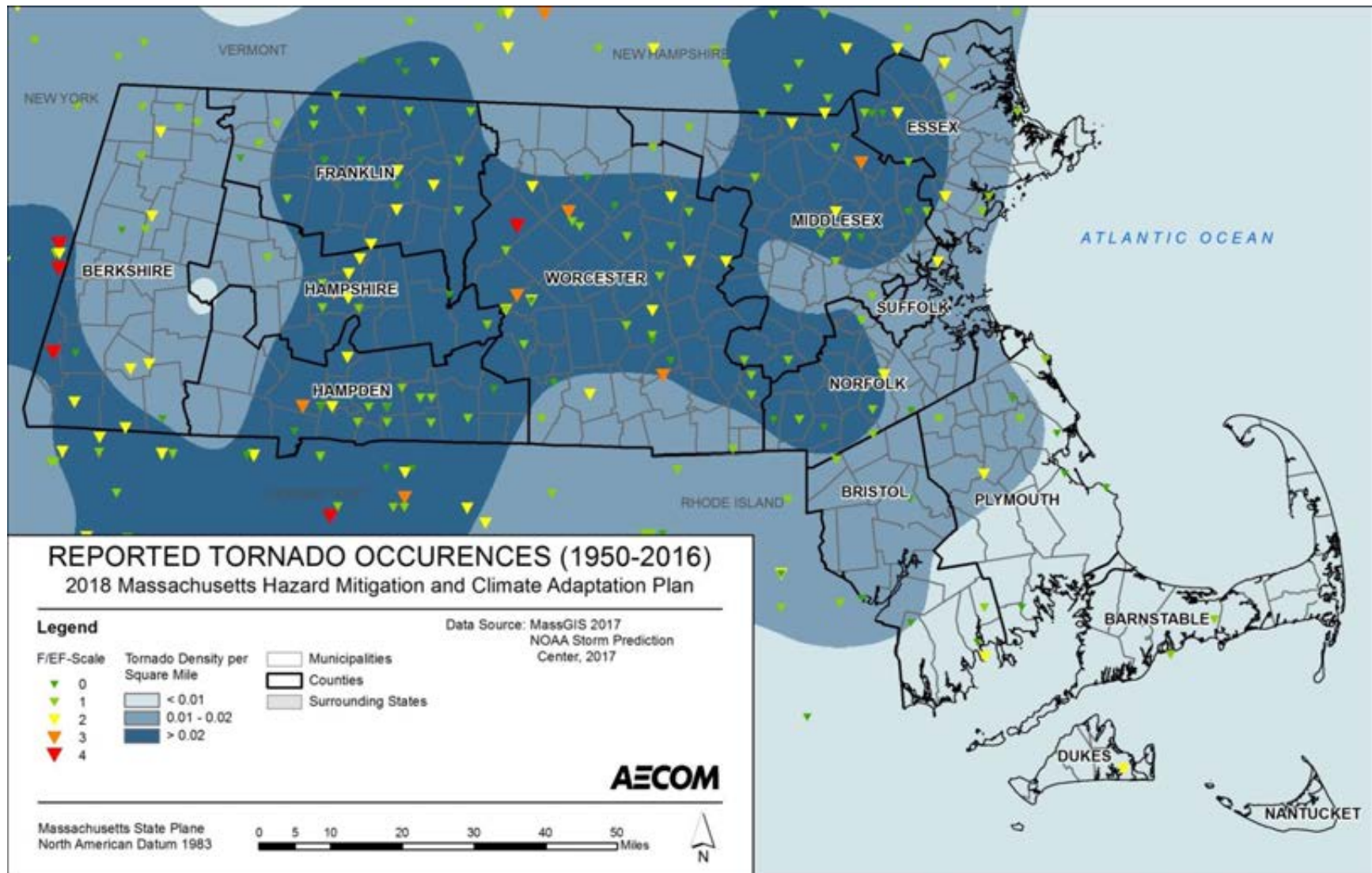
HAZARD PROFILE

Location

The U.S. experiences an average of 1,253 tornadoes per year, more tornadoes than any other country. (NOAA, n.d.). Because Massachusetts experiences far fewer tornadoes than other parts of the country, residents may be less prepared to react to a tornado.

Figure 4-65 illustrates the reported tornado occurrences, based on all-time initial touchdown locations across the Commonwealth as documented in the NOAA NCDC Storm Events Database. To calculate density, the ArcGIS kernel density tool was used to calculate an average score per square mile. The analysis indicated that the area at greatest risk for a tornado touchdown runs from central to northeastern Massachusetts.

Figure 4-65: Density of Reported Tornadoes per Square Mile



Source: NOAA Storm Prediction Center (SPC)

Previous Occurrences

Only two tornadoes in Massachusetts have ever received FEMA disaster declarations. These events are described in Appendix B, along with the less severe events documented by the NCDC Storm Center.

The most destructive tornado in New England history was the Worcester tornado of June 9, 1953. The F4 tornado hit at about 3:30 p.m. The funnel quickly intensified, carving a 46-mile path of death and destruction as it moved through seven towns. The twister tore through Barre, Rutland, Holden, Worcester, Shrewsbury, Westborough, and Southborough. It killed 90 people and left approximately 1,200 people injured. The National Storm Prediction Center has ranked this as one of the deadliest tornadoes in the nation's history. With wind speeds between 200 to 260 mph, the force of the tornado carried debris miles away and into the Atlantic Ocean.

The nature of measuring tornado severity, based on impact rather than inherent physical qualities, makes it challenging to attribute changing tornado frequency to changing physical conditions, and not just to growing populations in the areas where tornadoes occur. Additionally, tornadoes are too small to be simulated well by climate models. Therefore, specific predictions about how this hazard will change are not possible, given current technical limitations. As discussed in other sections in this Plan, the conditions that are conducive to tornadoes (which are also conducive to other weather phenomena, such as hurricanes and tropical storms) are expected to become more severe under global warming.

Frequency of Occurrences

From 1950 to 2017, the Commonwealth experienced 171 tornadoes, or an average annual occurrence of 2.6 tornado events per year. In the last 20 years, the average frequency of these events has been 1.7 events per year (NOAA, 2018). Massachusetts experienced an average of 1.4 tornadoes per 10,000 square feet annually between 1991 and 2010, less than half of the national average of 3.5 tornadoes per 10,000 square feet per year (NOAA, n.d.). As highlighted in the National Climate Assessment, tornado activity in the U.S. has become more variable, and increasingly so in the last 2 decades. While the number of days per year that tornadoes occur has decreased, the number of tornadoes on these days has increased. Climate models show projections that the frequency and intensity of severe thunderstorms (which include tornadoes, hail, and winds) will increase (USGCRP, 2017).

Severity/Extent







Tornadoes are potentially the most dangerous of local storms. If a major tornado were to strike in the populated areas of the Commonwealth, damage could be widespread. Fatalities could be high; many people could be displaced for an extended period of time; buildings could be damaged or destroyed; businesses could be forced to close for an extended period of time or even permanently; and routine services, such as telephone or power, could be disrupted.

Massachusetts ranks 35th among the states for the frequency of tornadoes, 14th for the frequency of tornadoes per square mile, 21st for injuries, and 12th for cost of damage.

Tornado Severity Scales

The NWS rates tornadoes using the Enhanced Fujita scale (EF scale), which does not directly measure wind speed but rather the amount of damage created. This scale derives 3-second gusts estimated at the point of damage based on the assignment of 1 out of 8 degrees of damage to a range of different structure types. These estimates vary with height and exposure. This method is considerably more sophisticated than the original Fujita scale, and it allows surveyors to create more precise assessments of tornado severity. Figure 4-66 provides guidance from NOAA about the impacts of a storm with each rating.

Figure 4-66: Guide to Tornado Severity

Scale	Wind speed		Relative frequency	Potential damage	
	mph	km/h			
EF0	65–85	105–137	53.5%	Minor damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over. Confirmed tornadoes with no reported damage (i.e., those that remain in open fields) are always rated EF0.	
EF1	86–110	138–178	31.6%	Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.	
EF2	111–135	179–218	10.7%	Considerable damage. Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.	
EF3	136–165	219–266	3.4%	Severe damage. Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations blown away some distance.	
EF4	166–200	267–322	0.7%	Extreme damage to near-total destruction. Well-constructed houses and whole frame houses completely leveled; cars thrown and small missiles generated.	
EF5	>200	>322	<0.1%	Massive Damage. Strong frame houses leveled off foundations and swept away; steel-reinforced concrete structures critically damaged; high-rise buildings have severe structural deformation. Incredible phenomena will occur.	

Source: Linn County EMA, n.d.

EF = Enhanced Fujita scale

Warning Time

Tornado watches and warnings are issued by the local NWS office. A tornado watch is released when tornadoes are possible in an area. A tornado warning means a tornado has been sighted or indicated by weather radar. The current average lead time for tornado warnings is 13 minutes. Occasionally, tornadoes develop so rapidly that little, if any, advance warning is possible.

SECONDARY HAZARDS

The most significant secondary hazards associated with tornadoes are significant structural damage, power failures, falling and downed trees, and interruption of emergency services. Large hail commonly accompanies a tornado, and can damage cars and buildings as well as cause serious injuries for individuals without shelter. Heavy rain can overwhelm both natural and man-made drainage systems, causing overflow and further property destruction.

EXPOSURE AND VULNERABILITY

Populations



The entire Commonwealth has the potential for tornado formation, although residents of areas described above as having higher-than-average tornado frequency face additional risk. Residents of impacted areas may be displaced or require temporary to long-term shelter due to severe weather events. In addition, downed trees, damaged buildings, and debris carried by high winds can lead to injury or loss of life.

Vulnerable Populations

In general, vulnerable populations include people over the age of 65, people with low socioeconomic status, people with low English language fluency, people with compromised immune systems, and residents living in areas that are isolated from major roads. Power outages can be life-threatening to those who are dependent on electricity for life support and can result in increased risk of carbon monoxide poisoning. Individuals with limited communication capacity, such as those with limited internet or phone access, may not be aware of impending tornado warnings. The isolation of these populations is also a significant concern, as is the potential insufficiency of older or less stable housing to offer adequate shelter from tornadoes.

Health Impacts

The primary health hazard associated with tornadoes is the threat of direct injury from flying debris or structural collapse as well as the potential for an individual to be lifted and dropped by the tornado's winds. After the storm has subsided, tornadoes can present unique challenges to search and rescue efforts because of the extensive and widespread distribution of debris. The distribution of hazardous materials, including asbestos-containing building materials, can present an acute health risk for personnel cleaning up after a tornado disaster and for residents in the

area. The duration of exposure to contaminated material may be far longer if drinking water reservoir or groundwater aquifers are contaminated. According to the EPA, properly designed storage facilities for hazardous materials can reduce the risk of those materials being spread during a tornado (EPA, n.d.). Many of the health impacts described for other types of storms, including lack of access to a hospital, carbon monoxide poisoning from generators, and mental health impacts from storm-related trauma, could also occur as a result of tornado activity.

Government



To analyze how tornadoes could impact state facilities, DCAMM data were overlaid with zones of historic tornado density. More than 2,000 buildings are located in the high- and medium-intensity zones (tornado densities above 0.02 and 0.01 tornado per square mile, respectively), while only 575 are located in the low-intensity zone (0 to 0.01 tornado per square mile). Overall, Middlesex and Worcester Counties have the greatest number of government buildings within the defined tornado zones.

Table 4-72 identifies both the count and the replacement cost value of the state-owned buildings located in the defined tornado hazard areas within each county. Replacement values assume 100 percent loss to each structure and its contents.

In addition to impacts to state-owned businesses, state land may incur the loss of trees.

Table 4-72: State-Owned Properties Exposed to Tornado Hazard Zones by County

County	High		Medium		Low	
	Count	Replacement Value	Count	Replacement Value	Count	Replacement Value
Barnstable	—	—	—	—	267	\$387,911,594
Berkshire	11	\$8,200,995	297	\$714,925,685	118	\$533,529,482
Bristol	—	—	167	\$827,951,104	9	\$11,109,395
Dukes	—	—	—	—	22	\$14,214,301
Essex	64	\$267,689,657	286	\$1,385,718,965	267	\$387,911,594
Franklin	152	\$319,777,601	32	\$6,841,721	—	—
Hampden	346	\$2470,776,924	22	\$5,425,611	—	—
Hampshire	414	\$2,235,711,211	26	\$5,153,258	—	—
Middlesex	663	\$3,149,162,446	130	\$548,325,330	—	—
Nantucket	—	—	—	—	3	\$3,168,858
Norfolk	291	\$1,138,205,516	206	\$456,930,547	10	\$3,315,473
Plymouth	—	—	371	\$2,013,574,201	146	\$138,134,768
Suffolk	—	—	238	\$6,607,395,765	—	—
Worcester	541	\$3,047,395,818	254	\$883,345,513	—	—
Total	2,482	\$12,636,920,168	2,029	\$13,455,587,700	842	1,479,295,465

Sources: DCAMM, 2017 (facility inventory); SPC, 2017

The Built Environment



All critical facilities and infrastructure are exposed to tornado events. Similar to the analysis conducted for state facilities, the number of critical facilities located within the defined tornado hazard zones are listed in Tables 4-73 and 4-74, by type and by county, respectively.

Table 4-73: Critical Facilities Exposed to Tornado Hazard Zones by Type

Facility Type	High	Medium	Low
Military	21	17	4
Police Facilities	40	26	8
Fire Facilities	5	5	3
Hospitals	4	4	—
Colleges	23	19	5
Social Services	29	31	4
Total	122	102	24

Sources: DCAMM,2017 (facility inventory); SPC, 2017

Table 4-74: Critical Facilities Exposed to Tornado Hazard Zones by County

County	High	Medium	Low
Barnstable	—	—	10
Berkshire	—	7	—
Bristol	—	12	7
Dukes	—	—	1
Essex	7	21	1
Franklin	7	—	—
Hampden	22	1	—
Hampshire	13	—	—
Middlesex	33	12	—
Nantucket	—	—	2
Norfolk	10	10	—
Plymouth	—	18	4
Suffolk	—	16	—
Worcester	30	7	—
Total	122	104	25

Sources: DCAMM,2017 (facility inventory); SPC, 2017

Agriculture

Forestry species and agricultural crops, equipment, and infrastructure may be directly impacted by tornadoes.

Energy

High winds could down power lines and poles adjacent to roads (resilient MA, 2018). Damage to aboveground transmission infrastructure can result in extended power outages.

Public Safety

Public safety facilities and equipment may experience direct loss (damage) from tornadoes. Shelters and other critical facilities that provide services for people whose property is uninhabitable following a tornado may experience overcrowding and inadequate capacity to provide shelter space and services.

Transportation

Incapacity and loss of roads and bridges are the primary transportation failures resulting from tornadoes, and these failures are primarily associated with secondary hazards, such as landslide events. Tornadoes can cause significant damage to trees and power lines, blocking roads with debris, incapacitating transportation, isolating populations, and disrupting ingress and egress. Of particular concern are bridges and roads providing access to isolated areas and to the elderly. The number of bridges within each hazard zone is shown in Table 4-75.

Table 4-75: Bridges within Tornado Hazard Zones by County

County	High	Medium	Low
Barnstable	—	—	97
Berkshire	79	355	2
Bristol	—	288	69
Dukes	—	—	4
Essex	155	200	18
Franklin	250	46	—
Hampden	377	48	1
Hampshire	190	61	4
Middlesex	503	277	—
Nantucket	—	—	1
Norfolk	137	199	3
Plymouth	—	132	137
Suffolk	—	463	—
Worcester	722	269	—
Total	2,413	2,338	336

Source: National Bridge Inventory

Prolonged obstruction of major routes due to secondary hazards, such as landslides, debris, or floodwaters, can disrupt the shipment of goods and other commerce. If the tornado is strong enough to transport large debris or knock out infrastructure, it can create serious impacts on power and aboveground communication lines.

Water Infrastructure

The hail, wind, debris, and flash flooding associated with tornadoes can cause damage to infrastructure, such as storage tanks, hydrants, residential pumping fixtures, and distribution systems. This can result in loss of service or reduced pressure throughout the system (EPA, 2015). Water and wastewater utilities are also vulnerable to potential contamination due to chemical leaks from ruptured containers. Ruptured service lines in damaged buildings and broken hydrants can lead to loss of water and pressure (EPA, 2015).

Natural Resources and Environment



The environmental impacts of tornadoes are similar to those described for straight-line winds in Section 4.4.4. Direct impacts may occur to flora and fauna small enough to be uprooted and transported by the tornado. Even if the winds are not sufficient to transport trees and other large plants, they may still uproot them, causing significant damage to the surrounding habitat. As felled trees decompose, the increased dry matter may increase the threat of wildfire in vegetated areas. Additionally, the loss of root systems increases the potential for soil erosion.

Disturbances created by blowdown events may also impact the biodiversity and composition of the forest ecosystem. Invasive plant species are often able to quickly capitalize on the resources (such as sunlight) available in disturbed and damaged ecosystems. This enables them to gain a foothold and establish quickly with less competition from native species.

In addition to damaging existing ecosystems, material transported by tornadoes can also cause environmental havoc in surrounding areas. Particular challenges are presented by the possibility of asbestos-contaminated building materials or other hazardous waste being transported to natural areas or bodies of water, which could then become contaminated. Public drinking water reservoirs may also be damaged by widespread winds uprooting watershed forests and creating serious water quality disturbances.

Economy



Tornado events are typically localized; however, in those areas, economic impacts can be significant. Types of impacts may include loss of business functions, water supply system damage, damage to inventories, relocation costs, wage losses, and rental losses due to the

repair or replacement of buildings. Recovery and clean-up costs can also be costly. The damage inflicted by historical tornadoes in Massachusetts varies widely, but the average damage per event is approximately \$3.9 million.

Because of differences in building construction, residential structures are generally more susceptible to tornado damage than commercial and industrial structures. Wood and masonry buildings in general, regardless of their occupancy class, tend to experience more damage than concrete or steel buildings. High-rise buildings are also very vulnerable structures. Mobile homes are the most vulnerable to damage, even if tied down, and offer little protection to people inside.

4.4.4 Other Severe Weather

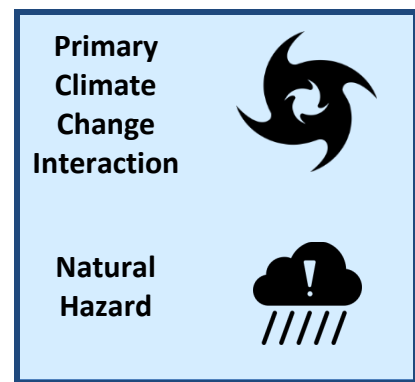
GENERAL BACKGROUND

Several frequent natural hazards in Massachusetts—particularly strong winds and extreme precipitation events—occur outside of notable storm events. This section discusses the nature and impacts of these hazards, as well as ways in which they are likely to respond to climate change.

HAZARD PROFILE

High Winds

Wind is air in motion relative to the surface of the earth. For non-tropical events over land, the NWS issues a Wind Advisory (sustained winds of 31 to 39 mph for at least 1 hour or any gusts 46 to 57 mph) or a High Wind Warning (sustained winds of 40 mph or more, or any gusts of 58 mph or more). For non-tropical events over water, the NWS issues a small craft advisory (sustained winds of 25 to 33 knots), a gale warning (sustained winds of 34 to 47 knots), a storm warning (sustained winds of 48 to 63 knots), or a hurricane-force wind warning (sustained winds 64 knots or more). For tropical systems, the NWS issues a tropical storm warning for any areas (inland or coastal) that are expecting sustained winds from 39 to 73 mph. A hurricane warning is issued for any areas (inland or coastal) that are expecting sustained winds of 74 mph. Effects from high winds can include downed trees and/or power lines and damage to roofs, windows, and other structural components. High winds can cause scattered power outages. High winds are also a hazard for the boating, shipping, and aviation industry sectors. Tornadoes are analyzed separately in Section 4.4.3 and are not discussed further in this section.





Natural Hazard Summary

OTHER SEVERE WEATHER






(including strong winds and thunderstorms)

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
Three components are required for a thunderstorm to form: moisture, rising unstable air, and a lifting mechanism. Wind is caused by differences in atmospheric pressure, as well as the Coriolis Effect.	The entire Commonwealth experiences thunderstorms. While the entire Commonwealth is also at risk to strong winds, the coastal zone is most frequently impacted by high-wind events.	Massachusetts experiences between 20 and 30 thunderstorm days each year. High winds occur more frequently, with an average annual frequency of 43.5 high wind events.

Potential Effects of Climate Change

	<p>EXTREME WEATHER AND CHANGES IN PRECIPITATION → MORE INTENSE AND FREQUENT THUNDERSTORMS AND DOWNPOURS</p>	<p>The Northeast has already experienced a larger increase in the intensity of rainfall events than any other region in the United States in the last fifty years, and this trend is expected to continue.</p>
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Exposure and Vulnerability by Key Sector 

	POPULATIONS	<p>General At-Risk Population: State-wide exposure.</p> <p>Vulnerable Populations: Populations over age 65, low income populations, populations with life-threatening illness, residents living in areas that are isolated from major roads, populations on life-support who are dependent on electricity.</p>
	GOVERNMENT	<p>According to the DCAMM facility data, 4,787 state-owned facilities are located in areas with winds greater than 90 miles per hour. The highest concentrations of these buildings occur in Worcester and Middlesex Counties. Thunderstorms occur regularly throughout the Commonwealth, and GIS analysis of exposure to this hazard was not conducted.</p>
	BUILT ENVIRONMENT	<p>All elements of the built environment are exposed to severe weather events such as high winds and thunderstorms. The highest number of critical facilities exposed to high winds is in Middlesex (43) and Worcester (36) Counties. Severe windstorms causing downed trees can create serious impacts on power and above-ground communication lines. Hail, wind, and flash flooding associated with thunderstorms and high winds can cause damage to water infrastructure.</p>
	NATURAL RESOURCES AND ENVIRONMENT	<p>Environmental impacts of precipitation events often include soil erosion, the growth of excess fungus or bacteria and direct impacts to wildlife. High winds can defoliate forest canopies and cause structural changes within an ecosystem that can destabilize food webs.</p>
	ECONOMY	<p>In addition to direct building losses, economic damage from severe weather events can include loss of business function, water supply system damage, damage to inventory, relocation costs, wage loss, and rental loss due to the repair/replacement of buildings.</p>

Thunderstorms

A thunderstorm is a storm originating in a cumulonimbus cloud. Cumulonimbus clouds produce lightning, which locally heats the air to 50,000 degrees Celsius, which in turn produces an audible shock wave, known as thunder. Frequently during thunderstorm events, heavy rain and gusty winds are present. Less frequently, hail is present, which can become very large in size. Tornadoes can also be generated during these events. A thunderstorm is classified as “severe” when it produces damaging wind gusts in excess of 58 mph (50 knots), hail that is 1 inch in diameter or larger (quarter size), or a tornado (NWS, 2013). Three basic components are required for a thunderstorm to form: moisture, rising unstable air, and a lifting mechanism. The sun heats the surface of the earth, which warms the air above it. If this warm surface air is forced to rise—by hills or mountains, or areas where warm/cold or wet/dry air bump together causing a rising motion—it will continue to rise as long as it weighs less and stays warmer than the air around it. As the warm surface air rises, it transfers heat from the surface of the earth to the upper levels of the atmosphere (the process of convection). The water vapor it contains begins to cool, releasing the heat, and the vapor condenses into a cloud. The cloud eventually grows upward into areas where the temperature is below freezing. Some of the water vapor turns to ice, and some of it turns into water droplets. Both have electrical charges. When a sufficient charge builds up, the energy is discharged in a bolt of lightning, which causes the sound waves we hear as thunder. An average thunderstorm is 15 miles across and lasts 30 minutes; severe thunderstorms can be much larger and longer. Southern New England typically experiences 10 to 15 days per year with severe thunderstorms.

Every thunderstorm has an updraft (rising air) and a downdraft (sinking air). Sometimes strong downdrafts known as downbursts can cause tremendous wind damage that is similar to that of a tornado. A small (less than 2.5 mile path) downburst is known as a “microburst” and a larger downburst is called a “macro-burst.” An organized, fast-moving line of microbursts traveling across large areas is known as a “derecho.” These occasionally occur in Massachusetts. The strongest downburst recorded was a downburst in North Carolina of 175 mph. Winds exceeding 100 mph have been measured from downbursts in Massachusetts.

Location

High Winds

The entire Commonwealth is vulnerable to high winds that can cause extensive damage. However, the coast is most frequently impacted by damage due to high-wind events. The U.S. is divided into four wind zones. States located in Wind Zone IV have experienced the greatest number of tornadoes and the strongest tornadoes. The Commonwealth is located within Wind Zone II, which includes wind speeds up to 180 mph. The entire Commonwealth is also located within the hurricane-susceptible region, and the western portion of the Commonwealth is located

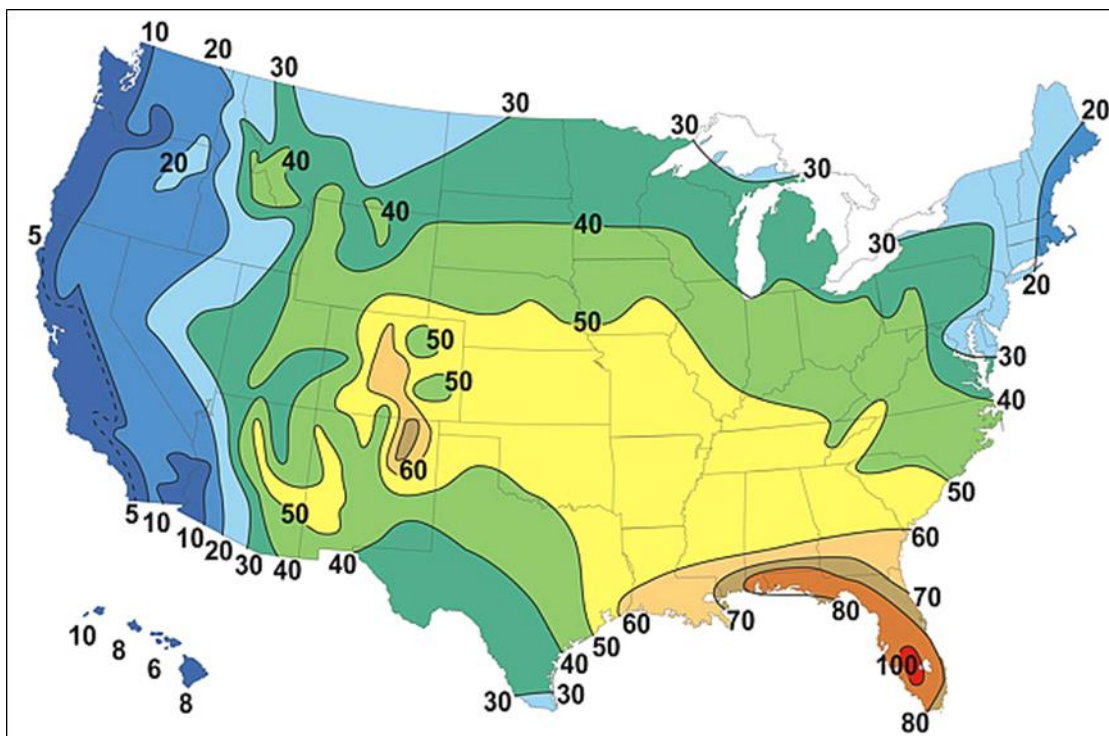
within the special wind region, in which wind-speed anomalies are present and additional consideration of the wind hazard is warranted.

Thunderstorms

Much like winter storms and hurricane events, thunderstorms affect relatively small areas rather than large regions. The entire state can experience the effect and impact from thunderstorms.

Figure 4-67 indicates that Massachusetts experiences between 20 and 30 thunderstorm days each year.

Figure 4-67: Annual Average Number of Thunderstorm Days in the U.S.

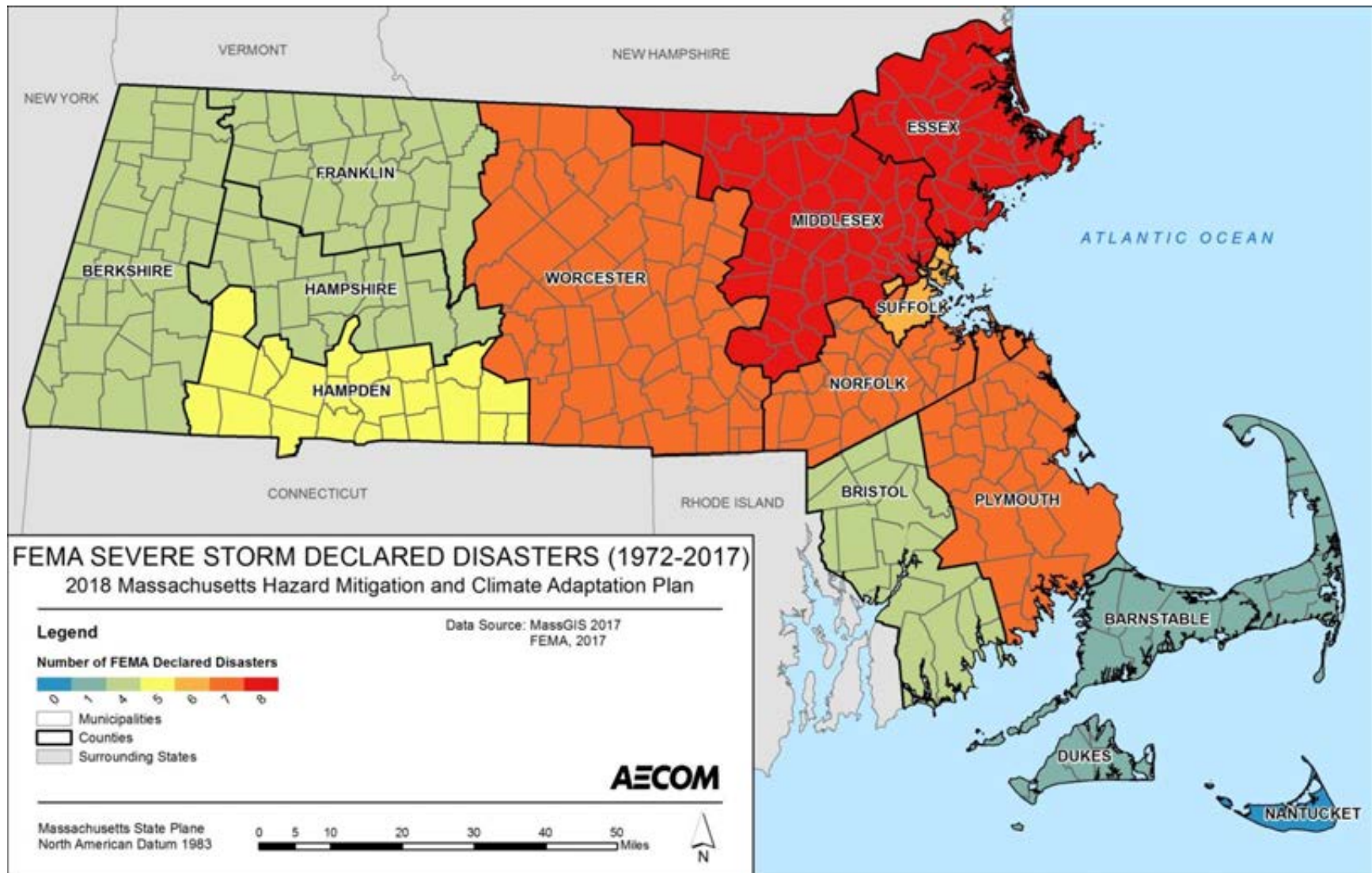


Source: NOAA NWS, n.d.

Previous Occurrences

Known severe weather events that have affected Massachusetts and received FEMA disaster declarations are identified in Appendix B. Figure 4-68 illustrates the number of storm-related disasters per county. It should be noted that this count of severe weather events encompasses a number of natural hazards, including nor'easters, thunderstorms, hurricanes, and flooding. Although this means storm events may also be accounted for in other sections, the overall number of occurrences per county provides valuable insight into each county's exposure and is therefore restated here.

Figure 4-68: FEMA Severe Storm Declared Disasters by County



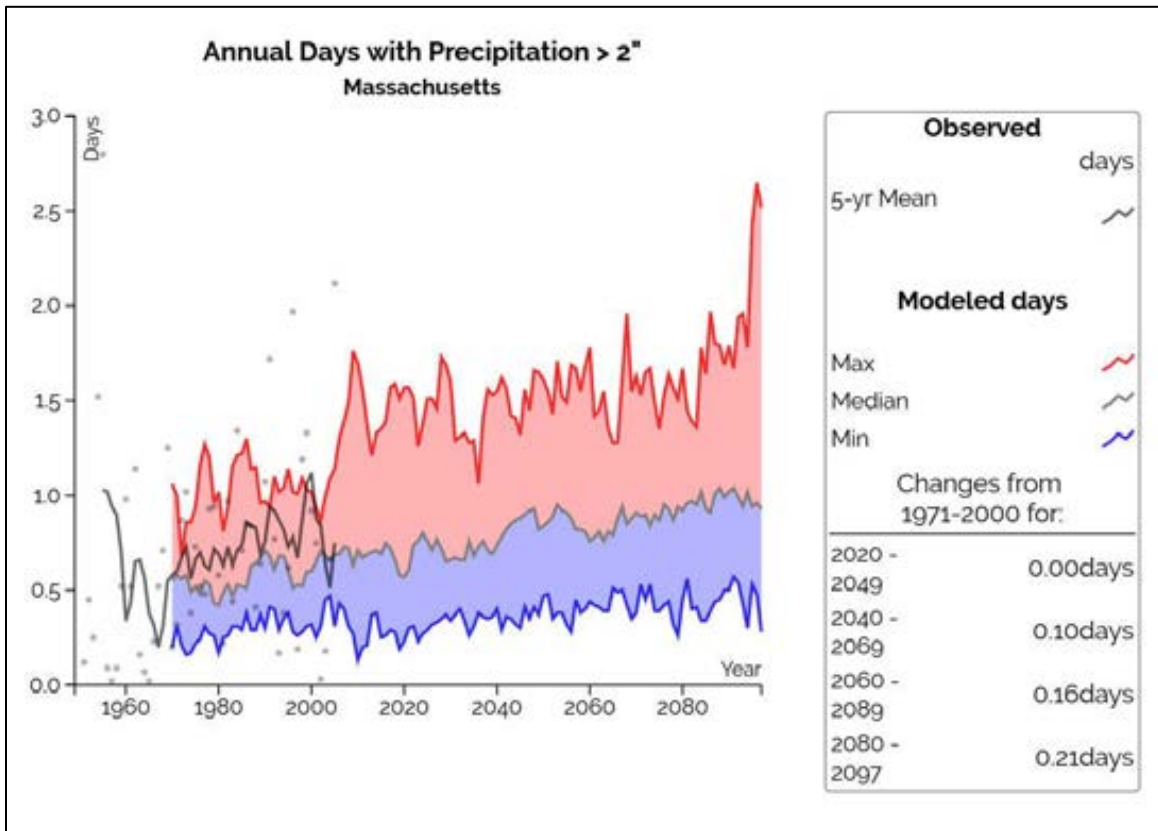
Frequency of Occurrences

High Winds

Over the last 10 years (between January 1, 2008, and December 31, 2017), a total of 435 high wind events occurred in Massachusetts on 124 days, and an annual average of 43.5 events occurred per year. High winds are defined by NWS 10-1605 as sustained non-convective winds of 35 knots (40 mph) or greater lasting for 1 hour or longer, or gusts of 50 knots (58 mph) or greater for any duration (NCDC, 2018). However, many of these events may have occurred as a result of the same weather system, so this count may overestimate the frequency of this hazard. The probability of future high wind events is expected to increase as a result of climate projections for the state that suggest a greater occurrence of severe weather events in the future.

Thunderstorms

As shown in Figure 4-67, Massachusetts experiences between 20 and 30 thunderstorm days each year. The NE CASC data support the trend of a slightly increased frequency of high-intensity rainfall events, defined here as days with above 2 inches of precipitation. Figure 4-69 shows the projected changes between 2020 and the end of this century. Although the median projections indicate minor increases from baseline conditions, the graph shows that there is a range of outcomes included in the projections. For example, by the end of this century, the high-end projections show the frequency may climb from less than 0.5 to approximately 2.5 days per year. Specific modeling results for the planning horizons identified in this plan (2030, 2050, 2070, and 2100) are provided in Table 4-76. Extreme precipitation projections indicate that the coast will experience the greatest number of high-intensity rainfall days, but increased precipitation will occur in every county (see Figures 4-70 through 4-73). Based on these available projections for future rainfall events, the probability of future thunderstorm events is anticipated to increase.

Figure 4-69: Projected Annual Days with Precipitation Greater Than 2 Inches

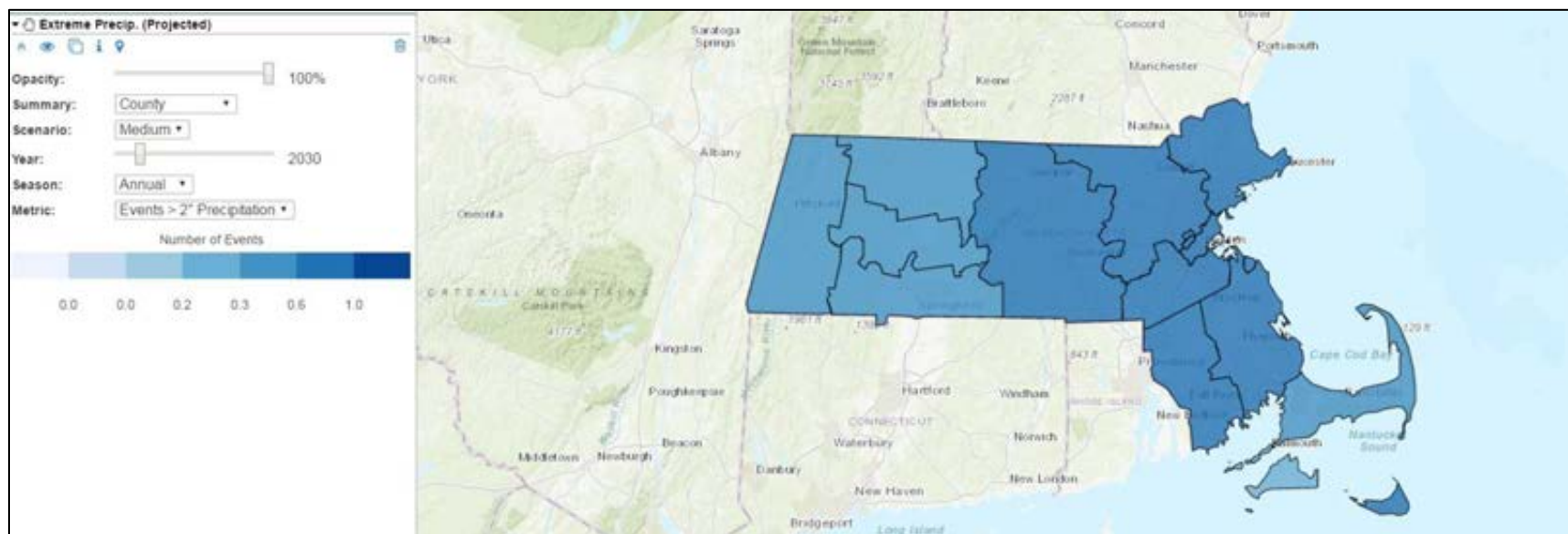
Source: resilient MA, 2018

Table 4-76: Projected Frequency of Future Annual Extreme Precipitation Events in Massachusetts

	2030	2050	2070	2100
Number of Days >1" precipitation	7-9	8-10	8-10	8-11
Number of Days >2" precipitation	1	1-2	1-2	1-2

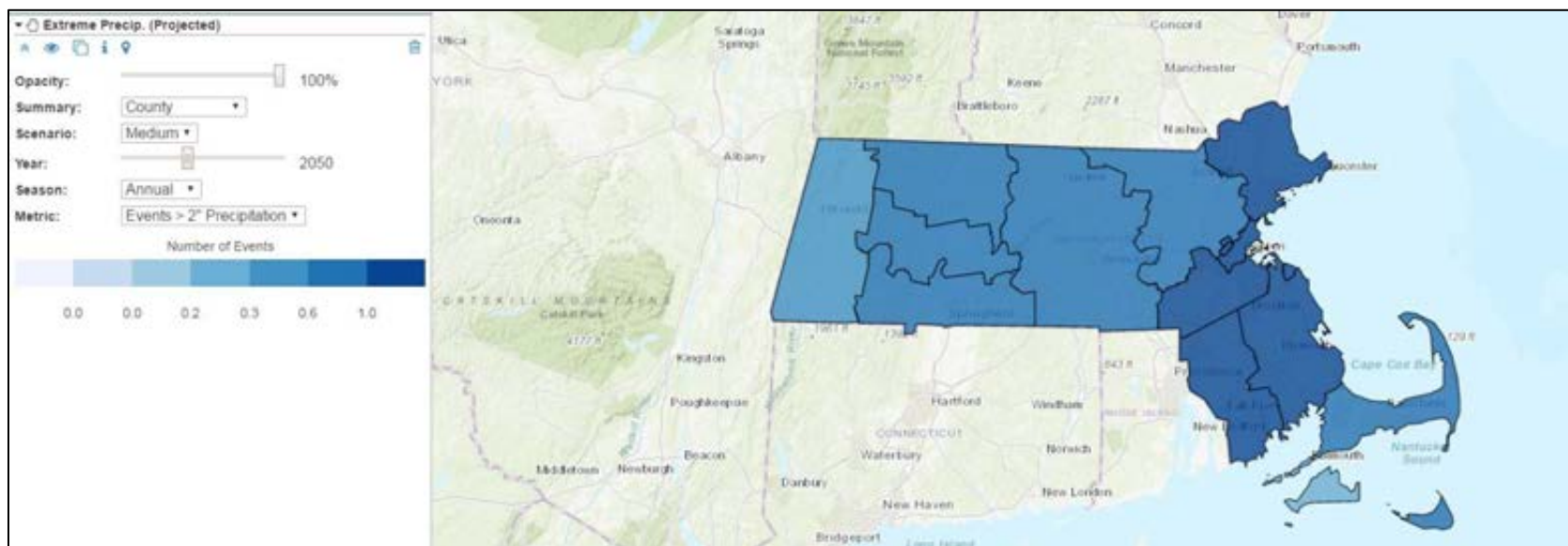
Source: resilient MA, 2018

Figure 4-70: Distribution of Greater Than 2 Inches Precipitation—2030



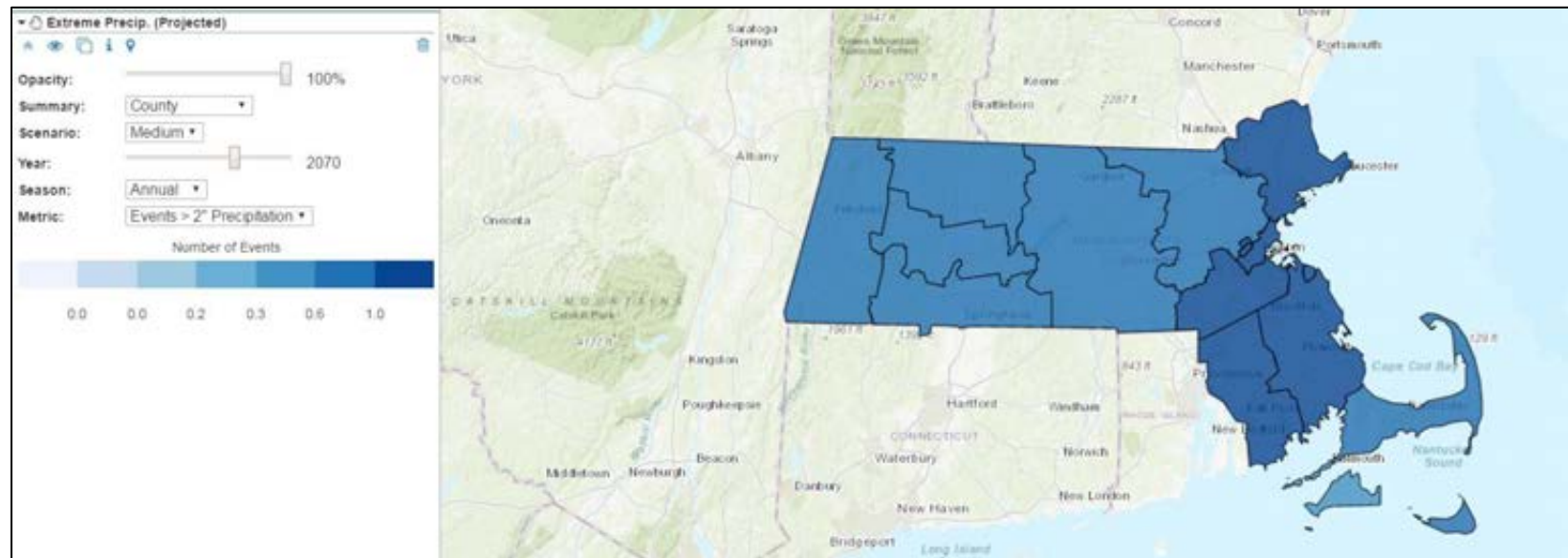
Source: resilient MA, 2018

Figure 4-71: Distribution of Greater Than 2 Inches Precipitation—2050



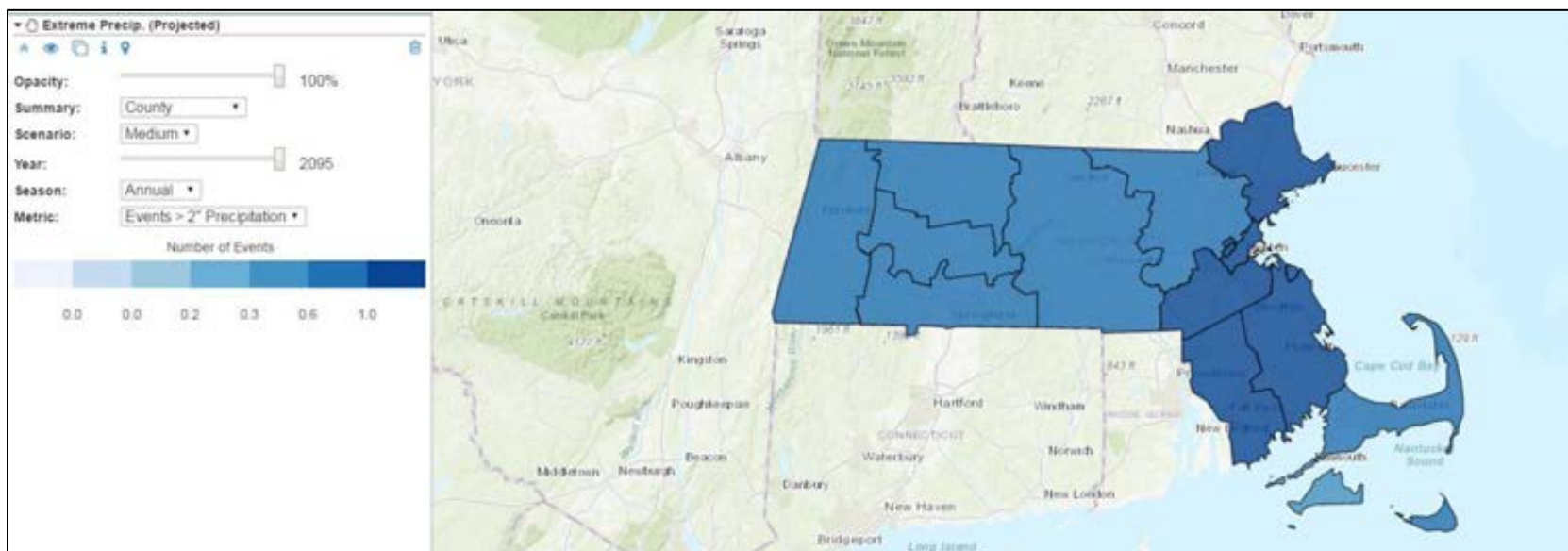
Source: resilient MA, 2018

Figure 4-72: Distribution of Greater Than 2 Inches Precipitation—2070



Source: resilient MA, 2018

Figure 4-73: Distribution of Greater Than 2 Inches Precipitation—2100



Source: resilient MA, 2018

Severity/Extent

High Winds

Massachusetts is susceptible to high winds from several types of weather events: before and after frontal systems, hurricanes and tropical storms, severe thunderstorms and tornadoes, and nor'easters. Sometimes, wind gusts of only 40 to 45 mph can cause scattered power outages from downed trees and wires. This is especially true after periods of prolonged drought or excessive rainfall, since both are situations that can weaken the root systems and make them more susceptible to the winds' effects. Winds measuring less than 30 mph are not considered to be hazardous under most circumstances.

Wind speeds in a hurricane are measured using the Saffir-Simpson scale, described in Section 4.4.2. Another scale developed for measuring wind is the Beaufort wind scale (see Table 4-77).

Table 4-77: Beaufort Wind Scale

Force	Wind (Knots)	WMO Classification	Appearance of Wind Effects	
			On the Water	On Land
0	Less than 1	Calm	Sea surface smooth and mirror-like	Calm, smoke rises vertically
1	1-3	Light Air	Scaly ripples, no foam crests	Smoke drift indicates wind direction, still wind vanes
2	4-6	Light Breeze	Small wavelets, crests glassy, no breaking	Wind felt on face, leaves rustle, vanes begin to move
3	7-10	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Leaves and small twigs constantly moving, light flags extended
4	11-16	Moderate Breeze	Small waves 1-4 ft. becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move
5	17-21	Fresh Breeze	Moderate waves 4-8 ft taking longer form, many whitecaps, some spray	Small trees in leaf begin to sway
6	22-27	Strong Breeze	Larger waves 8-13 ft, whitecaps common, more spray	Larger tree branches moving, whistling in wires
7	28-33	Near Gale	Sea heaps up, waves 13-19 ft, white foam streaks off breakers	Whole trees moving, resistance felt walking against wind
8	34-40	Gale	Moderately high (18-25 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks	Twigs breaking off trees, generally impedes progress
9	41-47	Strong Gale	High waves (23-32 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility	Slight structural damage occurs, slate blows off roofs

Force	Wind (Knots)	WMO Classification	Appearance of Wind Effects	
			On the Water	On Land
10	48-55	Storm	Very high waves (29-41 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
11	56-63	Violent Storm	Exceptionally high (37-52 ft) waves, foam patches cover sea, visibility more reduced	
12	64+	Hurricane	Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced	

Source: NOAA Storm Prediction Center. Developed in 1805 by Sir Francis Beaufort

ft = feet

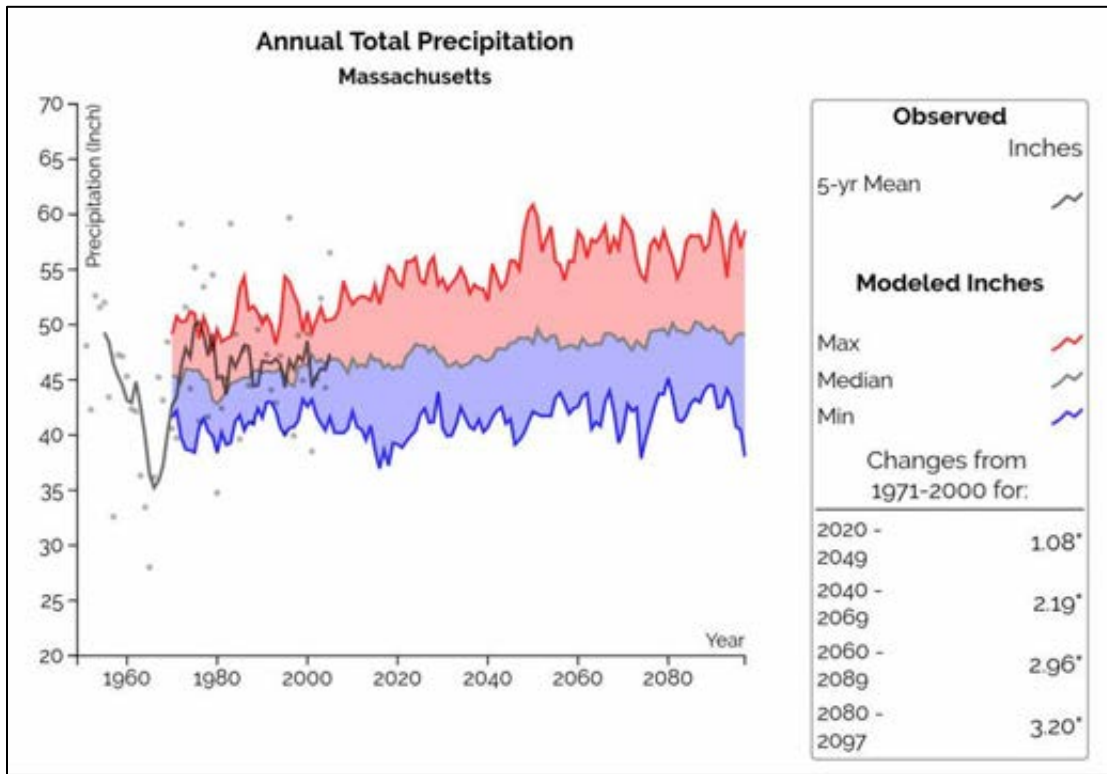
WMO = World Meteorological Organization

Thunderstorms

The severity of thunderstorms can vary widely, from commonplace and short-term events to large-scale storms that result in direct damage and flooding. Widespread flooding is the most common characteristic that leads to a storm being declared a disaster. The severity of flooding varies widely based both on characteristics of the storm itself and the region in which it occurs. Lightning can occasionally also present a severe hazard. According to the NOAA, there have been 8 fatalities and 145 injuries as a result of lightning events between 1993 and 2017 in the Commonwealth (NCDC, 2017).

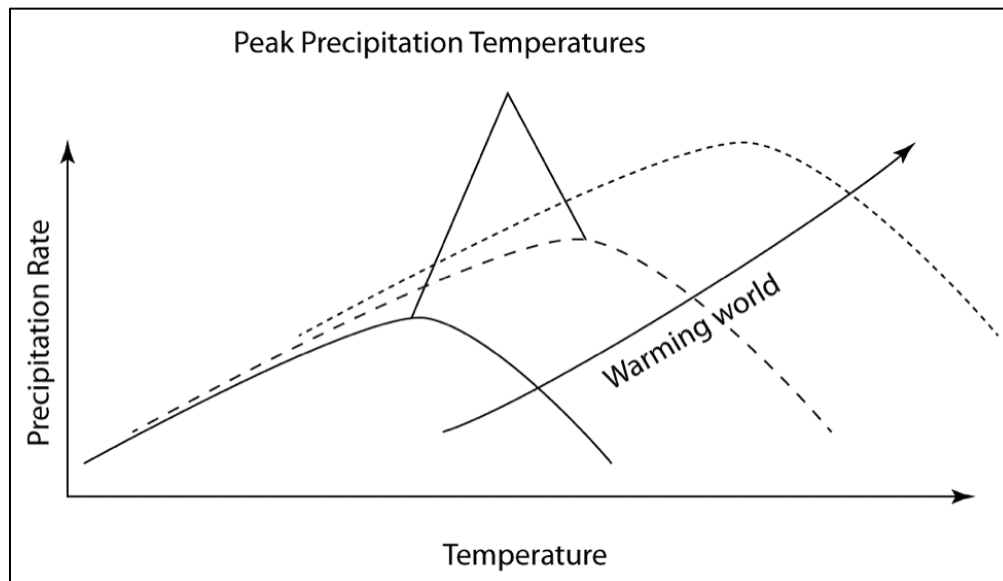
Figure 4-74 shows anticipated changes in total precipitation between 2020 and the end of this century. As shown in this graph, total precipitation is expected to increase, but the change is far less dramatic than in other variables, such as average and extreme temperatures (discussed further in Section 4.3.1). The relationship between global warming and rainfall is complex, and scientific consensus does not yet exist on the likely changes to this indicator. As the climate warms, the capacity of the atmosphere to hold water vapor will increase. As a result, more extreme precipitation events will be possible. However, observational studies thus far have shown that the relationship between temperature and precipitation likely depends on a number of variables, including location. An additional complication is that some evidence suggests the temperature at which peak precipitation occurs is likely to increase in a warming world (as shown in Figure 4-75), which may compound the impact of warming temperatures on precipitation rates around the globe.

Figure 4-74: Annual Total Precipitation



Source: resilient MA, 2018

Figure 4-75: Peak Precipitation Temperatures in a Warming Climate



Source: Abraham, 2017

Warning Time

Meteorologists can often predict the likelihood of a severe thunderstorm outbreak with several days of lead time. However, this prediction is only accurate to a certain resolution, and it cannot predict the exact time of onset or the severity of individual events. Some events, such as “pulse” type and “popcorn” afternoon thunderstorms, may develop quickly and offer only a few minutes of advance warning. Other storms, such as a well-organized squall line, can have lead times of up to an hour (from the time a Severe Thunderstorm Warning is issued to the time that severe criteria are observed). Tornadoes have the least amount of lead time. Doppler radar and a dense network of spotters and amateur radio operators across the region have helped increase the warning lead time across southern New England.

SECONDARY HAZARDS

The most significant secondary hazards associated with severe thunderstorms and high winds include falling and downed trees and power lines. Heavy rain can overwhelm both natural and man-made drainage systems, causing overflows and property destruction. Thunderstorms can also cause floods and landslides, particularly when the soil on slopes becomes oversaturated and fails. Severe lightning can also spark fires, even when accompanied by heavy rains. Lightning can cause severe damage, injury, and death.

EXPOSURE AND VULNERABILITY

Populations



The entire population of the Commonwealth is considered exposed to high-wind and thunderstorm events. Downed trees, damaged buildings, and debris carried by high winds can lead to injury or loss of life. Populations located outdoors are considered at risk and more vulnerable to many storm impacts, particularly lightning strikes, compared to those who are located inside. Moving to a lower risk location will decrease a person’s vulnerability.

Vulnerable Populations

Socially vulnerable populations are most susceptible to severe weather based on a number of factors, including their physical and financial ability to react or respond during a hazard, and the location and construction quality of their housing. In general, vulnerable populations include people over the age of 65, the elderly living alone, people with low socioeconomic status, people with low English language fluency, people with limited mobility or a life-threatening illness, and people who lack transportation or are living in areas that are isolated from major roads. The isolation of these populations is a significant concern.

Power outages can be life-threatening to those dependent on electricity for life support. Power outages may also result in inappropriate use of combustion heaters, cooking appliances and

generators in indoor or poorly ventilated areas, leading to increased risks of carbon monoxide poisoning. People who work or engage in recreation outdoors are also vulnerable to severe weather.

Health Impacts

Both high winds and thunderstorms present potential safety impacts for individuals without access to shelter during these events. Extreme rainfall events can also affect raw water quality by increasing turbidity and bacteriological contaminants leading to gastrointestinal illness. Additionally, research has found that thunderstorms may cause the rate of emergency room visits for asthma to increase to 5 to 10 times the normal rate (Andrews, 2012). Much of this phenomenon is attributed to the stress and anxiety that many individuals, particularly children, experience during severe thunderstorms. The combination of wind, rain, and lightning from thunderstorms with pollen and mold spores can exacerbate asthma (UG, 2017). The rapidly falling air temperatures characteristic of a thunderstorm as well as the production of nitrogen oxide gas during lightning strikes have also both been correlated with asthma.

Government



Damage to buildings is dependent upon several factors, including wind speed, storm duration, path of the storm track, and building construction. According to the Hazus wind model, direct wind-induced damage (wind pressures and windborne debris) to buildings is dependent upon the performance of components and cladding, including the roof covering (shingles, tiles, membrane), roof sheathing (typically wood-frame construction only), windows, and doors, and is modeled as such. Structural wall failures can occur for masonry and wood-frame walls, and uplift of whole roof systems can occur due to failures at the roof/wall connections. Foundation failures (i.e., sliding, overturning, and uplift) can potentially take place in manufactured homes.

Massachusetts is divided into three design wind speeds for four risk categories, the limits of which are defined by the Massachusetts State Building Code (9th Edition). National wind data prepared by the American Society of Civil Engineers serve as the basis of these wind design requirements (“Minimum Design Loads for Buildings and Other Structures,” American Society of Civil Engineers ASCE-7). Generally speaking, structures should be designed to withstand the total wind load of their location. Refer to the State Building Code (9th Edition [780 CMR] Chapter 16 Structural Design, as amended by Massachusetts) for appropriate reference wind pressures, wind forces on roofs, and similar data.

Using ArcMap GIS software, these data were overlaid with the 2017 DCAMM facility data; the appropriate wind load zone determination was assigned to each facility, as summarized in Table 4-78. Figure 4-76 illustrates the wind load zones and the number of facilities located in each. For Table 4-78, and for the subsequent built environment tables, all buildings exposed to higher-

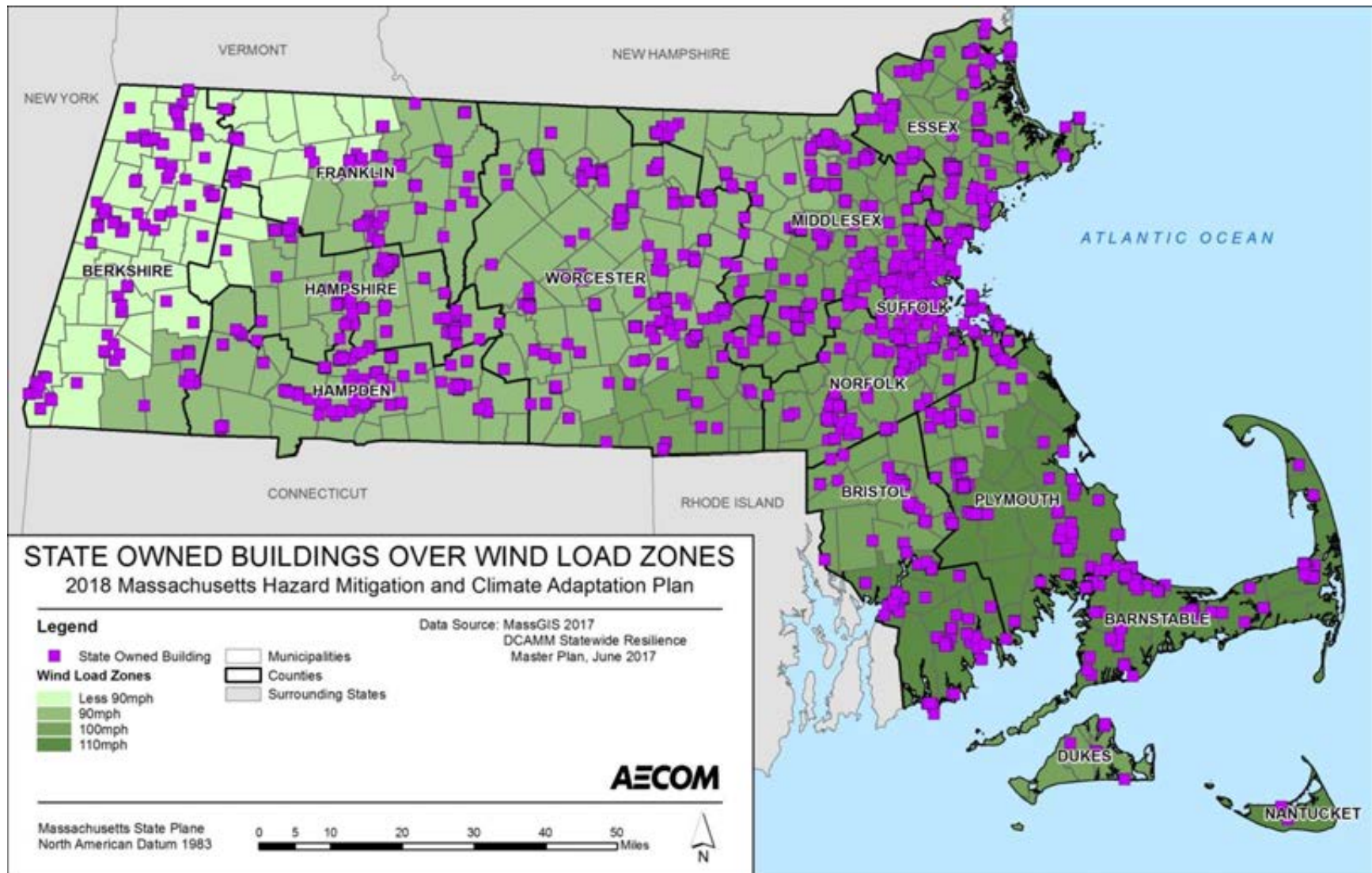
intensity winds should also be considered to be exposed to the lower-intensity categories. While these categories provide useful guidelines for the potential vulnerability of structures, it should be noted that winds far above 110 miles per hour occur on a regular basis in Massachusetts. Therefore, these categories should not be considered to represent the full range of possible wind conditions.

Table 4-78: State-Owned Buildings in Wind Zones by County

County	<90 mph		90 mph		100 mph		110 mph	
	Count	Replacement Value	Count	Replacement Value	Count	Replacement Value	Count	Replacement Value
Barnstable	—	—	—	—	—	—	265	\$387,500,825
Berkshire	264	\$718,112,474	39	\$4,811,724	—	—	—	—
Bristol	—	—	—	—	113	\$462,799,309	176	\$912,553,888
Dukes	—	—	—	—	9	\$11,109,395	—	—
Essex	—	—	32	\$235,046,344	349	\$1,436,524,194	—	—
Franklin	67	\$254,967,832	116	\$71,620,705	—	—	—	—
Hampden	—	—	370	\$2,476,366,525	—	—	—	—
Hampshire	3	\$621,208	439	\$2,238,708,041	—	—	—	—
Middlesex	—	—	282	\$1,206,270,761	506	\$2,485,462,556	—	—
Nantucket	—	—	—	—	—	—	3	\$3,168,858
Norfolk	—	—	—	—	507	\$1,597,525,186	—	—
Plymouth	—	—	—	—	359	\$2,005,812,621	165	\$153,821,999
Suffolk	—	—	—	—	253	\$6,625,082,010	—	—
Worcester	—	—	686	\$3,653,154,112	118	\$289,393,162	—	—
Total	334	\$973,701,514	1,964	\$9,885,978,212	2,214	\$14,913,708,433	609	\$1,457,045,570

Sources: ASCE wind zones; DCAMM, 2017 (facility inventory)

Figure 4-76: Wind Load Zones in the Commonwealth of Massachusetts



Source: DCAMM, 2017 (facility inventory)

The Built Environment



All elements of the built environment are exposed to severe weather events such as high winds and thunderstorms. As discussed in the other severe weather hazard hazard profile section, there are four wind load zones in the Commonwealth, which reflect the level of risk presented to elements of the built environment in that area. Table 4-79 summarizes the number of critical facilities within each of the upper three wind load zones by county, and Table 4-80 shows the number of number of critical facilities within each wind zone by facility type.

Table 4-79: Number of Critical Facilities in Wind Zones by County

County	90 mph	100 mph	110 mph
Barnstable	—	—	11
Berkshire	—	—	—
Bristol	—	7	13
Dukes	—	2	—
Essex	4	27	1
Franklin	2	—	—
Hampden	21	—	—
Hampshire	12	—	—
Middlesex	16	27	—
Nantucket	—	—	2
Norfolk	—	20	—
Plymouth	—	17	6
Suffolk	—	17	1
Worcester	28	8	—
Total	83	125	34

Sources: ASCE wind zones; DCAMM, 2017 (facility inventory)

Table 4-80: Number of Critical Facilities in Wind Zones by Facility Type

Facility Type	90 mph	100 mph	110 mph
Military	14	21	6
Police Facilities	24	36	7
Fire Departments	5	4	2
Hospitals	3	3	—
Colleges	20	18	9
Social Services	17	43	10
Total	83	125	34

Sources: ASCE wind zones; DCAMM, 2017 (facility inventory)

Agriculture

As discussed in the tornado hazard profile, forestry species and agricultural crops, equipment, and infrastructure may be directly impacted by high winds. Trees are also vulnerable to lightning strikes.

Energy

The most common problem associated with severe weather is loss of utilities. Severe windstorms causing downed trees can create serious impacts on power and aboveground communication lines. High winds caused one of the 24 NERC-reported electric transmission outages between 1992 and 2009, resulting in disruption of service to 225,000 electric customers in the Commonwealth (DOE, n.d.). During this period, lightning caused nearly 25,000 disruptions (DOE, n.d.). Downed power lines can cause blackouts, leaving large areas isolated. Loss of electricity and phone connections would leave certain populations isolated because residents would be unable to call for assistance. Additionally, the loss of power can impact heating or cooling provision to citizens (including the young and elderly, who are particularly vulnerable to temperature-related health impacts).

Utility infrastructure (power lines, gas lines, electrical systems) could suffer damage, and impacts can result in the loss of power, which can impact business operations. After an event, there is a risk of fire, electrocution, or an explosion.

Public Safety

Public safety facilities and equipment may experience a direct loss (damage) from high winds.

Transportation

Roads may become impassable due to flash or urban flooding, or due to landslides caused by heavy, prolonged rains. Impacts to transportation lifelines affect both short-term (e.g., evacuation activities) and long-term (e.g., day-to-day commuting) transportation needs.

Water Infrastructure

The hail, wind, and flash flooding associated with thunderstorms and high winds can cause damage to water infrastructure. Flooding can overburden stormwater, drinking water, and wastewater systems. Water and sewer systems may not function if power is lost.

Natural Resources and Environment



As described under other hazards, such as hurricanes and nor'easters, high winds can defoliate forest canopies and cause structural changes within an ecosystem that can destabilize food webs and cause widespread repercussions. Direct damage to plant species can include uprooting or total destruction of trees and an increased threat of wildfire in areas of tree debris. High winds can also erode soils, which can damage both the ecosystem from

which soil is removed as well as the system on which the sediment is ultimately deposited. Environmental impacts of extreme precipitation events are discussed in depth in Section 4.1.1 and often include soil erosion, the growth of excess fungus or bacteria, and direct impacts to wildlife. For example, research by the Butterfly Conservation Foundation shows that above-average rainfall events have prevented butterflies from successfully completing their mating rituals, causing population numbers to decline. Harmful algal blooms and associated neurotoxins can also be a secondary hazard of extreme precipitation events as well as heat. Public drinking water reservoirs may also be damaged by widespread winds uprooting watershed forests and creating serious water quality disturbances.

Economy

\$ Wind storms, thunderstorms, and tornado events may impact the economy, including direct building losses and the cost of repairing or replacing the damage caused to the building. Additional economic impacts may include loss of business functions, water supply system damage, inventory damage, relocation costs, wage losses, and rental losses due to the repair/replacement of buildings. Agricultural losses due to lightning and the resulting fires can be extensive.

According to the NOAA's Technical Paper on Lightning Fatalities, Injuries, and Damage Reports in the U.S. from 1959 to 1994, monetary losses for lightning events range from less than \$50 to greater than \$5 million (the larger losses are associated with forest fires, with homes destroyed, and with crop loss) (NOAA, 1997). Lightning can be responsible for damage to buildings; can cause electrical, forest and/or wildfires; and can damage infrastructure, such as power transmission lines and communication towers.

Recovery and clean-up costs can also be costly, resulting in further economic impacts. Prolonged obstruction of major routes due to secondary hazards such as landslides, debris, or floodwaters can disrupt the shipment of goods and other commerce. Large, prolonged storms can have negative economic impacts on an entire region.

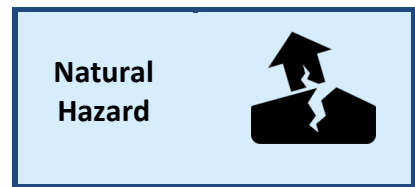
Because of differences in building construction, residential structures are generally more susceptible to wind damage than commercial and industrial structures. Wood and masonry buildings in general, regardless of their occupancy class, tend to experience more damage than concrete or steel buildings. High-rise buildings are also very vulnerable structures. Mobile homes are the most vulnerable to damage, even if tied down, and offer little protection to people inside.

4.5 Non-Climate-Influenced Hazards

4.5.1 Earthquake

GENERAL BACKGROUND

An earthquake is the vibration of the Earth’s surface that follows a release of energy in the Earth’s crust. These earthquakes often occur along fault boundaries. As a result, areas that lie along fault boundaries—such as California, Alaska, and Japan—experience earthquakes more often than areas located within the interior portions of these plates. New England, on the other hand, experiences intraplate earthquakes because it is located deep within the interior of the North American plate. Scientists are still exploring the cause of intraplate earthquakes, and many believe these events occur along geological features that were created during ancient times and are now weaker than the surrounding areas.



Methodology

Ground shaking is the primary cause of earthquake damage to man-made structures. This damage can be increased due to the fact that soft soils amplify ground shaking. A contributor to site amplification is the velocity at which the rock or soil transmits shear waves (S waves). The National Earthquake Hazards Reduction Program (NEHRP) developed five soil classifications, which are defined by their S-wave velocity, that impact the severity of an earthquake. The soil classification system ranges from A to E, where A represents hard rock that reduces ground motions from an earthquake and E represents soft soils that amplify and magnify ground shaking and increase building damage and losses. These soil types are shown in Figure 4-77. Soil types A, B, C, and D are reflected in the Hazus analysis that generated the exposure and vulnerability results later in the section. Soil types B/C and D/E cannot be imported into Hazus and therefore are only shown in Figure 4-77.



Natural Hazard Summary

EARTHQUAKES

CAUSE	MOST AT-RISK LOCATIONS	HISTORIC FREQUENCY
An earthquake is the vibration of the earth's surface that follows a release of energy in the earth's crust.	Earthquakes can occur throughout Massachusetts. Large earthquakes in Canada, which is more seismically active than New England, can affect tall buildings in Boston and elsewhere in eastern Massachusetts.	Earthquakes cannot be predicted and may occur at any time. Research has found that the probability of a magnitude 5.0 or greater earthquake centered somewhere in New England in a 10-year period is about 10%-15%.

Potential Effects of Climate Change

This report does not identify any effects of climate change on the earthquake hazard in Massachusetts.

Exposure and Vulnerability by Key Sector






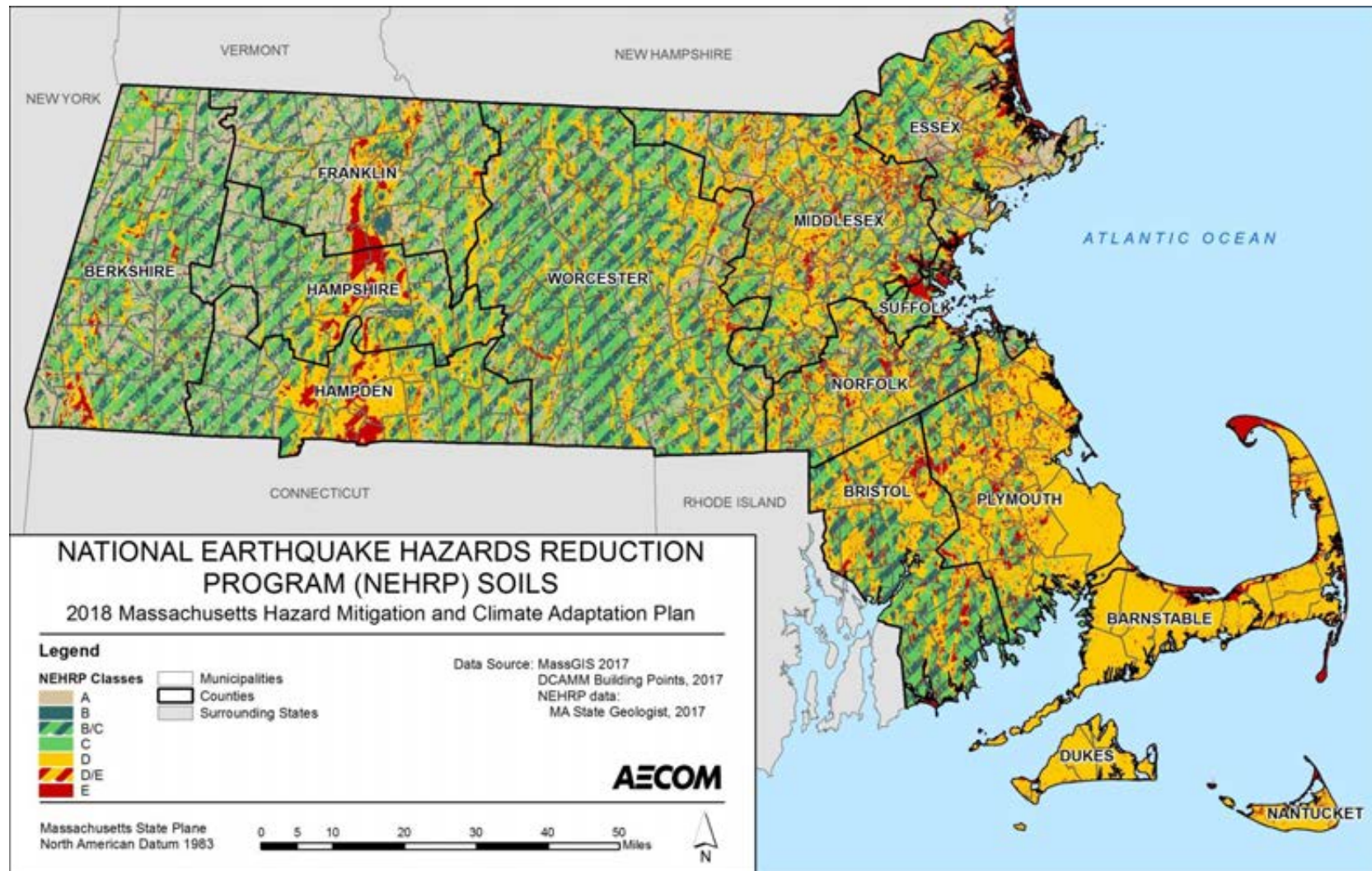
	POPULATIONS	<p>General At-Risk Population: State-wide exposure.</p> <p>Vulnerable Populations: Socially vulnerable populations, due to factors including their physical and financial ability to react or respond during a hazard event; the location and construction quality of housing; and the ability to be self-sustainable after an event due to limited ability to stockpile supplies.</p>
	GOVERNMENT	Due to the widespread effect of an earthquake generally there is no way to determine which state-owned government facilities will be impacted. By using Hazus data, it was determined that there would be approximately \$112,440,000 in building-related economic loss for the 100-year earthquake, reaching a total of \$31,114,950,000 by the 2500-year earthquake.
	BUILT ENVIRONMENT	In addition to direct impacts to roads, bridges, agriculture infrastructure, public health and safety facilities, and water infrastructure networks, earthquakes also present a risk associated with hazardous materials releases, which have the potential to be released at a production or storage facility or as a result of pipeline damage. These events could cause widespread interruption of services, as well as air and water contamination.
	NATURAL RESOURCES AND ENVIRONMENT	If strong shaking occurs in a forest, trees may fall – resulting not only in environmental impacts but also potential economic impacts to any industries relying on that forest. If shaking occurs in a mountainous environment, cliffs may crumble and caves may collapse. Disrupting the physical foundation of the ecosystem can modify the species balance in that ecosystem and leave the area more vulnerable to the spread of invasive species.
	ECONOMY	Earthquake losses can include structural and non-structural damage to buildings (which could include damage to architectural components like ceilings and lights, or power systems), loss of business function, damage to inventory, relocation costs, wage loss, and rental loss due to the repair/replacement of buildings.

Figure 4-77: NEHRP Soil Types in Massachusetts



Note: This map should be viewed as a first-order approximation of the NEHRP soil classifications. They are not intended for site-specific engineering design or construction. The map is provided only as a guide for use in estimating potential damage from earthquakes. The maps do not guarantee or predict seismic risk or damage. However, the maps certainly provide a first step by highlighting areas that may warrant additional, site-specific investigation if high seismic risk coincides with critical facilities, utilities, or roadways.

Sources: Mabey and Duncan, 2017; Preliminary NEHRP Soil Classification Map of Massachusetts

HAZARD PROFILE

Location

New England is located in the middle of the North American Plate. One edge of the North American Plate is along the West Coast where the plate is pushing against the Pacific Ocean Plate. The eastern edge of the North American Plate is located at the middle of the Atlantic Ocean, where the plate is spreading away from the European and African Plates. New England's earthquakes appear to be the result of the cracking of the crustal rocks due to compression as the North American Plate is being very slowly squeezed by the global plate movements. As a result, New England epicenters do not follow the major mapped faults of the region, nor are they confined to particular geologic structures or terrains. Because earthquakes have been detected all over New England, seismologists suspect that a strong earthquake could be centered anywhere in the region. Furthermore, the mapped geologic faults of New England currently do not provide any indications detailing specific locations where strong earthquakes are most likely to be centered. Instead, a probabilistic assessment conducted through a Level 2 analysis in Hazus (using a moment magnitude value of 5) provides information about where in Massachusetts impacts would be felt from earthquakes of various severities. For this plan, an assessment was conducted for the 100-, 500-, 1,000-, and 2,500-year mean return periods. The results of that analysis are discussed later in this section.

In addition to earthquakes occurring within the Commonwealth, earthquakes in other parts of New England can impact widespread areas. Large earthquakes in Canada, which is more seismically active than New England, can affect tall buildings in Boston and elsewhere in eastern Massachusetts. This is due in part to the fact that earthquakes in the eastern U.S. are felt over a larger area than those in the western U.S. The difference between seismic shaking in the East versus the West is primarily due to the geologic structure and rock properties that allow seismic waves to travel farther without weakening (USGS, 2012). The high number of unreinforced masonry buildings in Boston—typically constructed with old building codes or before building codes—make the city especially vulnerable to earthquakes. A liquefaction susceptibility mapping study in Boston found that when saturated, the downtown's non-engineered artificial fill is highly susceptible to liquefaction during seismic loading (Brankman and Baise, 2006).

In some places in New England, including locations in Massachusetts, small earthquakes seem to occur with some regularity. For example, since 1985 there has been a small earthquake approximately every 2.5 years within a few miles of Littleton, Massachusetts. It is not clear why some localities experience such clustering of earthquakes, but a possibility suggested by John Ebel of Boston College's Weston Observatory is that these clusters occur where strong earthquakes were centered in the prehistoric past. The clusters may indicate locations where there is an increased likelihood of future earthquake activity.

Previous Occurrences

Although it is well documented that the zone of greatest seismic activity in the U.S. is along the Pacific Coast in Alaska and California, in the New England area, an average of six earthquakes are felt each year. Damaging earthquakes have taken place historically in New England.

According to the Weston Observatory Earthquake Catalog, 6,470 earthquakes have occurred in New England and adjacent areas. However, only 35 of these events were considered significant. Additional detail is provided in Appendix B.

Frequency of Occurrences

Earthquakes cannot be predicted and may occur at any time. Peak Ground Acceleration (PGA) maps are used as tools to determine the likelihood that an earthquake of a given Modified Mercalli Intensity may be exceeded over a period of time, but they are not useful for predicting the occurrence of individual events. Therefore, geospatial information about the expected frequency of earthquakes throughout Massachusetts is not available. However, a 1994 report by the USGS, based on a meeting of experts at the Massachusetts Institute of Technology, provides an overall probability of occurrence. Earthquakes above about magnitude 5.0 have the potential for causing damage near their epicenters, and larger magnitude earthquakes have the potential for causing damage over larger areas. This report found that the probability of a magnitude 5.0 or greater earthquake centered somewhere in New England in a 10-year period is about 10 percent to 15 percent. This probability rises to about 41 percent to 56 percent for a 50-year period. The last earthquake with a magnitude above 5.0 that was centered in New England took place in the Ossipee Mountains of New Hampshire in 1940.

Severity/Extent

The location of an earthquake is commonly described by the geographic position of its epicenter and by its focal depth. The focal depth of an earthquake is the depth from the surface to the region where the earthquake's energy originates (the focus). Earthquakes with focal depths up to about 43.5 miles are classified as shallow. Earthquakes with focal depths of 43.5 to 186 miles are classified as intermediate. The focus of deep earthquakes may reach depths of more than 435 miles. The focus of most earthquakes is concentrated in the upper 20 miles of the Earth's crust. The depth to the Earth's core is about 3,960 miles, so even the deepest earthquakes originate in relatively shallow parts of the Earth's interior. The epicenter of an earthquake is the point on the Earth's surface directly above the focus.

Seismic waves are the vibrations from earthquakes that travel through the Earth and are recorded on instruments called seismographs. The magnitude or extent of an earthquake is a seismograph-measured value of the amplitude of the seismic waves. The Richter magnitude scale (Richter scale) was developed in 1932 as a mathematical device to compare the sizes of earthquakes. The Richter scale is the most widely known scale for measuring earthquake magnitude. It has no

upper limit and is not used to express damage. An earthquake in a densely populated area, which results in many deaths and considerable damage, can have the same magnitude as an earthquake in a remote area that causes no damage.

The perceived severity of an earthquake is based on the observed effects of ground shaking on people, buildings, and natural features, and severity varies with location. Intensity is expressed by the Modified Mercalli Scale, which describes how strongly an earthquake was felt at a particular location. The Modified Mercalli Scale expresses the intensity of an earthquake's effects in a given locality in values ranging from I to XII. Seismic hazards are also expressed in terms of PGA, which is defined by USGS as “what is experienced by a particle on the ground” in terms of percent of acceleration force of gravity. More precisely, seismic hazards are described in terms of Spectral Acceleration, which is defined by USGS as “approximately what is experienced by a building, as modeled by a particle on a massless vertical rod having the same natural period of vibration as the building” in terms of percent of acceleration force of gravity (percent g).

Table 4-81 summarizes the Modified Mercalli Intensity scale, associated damage, and corresponding PGAs and Richter scale magnitudes.

Table 4-81: Modified Mercalli Intensity and Equivalent Peak Ground Acceleration and Richter Scale Magnitude

Mercalli Intensity	Equivalent Richter Scale Magnitude	Description	Abbreviated Modified Mercalli Intensity Scale Description ¹	Acceleration (percent g) (PGA)
I		Detected only on seismographs.	Not felt except by a very few under especially favorable conditions.	< .17
II	< 4.2	Some people feel it.	Felt only by a few persons at rest, especially on upper floors of buildings.	.17 – 1.4
III		Felt by people resting; like a truck rumbling by.	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.	.17 – 1.4
IV		Felt by people walking.	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.	1.4 – 3.9
V	< 4.8	Sleepers awake; church bells ring.	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.	3.9 – 9.2
VI	< 5.4	Trees sway; suspended objects swing; objects fall off	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage	9.2 – 18

Mercalli Intensity	Equivalent Richter Scale Magnitude	Description	Abbreviated Modified Mercalli Intensity Scale Description ¹	Acceleration (percent g) (PGA)
VII	< 6.1	shelves. Mild alarm; walls crack; plaster falls.	slight. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.	18 – 34
VIII		Moving cars are uncontrollable; masonry fractures, poorly constructed buildings damaged.	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.	34 – 65
IX	< 6.9	Some houses collapse; ground cracks; pipes break open.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.	65-124
X	< 7.3	Ground cracks profusely; many buildings destroyed; liquefaction and landslides are widespread.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.	>124
XI	< 8.1	Most buildings and bridges collapse; roads, railways, pipes and cables are destroyed; general triggering of other hazards occurs.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.	>124
XII	> 8.1	Total destruction; trees fall; ground rises and falls in waves.	Damage total. Lines of sight and level are distorted. Objects thrown into the air.	>124

Source: Swiss Seismological Service, n.d.; ¹USGS, n.d.
PGA = peak ground acceleration

Because of the low frequency of earthquake occurrence and the relatively low levels of ground shaking that are usually experienced, the entire Commonwealth can be expected to have a low to moderate risk to earthquake damage as compared to other areas of the country. However, impacts at the local level can vary based on types of construction, building density, and soil type, among other factors. This is demonstrated in the Hazus analysis summarized in later sections.

Warning Time

There is currently no reliable way to predict the day or month that an earthquake will occur at any given location. Research is being done with early-warning systems that use the low-energy waves preceding major earthquakes to issue an alert of the impending event. This applies to the West Coast and to other countries. It is not currently relevant in Massachusetts and this should be

clearly stated. These potential early-warning systems can give up to approximately 40 to 60 seconds notice that earthquake shaking is about to occur, with shorter warning times for places closer to the earthquake epicenter. Although the warning time is very short, it could allow immediate safety measures to be taken, such as getting under a desk, stepping away from a hazardous material, or shutting down a computer system to prevent damage.

SECONDARY HAZARDS

Secondary hazards can occur to all forms of critical infrastructure and key resources as a result of an earthquake. They can also impact structures not typically identified as critical, such as fires in residential buildings that can cause injury, loss of life, and significant damage. Earthquakes can also cause large and sometimes disastrous landslides as well as tsunamis (discussed further in Section 4.2.3) and wildfires (discussed further in Section 4.3.2). Soil liquefaction is a secondary hazard unique to earthquakes that occurs when water-saturated sands, silts, or gravelly soils are shaken so violently that the individual grains lose contact with one another and float freely in the water, turning the ground into a pudding-like liquid. Building and road foundations lose load-bearing strength and may sink into what was previously solid ground. Unless properly secured, hazardous materials can be released, causing significant damage to the environment and people. Liquefaction may occur along the shorelines of the ocean, rivers, and lakes, and can also happen in low-lying areas away from water bodies but where the underlying groundwater is near the Earth's surface. Earthen dams and levees are highly susceptible to seismic events, and the impacts of their eventual failures can be considered secondary risks for earthquakes.

EXPOSURE AND VULNERABILITY

Populations



The entire population of Massachusetts is potentially exposed to direct and indirect impacts from earthquakes. The degree of exposure depends on many factors, including the age and construction type of the structures where people live, work, and go to school; the soil type these buildings are constructed on; and the proximity of these building to the fault location. In addition, the time of day also exposes different sectors of the community to the hazard. There are many ways in which earthquakes could impact the lives of individuals across the Commonwealth. Business interruptions could keep people from working, road closures could isolate populations, and loss of utilities could impact populations that suffered no direct damage from an event itself. People who reside or work in unreinforced masonry buildings are vulnerable to liquefaction.

Hazus estimates the number of people that may be injured or killed by an earthquake depending on the time of day the event occurs. Estimates are provided for three times of day representing periods when different sectors of the community are at their peak: peak residential occupancy at

2:00 a.m.; peak educational, commercial, and industrial occupancy at 2:00 p.m.; and peak commuter traffic at 5:00 p.m. Table 4-82 shows the number of injuries and casualties expected for events of varying severity, occurring at various times of the day.

Table 4-82: Estimated Number of Injuries and Casualties, Hazus

County	100-Year MRP			500-Year MRP			1,000-Year MRP			2,500-Year MRP		
	2 am	2 pm	5 pm	2 am	2 pm	5 pm	2 am	2 pm	5 pm	2 am	2 pm	5 pm
Barnstable												
Injuries	0	1	22	5	12	29	12	27	39	38	82	76
Hospitalization	0	4	73	1	6	75	2	8	76	6	18	84
Casualties	0	0	9	0	1	9	0	1	9	1	3	11
Berkshire												
Injuries	0	0	0	4	6	4	9	13	10	22	35	25
Hospitalization	0	0	0	0	1	1	1	2	1	3	6	5
Casualties	0	0	0	0	0	0	0	0	0	1	1	1
Bristol												
Injuries	0	1	5	20	32	27	20	32	27	20	32	20
Hospitalization	0	2	40	2	6	43	2	6	43	2	6	43
Casualties	0	0	4	0	1	5	0	1	5	0	1	5
Dukes												
Injuries	0	0	6	0	1	6	1	2	7	3	6	9
Hospitalization	0	1	19	0	1	19	0	2	19	0	2	19
Casualties	0	0	2	0	0	2	0	0	2	0	0	2
Essex												
Injuries	5	9	38	67	104	107	178	282	234	614	1,032	762
Hospitalization	2	9	144	10	23	154	29	56	178	122	230	306
Casualties	0	1	17	2	3	19	5	9	23	24	46	49
Franklin												
Injuries	0	0	0	3	4	3	6	10	7	17	27	20
Hospitalization	0	0	0	0	1	0	1	1	1	2	4	5
Casualties	0	0	0	0	0	0	0	0	0	0	1	2
Hampden												
Injuries	2	3	2	27	40	29	60	92	65	162	282	194
Hospitalization	0	0	0	3	5	5	9	14	13	29	55	47
Casualties	0	0	0	1	1	1	1	2	2	5	10	8

County	100-Year MRP			500-Year MRP			1,000-Year MRP			2,500-Year MRP		
	2 am	2 pm	5 pm	2 am	2 pm	5 pm	2 am	2 pm	5 pm	2 am	2 pm	5 pm
Hampshire												
Injuries	0	1	1	8	11	9	17	25	20	44	72	55
Hospitalization	0	0	0	1	1	1	2	4	3	7	13	11
Casualties	0	0	0	0	0	0	0	1	0	1	2	2
Middlesex												
Injuries	5	11	10	120	178	135	314	475	359	1,070	1,695	1,262
Hospitalization	0	0	11	17	25	30	49	81	80	215	363	317
Casualties	0	0	1	1	1	4	9	13	14	45	72	59
Nantucket												
Injuries	0	0	0	0	0	0	0	1	1	1	2	2
Hospitalization	0	0	0	0	0	0	0	0	0	0	0	1
Casualties	0	0	0	0	0	0	0	0	0	0	0	0
Norfolk												
Injuries	1	3	9	33	57	48	84	142	108	257	469	337
Hospitalization	0	2	45	4	10	51	12	24	61	44	91	113
Casualties	0	0	5	1	1	6	2	4	8	8	16	17
Plymouth												
Injuries	0	1	5	20	38	30	49	93	67	153	309	212
Hospitalization	0	1	15	2	6	18	7	15	24	24	58	53
Casualties	0	0	2	0	1	2	1	2	3	4	10	8
Suffolk												
Injuries	6	7	16	89	104	96	227	279	236	796	1,050	845
Hospitalization	1	4	47	14	19	59	40	52	88	178	243	248
Casualties	0	0	6	2	3	8	7	9	13	39	51	48
Worcester												
Injuries	0	2	0	34	53	38	82	129	93	237	391	279
Hospitalization	0	0	0	3	6	4	11	17	13	38	71	54
Casualties	0	0	0	0	0	0	1	3	2	7	13	9
Total	22	63	554	494	762	1,077	1,250	1,929	1,954	4,239	6,870	5,625

MRP = mean return period

Vulnerable Populations

The populations most vulnerable to an earthquake event include people over the age of 65 and those living below the poverty level. These socially vulnerable populations are most susceptible, based on a number of factors, including their physical and financial ability to react or respond

during a hazard, the location and construction quality of their housing, and the inability to be self-sustaining after an incident due to a limited ability to stockpile supplies.

Residents may be displaced or require temporary to long-term sheltering due to the event. The number of people requiring shelter is generally less than the number displaced, as some who are displaced use hotels or stay with family or friends following a disaster event. Impacts on people and households in the planning area were estimated for the 100-, 500-, 1,000-, and 2,500-year earthquakes through the Level 2 Hazus analysis. Table 4-83 summarizes the results. This analysis was conducted in Hazus 4.2, which has improved accuracy in estimated shelter populations compared to previous versions. Shelter estimates from Hazus are intended for general planning purposes and should not be assumed to be exact. It should also be noted that, in Massachusetts, the season in which an earthquake occurs could significantly impact the number of residents requiring shelter. For example, if an earthquake occurred during a winter weather event, more people might need shelter if infrastructure failure resulted in a loss of heat in their homes. These numbers should be considered as general, year-round average estimates.

Table 4-83: Estimated Shelter Requirements Hazus Probabilistic Scenarios

County	100-Year MRP		500-Year MRP		1,000-Year MRP		2,500-Year MRP	
	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs
Barnstable	0	0	20	9	53	25	178	84
Berkshire	0	0	21	12	51	29	143	82
Bristol	0	0	104	63	104	63	104	63
Dukes	0	0	0	0	2	1	7	3
Essex	20	12	397	255	1,136	731	4,500	2,892
Franklin	1	0	16	9	38	21	110	61
Hampden	11	8	158	119	366	276	1,129	854
Hampshire	2	1	38	25	89	59	256	169
Middlesex	28	16	723	417	2,034	1,183	7,798	4,562
Nantucket	0	0	0	0	1	0	3	1
Norfolk	6	3	194	102	522	275	1,812	953
Plymouth	1	0	81	49	216	130	738	444
Suffolk	30	20	621	418	1,727	1,160	6,691	4,484
Worcester	2	1	162	106	456	283	1,480	922
Total	101	61	2535	1584	6,795	4,236	24,949	15,574

MRP = mean return period

Health Impacts

The most immediate health risk presented by the earthquake hazard is trauma-related injuries and fatalities, either from structural collapse, impacts from nonstructural items such as furniture, or the secondary effects of earthquakes, such as tsunamis, landslides, and fires. Following a severe earthquake, health impacts related to transportation impediments and lack of access to hospitals may occur, as described for other hazards. Hazus provides estimates of the functionality of hospitals based on the estimated number of available beds following the event. The information that should be included here is an analysis of the number of available beds after the event in relation to the increase in injuries requiring hospital treatment. If ground movement causes hazardous material (in storage areas or in pipelines) to enter the environment, additional health impacts could result, particularly if surface water, groundwater, or agricultural areas are contaminated.

Government



All Commonwealth-owned buildings and operations are exposed to the earthquake hazard. Hazus does not specifically address impacts to state government buildings, as these facilities cannot be differentiated from those of other types of government.

Therefore, specific exposure analyses or estimates of potential damage cannot be provided.

The Built Environment



All elements of the built environment in the planning area are exposed to the earthquake hazard. Tables 4-84 and 4-85 summarize the estimated damage to essential facilities, transportation infrastructure, and utilities from earthquake events of varying severity. In addition to these direct impacts, there is increased risk associated with hazardous materials releases, which have the potential to occur during an earthquake from fixed facilities, transportation-related incidents (vehicle transportation), and pipeline distribution. These failures can lead to the release of materials to the surrounding environment, including potentially catastrophic discharges into the atmosphere or nearby waterways, and can disrupt services well beyond the primary area of impact.

Agriculture

Earthquakes can result in loss of crop yields, loss of livestock, and damage to barns, processing facilities, greenhouses, equipment, and other agricultural infrastructure. Earthquakes can be especially damaging to farms and forestry if they trigger a landslide.

Energy

Earthquakes can damage power plants, gas lines, liquid fuel storage infrastructure, transmission lines, utilities poles, solar and wind infrastructure, and other elements of the energy sector. Damage to any components of the grid can result in widespread power outages.

Public Health

Hospitals and medical provider facilities can experience direct losses (damage) from earthquakes. A significant earthquake may result in numerous injuries that could overburden hospitals.

Public Safety

Police stations, fire stations, and other public safety infrastructure can experience direct losses (damage) from earthquakes. The capability of the public safety sector is also vulnerable to damage caused by earthquakes to roads and the transportation sector.

Transportation

Earthquakes can impact many aspects of the transportation sector, including causing damage to roads, bridges, airports, vehicles, and storage facilities and sheds. Damage to road networks and bridges can cause widespread disruption of services and impede disaster recovery and response.

Water Infrastructure

Due to their extensive networks of aboveground and belowground infrastructure—including pipelines, pump stations, tanks, administrative and laboratory buildings, reservoirs, chemical storage facilities, and treatment facilities—water and wastewater utilities are vulnerable to earthquakes (EPA, 2018). Additionally, sewer and water treatment facilities are often built on ground that is subject to liquefaction, increasing their vulnerability. Earthquakes can cause ruptures in storage and process tanks, breaks in pipelines, and building collapse, resulting in loss of water and loss of pressure, and contamination and disruption of drinking water services. Damage to wastewater infrastructure can lead to sewage backups and releases of untreated sewage into the environment (EPA, 2018).

Natural Resources and Environment



Earthquakes can impact natural resources and the environment in a number of ways, both directly and through secondary impacts. For example, damage to gas pipes may cause explosions or leaks, which can discharge hazardous materials into the local environment or the watershed if rivers are contaminated. Fires that break out as a result of earthquakes can cause extensive damage to ecosystems, as described in Section 4.3.2. Primary impacts of an earthquake vary widely based on strength and location. For example, if strong shaking occurs in a forest, trees may fall, resulting not only in environmental impacts but also potential economic impacts to any industries relying on that forest. If shaking occurs in a mountainous environment, cliffs may crumble and caves may collapse. Disrupting the physical foundation of the ecosystem can modify the species balance in that ecosystem and leave the area more vulnerable to the spread of invasive species.

Economy

\$ Earthquakes also have impacts on the economy, including loss of business functions, damage to inventories, relocation costs, wage losses, and rental losses due to the repair or replacement of buildings. Hazus estimates the total economic loss associated with each earthquake scenario, which includes building and lifeline-related losses (transportation and utility losses) based on the available inventory (facility [or GIS point] data only). Direct building losses are the estimated costs to repair or replace the damage caused to the building. The business interruption losses are the losses associated with the inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses of those people displaced from their homes because of the earthquake. Refer to Table 4-84, which summarizes the estimated potential building-related losses per earthquake scenario per county.

Lifeline-related losses include the direct repair cost for transportation and utility systems and are reported in terms of the probability of reaching or exceeding a specified level of damage when subjected to a given level of ground motion. Additionally, economic losses include the business interruption losses associated with the inability to operate a business due to the damage sustained during the earthquake as well as temporary living expenses for those displaced. These losses are presented in Table 4-85.

Table 4-84: Building-Related Economic Loss Estimates, Hazus Probabilistic Scenarios

County	100-Year MRP	500-Year MRP	1,000-Year MRP	2,500-Year MRP
Barnstable	\$350,000	\$57,160,000	\$170,690,000	\$614,880,000
Berkshire	\$570,000	\$25,660,000	\$66,220,000	\$200,810,000
Bristol	\$790,000	\$118,820,000	\$357,910,000	\$1,294,480,000
Dukes	\$0	\$4,680,000	\$14,460,000	\$54,450,000
Essex	\$17,530,000	\$486,240,000	\$1,516,950,000	\$4,906,560,000
Franklin	\$950,000	\$17,990,000	\$45,890,000	\$136,750,000
Hampden	\$10,660,000	\$17,497,000	\$444,330,000	\$1,364,450,000
Hampshire	\$2,110,000	\$43,500,000	\$109,580,000	\$325,070,000
Middlesex	\$33,460,000	\$928,330,000	\$2,825,580,000	\$9,209,330,000
Nantucket	\$0	\$2,750,000	\$8,270,000	\$30,050,000
Norfolk	\$7,310,000	\$266,810,000	\$791,580,000	\$2,685,660,000
Plymouth	\$2,530,000	\$140,070,000	\$418,370,000	\$1,467,810,000
Suffolk	\$31,110,000	\$695,380,000	\$2,034,330,000	\$6,660,800,000
Worcester	\$5,070,000	\$225,010,000	\$655,480,000	\$2,163,850,000
Total	\$112,440,000	\$3,029,897,000	\$9,459,640,000	\$31,114,950,000

MRP = mean return period

Table 4-85: Transportation and Utility Losses for the Commonwealth of Massachusetts

County	100-Year MRP	500-Year MRP	1,000-Year MRP	2,500-Year MRP
Barnstable	\$33,840,000	\$36,470,000	\$41,470,000	\$58,050,000
Berkshire	\$170,000	\$7,800,000	\$23,180,000	\$74,200,000
Bristol	\$91,970,000	\$106,820,000	\$144,660,000	\$296,590,000
Dukes	\$9,880,000	\$10,490,000	\$12,600,000	\$22,580,000
Essex	\$539,200,000	\$580,140,000	\$681,360,000	\$969,020,000
Franklin	\$220,000	\$12,220,000	\$38,190,000	\$123,620,000
Hampden	\$500,000	\$24,200,000	\$74,720,000	\$244,110,000
Hampshire	\$240,000	\$9,280,000	\$25,990,000	\$77,910,000
Middlesex	\$83,410,000	\$198,660,000	\$437,990,000	\$1,048,070,000
Nantucket	\$2,610,000	\$3,110,000	\$4,620,000	\$10,840,000
Norfolk	\$68,260,000	\$101,210,000	\$173,850,000	\$394,540,000
Plymouth	\$5,530,000	\$19,840,000	\$52,440,000	\$135,260,000
Suffolk	\$170,680,000	\$235,630,000	\$374,270,000	\$807,690,000
Worcester	\$540,000	\$39,070,000	\$130,880,000	\$423,540,000
Total	\$1,007,050,000	\$1,384,940,000	\$2,216,220,000	\$4,686,020,000

MRP = mean return period



5. Technological and Human-Caused Hazards

As discussed in *Chapter 3: Introduction to Risk Assessment* and the Risk Assessment Methodology appendix (Appendix A), the Hazard Identification and Risk Assessment (HIRA) portion of the State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) meets the requirements of the Federal Emergency Management Agency (FEMA) State Mitigation Plan Guide (FP 302-094-2) and Emergency Management Accreditation Program (EMAP) Standard 4.1: Hazard Identification, Risk Assessment and Consequence Analysis for the natural hazards that were assessed.

The purpose of this chapter is to introduce other state emergency management plans that assess technological and human-caused hazards to demonstrate that the Commonwealth's Emergency Management Program accounts for both natural and non-natural hazards and to aid in maintaining the Commonwealth's EMAP accreditation.

5.1 Massachusetts THIRA

In 2012, FEMA issued guidelines that required all state administrative agencies and urban areas (designated under the Urban Areas Security Initiative) receiving FEMA Preparedness Grant funding to complete and submit a Threat Hazard Identification and Risk Assessment (THIRA) to the FEMA regional federal preparedness coordinator. The Comprehensive Preparedness Guide

(CPG) 201 was issued by FEMA to provide guidance for conducting a THIRA (FEMA, 2018). The Commonwealth maintains a THIRA that is developed following CPG 201 and updated annually; the THIRA serves as a risk assessment and consequence analysis process for technological and human-caused hazards as well as some natural hazards that are addressed in the HIRA included in this SHMCAP. The last version of the THIRA was issued in 2017 (Commonwealth of Massachusetts, 2017a). Development of the THIRA involved approximately 50 stakeholders representing local, regional, and State government offices, the Federal Government, as well as nongovernmental organizations (NGOs) and the private sector.

The Massachusetts THIRA follows a four-step process, as described in CPG 201:

1. **Identify the Threats and Hazards of Concern.** Based on a combination of past experience, forecasting, expert judgment, and other available resources, identify a list of the threats and hazards of primary concern to a community.
2. **Give the Threats and Hazards Context.** Describe the threats and hazards of concern, showing how they may affect a community.
3. **Establish Capability Targets.** Assess each threat and hazard in context to develop a specific capability target for each core capability. The capability target defines success for the capability. This step consists of two substeps: the first is to develop impact and outcome statements, and the second is to establish targets. The capability targets outlined in the most recent THIRA were integrated into the goals of this SHMCAP.
4. **Apply the Results.** For each core capability, estimate the resources required to meet the capability targets.

The 2017 THIRA assesses the consequences and capability targets for the following technological and human-caused hazards:

- Cyberattack – Critical Infrastructure (human-caused)
- Hazmat Release – Chemical (technological)
- Complex Coordinated Attack – Active Shooter (human-caused)

In addition to technological and human-caused hazards, earthquakes and floods are assessed. The context and profile of the natural hazards is closely linked to the risk assessment in this plan. The THIRA demonstrates how the capability targets are met through identification and application of required resources and procedures. The results of the assessment are included in the 2017 THIRA.

5.2 Comprehensive Emergency Management Plan

The Comprehensive Emergency Management Plan (CEMP), together with its functional and incident-specific annexes, is an all-hazards plan developed to address the natural and human-caused hazards that threaten Massachusetts. The plan describes the system that will be used in Massachusetts to prevent, prepare for, respond to, and recover from an emergency or disaster. It also identifies and assigns specific areas of responsibility for coordinating resources to support the response to an emergency or disaster (Commonwealth of Massachusetts, 2017b). The CEMP was developed with critical stakeholder input and was drafted in accordance with relevant federal and state laws. It conforms to federal guidance, including the CPG 101, FEMA's National Response Framework, and FEMA's National Incident Management System. The CEMP also complies with the Emergency Management Standard published by EMAP.

The CEMP includes several annexes that are grouped into the following categories:

- **Massachusetts Emergency Support Function (MAESF) Annexes:** These annexes identify state agencies, NGOs, and volunteer and private sector organizations that have been assigned responsibilities, each of which is designated a MAESF. These annexes describe the policies, planning assumptions, concept of operations, and responsibilities for their activities.
- **Functional Annexes:** These annexes describe the framework through which MAESFs coordinate and execute activities related to a specific response strategy. Each annex sets forth the concepts and procedures for critical emergency response actions.
- **Hazard Annexes:** These annexes detail special planning and response considerations and response protocols associated with specific hazards that have been identified through the THIRA process.

Table 5-1 identifies these annexes, which illustrate the extent of natural, technological, and human-caused hazards that are addressed through the CEMP.

5.3 Nuclear Plans

The Massachusetts Emergency Management Agency (MEMA) has developed and maintains detailed radiological emergency response plans and implementing procedures for communities and facilities falling within the two nuclear Emergency Planning Zones in Massachusetts. All plans and procedures are reviewed annually, updated as needed, and tested through regular exercises (Commonwealth of Massachusetts, 2017b).

Table 5-1: Comprehensive Emergency Management Plan Annexes

Annex Category	Annex Title	
Massachusetts Emergency Support Function Annexes	Transportation	Hazardous Materials and Environmental Protection
	Communications	Agriculture, Animals, and Natural Resources
	Public Works and Engineering	Energy
	Firefighting	Public Safety and Security
	Business and Industry	Recovery
	Mass Care, Emergency Assistance, and Human Services	Public Information and External Affairs
	Volunteers and Donations	Military Support
	Public Health and Medical Services	
	Search and Rescue	
Functional Annexes	Access and Functional Needs	MEMA Continuity of Operations Plan
	Air Operations Plan	Preventive Radiological / Nuclear Detection Plan
	Cape Cod Emergency Traffic Plan	Recovery Annex
	Communications and Warning Plan	Regional Catastrophic Coordination Plan (RCCP)
	Continuity of Operations / Continuity of Government Plan	Staging and Logistics Annex
	Cultural / Historical Resources Annex	State Emergency Dispensing Site Plan
	Debris Management Plan	State Emergency Repatriation Plan
	Disaster Housing Plan	State Law Enforcement Mobilization Plan
	Emergency Alert System Plan	Strategic National Stockpile Plan
	Emergency Petroleum Fuel Plan	Technical Search and Rescue Coordination Plan
	Evacuation Coordination Plan	Volunteers and Donations Management Plan
	Family Assistance Center Plan	
	Fire Mobilization Plan	
	Mass Care and Shelter Coordination Plan	
Hazard Annexes	Drought Management	Massachusetts Radiological Emergency Response
	Energy Assurance	Pandemic Influenza Operations
	Hazardous Materials	Regional Catastrophic Coordination Plan (RCCP) Cyber Disruption
	Improvised Nuclear Device	RCCP Improvised Explosive Device
	Large Volume / High Concentration Ethanol	State Cyber Disruption
	Major Air Crash Event	Terrorism Incident Response
	Mass Fatality Management	

Source: Commonwealth of Massachusetts, 2017b.

5.4 Dam Emergency Action Plans

Owners of all dams classified or reclassified as having "high" or "significant" hazard potential by the Department of Conservation and Recreation's Office of Dam Safety are required by law to develop an Emergency Action Plan (EAP) for the dam and to provide this plan to the Office of Dam Safety and local and state emergency management officials. The EAP must be prepared, maintained, and updated by the dam owner. All EAPs must be updated annually and submitted to the Department of Conservation and Recreation and MEMA. EAPs are subject to approval by the Commissioner of the Department of Conservation and Recreation.

Each EAP must include the following items: a list of equipment, personnel, and material available to implement the plan; a notification procedure for informing local emergency agencies; an inundation map showing the area that would be flooded in the event of a dam failure; and a procedure for warning local residents in the event of a dam failure, with a list of names and telephone numbers of downstream residents who may be affected by a dam failure (Commonwealth of Massachusetts, 2017b).

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6. State Capability and Adaptive Capacity Analysis

6.1 Introduction and Purpose

To develop a comprehensive and effective hazard mitigation and climate adaptation strategy, the Commonwealth of Massachusetts has done more than assess its current and future risk to potential impacts—it has also analyzed its current capability and capacity to address this risk through existing resources. The Commonwealth can use this information to determine improvement opportunities to incorporate into the plan. It can also better identify new ideas or innovative solutions that will further enhance the state’s overall resiliency.

The capability and adaptive capacity analysis includes two integral components: (1) a *capability assessment* that evaluates the Commonwealth’s existing capabilities to enable and implement hazard mitigation and climate adaptation activities on a statewide level; and (2) an *adaptive capacity analysis* that is more specific to individual state agencies.

As defined for the purposes of this plan, **state capabilities** include the authorities, laws, policies, programs, staff, funding, and other resources available to the Commonwealth to support hazard mitigation and climate adaptation efforts. **Adaptive capacity** is defined as the ability of state agencies (including their key assets, functions, missions, and services/programs) to adjust or

modify their operations, policies, or other functions to adapt to changing natural hazards and climate change impacts, both in the short- and long-term.

In combination with the risk assessment, this analysis serves as a background study to support the identification of specific actions to be included in the hazard mitigation and climate adaptation strategy, and the specific capabilities or resources required for implementation.

6.2 State Capabilities and Adaptive Capacity

6.2.1 Comprehensive Statewide Program

The Commonwealth has a long history of demonstrating its commitment to advancing risk reduction and resilience across the state. This encompasses a broad range of State-supported initiatives and activities that include a combination of outreach, training, technical assistance, funding, partnerships, regulatory codes and statutes, infrastructure projects, and other activities to increase statewide resilience. Some specific examples include the following:

- The Commonwealth actively manages a **statewide program of hazard mitigation and climate adaptation** through the development of legislative initiatives, multi-agency committees or councils, public/private partnerships, and/or other executive actions that promote hazard risk reduction and resilience. This includes the long-standing service of the State Hazard Mitigation Team (SHMT), and the more recent *Executive Order 569 Establishing an Integrated Climate Change Strategy for the Commonwealth*, which is described in this section.
- The Commonwealth has maintained a Federal Emergency Management Agency (FEMA)-approved **state hazard mitigation plan** since 1986, but its commitment to developing and implementing measures to reduce the impact of natural disasters dates back further than this. This commitment includes supporting the administration of the National Flood Insurance Program (NFIP) in coordination with participating communities since 1978. Even before that, Massachusetts became the first state to develop enabling legislation and programs for wetlands protection. Implementation of other risk reduction efforts has long been supported through the development and integration of various State laws, policies, and programs, in addition to support provided by nongovernment and private nonprofit agencies.
- The Commonwealth supports **local hazard mitigation and climate adaptation planning** by providing workshops and training, State planning grants, and other coordinated resource and capability development of local officials. This includes the technical support and coordination that is described in detail in *Chapter 10: Coordination of Local Hazard Mitigation and Climate Adaptation Planning*, and a variety of other state agency programs that are identified in Section 6.2.2.

- Most recently, the Commonwealth launched the Municipal Vulnerability Preparedness (MVP) grant program, as described in this section, which provides support for cities and towns in Massachusetts to begin or enhance the process of planning for resiliency to extreme weather and other natural or climate-related hazards.
- In May 2018, the Governor released the Administration's **Capital Investment Plan** for Fiscal Year (FY) 2019, providing a \$2.34 billion investment for the Commonwealth's capital needs. The plan reinforces the major themes of previous capital plans, while incorporating climate change adaptation as a critical new component. The plan integrates climate change preparedness and resiliency, with all of its investments analyzed for climate impact, and more than \$60 million to directly address climate change, including \$12 million to repair and rebuild seawalls and inland dams, \$11 million for MVP grants to help cities and towns plan for and protect against the impact of a changing climate, and \$5 million for energy efficiency improvements in public housing.
- In 2017, the Commonwealth's Division of Capital Asset Management and Maintenance (DCAMM) developed a **Statewide Resilience Master Plan** (SRMP) to identify and address potential climate impacts to the State's portfolio of more than 8,300 facility assets. The purpose of the SRMP was to develop a process to identify potential climate exposures, evaluate risks and vulnerabilities, and implement adaptation strategies to achieve resilience against climate impacts. This supports the Commonwealth's comprehensive, multi-year strategy to mitigate the risks posed to existing State-owned buildings, including those that have been identified as necessary for post-disaster response and recovery operations.
- The Commonwealth uses its own Coastal Resilience Grant Program as a non-federal match for National Oceanic and Atmospheric Administration Regional Coastal Resilience Grant funds, and it provides 50 percent of the non-federal share of the costs of major local flood control projects developed in conjunction with the U.S. Army Corps of Engineers (USACE).
- Since 1991, the State has contributed more than \$27 million as cost share to FEMA's Hazard Mitigation Grant Program (HMGP). This match has been accomplished through a combination of state fund grant programs, Community Development Block Grant (CDBG), and Legislative appropriations.
- The Commonwealth **requires local governments to use a nationally applicable model building code** that addresses natural hazards (including wind, flood, snow, seismic, and other hazards) as a basis for design and construction of new buildings and any State-sponsored mitigation projects. The 9th Edition of the State Building Code became effective October 20, 2017, and is based on modified versions of the 2015 International Codes (I-Codes), as published by the International Code Council (ICC). Under the 9th Edition, the design and construction of buildings and structures located in flood hazard areas

must be in accordance with American Society of Civil Engineers (ASCE) standards, which are consistent with, and in some cases, exceed minimum NFIP requirements.

- The Commonwealth routinely **integrates risk reduction into its post-disaster response and recovery operations**. To ensure this integration, the State's Disaster Recovery Manager at the Massachusetts Emergency Management Agency (MEMA) also oversees the Mitigation Unit, providing seamless coordination with the implementation of post-disaster mitigation and recovery programs, including FEMA's Hazard Mitigation Grant Program, Public Assistance (PA) program, and Individuals and Households Program. During Joint Field Office operations, the State Hazard Mitigation Officer is present for the duration of the recovery process.

State Agency Partnerships and Initiatives

As described in this section, the Commonwealth continues to take many steps to enhance its hazard mitigation and climate adaptation efforts. Some state agencies and offices routinely conduct hazard mitigation and resilience building as part of their organizational missions. Descriptions of many of the agencies' functions, including their enabling legislation and current resilience-building efforts, can be found in Table C-1 in Appendix C. Many of the Commonwealth's initiatives to strengthen resilience to natural hazards have been accomplished through partnerships and coordination between state agencies. This includes efforts to expand planning and programmatic development, provide funding opportunities, and develop policies and procedures to enhance resilience at a statewide level. Some notable examples of these interagency partnerships and initiatives are highlighted below.

State Hazard Mitigation Team

The SHMT consists of staff members employed by the Department of Conservation and Recreation (DCR) and MEMA, who work full-time on hazard mitigation planning, grants management, and project management. The team is co-chaired by the State Hazard Mitigation Officer at DCR and the Disaster Recovery and Mitigation Manager at MEMA. The team generally meets on a monthly basis—and on a more frequent basis after disasters—to coordinate team members' individual hazard mitigation work assignments, and to give progress reports on statewide mitigation plans, mitigation projects, and technical assistance.

Executive Order 569 – Establishing an Integrated Climate Change Strategy for the Commonwealth

In September 2016, building on the Commonwealth's leadership to mitigate and adapt to climate change, Governor Charlie Baker signed an Executive Order that lays out a comprehensive approach to further reduce greenhouse gas (GHG) emissions; safeguard residents, municipalities, and businesses from the impacts of climate change; and build a more resilient Commonwealth.

Executive Order 569 Establishing an Integrated Climate Change Strategy for the

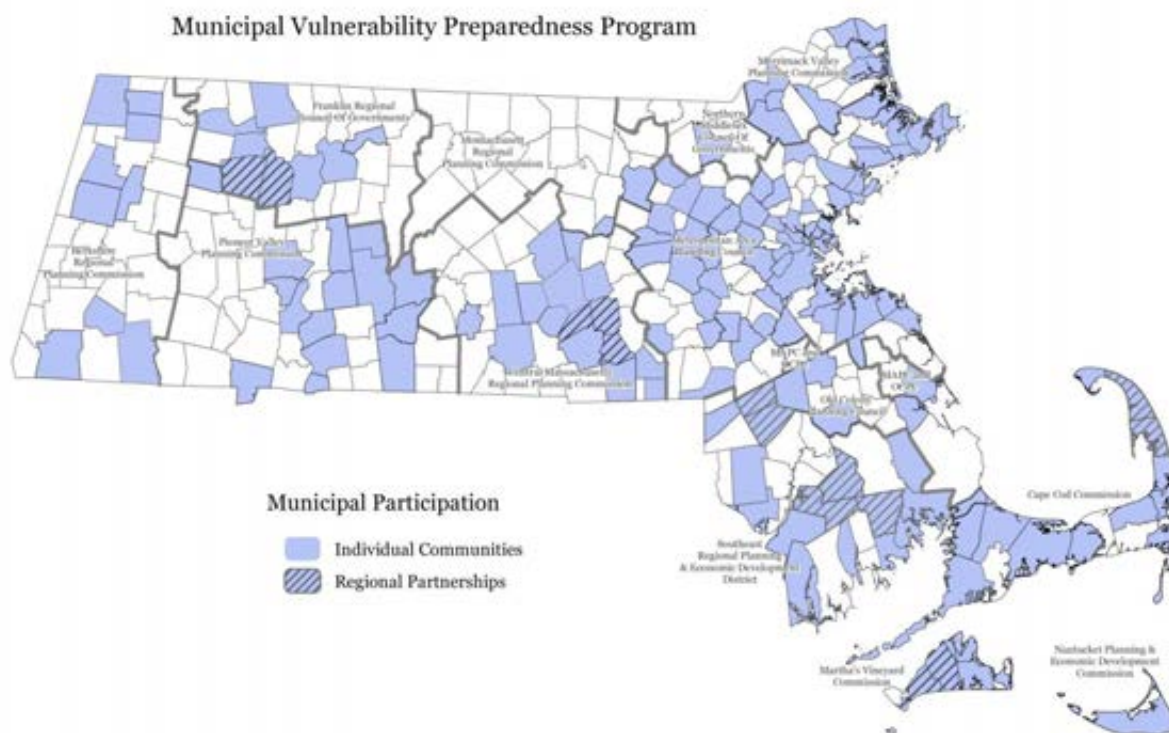
Commonwealth represents a collaboration between the Office of the Governor, the Executive Office of Energy and Environmental Affairs (EOEEA), the Executive Office of Public Safety and Security (EOPSS), and other key state, local, and environmental stakeholders.

The Executive Order ensures that Massachusetts will continue to lead by example and collaborate across State government to reduce GHG emissions and build resiliency within government operations. The Executive Order also directs EOEEA and EOPSS to lead the development and implementation of a statewide comprehensive climate adaptation plan that will provide a blueprint for protecting the built and natural environment of the Commonwealth, based on the best available data on existing and projected climate change impacts. Additionally, each Executive Office in the Baker-Polito Administration was required to designate a Climate Change Coordinator to work to complete a vulnerability assessment for each office, and assist with implementation and coordination of adaptation and mitigation efforts across State government. This State Hazard Mitigation and Climate Adaptation Plan (SHMCAP), along with the separate vulnerability assessment reports created for state agencies as part of the plan development process, have been developed pursuant to the Executive Order's framework.

Municipal Vulnerability Preparedness

Launched in 2017 in support of Executive Order 569, the Municipal Vulnerability Preparedness Program (MVP) grant program provides support for cities and towns in Massachusetts to begin the process of planning for resiliency. Under the MVP planning program, the Commonwealth awards funding to communities to complete vulnerability assessments and develop action-oriented resiliency plans. The program helps communities: (1) define extreme weather and natural and climate-related hazards; (2) identify existing and future vulnerabilities and strengths; (3) develop and prioritize actions for the community; and (4) identify opportunities to take action to reduce risk and build resilience. Communities that complete the MVP planning program become designated as an MVP community and are eligible for follow-up grant funding to implement actions in their resiliency plans.

In 2017, more than \$1 million in MVP planning grant funding was awarded to 71 towns and cities across the Commonwealth. In addition, more than 250 people, including 23 state employees, were trained in workshops across the state to provide technical assistance to communities in completing their assessment and resiliency plans using the Community Resilience Building workshop guide developed by The Nature Conservancy, which is now used in more than 200 communities across the country. In 2018, more than \$2 million in MVP planning grant funding was awarded to an additional 82 communities, and an additional \$3 million was awarded for MVP action grants to help communities implement priorities identified through their MVP planning process. Figure 6-1 identifies all of the communities enrolled in the MVP program as of June 2018.

Figure 6-1: Map of Municipal Vulnerability Preparedness Communities

Although administered primarily through EOEEA, the MVP program is supported by other state agencies, including MEMA, DCR, the Department of Environmental Protection (DEP), and the Office of Coastal Zone Management (CZM). External partners include the Nature Conservancy and Mass Audubon, who provide voluntary support, outreach, and content for the program. For example, MEMA mitigation staff work closely with EOEEA to ensure opportunities to leverage existing mitigation planning efforts and resources are effectively coordinated at both the State and municipal levels. This includes promoting the integration of MVP with existing processes to develop or update local hazard mitigation plans. Other providers include representatives from regional planning agencies, local municipalities, nonprofit organizations, academia, and private-sector companies.

Silver Jackets

The Massachusetts Silver Jackets Team launched in 2016 in conjunction with the USACE national program. The goal of the Massachusetts Silver Jackets Team is to reduce the risk of flooding and other natural disasters by bringing together multiple federal and state agencies. The interagency team facilitates a collaborative process of strategic and integrated mitigation actions to reduce the threat, vulnerability, and consequences of flooding in the Commonwealth of Massachusetts. Through the process of sharing and combining resources, funding, programs, and technical expertise, the team works toward the goal of proactively reducing flood risk.

In 2017, the Commonwealth of Massachusetts was awarded an Interagency Flood Risk Management Project from the USACE for the Town of Charlemont. To help extend its capacity and deal with significant flood risks, Charlemont worked in partnership with the Silver Jackets Team to integrate existing and new data to assess its vulnerabilities and develop a Flood Risk Action and Evacuation Plan. This plan has improved the Town's preparation for future flood events, and its capabilities to launch a coordinated response between numerous entities, including the Town, Sewer District, and local industries.

Floodplain Management Initiatives

Federal Executive Orders 11988 (Floodplain Management) and 11990 (Protection of Wetlands) require that federal agencies avoid direct or indirect support of development in the floodplain, and work to minimize harm to floodplains and wetlands. State agencies reviewing federally funded projects or receiving federal grants for projects must take these Executive Orders into consideration.

Federal Executive Order 13690 (January 2015) established a higher level of federal flood risk management, requiring the use of one of three alternatives for federal development activities that could not be located outside of the floodplain. The Commonwealth adopted these practices when considering floodplain requirements for projects under federal mitigation grants. In August of 2017, however, the Federal Administration rescinded the Order. While no longer a requirement, the Commonwealth continues to regard this as a best practice.

Numerous state agencies are involved in the review of state and federal projects in the floodplain, as well as the implementation of the following Massachusetts state laws and policies regarding floodplain management:

- Massachusetts Executive Order 149 (1978), State Coordination and Participation with the Federal Administration under the National Flood Insurance Act, designates the Massachusetts Water Resources Commission as the state agency to implement floodplain management programs in Massachusetts. The Office of Water Resources in DCR provides technical and staff support, including scientists, hydrogeologists, and water policy specialists who undertake activities of the Commission.
- Massachusetts Executive Order 181 (1980), Barrier Beaches, recognized the vulnerability of development on barrier beaches and the important role natural barriers play in providing storm damage prevention and flood control. To mitigate future loss of life and property, Executive Order 181 prohibited new development in velocity zones or primary dunes, as well as seawalls and revetments on barrier beaches. It constrains the use of state funds and federal grants for construction projects that could encourage growth and development in barrier beach areas. CZM was tasked with barrier beach policy coordination, and continues to provide technical assistance to local and state agencies on barrier beach management.

- Massachusetts was one of the first states in the nation to pass wetlands protection laws, in the early 1960s. The Wetlands Protection Act (WPA) (Massachusetts General Laws [MGL] Chapter 131, Section 40) was codified as 310 Code of Massachusetts Regulations (CMR) Section 10.00. These regulations protect wetlands functions and their public interests, including flood control, prevention of pollution and storm damage, and protection of water supplies and other natural resources and habitats. Multiple state agencies review proposed work that may alter these resources, including wetlands, all floodplains, lands under water, waterways, salt ponds, fish runs, and the ocean.
- Enacted in 1996, the Massachusetts Rivers Protection Act amends the WPA to provide protection to rivers and implements hazard mitigation by regulating activities within a 200-foot-wide resource area called the Riverfront Area.
- The Massachusetts Building Code (further described below) is a statewide mandated construction code that is updated periodically, based on the ICC's recommended codes; it includes most of the federal construction requirements listed in the U.S. Code of Federal Regulations (CFR) Title 44, Section 60.3 for floodplains as defined by FEMA Flood Insurance Rate Maps (FIRMs) under the NFIP. Other NFIP development requirements are included in the WPA or in the Commonwealth's Title V (310 CMR 15) requirements for sewage treatment and disposal. Finally, remaining NFIP standards can be found in the State's model floodplain ordinance; these must be adopted at the community level, typically through municipal zoning bylaws. The State monitors changes to the local codes as they pertain to mapped floodplain changes or related local practices.

Massachusetts Building Code Update and Enhancement

The State Board of Building Regulations and Standards (BBRS) administers the Massachusetts State Building Code (MSBC, found at 780 CMR), which consists of a series of international model codes and any state-specific amendments adopted by the BBRS during the promulgation process. The BBRS regularly updates relevant provisions of the MSBC as new information and technology become available, and a change is warranted.

The Commonwealth requires mandatory enforcement, and does not allow local amendments to the residential code. In addition, the Commonwealth adopts a plumbing and electrical code. The Commonwealth also has a program in place for code official certification, which includes taking code classes prior to examination and certification, requires continuing education, and allows consumers to file complaints against inspectors. Massachusetts also requires licensing of general, plumbing, electrical, and roofing contractors; requires licensing candidates to pass an examination prior to licensing; and requires continuing education.

The current 9th Edition of the MSBC (2017) is based on the 2015 ICC's recommend codes (I-Codes), and contains a series of requirements for flood-resistant design and construction that are

in accordance with the ASCE 24 standard, which incorporates—and in certain areas exceeds—FEMA’s NFIP construction standards. Highlights of ASCE 24 that complement the NFIP minimum requirements include requirements for building performance; flood-damage-resistant materials, utilities and service equipment, and siting considerations. Specific requirements for design flood elevations and the use of flood-resistant materials may be found in the ASCE Tables included in 780 CMR Section 1612.4. Additional state-specific higher standards for flood-resistant construction in coastal dunes may be found in Appendix G of the MSBC. For example, the State requires the use of pilings in coastal dune areas, even if the areas are not in a mapped Velocity flood zone (V Zone), and has higher elevation requirements than the NFIP (the lowest floor must be built to at least 2 feet above a dune).

Specific changes to the Building Code that affect development and redevelopment in coastal flood zones include: (1) in new or substantially improved buildings in V Zones, utilities can no longer be located below the FEMA base flood (1 percent annual chance) elevation; and (2) new or substantially improved buildings in A Zones have to be elevated so that the lowest floor surface is at least 1 foot above the FEMA base flood elevation. New or substantially improved buildings in V Zones must continue to be elevated so that the lowest floor is at least 2 feet above the FEMA base flood elevation.

Coastal Management Initiatives

With more than 1,500 miles of coastline, including some areas that are considered most vulnerable to natural hazards, climate change, and extreme weather, the Commonwealth’s coastal management initiatives are especially important to highlight. CZM is the lead policy, planning, and technical assistance agency on coastal issues in EOEEA. Similar to MEMA and DCR, natural hazard mitigation and climate change adaptation are fundamental to CZM’s mission and program areas, which play a strong role in various risk reduction activities at State, regional, and local levels. Some of the more notable recent initiatives include the following:

- *StormSmart Coasts* – This national model developed by CZM is designed to help communities and homeowners address coastal erosion, storm damage, flooding, and related issues. The StormSmart Coasts website includes information on available grants and on assessing the vulnerability of coastal properties to erosion and flooding; tools for local officials to improve coastal floodplain management; options for coastal property owners to effectively reduce erosion and storm damage while minimizing impacts to shoreline systems; landscaping options for controlling erosion and storm damage; interactive maps of erosion along the Massachusetts coast; and more.
- *Coastal Resilience Grant Program* – Massachusetts coastal communities face significant risks from coastal storms, flooding, erosion, and sea level rise—challenges that are exacerbated by climate change. To help address these issues, CZM administers the Coastal Resilience Grant Program to provide financial and technical support to the Commonwealth’s

78 coastal communities and certified 501(c)(3) nonprofit organizations with vulnerable coastal property for local efforts to increase awareness and understanding of climate impacts, identify and map vulnerabilities, conduct adaptation planning, redesign vulnerable public facilities and infrastructure, and implement nonstructural (or green infrastructure) approaches that enhance natural resources and provide storm damage protection.

- *Sea Level Rise and Coastal Flooding Viewer* – CZM developed this online tool to support the assessment of coastal flooding vulnerability and risk for community facilities and infrastructure, consistent with Governor Baker’s Executive Order 569. This viewer includes interactive maps of flooding extents and water level elevations associated with sea level rise scenarios, current coastal flood zones, and hurricane storm surge. It also includes location data for a wide range of public facilities and infrastructure to assist state, regional, and local planners and other stakeholders in conducting general vulnerability assessments to these coastal hazards.
- *Coastal A Zone Mapping*: To improve coastal flood hazard mapping in Massachusetts, DCR and CZM recently partnered to map the delineation of Limit of Moderate Wave Action (LiMWA) for 15 coastal communities. LiMWA is the inland limit of the area expected to receive 1.5-foot or greater breaking waves during the 1 percent annual chance flood event. FEMA FIRMs that went into effect in 2009-2013 for Massachusetts coastal counties were based on studies initiated in 2005, and did not include LiMWA lines. The addition of the LiMWA to FIRMs allows communities and individuals to better understand the flood risks to their property. To make the most accessible and accurate information on Coastal A Zone boundaries available, DCR and CZM use information on Coastal A Zone boundaries for the entire Massachusetts coast from FEMA’s published Flood Insurance Studies (FIS). Through this initiative, the LiMWA was mapped based on the coastal storm surge and wave modeling data from the most recent FEMA coastal FIS for coastal communities. The data have since been approved and incorporated into FEMA’s National Flood Hazard Layer.
- *Increasing Resilience through Application of Nature-Based Infrastructure*: CZM is participating in a regional effort to increase resilience to sea level rise in New England that is focused on increasing the effective use of nature-based infrastructure for reduced erosion and enhanced wave attenuation. The team is developing region-specific information on suitable natural infrastructure types (i.e., “living shorelines”), and is working with several communities to implement and monitor a range of nature-based coastal infrastructure projects. The experience and lessons gained through this project will help to identify successful approaches and models to reduce erosion.

These and other capabilities and resources relevant to the Commonwealth’s management of hazardous coastal areas are included in Section 6.2.2.

Energy Resilience Initiatives

The Massachusetts Department of Energy Resources (DOER) develops and implements policies and programs aimed at ensuring the adequacy, security, diversity, and cost-effectiveness of the Commonwealth's energy supply to create a clean, affordable, and resilient energy future for all residents, businesses, communities, and institutions. These are:

- Continued Support of Energy Assurance Initiatives and Planning
 - Support FEMA Region I in the development of a Power Outage Incident Annex.
 - Support National Association of State Energy Officials initiatives for Petroleum Shortage Response Planning.
 - Provide support during emergencies or disasters to the State's emergency management team via Emergency Support Function #12 – Energy.
 - Update and maintain Energy Assurance Plans.
 - Maintain Hours of Service Waiver Guidance to ensure the availability of delivered fuels during an emergency or disaster.
- The Community Clean Energy Resiliency Initiative is designed to help address service interruptions at critical infrastructure caused by severe weather. The \$40 million grant program funds technical assistance, as well as project implementation, for police and fire dispatch, emergency shelters, hospitals, and critical water infrastructure facilities to use clean energy technologies; including combined heat and power, solar photovoltaic (PV), and energy storage, to mitigate and address the impacts of climate change.
- The Energy Storage Initiative is a \$20 million grant program designed to demonstrate how energy storage can improve grid operations, reduce energy costs, provide backup power through storms, and benefit the local economy.
- The Clean Energy Plan examines a varied portfolio of energy pathways that seek to balance a clean, affordable, and reliable energy future while investigating the impact of policies over a long-term planning horizon.
- The Solar Massachusetts Renewable Target (SMART) Program incentivizes the continued development of distributed solar PV electricity generation across the Commonwealth. The SMART Program is the nation's first to incorporate an incentive to pair energy storage with the solar resource. The addition of energy storage with distributed solar generation can enable the solar resource and the stored energy to continue to serve on-site loads through the outage, improving the facility's energy resilience.
- Energy Diversification through DOER's clean energy procurements (hydroelectric and offshore wind) will decrease the Commonwealth's reliance on natural gas and oil, which are

delivered on long supply chains across multiple national and state lines. The long supply chains are vulnerable to severe weather events anywhere along the chain.

- Leading by Example demonstrates energy best practices at state facilities, including initiatives to identify energy vulnerabilities and demonstrate clean technologies to improve facility resilience.
- Energy Efficiency reduces demand for electricity and fuels. Reducing demand, particularly coincident with system peaks, increases reliability by reducing thermal stresses on the system. Energy efficiency reduces peak demand, but also decreases the high costs and emissions associated with peak demand. The American Council for an Energy-Efficient Economy has ranked the Massachusetts Energy Efficiency Program #1 in the nation for the past 7 consecutive years.

Transportation Resiliency Initiatives

In 2015, MassDOT conducted a Climate Change Summit to begin charting a course to identify and adapt to climate-related threats to its key assets and infrastructure. The breakout sessions conducted during the summit and subsequent discussion at the Summit Leadership Session generated numerous ideas to enhance MassDOT's climate preparedness and mitigation efforts. Of the many initiatives identified, MassDOT selected nine for implementation, and has since been working in conjunction with many partner agencies to further develop and implement them. These initiatives include the following:

- Capture and document institutional knowledge on vulnerabilities from staff through interviews and the Mapping Our Vulnerable Infrastructure Tool.
- Incorporate climate change adaptation into the MassDOT Highway Division asset management system and process, and coordinate asset management across divisions and partner agencies.
- Use the Boston Harbor Flood Risk Model and data from the vulnerability assessments to identify current and future high-risk areas, and strengthen emergency management with local, state, and federal agencies.
- Leverage permit-granting authority and ability to influence Section 61 findings and mitigation.
- Coordinate with state and federal agencies to evaluate environmental regulation and permitting processes to address current roadblocks in climate change adaptation; identify opportunities to streamline permitting.
- Pilot the Deerfield Watershed Stream Crossing Resilience Program.

- Develop adaptation design guidance and other resources, and provide training for project managers and design teams.
- Require a holistic evaluation of all vulnerability, environmental, transportation, and social data sets in the earliest project planning phases.
- Incorporate sustainability and resiliency review items into the Early Environmental Coordination Checklist (EECC), which is a required document for all MassDOT Highway Division roadway and bridge construction projects. The EECC requests information related to the environmental aspects of a project, such as nearby sensitive resource areas, and helps MassDOT Environmental Services scope the project for permitting needs and potential design considerations.

Recovery Planning Initiative

MEMA staff attends semi-annual Recovery and Mitigation meetings to discuss important aspects of the programs, changes in priorities, and lessons learned from disaster events. In addition, Mitigation staff provide support to the Recovery Unit during immediate post-disaster operations, such as attending applicants' briefings for PA and other administrative duties. In 2018, the Commonwealth initiated the development of a new State Disaster Recovery Plan to be consistent and compliant with the National Disaster Recovery Framework, and to update the Massachusetts ESF-14 Recovery Annex to the Massachusetts Comprehensive Emergency Management Plan. It is also aiming to establish a formal State Disaster Recovery Committee that will include the State Hazard Mitigation Officer as an appointed member.

6.2.2 Existing State Capabilities

The Commonwealth of Massachusetts has a wide range of policies, programs, and other capabilities to mitigate natural hazards and adapt to a changing climate. Many of these capabilities do so explicitly (e.g., providing funding for specific mitigation/adaptation projects), while others do so more implicitly (supporting the protection of natural resources in ways that provide ancillary or co-benefits of risk reduction).

Table C-1 in Appendix C summarizes the Commonwealth's primary hazard mitigation and climate adaptation capabilities (see excerpt in Figure 6-2). This table has been updated for the 2018 SHMCAP with the most current information on hazard mitigation capabilities, and it has been amended to include additional capabilities to support climate adaptation. Other notable changes since the 2013 State Hazard Mitigation Plan include the following:

Figure 6-2: Screenshot of Table C-1 (2018 State Capability Assessment Summary) in Appendix C

Existing Capability	Lead / Responsible Agency	Description of Capability	Effectiveness for Reducing Risk and Vulnerability	2018 Update Notes / Opportunities for Improvement	Related 2018 Plan Goal(s)
Planning and Regulatory					
Massachusetts State Building Code (780 Code of Massachusetts Regulations (CMR))	BBRS	Massachusetts State Building Code (MSBC) covers the entire state, applies to both public and private construction, and is administered through the local building inspectors with state oversight. The Code addresses multiple natural hazards including wind, seismic, snow, and flood hazards. Section 1612 of the MSBC contains most of the NFIP construction requirements related to buildings or structures.	NFIP standards are an integral section of the MSBC, ensuring that all new construction and substantial improvements meet national flood resistant standards. Many communities have enacted stricter standards under their local floodplain ordinances. Allows for the application of NFIP standards on all new construction of buildings and structures throughout the Commonwealth.	Updated. In 2017 the MSBC was updated based on the ICC's most recent (2015) model codes (I-Codes). Significant improvements were made to the design and construction requirements for buildings and structures in flood hazard areas. The new 9 th Edition of the MSBC became effective on October 20, 2017.	3
The Massachusetts Public Waterfront Act - Chapter 101 Program; (MGL Ch. 91)	CZM	Protects the coastal tidal area for public open space purposes and regulates new and expanded construction within this area.	Very effective tool for risk reduction by restricting development along coastal shores, which are high hazard areas.	Although it includes language regarding sea level rise, Chapter 101 only requires sea level rise projections to be based on historical data and does not require specific actions for adaptation.	3

- The column previously titled “Existing Mitigation Efforts” was renamed “Existing Capability” and includes information on hazard mitigation and climate adaptation efforts.
- Existing capabilities have been reorganized under five categories, which are described below:
 - **Planning and Regulatory** – State laws, regulations, executive orders, enabling legislation, plans, policies, strategies, and guidelines that support risk reduction for the built environment and natural systems.
 - **Administrative and Technical** – State staff and technical resources or programs, including the expertise, data, tools, and other capabilities that support institutional capacity building.
 - **Capital Projects and Asset Management** – Capital improvement programs or other investments that support risk reduction for key state assets or critical infrastructure.
 - **Financial** – Grants, capital projects/improvements, land acquisition, and other monetary investments by the State that support risk reduction for the built environment and natural systems.
 - **Education, Outreach, and Capacity Building** – Technical assistance, training, education and awareness initiatives, public-private partnerships, and nonregulatory incentives that support external capacity building.

- Existing capabilities are listed in alphabetical order according to the lead or responsible agency.
- A new column titled “Related 2018 Plan Goal(s)” was added to the matrix to identify the specific goals of this plan that are most relevant to the listed capability.

6.2.3 Adaptive Capacity of State Agencies

In addition to the assessment of existing State capabilities, this study also included an analysis of the adaptive capacity of individual state agencies. Adaptive capacity is defined as the ability of state agencies (including their key assets, functions, missions, and services/programs) to adjust or modify their operations, policies, or other functions to adapt to changing natural hazards and climate change impacts, both in the short- and long-term. For purposes of this plan, the adaptive capacity analysis relied heavily on the agency-specific self-assessments that were completed as part of the state agency vulnerability assessment survey process in support of the risk assessment (see Section 9.5 in *Chapter 9: Planning Process* for additional information).

In response to the state agency vulnerability assessment survey, the following information was collected and reviewed for each specific agency as it relates to their adaptive capacity. A summary of the key findings from the analysis of this information is provided in Section 6.4.1.

- **Overall Capacity Rating** – Self-assessment rating of the agency’s overall ability to withstand natural hazards and climate impacts in terms of potential physical damage or disruption to its assets, mission, functions, staff, and the public. Ratings were identified in response to a closed-ended survey question with the following potential ratings:
 - *Excellent (very unlikely to result in damage/disruption)*
 - *Good (unlikely to result in damage/disruption)*
 - *Satisfactory (may result in damage/disruption)*
 - *Fair (likely to result in damage/disruption)*
 - *Poor (very likely to result in damage/disruption)*
- **Incorporation of Hazard Mitigation / Climate Adaptation** – Description of the agency’s current efforts to incorporate natural hazard mitigation and climate change adaptation into existing programs.
- **Current Obstacles, Challenges, or Needs** – Summary narrative description of existing barriers to improving or maintaining the agency’s ability to withstand natural hazards and climate impacts.

- **Examples / Additional Comments on Adaptive Capacity** – Notable examples or additional comments on specific agency capabilities, plans, policies, or other available resources that relate to adaptive capacity.
- **Opportunities for Improvement** – Identification of any noted opportunities for improving the agency’s adaptive capacity, especially as it relates to critical agency plans, policies, regulations, or procedures that could be adjusted to better consider climate change.

Additional data collected as part of the state agency vulnerability assessment process included information on the functionality and continuity of agency operations during an extreme weather event (including remote operation capability), as well as emergency response measures that have been identified to intervene and reduce the vulnerability of the agency’s at-risk critical assets, function, or population groups.

6.2.4 Administration of FEMA Mitigation Programs

The Commonwealth’s administration of the federally established NFIP, Community Rating System (CRS), Hazard Mitigation Assistance (HMA), and Risk Mapping, Assessment, and Planning (Risk MAP) programs is directly related to the Commonwealth’s commitment and capability to manage and implement sustained risk reduction initiatives across the state. The administration of these programs is routinely coordinated through the SHMT, a joint effort between MEMA and DCR. The SHMT consists of the staff in MEMA and DCR who work full-time on hazard mitigation programs, projects, and planning. Descriptions of these programs follow.

NATIONAL FLOOD INSURANCE PROGRAM

The NFIP is a federal program administered by FEMA that makes flood insurance available in communities that agree to adopt floodplain management regulations that will reduce future flood damage. The program is intended to be a partnership between the Federal Government, states, and participating local jurisdictions. Congress created the NFIP in 1968 through the National Flood Insurance Act, which was passed to address the fact that homeowner’s insurance does not cover flood damage, leaving much of the burden of flood recovery to general taxpayers through federal disaster relief programs. NFIP flood insurance is available anywhere, with limited exceptions (e.g., buildings entirely underground or entirely over water are not insurable), in an NFIP participating community, regardless of the flood risk zone. Federal law requires that flood insurance be purchased as a condition of federally insured financing used for the purchase of buildings in an identified Special Flood Hazard Area (SFHA), which is the area subject to inundation from the 1 percent annual chance flood (also known as the base flood or the 100-year flood).

Currently, 341 out of 351 Massachusetts communities participate in the NFIP. As of March 2018, there were more than 63,000 NFIP policies in place, with total insurance coverage of \$16.2 billion, and \$78.2 million in annual premiums paid. Since 1978, there have been more than 33,000 total claims, and nearly \$382 million has been paid for insured flood losses.

The DCR Flood Hazard Management Program (FHMP) in the Office of Water Resources is the state coordinating office for the NFIP. Program staff work with FEMA and officials from NFIP-participating local communities to implement the NFIP in Massachusetts. The FHMP is a technical assistance program and has no regulatory authority, but staff provide a range of assistance to local communities in support of their local floodplain management efforts. This assistance includes, but is not limited to, the following activities:

- Conducting Community Assistance Visits and Community Assistance Contacts in coordination with FEMA.
- Providing support in reviewing and developing required ordinances for NFIP compliance.
- Conducting and/or supporting technical workshops and training events for local officials.
- Providing on-call and as-needed assistance to all interested parties on issues such as the NFIP, floodplain management, floodplain building requirements, floodplain mapping, flood mitigation, and flood insurance.

FHMP staff also routinely support and work with other state agencies to develop and implement the Commonwealth's laws regulating the program. This includes supporting any ongoing mapping initiatives, State model ordinance updates, and revisions or improvements to the adoption and enforcement of applicable State regulations, such as the State Building Code and WPA. Program staff also serve on the SHMT and work closely with MEMA on hazard mitigation planning and project activities across the state.

Flood Insurance Rate Maps

FEMA produces FIRMs based on technical studies that identify and map the SFHAs where development is regulated. As described above, the SFHA determines where flood insurance is required as a condition of a federally insured loan through the NFIP mandatory purchase requirement. The risk zones and flood elevations shown on the FIRMs in the SFHA are used to determine flood insurance rates. The geographic boundaries of the SFHA determine where NFIP floodplain management requirements must be enforced by communities that participate in the program. These include design and construction standards as codified in State regulations, and per local flood damage prevention ordinances in compliance with minimum NFIP standards. In addition to the NFIP, the FIRMs have taken on additional uses. They are used in FEMA's individual and public disaster assistance programs and in FEMA's mitigation grant programs,

and for emergency management purposes. In Massachusetts, the FIRMs are predominantly used to identify areas where certain State Building Code and WPA regulations are to be applied.

FIRMs are made available to view through online mapping viewers or downloadable files provided through municipal websites, publicly accessible computer stations, and/or links to FEMA's Map Service Center website. These maps can be amended or revised to reflect existing topography or changes in flood characteristics. The Letter of Map Amendment process is often used to challenge a lender's determination that a building is in the floodplain.

Risk Mapping, Assessment, and Planning

Risk MAP is a FEMA program that builds on the products of the Flood Map Modernization Program. FEMA began Risk MAP in 2009 with funding from the National Flood Insurance Fund and congressional appropriations for flood hazard mapping. Risk MAP is expected to integrate and align individual risk analysis programs into a more effective unified strategy:

“[Risk MAP] provides communities with flood information and tools they can use to enhance their mitigation plans and take action to better protect their citizens. Through more precise flood mapping products, risk assessment tools, and planning and outreach support, Risk MAP strengthens local ability to make informed decisions about reducing risk” (FEMA, 2012).

FEMA's Risk MAP product development is ongoing. FEMA's other mapping efforts include the following:

- Map Modernization activities are ongoing in Chicopee, Middle Connecticut, and Westfield Watersheds. This includes the processing of basemaps and topographic data (light detection and ranging [LiDAR]) for the purpose of developing a digital FIRM database. The hydrology and hydraulics, as well as the resulting approximate Zone A floodplain mapping, have been reviewed, and will be incorporated into the database for use in future flood study projects. Discovery activities are under way, with Discovery Meetings projected to take place late November/early December 2018. Field survey will commence once Discovery is completed and study miles are prioritized.
- Discovery activities are under way in the Deerfield Watershed, with Discovery Meetings projected to take place early 2019.
- Discovery activities are under way in the Miller Watershed, with Discovery Meetings projected to take place early 2019. Field survey will commence once Discovery is completed and study miles are prioritized.
- A Coastal Erosion Hazard Mapping pilot study was completed in Nantucket, as well as areas of the shoreline in Salisbury up to the New Hampshire state border. The methodology developed during this pilot study is being used in the FY 2017 study to map coastal erosion hazard potential in other vulnerable areas such as Barnstable, Dukes, and other parts of the Nantucket coastlines. Community outreach to discuss the coastal erosion hazard mapping in

Nantucket took place on June 26, 2018. FEMA's consultants are reviewing the comments provided by Nantucket on August 6, 2018. Data collection and initial analysis of areas in Barnstable and Dukes are currently under way.

- Field survey and hydrologic analysis of the Quinebaug Watershed were completed at the end of 2017. Hydraulic analysis of the Quinebaug Watershed is ongoing, and projected to be completed in September 2018. Floodplain mapping will commence in October 2018. This study has been funded through the issuance of Preliminary FIRMs and the FIS.
- The Canton Levee study is ongoing, with Floodplain Mapping. Compass is coordinating with the U.S. Geological Survey on the Charles River Watershed study, which encompasses the Canton Levee study footprint. Compass met with the Town of Canton at the work map meeting for the Charles River Watershed on July 9, 2018. Compass will address comments from the community prior to finalizing the levee mapping in fall 2018.
- Levee Analysis and Mapping Procedures (LAMP) have commenced in the Town of Southbridge with a Webinar to explain the LAMP process on July 19, 2018. There will be an in-person meeting with the community in September/October once the Natural Valley analysis of the levee is conducted.
- LAMP studies for the levees in the Towns of Adams, North Adams, and Hatfield will start with community outreach activities in November 2019. A webinar for these communities will be held in early 2019.
- Upcoming Regional Standard Ops studies – 2D Rain on Grid Large Scale Automated Engineering will be conducted for the Narragansett Watershed over the next year (fall 2018 – summer 2019). The engineering results will be used to map the approximate Zone A's in future studies.
- Charles Watershed – Community work map review meeting occurred July 9 and 10, 2018. Comment period was scheduled to end on August 10, 2018. Several communities have requested and were granted extensions for providing comments.
- Merrimack Watershed – Surveying and hydrology are completed. Hydraulics for enhanced studies is almost complete. Base-level engineering will be completed in August 2018. Floodplain mapping will begin immediately afterward, and is scheduled for completion in October 2018. Draft work maps will be reviewed by FEMA, Massachusetts, and New Hampshire in late-fall 2018. Community outreach for work map review meeting will proceed approximately 6 weeks later.
- Cape Cod Watershed – A review of mapping data is under way, and Federal Register publication of preliminary maps is anticipated in August 2018. The 90-day appeal period will begin in September 2018, and conclude in December 2018. Additional quality review

will take place in December 2018 in preparation for Letter of Final Determination in January 2019, and effective date in July 2019.

- Nashua Watershed – Surveying and base-level engineering are completed. Hydrology and hydraulics are under way, and are scheduled to be completed in fall 2018.
- Lower Connecticut Watershed – Priority reach selection is complete and final Discovery packages should be mailed out in September 2018.
- Blackstone Watershed – Discovery is complete and surveying has started.
- Housatonic Watershed – Discovery meetings were held in May 2017. Community input is completed. Selection of priority reaches is on hold until First Order Approximation (FOA) is completed. FOA (base-level engineering) is on hold until LiDAR for Connecticut is released, and LiDAR for Massachusetts is repaired (both likely in September 2018). No date is available for this release at this time.
- Shetucket Watershed – Selection of priority reaches is completed and through review. Discovery was completed in the Mapping Information Platform in March 2018. Field surveying began in June 2018.

COMMUNITY RATING SYSTEM

The CRS is a voluntary program within the NFIP that encourages floodplain management activities that exceed minimum NFIP requirements. Flood insurance premiums are discounted to reflect the reduced flood risk resulting from community actions to meet the CRS goals of reducing flood losses, facilitating accurate insurance rating, and promoting awareness of flood insurance.

For participating communities, flood insurance premium rates are discounted in increments of 5 percent. For example, a Class 1 community receives a 45 percent premium discount, and a Class 9 community receives a 5 percent discount. Class 10 communities are those that do not participate in the CRS; they receive no discount. The CRS classes are based on 19 activities in the following categories:

- Public Information Activities
- Mapping and Regulations
- Flood Damage Reduction Activities
- Warning and Response

CRS activities can help to save lives and reduce property damage. Communities participating in the CRS represent a significant portion of the nation's flood risk; more than 69 percent of the NFIP's policy base is located in these communities. Communities receiving premium discounts through the CRS range from small to large; and represent a broad mixture of flood risks,

including both coastal and riverine flood risks. The Insurance Services Office (ISO) administers the CRS program under FEMA contract.

Currently, there are 20 Massachusetts communities actively participating in the CRS program, as listed in Table 6-1. These communities represent approximately 27 percent of the flood insurance policy base in the Commonwealth. The CRS classifications range from a Class 9 (5 percent discount) to Class 7 (15 percent discount). These classifications are updated by FEMA bi-annually in May and October of each year. The total annual flood insurance premium discount for the Commonwealth as of September 10, 2018 was \$1,785,398. This represents an average savings of \$96.00 per NFIP policy in participating CRS communities, and 2.24 percent of the total annual premiums paid in the Commonwealth.

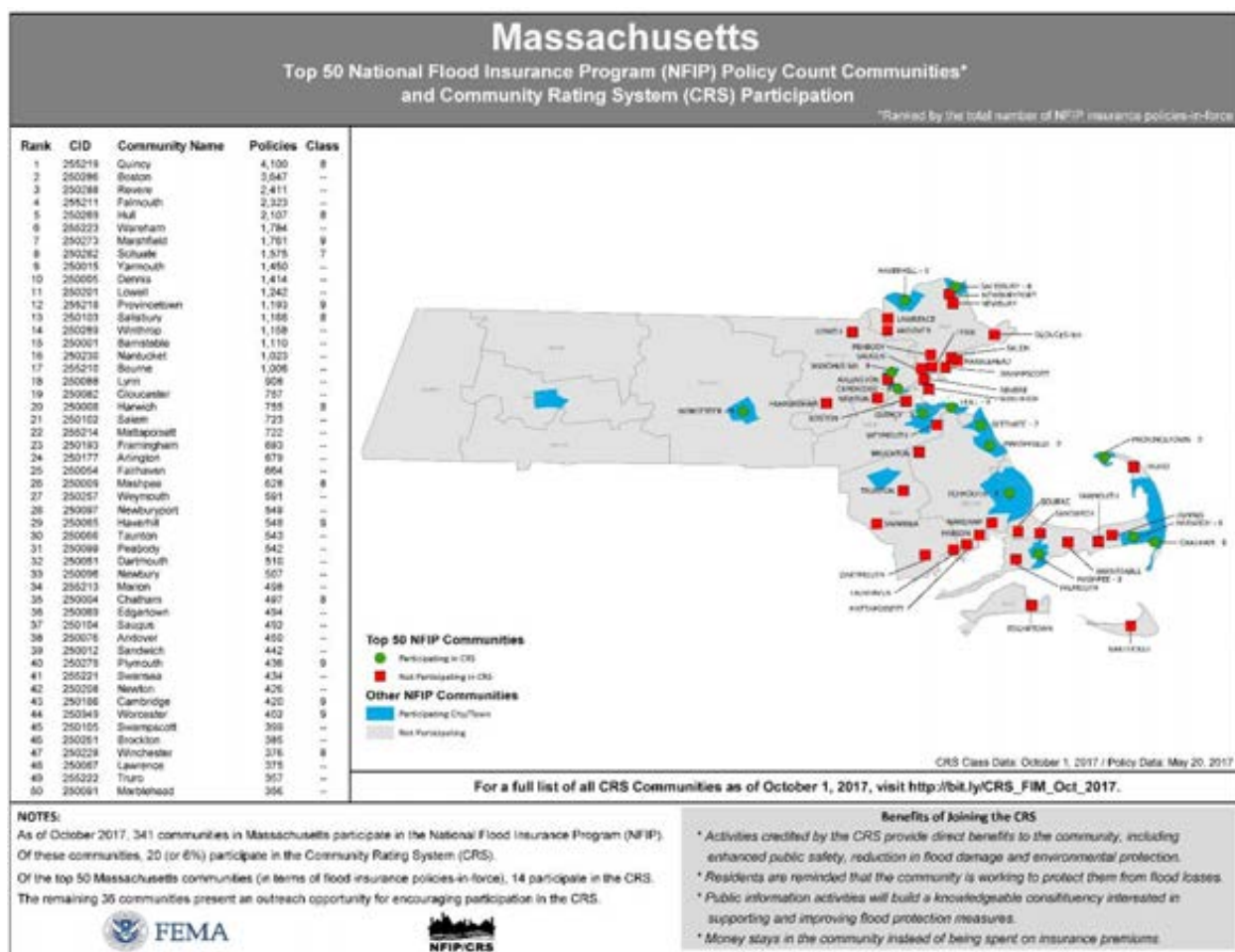
Table 6-1: Massachusetts Participating CRS Communities

NFIP #	Community	CRS Entry Date	Current Effective Date	Current Class	% Discount for SFHA	% Discount for non-SFHA
250233	Braintree	10/1/92	05/1/18	8	10	5
250186	Cambridge	10/1/15	10/1/15	9	5	5
250004	Chatham	10/1/92	10/1/93	8	10	5
250006	Eastham	10/1/17	10/1/17	8	10	5
250008	Harwich	10/1/95	10/1/15	8	10	5
250085	Haverhill	10/1/92	10/1/92	9	5	5
250269	Hull	05/1/08	05/1/08	8	10	5
250273	Marshfield	10/1/15	10/1/15	9	5	5
250009	Mashpee	10/1/17	10/1/17	8	10	5
250167	Northampton	05/1/17	05/1/17	8	10	5
250060	Norton	10/1/91	10/1/91	9	5	5
250010	Orleans	10/1/93	10/1/93	9	5	5
250278	Plymouth	10/1/91	10/1/91	9	5	5
255218	Provincetown	10/1/11	10/1/11	9	5	5
255219	Quincy	10/1/93	10/1/12	8	10	5
250103	Salisbury	05/1/16	05/1/16	8	10	5
250282	Scituate	10/1/91	05/1/17	7	15	5
250014	Wellfleet	05/1/17	05/1/17	8	10	5
250228	Winchester	10/1/13	05/1/18	8	10	5
250349	Worcester	10/1/95	10/1/95	9	5	5

CRS = Community Rating System; NFIP = National Flood Insurance Program; SFHA = Special Flood Hazard Area

Figure 6-3 shows the location of participating CRS communities, in addition to those communities identified by FEMA as having the highest number of NFIP policies.

Figure 6-3: Top 50 NFIP Policy Count Communities and CRS Participation, FEMA



State-Based and Other Potential Credit

The CRS provides credit to communities for certain state laws, regulations, and standards that support floodplain management within a state, and have proven effective in reducing flood damage. State-based credit is awarded to communities for activities that are implemented and enforced by the state (e.g., mandatory flood hazard disclosure laws for developers, realtors, or sellers). This type of CRS credit is verified by ISO annually, and does not require any further information or documentation from the community.

Additional potential credit is available to communities for state-mandated or common state activities implemented and enforced at the local level. A summary of applicable CRS activities for other potential credits is provided in Table 6-2, but individual communities must determine which credits may apply to their specific jurisdiction in coordination with ISO.

Table 6-2: Summary of Activities for Potential CRS Credit

CRS Activity	CRS Element
430 – Higher Regulatory Standards	Development Limitations (DL)*
430 – Higher Regulatory Standards	Building Codes (BC)*
430 – Higher Regulatory Standards	Local Drainage Protection (LDP)*
430 – Higher Regulatory Standards	State-Mandated Standards (SMS)
450 – Stormwater Management	Stormwater Management Regulations (SMR)
450 – Stormwater Management	Erosion and Sediment Control (ESC)
450 – Stormwater Management	Water Quality (WQ)
630 – Dams	State Dam Safety (SDS)
430 – Higher Regulatory Standards	Development Limitations (DL)*

* Indicates potential state-mandated credits
 CRS = Community Rating System

6.2.5 Hazard Mitigation Assistance

Currently, there are three programs available to states through FEMA that provide funding for eligible mitigation planning and projects that reduce disaster losses and protect life and property from future disaster damages. The three programs are the HMGP, the Pre-Disaster Mitigation (PDM) program, and the Flood Mitigation Assistance (FMA) program. HMGP assists in implementing long-term hazard mitigation planning and projects following a major Presidentially Declared Disaster. The PDM and FMA programs provide funds for mitigation planning and projects on an annual basis, with the latter focused on reducing flood hazard risks to buildings that are insured under the NFIP. HMGP funding is generally 15 percent of the total amount of federal assistance provided to a state, territory, or federally recognized Tribe following a major disaster declaration. PDM and FMA funding depends on the amount Congress appropriates each year for those programs.

Although FEMA's HMA programs are federally funded and managed, they must be administered by the State (Grantee), which in turn coordinates with local applicants (Subgrantees). FEMA must certify that the Commonwealth of Massachusetts has demonstrated that it has the capability to effectively manage FEMA-funded hazard mitigation grant programs.

Since 1991, Massachusetts has supported more than 400 hazard mitigation projects and plans with more than \$120 million in federal funding from pre-disaster and post-disaster hazard mitigation grant programs, as summarized in Table 6-3 and Table 6-4. The Commonwealth emphasizes effectiveness in hazard mitigation, in part by marketing the grant programs to all eligible applicants and then working with them to develop the best possible projects. For the

Table 6-3: Summary of Mitigation Projects Funded through Post-Disaster Grant Program

Disaster Event	Disaster Number	Federal Funding	# of Projects	Status
Hazard Mitigation Grant Program				
Hurricane Bob, Aug-91	914	\$651,881	17	Closed
Winter Storm, Oct-91	920	\$626,406	10	Closed
Winter Storm, Dec-92	975	\$400,943	7	Closed
Flooding, Oct-96	1142	\$12,262,500	37	Closed
Flooding, Jun-98	1224	\$1,769,145	22	Closed
Flooding, Apr-01	1364	\$1,562,356	17	Closed
Flooding, Apr-04	1512	\$243,225	1	Closed
Flooding, Oct-05	1614	\$763,899	4	Closed
Flooding, May-06	1642	\$2,600,528	14	Closed
Nor'easter, Apr-07	1701	\$1,364,794	5	Closed
Ice Storm, Dec-08	1813	\$8,325,842	26	Closed
Flooding, Mar-10	1895	\$13,280,510	34	Open
Snowstorm, Mar-11	1959	\$3,805,002	14	Open
Tornadoes, Jun-11	1994	\$7,044,043	11	Open
Tropical Storm Irene, Sep-11	4028	\$5,481,585	6	Open
Snowstorm, Jan-12	4051	\$10,776,528	20	Open
Hurricane Sandy, Oct-12	4097	\$2,094,349	4	Open
Snowstorm, Feb-13	4110	\$7,748,110	23	Open
Snowstorm, Jan-15	4214	\$13,277,200	TBD	Open
Nor'easter, Mar-18	4372	TBD	TBD	Open
Nor'easter, Mar-18	4379	TBD	TBD	Open

Table 6-4: Summary of Mitigation Projects Funded through Non-Disaster Grant Programs

Grant Type	Fiscal Year (FY)	Federal Funding	# of Projects	Status
Flood Mitigation Assistance (FMA)				
FMA	FY 97	\$286,544	4	Closed
FMA	FY 98	\$238,428	3	Closed
FMA	FY 99	\$457,367	6	Closed
FMA	FY 00	\$240,713	5	Closed
FMA	FY 01	\$307,201	8	Closed
FMA	FY 02	\$173,081	3	Closed
FMA	FY 03	\$221,100	2	Closed
FMA	FY 04	\$291,601	3	Closed
FMA	FY 05	\$143,250	2	Closed
FMA	FY 06	\$1,119,737	3	Closed
FMA	FY 07	\$634,335	5	Closed
FMA	FY 09	\$240,889	1	Closed
FMA	FY 10	\$65,369	1	Closed

Grant Type	Fiscal Year (FY)	Federal Funding	# of Projects	Status
FMA	FY 13	\$2,155,932	1	Closed
FMA	FY 15	\$675,410	1	Open
FMA	FY 16	\$360,501	2	Open
FMA	FY 17	\$ 168,478	1	Pending
Pre-Disaster Mitigation (PDM)				
PDM	FY 02	\$352,990	4	Closed
PDM	FY 03	\$222,497	4	Closed
PDM-C	FY 03	\$483,272	3	Closed
PDM-C DRU	FY 04	\$199,750	2	Closed
PDM-C	FY 05	\$4,346,890	13	Closed
PDM-C	FY 06	\$255,750	2	Closed
PDM-C	FY 07	\$162,000	1	Closed
PDM-C	FY 08	\$3,000,000	1	Closed
PDM-Earmark	FY 08	\$100,000	1	Closed
PDM-C	FY 09	\$516,421	4	Closed
PDM-Earmark	FY 09	\$100,000	1	Closed
PDM-C	FY 10	\$949,583	4	Closed
PDM-C	FY 11	\$335,764	4	Closed
PDM-C	FY 13	\$274,448	5	Closed
PDM-C	FY 14	\$907,381	7	Open
PDM-C	FY 15	\$119,206	4	Open
PDM-C	FY 16	\$623,910	3	Open
PDM-C	FY 17	\$469,855	2	Open
Severe Repetitive Loss (SRL) Program				
SRL	FY 08	\$653,166	1	Closed
SRL	FY 12	\$295,209	1	Closed
Community Development Block Grant (CDBG)				
CDBG	FY 97	\$3,977,889	12	Closed
CDBG	FY 98	\$1,494,878	2	Closed

HMGP, the Commonwealth typically receives applications for amounts far in excess of the amount of available funding. The Commonwealth selects and recommends for funding only the most cost-effective projects, as further described below.

Massachusetts has had a FEMA-approved Administrative Plan for HMGP since the federal program was authorized in 1988. Most recently updated in 2018, the plan details the process and criteria for prioritizing post-disaster mitigation funding of local mitigation projects.

Massachusetts uses similar criteria to prioritize pre-disaster grant applications (PDM and FMA). Chapter 10 provides more information on the eligibility, selection, and prioritization of local

assistance; and the State Grants Administrative Plan provides specific criteria for prioritizing hazard mitigation grants.

To facilitate the effective administration of these hazard mitigation grant programs, the SHMT provides technical assistance to state agencies, local jurisdictions, and Tribes for mitigation planning and project applications. The staff generally provide any assistance requested by sub-applicants to complete a successful application. More information on the technical assistance provided in support of these programs can be found in Chapter 10.

Since 1997, the SHMT has been providing grant funding for local mitigation plans, formerly flood mitigation plans, along with technical support and assistance. Today, the State's mitigation planner and other members of the SHMT help communities working on developing or updating hazard mitigation plans that may be funded through any of FEMA's mitigation grant programs. More details on the types of assistance provided can be found in Chapter 10.

In 1999, the SHMT developed a comprehensive database to track and monitor all open and completed hazard mitigation project and planning grants funded under the HMGP, FMA, PDM, and U.S. Department of Housing and Urban Development programs. This tool has allowed the Commonwealth to track and monitor project and plan timelines and completion dates. It allows the Commonwealth to track projects and plans by a specific grant program, by community, by project type, by project cost balances, and by other related data. For instance, the database allows tracking by project type, such as dam improvements, stormwater management, and elevation.

MITIGATION IN POST-DISASTER RECOVERY OPERATIONS

Hazard mitigation is an integral part of the Commonwealth's post-disaster recovery operations. Following Presidential Disaster Declarations, staff from the MEMA Mitigation and Recovery Unit co-locates with mitigation staff from FEMA at joint field offices, in addition to staff from other state agencies that may have an interest or jurisdiction in recovery operations. State and FEMA staff work to identify mitigation opportunities to be leveraged through the Individuals and Households Program (IHP) and the PA program, in addition to the subsequent HMGP program.

During post-disaster recovery operations, program staff members often provide mitigation information to disaster survivors. State and federal mitigation staff work together to identify public education needs or opportunities, and will use existing materials or develop new materials specific to the hazard and disaster event. PA program staff encourage potential project applicants to identify mitigation elements in repair and restoration projects, including through PA Section 406. Mitigation and PA program staff often jointly conduct applicant briefings to discuss mitigation opportunities through both PA and HMGP. State mitigation staff quickly disseminate letters of intent and information on the HMGP to potential applicants, and provide technical assistance to potential applicants on the grant application process. In addition, MEMA staff

attend semi-annual Recovery and Mitigation meetings to discuss important aspects of the programs, changes in priorities, and lessons learned from disaster events.

MEMA's fiscal department ensures that all disaster and non-disaster FEMA funding is obligated and spent in accordance with all State and local regulations. Having a singular contracting and fiscal approval process ensures proper fiscal management. With the recent reorganization at MEMA, the Disaster Recovery Manager now also oversees the Mitigation Unit, providing a seamless coordination with the implementation of FEMA PA, IHP, and mitigation programs.

6.3 Local Capabilities and Coordination

The local capability assessment is an opportunity for the State to examine the effectiveness of local and Tribal governments with mitigating risk. The State supports local and Tribal governments with mitigating risk by providing training, technical assistance, and funding. This section aims to provide a view of local capabilities across the state.

Massachusetts has 351 cities and towns and two American Indian Reservations, each of which develops and enforces local laws and policies related to hazard mitigation and climate adaptation. The General Laws of Massachusetts, Title VII, Cities, Towns and Districts outlines the powers and duties of cities and towns. Included in MGL Chapter 40 are powers related to public authority for construction of public works, growth and development policy committees, public safety mutual aid agreements, municipal waterways improvement and maintenance funds, prevention of forest fires, purchase of land conditions and limitations, protection of the water supply, and building permit restrictions.

In preparing local hazard mitigation plans, many local governments use the following four categories to assess their capabilities, strengths, and weaknesses: (1) planning and regulatory; (2) administrative and technical; (3) financial; and (4) education and outreach (see Table 6-5). For the purposes of the SHMCAP, the State has examined local capabilities in terms of these four categories. The NFIP is included in the planning and regulatory description for this local assessment. Currently, there is no requirement or standard for local or tribal governments to quantify their ability to adapt to climate change.

Table 6-5: Categories of Local Capability

Categories of Local Capability	Description
Planning and Regulatory	Includes capabilities based on the jurisdiction's implementation of ordinances, policies, local laws and State statutes, and plans and programs that relate to guiding and managing growth and development.
Administrative and Technical	Includes capabilities associated with the jurisdiction's staff and their skills and tools that can be used for mitigation planning and to implement specific mitigation actions.
Financial	Refers to the fiscal resources that a jurisdiction has access to or is eligible for to fund mitigation actions.
Education and Outreach	Refers to education and outreach programs and methods already in place that could be used to implement mitigation activities and communicate hazard-related information.

6.3.1 Planning and Regulatory

A city or town's planning and regulatory policies related to growth and development generally relate to land use, economic development, stormwater management, open space, and coastal zone management, among others. Depending on the city or town, they may have one or more of the following plans in place: Comprehensive or Master Plan, Open Space and Recreation Plan, Harbor Plan, Economic Development Plan, Stormwater Management Plan, Historic Preservation Plan, Coastal Zone Management Plan, and a Climate Change Adaptation Plan.

City or town planning departments and planning boards have the general authority to implement the laws related to planning and zoning, which can be used along with other regulatory incentives for hazard risk reduction purposes. For example, the Town of Hull created a freeboard incentive program to encourage the elevation of flood-prone buildings above currently predicted floodwater levels to address the risk from future coastal storm events and sea level rise. This program was developed through the support of the State's Office of Coastal Zone Management and the Town's Building Commissioner, and it enables the Town to credit up to \$500 for permit fees to builders who elevate their new or renovated structures 2 feet above the highest Federal or State requirement (Mass.gov, n.d.).

Planning boards typically oversee the preparation of comprehensive plans or master plans. They also often coordinate the hazard mitigation planning process and the implementation of hazard mitigation plans. These boards provide professional expertise in plan development, bylaw drafting, and grant application. A review of local hazard mitigation plans received by the State indicates that most local governments minimally include hazards and hazard mitigation in their local comprehensive or master plan. In recent years, communities have begun to develop coastal resilience and climate adaptation plans. For instance, in addition to its recently completed citywide master plan, the City of Boston prepared a comprehensive *Climate Ready Boston* report, and is working with the community and other partners to become more prepared for and resilient to the impacts of climate change.

A planning board is the primary local vehicle to ensure that new development incorporates federal and state best management practices (BMPs). Planning boards maintain floodplain bylaws and ordinances to address current floodplain issues, and update them to ensure compliance with state and federal regulations. Planning boards may propose, review, make recommendations or hold hearings on zoning ordinances and zoning changes. Regulations may be included in building codes, zoning bylaws, subdivision regulations, floodplain regulations, open space preservation, and wetlands regulations.

To encourage the adoption of BMPs by communities, state agency programs provide technical assistance and funding to municipalities. Examples include:

- The MVP Program, which provides municipalities with planning and action grants to implement adaptation and resiliency strategies.
- The Community Compact Program, in which communities agree to adopt and implement BMPs in a wide range of municipal services, and receive State assistance.
- DOER's Green Communities Program, which provides municipalities with funding and technical assistance for energy conservation and efficiency projects to reduce the energy demand of municipal facilities, and require communities to adopt ordinances and bylaws for renewable energy siting and the stretch building code.
- DEP's Municipal Recycling Program, which provides recycling equipment to those communities that reduce waste, such as by providing recycling access for all residents.

The City of Salem developed the *Ready for Tomorrow: The City of Salem Climate Change Vulnerability Assessment and Adaptation Plan*, which “focuses on steps the city can take to remain a livable city with a strong economy and tourism sector in the face of climate change impacts.” Key expected climate change impacts for Salem include extreme heat events, extreme precipitation events, sea level rise, and storm surge. The report addresses these impacts across the priority sectors of critical building infrastructure, water, energy, stormwater, transportation, and vulnerable populations.

Zoning regulations under MGL Chapter 40A give cities and towns the authority to adopt ordinances and bylaws to regulate the use of land, buildings, and structures. Planning boards may recommend land use regulations to protect public health, safety, and welfare, including measures for hazard mitigation and climate adaptation.

MGL 40R encourages “smart growth” to preserve open space, while increasing affordable housing. A planning board is able to adopt its own subdivision rules and regulations without an action at the town meeting. Cities and towns may not adopt higher standards than the 9th Edition of the State Building Code, which limits cities and towns from mitigating risk.

Cities and towns have local boards of health and municipal conservation commissions. Each provides planning and regulatory responsibilities, as well as administrative and technical responsibilities. Each local community determines the roles of its board of health; some may manage school health programs or assist with community-based health improvement planning, policy, and program development, or prevention activities.

The local Board of Health implements the State Environmental Code, including Title 5 relating to sewage disposal. Title 5 protects public health and mitigates losses due to adverse effects of improper sewage treatment in high hazard areas.

Local conservation commissions are required to review development with potential impacts on any type of river, stream, pond, or wetland. These commissions play a role in enforcing regulations that minimize flood impacts.

Conservation commissions have primary responsibility for implementing the Massachusetts Rivers Protection Act (MGL Chapter 258, 310 CMR 10.58) and the Massachusetts WPA (MGL Chapter 131, Section 40; 310 CMR 10.00). A conservation commission reviews, approves, or denies applications for any project in the regulatory 100-year floodplain, in the floodplain of a small water body not covered by a FEMA study, or within 100 feet of any wetland or 200 feet of any river or stream (except in the case of densely developed urban areas, where buffers may extend only 25 feet from a river or stream). The WPA, enacted in 1972, significantly increased the responsibilities of these commissions, and requires a more advanced level of expertise than commissioners had needed previously. The Massachusetts Association of Conservation Commissions has guidebooks and model bylaws for local governments to use when enforcing or strengthening their adherence to the WPA.

The Green Communities Act, Chapter 169, signed into law July 2, 2008, increases opportunities for energy efficiency and renewable generation, aligns the Massachusetts State Building Code with the International Energy Conservation Code, and provides new programs for municipal clean energy development. The Massachusetts Department of Energy Green Communities Division provides grants, technical assistance, and local support from Regional Coordinators to help municipalities reduce energy use and costs by implementing clean energy projects in municipal buildings, facilities, and schools.

Current Challenges / Opportunities

Many of the local governments that have submitted FEMA-approved hazard mitigation plans have the required government infrastructure for planning in place. However, many of the smaller locales often have staff serving in more than one role, and do not have the ability to author and adopt specific planning mechanisms such as economic development plans, stormwater plans, or disaster-specific plans. The majority of local hazard mitigation plans include a list of mitigation projects or activities for the community to pursue. For instance, the 2018 Town of Fairhaven

Hazard Mitigation Plan identifies 38 mitigation actions in order of priority. However, many communities struggle with the implementation of these proposed mitigation measures due to limited administrative or financial capabilities, as further described in this section.

The responsibility of local conservation commissions, public health boards, and planning boards to mitigate risk provides an opportunity for the State to support these boards with additional forms of education and technical assistance.

6.3.2 Administrative and Technical

The Administrative and Technical category examines a local government's ability to mitigate risk and adapt to climate change based on the capabilities of their staff and technical resources.

Each Massachusetts community is required to appoint an emergency manager (Chapter 639 of the Acts of 1950) who is primarily responsible for local preparedness, mitigation, response, and recovery, as well as mutual aid for natural and human-caused hazards. Emergency managers play a primary role in developing local comprehensive emergency management plans required by Massachusetts state law, as well as other plans required by MEMA and FEMA. The State frequently looks to the emergency management director as the key point of contact for MEMA- or FEMA-related business. This is a key link for outreach and involvement in mitigation planning and grants. The designation of an emergency management director is frequently a duty or responsibility assigned to an existing full-time employee of the community, rather than a separate full-time position.

Public works departments or water and sewer departments, which are primarily responsible for municipal drainage and stormwater management systems, take the lead in ensuring communities' compliance with the U.S. Environmental Protection Agency's Phase II Stormwater Regulations (National Pollutant Discharge Elimination System). Because stormwater is one of the major flood hazards in Massachusetts, ongoing maintenance and upgrading of local stormwater systems by public works departments is important to reducing flood risks. Public works staff are integral in implementing local hazard mitigation plans, especially in identifying and implementing local hazard mitigation projects related to infrastructure. Communities have varying degrees of capabilities, although many do maintain a significant level of engineering or public works capability through their own municipal staff, master services agreements, and/or other contractual arrangements with service providers.

The building inspector implements and enforces the Massachusetts State Building Code (specifically, Section 3107, "Flood Resistant Construction"), which incorporates NFIP construction standards. The State Building Code includes sections on wind, snow, structural loads, and seismic retrofitting; and ensures that NFIP standards and other mitigation standards are applied uniformly statewide. The building inspector also enforces local bylaws, especially to prevent floods. For instance, the building inspector is responsible for administering municipal

zoning ordinances, including those addressing floodplains. Building inspectors may find problems or violations of the State Building Code related to other hazards in addition to flooding. According to the review of local mitigation plans, the administration of the NFIP may fall to building inspectors, but also conservation commissions, public works staff, or local planning departments.

According to the review of local mitigation plans, the administration of the NFIP may fall to conservation commissions, building inspectors, or engineers.

When drafting hazard mitigation plans, most communities request a list of repetitive loss and severe repetitive loss properties from DCR. They are then able to include these structures, or their general vicinities, in local risk assessments; and identify flood mitigation actions to prevent future losses. Some communities identify and evaluate the need to acquire, elevate, or otherwise floodproof these structures; and many will encourage residents to retrofit structures that suffer repeated flood damages.

The Northeast States Emergency Consortium (NESEC) offers no-cost technical assistance to communities to understand and mitigate their risk from natural hazards; using programs such as HAZUS, they can model impacts of earthquakes, hurricanes, floods, and coastal storm surge. Agencies or organizations interested in obtaining NESEC's assistance with multi-hazard risk mapping can find an application online.

In addition, the regional planning agencies frequently support communities with hazard mitigation and climate adaptation planning, and many of them have extensive GIS capabilities. For example, the Metropolitan Area Planning Council (MAPC) has worked extensively with the 101 cities and towns in its jurisdiction to mitigate risk and adapt to climate change. MAPC has supported its communities with development of master plans, hazard mitigation plans, open space plans, and zoning and land use regulations.

Universities in Massachusetts are also partners in hazard mitigation and climate adaptation by providing technical expertise. For example, the University of Massachusetts has developed hazard mitigation plans for each of their campuses. They have also participated in the planning process for the communities in which they are located.

[Current Challenges / Opportunities](#)

Municipalities in Massachusetts have a fairly high degree of technical and administrative capability, with many local governments supported by experienced staff, citizen volunteers, and external service providers such as regional planning agencies, non-profit organizations, and private-sector businesses. However, it is also generally recognized that local communities may lack the overall capacity to more fully engage in resiliency planning and implementation, given competing priorities or activities, coupled with the fact that municipal staff are often tasked with

multiple local roles and responsibilities. The Commonwealth's MVP program is helping to address this challenge through the engagement and leveraging of additional community stakeholders, as well as the provision of technical assistance and other resources. More education is needed concerning the benefits of hazard mitigation and climate adaptation, but this is also something the MVP program is beginning to address through its planning and actions grants. In the future, there may be more opportunities for the Commonwealth to provide additional training to local building inspectors concerning new hazard mitigation measures, or increasing the local enforcement and encouragement of sound building practices.

6.3.3 Financial

Financial capabilities generally refer to the monetary resources available to local governments to help fund hazard mitigation or climate adaptation actions. The costs associated with implementing these actions may vary greatly, because some measures such as public outreach and communication could require little to no costs other than staff time and existing operating budgets. Other actions, such as open space preservation, infrastructure adaptation, or other capital projects could require funding from local, state, and/or federal funding sources.

Massachusetts municipalities have access to recurring sources of revenue through local property taxes, and some may have sources beyond that (such as local option taxes; e.g., meals tax, and utility-, special purpose-, or development-related fees). The municipal budget process is the means by which local government decides on how and where available municipal funds shall be spent. For many communities in Massachusetts, all appropriations for the upcoming fiscal year must be voted on and approved by town meeting in advance of setting a tax rate.

Although the annual budget focuses mainly on operating expenses, most communities are able to use these general municipal funds to support local hazard mitigation or climate adaptation efforts independently, or as the local match or cost-share often required for external grant funding. However, in most communities, there are also constant and competing demands for new or expanded services. The MVP program and local hazard mitigation grants attempt to address some of these funding challenges by providing direct funding to communities, and also guidance on how to better include these priorities in the overall municipal budgeting process.

In addition to general funds, many municipalities in Massachusetts have developed a capital improvement program to address major costs that have a multi-year impact on the finances of the municipality. A capital item is usually something that has a high acquisition cost, but also has an economic life of several years. Buildings, fire engines, and dump trucks are common examples of capital items—as are larger infrastructure developments or improvements such as schools or roadways. Structural hazard mitigation or climate adaptation projects such as dams, seawalls, stormwater systems, or other flood protection measures are also often included as capital items.

Most capital improvement programs plan for 5 or 6 years into the future, and schedule the acquisition of capital items sequentially to be least disruptive to any given annual budget.

For large capital expenses, many communities will seek to leverage external grant funding and/or borrow money through debt financing to pay over multiple years. Municipalities wishing to borrow money for extended periods of time issue bonds to investors, which are repaid over time with interest. State laws regulate the purposes for which municipalities may borrow, and how long such loans may last. Some cities and towns in Massachusetts typically use debt service for only a small percentage of their budgeting process, opting to maintain a structurally balanced budget, where operating revenues meet or exceed operating expenses.

State and federal grants, private funding, and other community resources are also available to communities for specific types of hazard mitigation or climate adaptation projects, depending on various eligibility requirements. The most common sources of state and federal grant funding for these projects in Massachusetts are identified in Appendix C (“Financial” category in Table C-1) and Appendix D (*Section 4: Funding Sources for Hazard Mitigation and Climate Adaptation Actions*). These include, but are not limited to, the Commonwealth’s MVP program administered by EOEEA, Community Coastal Resilience Grant Program administered by CZM, and FEMA’s HMA programs administered by MEMA.

In addition to coordination with state agencies, local communities in Massachusetts also routinely work cooperatively with their regional planning agencies, neighboring municipalities, or other partners on the pursuit of external funding. This often includes the application for and use of financial sources that can be leveraged for the implementation of projects or activities that provide the benefit of hazard risk reduction on a regional or multi-jurisdictional scale.

Current Challenges / Opportunities

Although most communities in Massachusetts have participated—and continue to participate—in local resiliency planning efforts, many still rely heavily on external funding sources for the implementation of hazard mitigation or climate adaptation projects. Those with the capacity to develop and submit competitive applications for grant programs can be successful, but there are many municipalities with limited numbers of staff or other resources to compete for these grants that require additional support. The Commonwealth continues to work to increase awareness and accessibility of guidance, grant funding, and technical assistance to local communities where it is needed most.

6.3.4 Education and Outreach

The Education and Outreach category looks to programs in local communities related to hazard mitigation, climate adaptation, and emergency preparedness. These programs may be citizen groups focused on sustainability or emergency preparedness, or they may be ongoing public education campaigns or school-related safety programs. They also may include public participation in State-funded projects such as the MVP program. For example, the Town of Hingham announced in May 2018 that they are preparing for climate change by entering the MVP program. They previously had developed a hazard mitigation plan, and have a Climate Change Vulnerability, Risk Assessment and Adaptation Study from 2015 (Wicked Local Hingham, 2018). To date, 71 communities have participated in the MVP program, as identified earlier in this chapter.

Many communities in Massachusetts have Community Emergency Response Teams (CERT). The CERT “program educates volunteers about disaster preparedness for the hazards that may impact their area and trains them in basic disaster response skills, such as fire safety, light search and rescue, team organization, and disaster medical operations. CERT offers a consistent, nationwide approach to volunteer training and organization that professional responders can rely on during disaster situations, which allows them to focus on more complex tasks. Through CERT, the capabilities to prepare for, respond to and recover from disasters is built and enhanced” (Ready.gov, n.d.).

Two national programs that offer local communities the opportunity to prepare and mitigate risk are the StormReady program and the Firewise USA program. The StormReady program operates as part of the Weather-Ready Nation program of the National Weather Service. The program is about preparing communities for the increasing vulnerability to extreme weather and water events. To date, 15 cities and towns in Massachusetts have the StormReady designation, including the City of Boston (City of Boston, 2016b). In addition, five universities have this designation; Boston College, Boston University, Harvard University, Tufts University, and the University of Massachusetts at Amherst.

Cuttyhunk Island and Hopps Farm Road Association are the two communities in Massachusetts that have received the Firewise USA designation. Firewise USA is a program of the National Fire Protection Association. The program teaches communities how to adapt to living with wildfire, and encourages neighbors to work together and take action now to prevent losses. Cuttyhunk Island, located in Gosnold, Massachusetts, is home to 60 people. Cuttyhunk Island has been a recognized Firewise USA site since 2014. To date, they have invested more than \$17,700 towards reducing their wildfire risk. Hopps Farm Road Association, located in West Tisbury, Massachusetts, is home to 32 people. Hopps Farm Road Association has been a recognized Firewise USA site since 2010. To date, they have invested more than \$11,269 towards reducing their wildfire risk (NFPA, n.d.).

Current Challenges / Opportunities

The opportunity for the State to continue to support and increase the availability of outreach and education program will benefit local communities. These programs do not have to be tailored to a specific jurisdiction, which gives the State a greater opportunity to provide regional or even statewide educational opportunities. Current programs like MVP and CZM's coastal resiliency grants that provide funding, technical support, educational materials, supplemental webinars, outreach, and education are good examples of state programs that go beyond grant funding alone to boost overall municipal capacity.

6.4 Conclusions

The Commonwealth of Massachusetts has a high degree of capability to address the risks it faces from natural hazards and climate change. The Commonwealth has a long history of demonstrating its commitment to advancing risk reduction and resilience through a variety of policies, programs, and other capabilities; and in recent years, has bolstered this commitment even more through a series of new and innovative State-led initiatives. The Commonwealth is making significant investments in scientific research and data collection, such as the development of downscaled climate projections, as well as increased support and capacity building at the state and local level through technical assistance, training, funding, and other activities to increase statewide resilience. The development of this integrated SHMCAP exemplifies these advances in State capabilities and resources to lead by example on climate change adaptation and natural hazard mitigation.

The Commonwealth also maintains a strong institutional capacity to adapt to changing future conditions related to natural hazards and climate change impacts, both in the short- and long-term. The results of the state agency self-assessments described in Section 6.2.3 suggest that the agencies are well-positioned to adjust or modify their operations, policies, or other functions to protect their key assets, accomplish their missions, and deliver their services or programs in the face of increasing threats from natural hazards and climate change. For some state agencies, these threats are significant; but for others, they do not pose any major risks or vulnerabilities of concern. Regardless, the SHMCAP provides a framework for State government to continue to evaluate risk, assess vulnerability, and work across all agencies to adapt and maintain their resiliency to changing natural hazards and the impacts of climate change.

To ensure continued access to information and provide communities with the resources needed to improve their own resilience, the State will continue to invest in providing the best available science and data on expected climate changes, working with communities to track information on local vulnerabilities and resiliency strategies through the MVP program, and providing education and outreach related to grant programs and technical assistance available from the State.

The Commonwealth will also continue seeking ways to leverage emerging capabilities and opportunities to facilitate actionable hazard mitigation and climate adaptation strategies. Most notably, this includes implementation of the \$2.4 billion Environmental Bond Bill signed into law in August 2018, which dedicates over \$500 million to climate change resiliency efforts, and stipulates that such investments must be consistent with the SHMCAP. This extraordinary commitment promotes climate change adaptation and the importance of investing now for the future resilience of the Commonwealth.

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7. Hazard Mitigation and Climate Adaptation Strategy

This hazard mitigation and climate adaptation strategy is a culmination of the previous work in the planning process, including significant stakeholder engagement, as well as specific findings from the risk and vulnerability assessments and the state capability and adaptive capacity analysis.

The plan's mission statement and goals represent the vision of the Commonwealth of Massachusetts for a future in which vulnerabilities from natural hazards and climate change are reduced or eliminated through specific hazard mitigation and climate adaptation actions. They also reflect the needs identified in the risk and vulnerability assessments and the state capability and adaptive capacity analysis. For instance, an obstacle identified in the capability and adaptive capacity analysis related directly to the challenge of institutionalizing hazard and climate resilience within state agencies that will require more clear emphasis, direction, and operational

SHMCAP Mission Statement

Reduce the statewide loss of life, and protect natural resources, property, infrastructure, public health, and the economy from natural hazards and climate change through the development of a comprehensive and integrated hazard mitigation and climate adaptation program.

commitments from each Cabinet Secretary. Institutional change often encounters cultural resistance, and will likely need to be incremental, and sustained over the long term. This need is directly reflected in the first goal statement, which emphasizes enhancing resiliency by integrating programs and building institutional capacity.

7.1 Mission Statement

The mission statement developed with stakeholder input outlines an ambitious vision for mitigating risk and adapting to climate change across the Commonwealth:

Reduce the statewide loss of life, and protect natural resources, property, infrastructure, public health and the economy from natural hazards and climate change impacts through the development of a comprehensive and integrated hazard mitigation and climate adaptation program.

7.2 Goals

Five goals were developed to provide a framework to implement the vision of the Commonwealth for mitigating risk and adapting to climate change. The bold text in the following goal statements are the key ideas that are essential for addressing the vulnerabilities identified in the risk assessment.

1. Enhance the Commonwealth's resiliency to natural hazards and climate change by **integrating programs and building institutional capacity**.
2. Reduce the impacts of natural hazards and climate change with forward-looking **policies, plans, and regulations**.
3. Understand our **vulnerabilities and risks** and develop immediate and long-term risk reduction strategies for current and future conditions using the best available science.
4. Increase the resilience of State and local government, people, natural systems, the built environment, and the economy by investing in **performance-based solutions**.
5. Support implementation of this plan through increased **education, awareness, and incentives** for action for state agencies, local governments, private industry, non-profits, and the general public.

The process of developing the goal statements, including an analysis of the change in priorities, is fully outlined in *Chapter 9: Planning Process* and in Appendix D.

Although not specifically referenced in the goal statements, the need to address repetitive loss (RL) and severe repetitive loss (SRL) properties, as identified by the Federal Emergency

Management Agency (FEMA), is recognized by the Commonwealth in our specific actions and in our funding prioritization criteria for Hazard Mitigation Assistance (HMA) grants.

7.3 Importance of Nature-Based Solutions in Hazard Mitigation and Climate Adaption

Nature-based solutions (NBS) are defined as:

The conservation, enhancement, and restoration of nature to reduce emissions, adaptation, and enhance resiliency. These types of solutions use natural systems, mimic natural processes, or work in tandem with traditional engineering approaches to address natural hazards like flooding, erosion, drought, and heat islands.

Examples of NBS include restoring wetlands and floodplains to reduce flooding, planting trees to reduce the heat island effect, and conserving and managing agricultural soils to sequester carbon. NBS projects like open space conservation have been shown to reduce storm surge damages in hurricanes, provide habitat services, support a restoration economy, improve water quality, and improve housing values.

Nature-based solutions offer numerous co-benefits, including minimizing costs, improving water quality, and enhancing quality of life. Listed below are some co-benefits that should be taken into account when considering the cost and benefits of NBS:

- **Flooding:** Floodplains provide flood protection and reduce infrastructure damage.
- **Public Health:** Managing stormwater from precipitation events and reducing retention ponds reduces the creation of mosquito habitat and vector-borne illnesses.
- **Air Quality and Public Health:** Trees reduce the urban heat island effect, reducing smog creation and resulting asthma occurrences, as well as reducing nitrogen dioxide and particulate matter.
- **Water Quality:** Streamside vegetation filters pollutants, reduces erosion, and reduces velocity in high flow events.
- **Water Quantity:** Forests and wetlands store water during high flow events, improve water quality, and recharge groundwater.
- **Recreation:** Clean, flowing waters support recreation, including boating, fishing, and swimming; while open space provides areas for hiking and biking.
- **Quality of Life:** Open space and street trees create a more enjoyable outdoor environment, benefiting community connection, health, and the economy in downtowns and commercial areas. Green spaces have also been shown to reduce stress and help with healing.

- **Property Value:** An increase in natural features can increase property values and the tax base; for example, healthy, mature trees add an average of 10 to 30 percent to a property's value.
- **Carbon Sequestration:** Massachusetts has carbon-rich natural resources—forests, wetlands, salt marshes, and soils—that, if protected and restored, can retain carbon stocks and enhance the natural cycles to absorb carbon. Massachusetts forests currently absorb more than 15 percent of the carbon generated in Massachusetts every year.
- **Energy Usage and Carbon Emissions:** Trees planted in urban environments can reduce heating and cooling needs in buildings and lead to more efficient use of energy resources, therefore helping to reduce carbon emissions.

These co-benefits should also be considered in decision-making. When making funding and policy decisions, NBS should receive strong consideration over “hard” infrastructure solutions, where feasible. *Executive Order 569 Establishing an Integrated Climate Change Strategy for the Commonwealth* calls for Secretariats to employ NBS (Section 3.1):

(v) policies and strategies for ensuring that adaptation and resiliency efforts complement efforts to reduce greenhouse gas emissions and contribute towards the Commonwealth meeting the statewide emission limits established pursuant to the GWSA;

(vi) strategies that conserve and sustainably employ the natural resources of the Commonwealth to enhance climate adaptation, build resilience and mitigate climate change;

The prioritization framework used to rank the action items (as outlined in Appendix D) includes nature-based approaches specifically designed to conserve and/or employ natural resources as the highest-priority ranking.

In addition, for the implementation of certain State grant or State-administered grant programs, emphasis may be placed on projects that outline a nature-based solution, such as the Executive Office of Energy and Environmental Affairs' (EOEEA's) Municipal Vulnerability Preparedness (MVP) Action Grants, FEMA's HMA grants, the Office of Coastal Zone Management's (CZM) Coastal Resiliency Grants, and others.

7.4 Hazard Mitigation and Climate Adaptation Actions

Identifying hazard mitigation and climate adaptation actions for this plan began when the planning process was initiated. Each opportunity for stakeholder involvement provided a chance for stakeholders to recommend their ideas for how the State could address risks and vulnerabilities from natural hazards and climate change. For the purposes of this plan, hazard mitigation was defined as:

*The effort to reduce loss of life and property by **lessening the impact of disasters**. In order for mitigation to be effective we need to take action now—before the next disaster—to reduce human and financial consequences later (analyzing risk, reducing risk, and insuring against risk).*

Climate adaptation was defined as:

Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. (IPCC, 2007)

Resilience was defined as:

The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.

This plan defines a hazard mitigation or climate adaptation action as a specific **action, project, activity, or process** taken to reduce or eliminate long-term risk to people, property, and natural systems from climate change and/or natural hazards and their impacts. This section provides an initial list of actions developed by the Executive Offices and agencies of the Commonwealth as part of the planning process. These were developed through a comprehensive stakeholder engagement process with final review and development by the Commonwealth's state agencies, Executive Office Climate Change Coordinators, and Cabinet Secretaries. The actions are also informed by the Massachusetts Emergency Management Agency's (MEMA's) review and working knowledge of the actions and strategies identified in local hazard mitigation plans. In addition, the actions from the 2013 State Hazard Mitigation Plan (SHMP) were reviewed at the start of the planning process. See Appendix D for a complete review and summary of the status of these actions.

Many agency actions relate directly to the vulnerabilities identified in the state agency vulnerability assessment reports that were completed as a part of this plan (see Chapter 9 for additional details). Eight Executive Offices and 21 state agencies contributed actions for inclusion in the plan.

The state capability and adaptive capacity analysis led to recommendations for mitigating risk by identifying challenges and opportunities at the state and local level. These conclusions were shared by the Project Management Team (PMT) with stakeholders when developing action ideas.

Typically, hazard mitigation actions may be developed to mitigate risk identified by a specific hazard. As detailed in

Actions

A hazard mitigation or climate adaptation action is a specific **action, project, activity, or process** taken to reduce or eliminate long-term risk to people, property, and natural systems from climate change and/or natural hazards and their impacts.

Chapter 3: Introduction to Risk Assessment, a categorization of traditional natural hazards in the context of climate change was used to demonstrate the connections between traditional natural hazard analysis and climate change projections. All actions considered in the plan address at least one of the primary climate change interactions, and associated climate change impacts identified in *Chapter 4: Risk Assessment*. This directly connects the hazard mitigation and climate adaptation strategy to the risk assessment conducted for the plan. The range of actions is broad, and covers topics such as protecting assets, developing additional studies, supporting local governments, and meeting the needs of vulnerable populations. Below are several examples of actions identified by state agencies to mitigate risks identified in the state capability and adaptive capacity analysis:

- The Department of Public Health (DPH) developed an action titled *State Employee Education on Climate Change and Hazards*.
- The Department of Conservation and Recreation (DCR) developed an action to Understand DCR Asset Vulnerability. One of the financial recommendations is to “develop specific procedures to encourage and maximize the use of the FEMA’s Public Assistance (PA) 406 Mitigation program funding following future Presidentially Declared Disasters. PA 406 is a historically underused source of discretionary funding for building resilience into the repair, replacement, or restoration of publicly owned facilities damaged by a hazard event.”
- MEMA has an action titled *Enhance the effectiveness of 406 funding by working to further integrate mitigation into the FEMA Public Assistance Program*. This action was also included in the 2013 SHMP, and progress was made by MEMA’s mitigation and recovery units working collaboratively to identify areas where 406 funding could be leveraged to maximize tax dollars.

Every challenge identified in the state capability and adaptive capacity analysis does not have a representative action; however, many do, as shown above.

All of the actions are designed to achieve goals established by the Commonwealth for mitigating risk and adapting to climate change. Table 7-1 outlines the comprehensive range of actions by goal. Many actions address more than one goal.

Table 7-1: Number of Actions for Each Goal Statement

Total Number of Actions	Goal 1: Integrating Programs and Building Institutional Capacity	Goal 2: Policies, Plans, and Regulations	Goal 3: Vulnerabilities and Risks	Goal 4: Performance-Based Solutions	Goal 5: Education, Awareness, and Incentives
108	68	69	82	56	39

The State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) actions are maintained in an “action tracker” spreadsheet that can be sorted in multiple ways, and viewed and maintained by the State. Table 7-2 identifies the columns listed in the action tracker spreadsheet. The actions are also included in tables in Appendix D.

Table 7-2: Action Tracker Sheet Column Descriptions

Columns	Descriptions
Global Actions	Represent actions that have cross-cutting impacts on risk reduction across the administration.
Completion Time Frame	These time frame categories are a guide to implementation of this action plan: <ul style="list-style-type: none"> • Less than 3 years • 3 to 5 years • Greater than 5 years
Action Title	This is a short sentence describing the action. It typically includes an action word (engage, perform, develop) to facilitate measurable outcomes.
Action Description	Brief description about why the action is relevant and what problem it addresses. It may also include how it complements other actions or an agency mission.
Executive Office	Organizing by Executive Office facilitates leadership by the Climate Change Coordinators.
Lead Agency	The responsible state agency.
Partner(s)	State agencies, programs, or nonprofit organizations that may participate in the action.
Agency Priority Score	State agencies self-assigned a priority score for their actions relative to their other identified agency actions using a tool developed by the PMT.
Possible Funding Source(s)	Any pre-identified or anticipated funding source options. Sources may include combinations of the below: <ul style="list-style-type: none"> • State Funding – Operating Budget • State Funding – Capital Budget • Federal Funding • Departmental Revenue or Other Sources
SHMCAP Goal(s)	Each action is connected to one or more plan goal statements.
Primary Climate Change Interaction(s)	This identifies the primary climate interactions and associated impacts that an action is proposed to address (these categories are used in the climate change and natural hazard taxonomy that has been developed for the plan). All appropriate boxes are checked.

The following sections present an initial list of actions identified during the development of this plan. Section 7.4.1 includes “global” actions that are intended to reduce risk across State government and the Commonwealth. The global actions are organized by the following completion time frame categories: less than 3 years, 3 to 5 years, and greater than 5 years. Actions within each completion time frame category are presented by Executive Office in alphabetical order, followed by Lead Agency in each Executive Office in alphabetical order. Section 7.4.2 includes the specific actions of the Executive Office and Lead Agency, which are organized in the same manner as the global actions. Detail from the action tracker spreadsheet is provided for each action.

Actions were prioritized by each agency using a prioritization tool developed by the consultant team and PMT using agreed-on metrics. The prioritization tool (Appendix D) allowed agencies to rank actions against other agency-specific actions based on 21 different factors. Prioritization criteria included considerations of cost-effectiveness, ability to meet multiple goals, environmental soundness, avoided losses, and technical feasibility, in addition to many other factors the PMT agreed were important in evaluating and prioritizing actions to be included in the SHMCAP. In total, the prioritization system included 21 different parameters under three categories: Relevancy, Resiliency, and Cost & Time. Scores from the tool resulted in rankings of Very High, High, Medium, or Low Priority (Appendix D). Importantly, priority scores have not been evaluated collectively across Secretariats; these scores simply reflect a within-agency, initial evaluation.

7.4.1 Global Actions

Completion Time Frame	EOTSS: Migrate CommVault to the cloud.	
Less than 3 years	Action Description:	Migrate CommVault system to the cloud, removing the need to maintain and protect on premise servers for this system.
	Executive Office:	Executive Office of Technology Services and Security
	Lead Agency:	Executive Office of Technology Services and Security (EOTSS)
	Partner(s):	
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	EOTSS: Migrate critical operational systems to the cloud (MITC); move critical communications infrastructure to Markley.	
Less than 3 years	Action Description:	Migrate Commonwealth servers to cloud hosting to the fullest extent possible (handful of exceptions.) Move critical communications infrastructure to Markley (secure, local location). These migrations away from on premise hosting to cloud hosting reduce the risk of disruption due to sea level rise and extreme weather events.
	Executive Office:	Executive Office of Technology Services and Security
	Lead Agency:	Executive Office of Technology Services and Security (EOTSS)
	Partner(s):	Administration-wide
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	EOTSS: Migrate email to the cloud.	
Less than 3 years	Action Description:	Migrate legacy Microsoft Exchange systems to cloud-based Office 365 services.
	Executive Office:	Executive Office of Technology Services and Security
	Lead Agency:	Executive Office of Technology Services and Security (EOTSS)
	Partner(s):	Administration-wide
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	A&F: Budgeting, coordinating administrative functions, and planning.	
3-5 years	Action Description:	Incorporate climate change vulnerability, resiliency, and adaptation standards into budgeting, coordination, and capital planning.
	Executive Office:	Executive Office of Administration and Finance
	Lead Agency:	Executive Office of Administration and Finance (A&F)
	Partner(s):	Administration-wide
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	HRD: Incorporate hazard and climate change vulnerability into personnel and workplace policies, training, and guidance as appropriate.	
3-5 years	Action Description:	Executive Branch employees are subject to policies and guidance from HRD regarding weather and other hazard-related emergencies, workplace rules, and other information. HRD will evaluate current policies and guidance and will consider updates and other training opportunities about personnel readiness, workplace climate change vulnerabilities, hazard mitigation, and climate adaptation techniques, etc.
	Executive Office:	Executive Office of Administration and Finance
	Lead Agency:	Human Resources Division (HRD)
	Partner(s):	Administration-wide
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	DPU: Power system planning that incorporates climate change risk.	
3-5 years	Action Description:	Assess how power system planning may incorporate existing climate models to assess risk and deploy cost-effective infrastructure to reduce outages, repair, and replacement. Utilities could also identify key data gaps for system planning and identify that to DPU/EOEEA to coordinate with ongoing research.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Public Utilities (DPU)
	Partner(s):	DOER
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	EOEEA: Create and deploy a SHMCAP project database.	
3-5 years	Action Description:	The primary system for monitoring and evaluating plan implementation is through the SHMCAP Action Tracker, a customized tracking spreadsheet tool for reporting progress status updates on individual actions. The Action Tracker will be deployed as a consistent approach for updating and reporting in real-time and will be actively maintained on a restricted, password-protected file sharing site to be established by EOEEA. It will serve as the primary mechanism for the status updates on each action and will establish metrics to measure effectiveness.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	MEMA
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	EOEEA: In consultation with DCAMM, MassDOT, and EOHED develop climate change design standards.	
3-5 years	Action Description:	EOEEA will work with Climate Change Coordinators and agency staff across Secretariats to review and update design standards using Massachusetts climate change projections that will support best management and construction practices for new and improved agency structures, roads, parkways, parking lots, housing, and other facilities.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	DCAMM, A&F, EOHED
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operational and Capital Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	EOEEA: Maintain and enhance climate change projections and specific climate change data sets to support different groups of end users.	
3-5 years	Action Description:	EOEEA has partnered with the Northeast Climate Adaptation Science Center at University of Massachusetts Amherst to obtain climate change projections for temperature, precipitation, sea level rise, and inland hydrology through the end of the century. Now these datasets needs to be maintained, updated, and enhanced through additional studies, stakeholder engagement to determine key data needs, and ongoing incorporation of advancements in the field of climate change science. Updated climate change data will be maintained and made available to the public on the resilient MA website.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	Northeast Climate Adaption Science Center
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	OPSI: Review the state building code to assess feasibility of incorporating hazard mitigation and resilience.	
3-5 years	Action Description:	OPSI will review the state building code to assess feasibility of incorporating hazard mitigation and resilience into standards.
	Executive Office:	Executive Office of Housing and Economic Development
	Lead Agency:	Office of Public Safety and Inspections (OPSI)
	Partner(s):	BBRS
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	EOTSS: Migrate HRCMS/MMARS to the cloud.	
3-5 years	Action Description:	Migrate the EOTSS Human Resources Compensation Management System and Massachusetts Management Accounting and Reporting System to the cloud, removing the need to maintain and protect on premise servers for these systems.
	Executive Office:	Executive Office of Technology Services and Security
	Lead Agency:	Executive Office of Technology Services and Security (EOTSS)
	Partner(s):	Comptroller, A&F, HRD
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	DCAMM: Incorporate hazard and climate change vulnerability into capital planning, master planning, and facilities management functions.	
Greater than 5 years	Action Description:	DCAMM will incorporate climate change vulnerability, resilience, and adaptation standards into capital planning for new projects; refer to agency climate change vulnerability assessments in master planning exercises; and integrate climate change vulnerability assessments into a facilities management system.
	Executive Office:	Executive Office of Administration and Finance
	Lead Agency:	Division of Capital Asset Management and Maintenance (DCAMM)
	Partner(s):	EOHHS
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	EOEEA: Review, evaluate, and implement revisions as needed to environmental and energy policies, regulations, and plans.	
Greater than 5 years	Action Description:	Review, evaluate, conduct outreach with stakeholders, and implement revisions that may be needed to key state environmental and energy policies, regulations and plans maintained by EOEEA and its agencies. This action has cross-cutting impact on risk reduction across the administration.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	A&F
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	EOEEA: Utilize available climate change projections and risk assessment data to assess vulnerabilities of all EOEEA properties. Support efforts across the administration to assess facilities held by other Executive Offices.	
Greater than 5 years	Action Description:	Climate projection information and information on site specific vulnerabilities, agency adaptive capacity, populations served, and other information will be utilized to assess climate change vulnerability at all of EOEEA's land holdings, facilities, parkways, fisheries, dams, and other properties. This vulnerability assessment would result in scores and information for each asset, as well as a system of GIS layers depicting exposure and sensitivity and final vulnerability scores to help EOEEA to understand the risks present at each site.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	All EOEEA agencies, DCAMM
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	EOPSS: Incorporate climate change resilience into business continuity planning for state government.	
Greater than 5 years	Action Description:	EOPSS will work with A&F and EOTSS to update business continuity planning and to incorporate climate change hazards into plans and procedures across state government. This action has cross-cutting impact on risk reduction across the administration.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Executive Office of Public Safety and Security (EOPSS)
	Partner(s):	A&F, EOTSS, MEMA
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MEMA: Update the State Hazard Mitigation and Climate Adaptation Plan and submit for FEMA review and approval every 5 years.	
Greater than 5 years	Action Description:	The Commonwealth expanded its commitment to the mitigation program by continually updating the plan and by incorporating climate adaptation into the 2018 update. Incorporating climate change into the plan, creates a more practical and useful tool for the Commonwealth. The updated plan is referred to as the 2018 State Hazard Mitigation and Climate Adaptation Plan (SHMCAP). A project management team was formed and a contractor was hired to assist. This action has cross-cutting impact on risk reduction across the administration.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	EOEEA and RMAAT
	Agency Priority Score:	Very High
	Possible Funding Source(s):	Federal Funding - FEMA HMA Grants
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	MassDOT: Expand and improve the Boston Harbor Flood Risk Model to create the Massachusetts Coastal Flood Risk Model.	
Greater than 5 years	Action Description:	Create improved sea level rise and storm surge scenarios for the present tidal epoch, 2030, 2050, 2070/2100; create northern and southern model grids; consider future shoreline changes; correct CZM/MassGIS shoreline mapping; assess the storm surge vulnerability of the coastal transportation network; and make data available to state agencies, coastal communities, and other interested stakeholders.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	EOEEA, Coastal Zone Management (CZM), University of Massachusetts Boston
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

7.4.2 Executive Office and Agency Specific Actions

Completion Time Frame	DCR: Track and assess asset vulnerability by adding climate change/resiliency categories as part of the Asset Management Modernization Project.	
Less than 3 years	Action Description:	DCR has been working with DCAMM to create a comprehensive database of property information. To date, vulnerabilities to climate change and natural hazards have not been incorporated into the data. DCR will work to include climate change vulnerabilities and resiliency actions this for a more robust understanding of DCR properties and their vulnerabilities.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Conservation and Recreation (DCR)
	Partner(s):	DCAMM
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	DCR: Update the State Forest Action Plan to enhance climate change mitigation and adaptation strategies.	
Less than 3 years	Action Description:	Update State Forest Action Plan to incorporate strategies to deal with future conditions presented by a warming planet. These concepts will be incorporated into the 2020 update of the Plan.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Conservation and Recreation (DCR)
	Partner(s):	MassWildlife
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures
Completion Time Frame	DEP: Vulnerability assessment of hazardous waste sites.	
Less than 3 years	Action Description:	Conduct a vulnerability assessment of thousands of waste sites in state. Prioritize high concern based on water resources and indoor protections. Pilot studies of at risk sites for adaptations/mitigation measures. Provide assessment results to MVP Planning.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	OTA
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	DER: Update and share a dam removal decision support tool that directly incorporates new climate change projections, climate adaptation benefits and helps municipalities and others prioritize dams for removal.	
Less than 3 years	Action Description:	Municipalities, federal, state, and local agencies and non-profit organizations want to remove outdated dams to reduce risk, improve public safety, and restore habitat. With more than 3,000 dams and limited resources, it is important to select the projects that will yield the greatest environmental and risk reduction benefits. DER has developed and published a web-based tool that evaluates dams for removal based on the expected ecological benefit. DER will update and publish the web-based tool to include risk reduction and climate adaptation benefits.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	Office of Dam Safety; MassGIS. Users of the tools will include municipalities, NGOs, state agencies, and others.
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures, Extreme Weather
Completion Time Frame	EOEEA: Develop and implement a communications strategy to build state agency, municipal and public awareness of climate change resiliency issues and adaptation strategies.	
Less than 3 years	Action Description:	Working with MEMA, EOPSS and other Climate Change Coordinators, EOEEA will develop a communications strategy for the purpose of keeping state agency staff, municipal staff and volunteers, and residents informed of the risks, vulnerabilities and solutions as the impacts of climate change continue. EOEEA will use assets such as state parks to offer educational opportunities for residents across the Commonwealth and the resilient MA Climate Change Clearinghouse.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	MEMA, EOPSS, Climate Change Coordinators
	Agency Priority Score:	Low
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	EOEEA: Reassess and develop a climate change resiliency framework and criteria for all EOEEA agency land acquisition and grant funding for land acquisition to support natural resource conservation, wildlife, human health and public safety.	
Less than 3 years	Action Description:	While EOEEA has incorporated resiliency criteria into its land acquisition grant programs and agencies address it in their agency prioritization schemes, the overall natural land protection program should be reviewed, assessed and reprioritized to ensure protection of multiple resiliency goals including protecting critical ecosystem services, ensuring connectivity of wildlife, protecting climate-sensitive areas, avoiding repeat loss of infrastructure and property, increasing human health and safety, and preserving habitats of climate-sensitive species.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	All EOEEA agencies will be involved. Support from NGO's may be sought.
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	DPH: Provide support and direct care to vulnerable populations susceptible to climate change impacts.	
Less than 3 years	Action Description:	<p>Provide data with a social determinants framework to inform the Municipal Vulnerability Preparedness (MVP) Program and DPH preparedness plans. Identify adaptation and resiliency strategies that address health and racial equity. Strengthen the Environmental Public Health Tracking network and the Climate and Health Program in the DPH. Using DPH's current cross-state databases, perform data collection and needs assessment for particularly vulnerable populations (such as the homeless, the elderly, and people with mental illness or substance use disorders) and develop and implement adaptation and resiliency plans for these vulnerable populations.</p> <ul style="list-style-type: none"> • Provide data with a social determinants framework to inform the Municipal Vulnerability Preparedness (MVP) Program and DPH preparedness plans. • Identify adaptation and resiliency strategies that address health and racial equity. • Strengthen the Environmental Public Health Tracking network and the Climate and Health Program in the DPH. • Using DPH's current cross-state databases, perform data collection and needs assessment for particularly vulnerable populations (such as the homeless, the elderly, and people with mental illness or substance use disorders) and develop and implement adaptation and resiliency plans for these vulnerable populations.
	Executive Office:	Executive Office of Health and Human Services
	Lead Agency:	Department of Public Health (DPH)
	Partner(s):	EOEEA
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	EOHED: Incorporate climate change resilience/adaptation standards into grant programs including MassWorks.	
Less than 3 years	Action Description:	EOHED will incorporate climate change resilience and adaptation criteria into major grant programs to enhance vulnerability of resulting assets to climate hazards and risks, to increase the resilience of the MA economy to climate risks, and to assist local governments in making local infrastructure more resilient. EOHED will begin with MassWorks program and use results to model best practices for other programs.
	Executive Office:	Executive Office of Housing and Economic Development
	Lead Agency:	Executive Office of Housing and Economic Development (EOHED)
	Partner(s):	EOEEA
	Agency Priority Score:	Very High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	DLS: Review and consider updates to MASSsafetyWorks! resources given increased expectations of extreme weather events.	
Less than 3 years	Action Description:	DLS provides informational safety flyers for employers and employees with suggestions on how to improve workplace safety. DLS will review these to evaluate whether they should be updated in light of expectations of increased severity and frequency of extreme weather events.
	Executive Office:	Executive Office of Labor
	Lead Agency:	Department of Labor Standards (DLS)
	Partner(s):	
	Agency Priority Score:	Low
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 3, 5
	Primary Climate Change Interaction(s):	Rising Temperatures, Extreme Weather

Completion Time Frame	MEMA: Apply for available federal HMA funding to implement and update the completed and approved multi-jurisdictional and local hazard mitigation plans.	
Less than 3 years	Action Description:	Progress made / continual. At present, there are 78 plans in development. From 2013-2017 the SHMT received 36 applications for planning grants to develop and / or update local hazard mitigation plans. Beginning with PDM 16, the Commonwealth began managing the PDM planning applications so that funding could be provided to more communities. The Mitigation Unit developed a strengthened internal process to better track local plan statuses in order to notify communities so that they can update their plans without a lapse.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	RMAAT Agencies
	Agency Priority Score:	High
	Possible Funding Source(s):	Federal - State Management Cost, FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	MEMA: Create an Earthquake Risk Reduction Program.	
Less than 3 years	Action Description:	This project will develop a multi-jurisdictional/multi-disciplinary working group that will be convened and led by a facilitator hired by the Commonwealth utilizing NEHRP Direct State Assistance funding. Working group members will represent a wide variety of disciplines, levels of government, and sectors. The primary goals of this diverse group will be to establish a robust earthquake mitigation program for the Commonwealth that will develop and implement strategies to increase earthquake awareness, preparedness and education, and mitigate earthquake-related risks.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	USGS, FEMA, Northeast Stated Emergency Consortium (NESEC), Weston Observatory, State Building Code Officials, Structural Engineers, Academic Partners
	Agency Priority Score:	Medium
	Possible Funding Source(s):	Federal - Earthquake Hazards Reduction State Assistance Program
	SHMCAP Goal(s):	1, 3
	Primary Climate Change Interaction(s):	Earthquake

Completion Time Frame	MEMA: Hire a Disaster Survivor Assistance Planner.	
Less than 3 years	Action Description:	New and Ongoing. Develop and formalize plans, processes, and procedures for the direct and indirect delivery of services to citizens affected by man-made and natural disasters in the Commonwealth. To develop these, the Planner will convene one or more project management teams comprised of various local, state, and federal agencies, not-for-profit organization, and private sector partners.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	
	Agency Priority Score:	Medium
	Possible Funding Source(s):	Federal - FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	1, 2
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MEMA: Plan and host hazard mitigation grant workshops for state agencies and local governments after natural disasters, especially immediately following Presidential Disaster Declarations.	
Less than 3 years	Action Description:	MEMA conducts multiple grant briefings following declared disasters and upon release of PDM / FMA Notice of Funding Opportunities. In addition to the in-person briefings, MEMA has acquired webinar capability to provide increased opportunities for participation. MEMA also regularly speaks at various municipal meetings about the importance of mitigation.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	FEMA and Communities
	Agency Priority Score:	High
	Possible Funding Source(s):	Federal - State Management Cost, FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	MEMA: Prepare hazard mitigation best practices and case studies.	
Less than 3 years	Action Description:	The Mitigation Unit regularly shares best practices during grant briefings and through the widely distributed "MEMA Reports".
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	DCR, EOEEA, CZM, DER
	Agency Priority Score:	Medium
	Possible Funding Source(s):	Federal - FEMA HMA Grant
	SHMCAP Goal(s):	1, 2, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MassDOT: Incorporate climate resiliency into capital planning activities.	
Less than 3 years	Action Description:	Establish awareness and training to incorporate climate change impacts into project design, and Operations and Maintenance. Impacts of current state and federal regulation impacts, policy, standard operating procedures, design guides will be assessed.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	Highway Division staff, Consultants
	Agency Priority Score:	Very High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	DCR: Incorporate climate vulnerability in all planning efforts.	
3-5 years	Action Description:	As a large statewide agency, DCR has numerous plans which require periodic updates. This action item assures that impacts from climate change and natural hazards are considered in all planning efforts agency-wide.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Conservation and Recreation (DCR)
	Partner(s):	MassWildlife, DER, CZM
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DCR: Upgrade and strengthen control systems for both the New Charles River and Amelia Earhart dams.	
3-5 years	Action Description:	DCR oversees the New Charles River and Amelia Earhart dams, which address the Charles River and Mystic River, respectively. Together, these dams provide critical flood control functions in a heavily populated, trafficked, and economically significant portion of the Commonwealth. DCR will review its capital maintenance and modernization plans with respect to these dams and will incorporate relevant flood, tidal, and other hazard mitigation considerations to make them more resilient to flooding and severe weather events.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Conservation and Recreation (DCR)
	Partner(s):	Army Corps
	Agency Priority Score:	Very High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Extreme Weather

Completion Time Frame	DEP: Promulgate wetlands regulations to establish performance standards for work in land subject to coastal storm flowage.	
3-5 years	Action Description:	Promulgate wetlands regulations to establish performance standards for work in Land Subject to Coastal Zone Flowage. DEP Wetlands Protection Program is working to propose draft regulations that will establish performance standards for work in Land Subject to Coastal Zone Flowage. This resource area is critical for reducing coastal impacts from Storm event. DEP intends to align any proposed standards with FEMA mapping and the state building code for these areas.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DEP: Update precipitation data used by wetlands program.	
3-5 years	Action Description:	Update Precipitation projections (models) used by the wetlands program to condition work in wetland resource areas and design stormwater controls.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	University of Massachusetts at Boston and Amherst, Cornell University, MassDOT
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	DEP: Develop a Statewide River Hydraulic Model.	
3-5 years	Action Description:	This project will gather the paper printouts, microfiche, older software, and modern LIDAR to create a Statewide River Hydraulic Model. The Statewide Model will facilitate future updates to FEMA maps, including providing the ability to project the effects of higher hydrology on flooding elevations as well as project the river elevations during droughts. This project will allow for projection of future river elevations for both high and low flows and aid in estimating the effects of projects on river flooding.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	USGS New England Division. MassDOT, Northeast Climate Adaptation Science Center, EOEEA
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget, Federal - USGS cooperative funding
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DEP: Develop Future Extreme River Flow Projections.	
3-5 years	Action Description:	This project will develop streamflows predicted for the Year 2100 using a downscaled Global Circulation Model (GCM) with standardized Representative Concentration Pathways (RCP) from Coupled Model Intercomparison Project Phase 5 (CMIP5). The future streamflows will be added to the web-based USGS StreamStats Methods to make them widely available. This project will allow new and rebuilt roadway crossings to be designed using future expected streamflows which will eliminate uncertainty in the methods that convert precipitation to streamflow. Ultimately, the project will increase the resilience of new or rebuilt roadway crossings to convey river flow, aquatic organisms, and roadway automobile traffic.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	USGS New England Division. MassDOT, Northeast Climate Adaptation Science Center
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget, Federal - USGS cooperative funding
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	DEP: Improve Mapping to Enhance Resilience and Emergency Preparedness of Water Utilities.	
3-5 years	Action Description:	DEP's Water Utility Resilience Program (WURP) and Geographic Information Systems (GIS) Program initiated a collaborative effort in 2016 to develop a uniform approach in creating and tracking maps of public water systems and publicly owned treatment works. The project improves internal access to water utility critical infrastructure information, aids in identifying system vulnerabilities and local climate change planning, improves emergency preparedness and response capabilities, and develops consistently formatted, statewide water utility infrastructure maps for multiple uses. To date the project has developed detailed GIS maps for 89 water utilities in over 50 communities as well as general service area maps. Ongoing project implementation will create GIS mapping to improve system resiliency for additional water utilities. The project further aims to establish secure access to critical infrastructure information by DEP staff and collaborating agencies to enhance emergency response and recovery efforts.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	DPH, Water utilities/DPWs, Local municipal emergency managers
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DEP: Regional water quality monitoring initiative.	
3-5 years	Action Description:	DEP is participating in a regional surface water quality monitoring initiative with the other New England states, EPA Regional offices, and tribes in the Northeast, Mid-Atlantic and Southeast. This effort monitors freshwater streams to detect climate-related changes related to temporal trends in biological, thermal, hydrologic, habitat and water chemistry data, and to gather information on response and recovery of organisms to extreme weather events.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	MassWildlife, DER, CZM
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	DER: Develop a prioritization and implementation strategy for barrier removal on cold water streams most impacted by warming temperatures to allow climate adaptation and habitat restoration.	
3-5 years	Action Description:	DER will work with federal, state, and local organizations and property owners to identify, prioritize, design, permit, and guide the removal of dams and replacement of culverts for the benefit of cold water habitat, public safety, and municipal infrastructure resilience. Removing barriers results in-stream temperatures decreasing and connectivity increasing for sensitive species in cold water streams, while also improving the safety of roadways, infrastructure and residents living in close proximity to dams and culverts.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	Municipalities; Office of Dam Safety; state and federal regulatory agencies; EOEEA; NOAA; U.S. Fish and Wildlife Service; NGOs
	Agency Priority Score:	Very High
	Possible Funding Source(s):	Federal - NOAA, U.S. Fish and Wildlife Service, Natural Resources Conservation Service, the National Fish and Wildlife Foundation, and others
	SHMCAP Goal(s):	1, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures, Extreme Weather
Completion Time Frame	DER: Develop an implementation plan to complete priority water quality restoration projects for climate adaptation and habitat restoration.	
3-5 years	Action Description:	DER will work with partners to identify, prioritize, plan and complete projects that improve water quality and increase community resilience to water quality impacts stemming from climate change. Projects may include green infrastructure stormwater treatments; enhancing local and regional capacity for data collection, analysis, and leading restoration projects; restoration of riparian buffer functions and values; and support to communities developing ordinances and stormwater utilities.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	DEP, CZM
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures

Completion Time Frame	DER: Develop an implementation plan to reprioritize and accelerate tidal wetland restoration for climate adaptation and habitat restoration.	
3-5 years	Action Description:	DER will work with towns and private property owners as well as federal, state, and local organizations to identify, design, permit, and guide the construction of salt marsh restoration projects that benefit public safety, build resilience to extreme weather and sea level rise, and restore coastal habitat. Coastal wetlands provide benefits to people and communities such as flood reduction, protection from coastal storms, water quality improvement, and recreation.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	Municipalities; state and federal regulatory agencies; EOEEA; NOAA; U.S. Fish and Wildlife Service; NRCS, NGOs
	Agency Priority Score:	High
	Possible Funding Source(s):	Federal - NOAA, U.S. Fish and Wildlife Service, Natural Resources Conservation Service, the National Fish and Wildlife Foundation, and many others. EOEEA's Dam and Seawall Repair or Removal Program, MVP action grants, or other sources fund projects within municipalities.
	SHMCAP Goal(s):	1, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DER: In support of EOEEA's efforts on MVP, build the capacity of regional organizations to implement climate adaptation and habitat restoration at the local level.	
3-5 years	Action Description:	DER will partner with and support up to five regional organizations that help municipalities identify, develop, and implement projects that provide climate change adaptation and improved public safety for communities and habitat restoration benefits for fish and wildlife. DER will facilitate regional solutions at the watershed, river corridor, or coastline scale, which may cross municipal boundaries.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	NGOs
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MassWildlife: Evaluation of climate change impacts on common species.	
3-5 years	Action Description:	MassWildlife is largely funded through the purchase of fishing and hunting licenses. Common species (e.g., yellow perch, pumpkinseed, chain pickerel, wild turkey, deer, bear,) provide recreational opportunities to the broadest number of anglers and hunters and yet little work has focused on understanding how these species will respond to climate change in Massachusetts. Climate change is likely to shift habitats that support common species as well as angler and hunter behavior. Understanding the direct and indirect effects of climate change on common species and angler/hunter behavior will allow the Division to foresee how management strategies may need adjustment to provide recreational opportunities to Commonwealth citizens into the future.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	
	Agency Priority Score:	Low
	Possible Funding Source(s):	Departmental Revenue or Other Sources
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MassWildlife: Updates to BioMap2.	
3-5 years	Action Description:	In 2010, the MassWildlife's Natural Heritage and Endangered Species Program completed a rigorous analysis of the status and location of rare species and natural communities in collaboration with The Nature Conservancy. The resulting document, BioMap2, identified areas where conservation efforts should be focused in order to protect plant and wildlife biodiversity in Massachusetts. For example, the document has been used to identify where land acquisition is likely to benefit the protection of rare species. Since completion of the document newer and finer-scaled climate change predictions have become available. Incorporation of the newer predictions as well as more recent species and habitat data can help the Division prioritize and tailor effective management actions.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	NGOs
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MassWildlife: Work with MassDOT to incorporate habitat and cold water fisheries considerations into MassDOT climate vulnerability assessments, adaptation projects, and community planning tools.	
3-5 years	Action Description:	<p>Ongoing efforts by MassDOT (e.g. Deerfield River Watershed Climate Change Vulnerability Assessment Pilot Project) are identifying road stream/wetland crossings that are vulnerable to climate change, storm damage and flooding. Information from this assessment will be incorporated into an existing GIS-based project planning tool used by MassDOT staff and shared with municipalities and regional planning authorities. Building on the existing “Linking Landscapes” MassWildlife/MassDOT partnership—a nationally recognized model for State Wildlife/Transportation Agency coordination, the proposed project will:</p> <ul style="list-style-type: none"> Expand the pilot MassDOT Road Infrastructure Vulnerability Assessment statewide. Identify the important habitat areas that would benefit from improved stream and wetland crossing structures and that intersect with the most vulnerable road infrastructure (e.g. Rare Species key sites, Cold Water Fisheries priority areas, Natural Communities). Conduct a comprehensive assessment that builds on existing models to (SHEDS-ICE) to map stream reaches in Massachusetts that are likely to remain cold water refugia under different climate scenarios and timescales (2030-2100). Incorporate project results into an existing GIS-based project planning tool used by MassDOT staff and shared with municipalities and regional planning authorities. In addition to identifying vulnerable road infrastructure that intersect habitat features of statewide and regional significance the planning tool will make specific project design recommendations, and highlight available technical assistance and funding opportunities.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	MassDOT
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MassWildlife: Evaluation of shifts in habitats and species distributions.	
3-5 years	Action Description:	Species habitats and distributions are expected to shift with changing environmental conditions, resulting in changes to the function and structure of ecosystems. The Division of Fisheries and Wildlife will need to understand the rate and extent of changes to ecosystems over different timescales in order to effectively manage resources. The Division is already considering these shifts in management decisions. For instance, emphasis has fallen away from purchasing areas that will likely be lost to sea level rise (e.g., salt marshes). However, comprehensive spatially-explicit analysis (where, how) of impacts to ecosystems and vulnerable species and habitats has not been completed.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital and Operating Budget and Departmental Revenue
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MassWildlife: In partnership with CZM, improve management of beach nourishment projects and other shoreline protection strategies and incorporate habitat considerations into coastal storm disaster response habitat and infrastructure on barrier beaches.	
3-5 years	Action Description:	The proposed project will strengthen technical expertise in management of beach nourishment projects and other strategies (e.g. dune revegetation) to simultaneously enhance wildlife habitat and protect shoreline infrastructure, ensuring key habitat considerations are made in coastal storm disaster response.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	USFWS
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MassWildlife: Study impact of climate change on fish hatcheries held by MassWildlife.	
3-5 years	Action Description:	The Division owns and manages five fish hatcheries, Bitzer Hatchery (Montague), Sunderland Hatchery (Sunderland), McLaughlin Hatchery (Belchertown), Roger Reed Hatchery (Palmer), and Sandwich Hatchery (Sandwich). All hatcheries breed and raise trout that are stocked in lakes and streams statewide. Sea level rise, extreme weather, heat and changes in precipitation may all affect these resources and a study will be conducted to assess vulnerabilities and impacts and to determine next steps.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	
	Agency Priority Score:	Low
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	4
	Primary Climate Change Interaction(s):	Sea Level Rise

Completion Time Frame	EOEEA: Update and maintain the resilientMA.org climate change clearinghouse site to include a Vulnerability Assessment Wizard for MVP communities, a clearinghouse to grant programs to fund MVP actions, and a dynamic version of the SHMCAP.	
3-5 years	Action Description:	<p>Key updates to the existing website include:</p> <ul style="list-style-type: none"> • Development of a Climate Change Vulnerability Assessment Wizard or tool to help cities and towns assess, track and address vulnerability. This tool would also allow users to spatially view the key vulnerabilities identified across the state and priority actions. • Creation of a municipal portal for MVP communities to store data, submit reports, and save resources. • A dynamic version of the state plan for interactive reading, searching, and resourcing. • A clearinghouse of State grant opportunities to help MVP recipients address priority climate change actions identified in their planning process. • Continually updated climate change projections and data, and ongoing curation of the repository of climate change literature, plans, and other documents.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	All EOEEA agencies will be involved. Support from NGO's may be sought.
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget, also Alternative Compliance Payment
	SHMCAP Goal(s):	1, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	EOEEA: Incorporate information on climate change risk and vulnerability from the SHMCAP and subsequent studies into all capital budget planning.	
3-5 years	Action Description:	Ensure all funding requests are consistent with vulnerability and risk assessments completed through the SHMCAP and subsequent studies so that future investments are resilient, do not increase exposure to climate change impacts, do not jeopardize life and safety, and seek to increase the resiliency of EOEEA's holdings.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	A&F
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DPH: Update and expand DPH and DPH provider/vendor Emergency Operations Plans (EOPs) and Continuity of Operations Plans (COOPs) to address climate impacts.	
3-5 years	Action Description:	Include all-hazards regional trainings for providers/vendors. These trainings cover, at a minimum, substance use, prevention, and treatment services including naloxone management; building communications redundancies for crisis intervention services; and health access, promotion, and prevention services for long-term resiliency.
	Executive Office:	Executive Office of Health and Human Services
	Lead Agency:	Department of Public Health (DPH)
	Partner(s):	
	Agency Priority Score:	Very High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	MOTT: Research and assess and potential effects of climate change on Commonwealth travel and tourism industry and assets.	
3-5 years	Action Description:	MOTT will Research and assess and potential effects of climate change on Commonwealth travel and tourism industry and assets.
	Executive Office:	Executive Office of Housing and Economic Development
	Lead Agency:	Massachusetts Office of Travel and Tourism (MOTT)
	Partner(s):	DCR
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget and Trust Funding
	SHMCAP Goal(s):	2
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	OPSI: Voluntary resilience audits for private property.	
3-5 years	Action Description:	Program with voluntary (or incentivized) resilience audits that consider private property is exposure to hazards (natural and climate change) and make mitigation/adaptation recommendations.
	Executive Office:	Executive Office of Housing and Economic Development
	Lead Agency:	Office of Public Safety and Inspections (OPSI)
	Partner(s):	Electric utilities
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	3, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	EOPSS: Create a statewide Threat and Hazard Identification and Risk Assessment (THIRA). In conjunction with the development of the THIRA conduct a statewide capabilities gap assessment.	
3-5 years	Action Description:	The THIRA was updated in December 2017 and is in the process of its annual update and revision. The THIRA is a foundational document for Homeland Security Planning and Preparedness. To the maximum extent the Commonwealths THIRA is integrated with the Risk Assessment in this plan.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Executive Office of Public Safety and Security (EOPSS)
	Partner(s):	Administration-wide and Federal partners
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State - Operating Budget, Federal - Grant
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	MEMA: Perform a statewide risk analysis for all hazards to include in future updates to this state hazard mitigation plan and other related plans. Address data deficiencies and improve analysis, when available, by partnering with federal, state, local, and other subject matter experts.	
3-5 years	Action Description:	A SHMCAP risk assessment was conducted in 2018. The Municipal Vulnerability Program (MVP) program was developed through the Executive Office of Energy and Environmental Affairs to assist local communities with creating resiliency plans.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	EOEEA and RMAAT
	Agency Priority Score:	Very High
	Possible Funding Source(s):	State Funding - Capital Budget, Federal - FEMA HMA Grants
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MEMA: Build out a mechanism to incorporate new data and recommendations from the FEMA-approved regional and local mitigation plans into the SHMCAP, ArcGIS online and/or Climate Clearinghouse, especially locations of critical facilities and assessments of vulnerability and estimates of potential losses by jurisdiction.	
3-5 years	Action Description:	Progress made / continual. The Office of Coastal Zone Management (CZM) created an accurate GIS layer for critical facilities for all Massachusetts coastal communities.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	EOEEA, CZM, DCR, Towns
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget, Federal - FEMA HMA Grant, FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	1, 2, 3, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MEMA: Improved Local Comprehensive Emergency Management Plan (CEMP) Program.	
3-5 years	Action Description:	Roll out and train local officials on the improved CEMP Program; CEMP Template, online document storage, and a mapping tool. The new mapping tool which will ingest the data from local communities using ArcGIS Online. This gives communities the ability to map critical infrastructure, hazardous facilities and routes, and points of interest, and provides a wider range of customization and mapping capabilities.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	
	Agency Priority Score:	Medium
	Possible Funding Source(s):	Federal - FEMA HMA Grant, FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	1, 2
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MEMA: Partner with stakeholders in Massachusetts to develop and implement regional and local multi-hazard mitigation plans by providing training and technical assistance.	
3-5 years	Action Description:	The SHMT works with local officials and regional planning agencies to provide technical assistance and funding for local hazard mitigation plans. In addition MEMA hosted a G318 Training for many local communities.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	FEMA, EOEEA, MVP Program Staff, NGOs
	Agency Priority Score:	Medium
	Possible Funding Source(s):	Federal - FEMA HMA Grant, FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	MassDOT: Pilot Deerfield Watershed Stream Crossing Resilience Project.	
3-5 years	Action Description:	This project will produce GIS layers and a web viewer ranking the vulnerability of culverts and wildlife to climate change. The final report will document the methods used in the project. Next steps will include an evaluation of how to transfer the methods to the remaining watersheds in Massachusetts.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	Staff and Consultants
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MassDOT: Incremental Development of Resiliency-Oriented Design Guidelines.	
3-5 years	Action Description:	MassDOT will work towards incrementally updating design standards across all Divisions for projects including roads, bridges, tunnels, and support facilities using the Massachusetts climate change projections.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	Internal Staff, Consultants, State partners, Federal partners, AASHTO, TRB
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MassDOT: State-wide Transportation Asset Vulnerability Assessment (inland flooding).	
3-5 years	Action Description:	The study aims to provide a better understanding of which MassDOT's assets (infrastructure) are most likely to be at risk due to future inland flooding by utilizing the latest climate model results, suitable hydrologic and hydraulic tools, geospatial analysis and scenario planning methods. The potential impact of extreme heat on transportation assets and operations is also investigated qualitatively. The study has delivered a prototype methodology for mapping out future climate-related inland flood plains at U8 watershed level and for assessing assets' vulnerability to extreme flood events. The study will eventually generate a prioritized list of assets for resilience actions.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	Highway Division
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	2, 3, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures, Extreme Weather

Completion Time Frame	EOE: Review and recommend standards for the safety and health of students in the Commonwealth informed by climate science.	
Greater than 5 years	Action Description:	EOE will work with DESE and EEC to review existing agency regulations and policies related to resiliency issues to gain a better understanding of how these regulations support licensed providers and public schools in resiliency planning. EOE will also work with DCAMM (with support from EOEEA and MEMA) to understand how resiliency planning related to public higher education facilities might be used to inform resiliency planning for licensed providers and public schools.
	Executive Office:	Executive Office of Education
	Lead Agency:	Executive Office of Education (EOE)
	Partner(s):	DESE, EEC, MSBA, DCAMM, EOEEA, MEMA
	Agency Priority Score:	Low
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 3, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	DCR: Develop strategy to implement priority DCR infrastructure projects in its Coastal Inventory.	
Greater than 5 years	Action Description:	The 2014 Coastal Infrastructure Inventory and Assessment Report covered 1,462 hard and soft structures located in 62 coastal communities. DCR proposes to develop implementation strategies for prioritized projects identified in the report.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Conservation and Recreation (DCR)
	Partner(s):	A&F
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget, Federal - grant funding if available
	SHMCAP Goal(s):	2, 4
	Primary Climate Change Interaction(s):	Sea Level Rise, Extreme Weather

Completion Time Frame	DCR: Revise current review procedures for DCR-managed dams and other flood control structures to incorporate climate change data.	
Greater than 5 years	Action Description:	The Office of Dam Safety works with dam owners across the state to manage their dams safely. The Office will incorporate data on climate change into standards used to review dam management plans, and will conduct outreach to private dam owners about potential risks related to climate change and extreme weather events.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Conservation and Recreation (DCR)
	Partner(s):	DER
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget, Federal - grant funding if available
	SHMCAP Goal(s):	2, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Extreme Weather
Completion Time Frame	DCR: Work in strong coordination with EOEEA to monitor coastal shoreline sediment migration.	
Greater than 5 years	Action Description:	As offshore storms increase in both magnitude and frequency, migration of sediment becomes a critical challenge in managing the Commonwealth's beaches and shores. DCR will continue to monitor sediment migration in order to understand and deal with the complexities of this natural phenomenon in a publicly and environmentally beneficial manner.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Conservation and Recreation (DCR)
	Partner(s):	EOEEA and CZM
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Sea Level Rise, Extreme Weather

Completion Time Frame	DOER: Build energy resiliency.	
Greater than 5 years	Action Description:	Continue to prioritize investments in clean energy resiliency infrastructure projects at state, municipal, and critical private facilities.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Energy Resources (DOER)
	Partner(s):	DCAMM, Municipalities, Universities
	Agency Priority Score:	High
	Possible Funding Source(s):	Regional Greenhouse Gas Initiative, Alternative Compliance Payment
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DEP: Enhance the Water Utility Resilience Program (WURP).	
Greater than 5 years	Action Description:	WURP supports the efforts of public drinking water and wastewater utilities in building or enhancing resilience to and recovery from severe weather events, including those caused or affected by climate change. Enhancing this program will provide additional technical assistance through DEP's regional offices for water utilities to improve asset management, address system vulnerabilities and support more outreach and provide educational materials and events for this sector.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	Water utilities, EPA, MWWA, MEMA
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	DEP: Implement Updated Stream crossing culvert replacement guidance.	
Greater than 5 years	Action Description:	DEP has an updated stream crossing / culvert replacement guidance to protect wildlife habitat and reduce flooding impacts. The agency will continue to partner with the Department of Fish and Game, the Division of Ecological Restoration and others to secure funding for culvert replacement projects that will improve the resiliency of new structures, protect habitat and reduce flood damage.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	Coastal Zone Management, Department of Fish and Game, Division of Ecological Restoration, NOAA, U.S. Fish and Wildlife Service, American Rivers, and other conservation partners
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DEP: Resiliency Grants for Water Infrastructure.	
Greater than 5 years	Action Description:	Resiliency grants for public water systems and wastewater systems to make system improvements that will increase capacity to withstand the effects of climate change and recover after severe events. Projects could include flood protection measures, elevation to avoid sea level rise or more severe precipitation events, securing backup power for critical services, anticipating rising temperatures, and replacing fragile aging infrastructure that is increasingly vulnerable because of climate changes. These grants would be designed to support resiliency projects that are not being regularly supported by other financial incentive programs while being consistent with and complementing them.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	
	Agency Priority Score:	Low
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	DEP: Demand strategies educational campaign.	
Greater than 5 years	Action Description:	DEP is piloting an education and outreach campaign aimed at reducing non-agricultural outdoor water use (e.g. lawn watering) in the Parker River and Ipswich River Watersheds, two of the state's most stressed basins. Work will be informed by municipal scale piloting by the Division of Ecological Restoration. DEP is also piloting demand management strategies in the Ipswich and Parker watersheds. Information gained may be useful in designing statewide conservation outreach and drought response strategies.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Environmental Protection (DEP)
	Partner(s):	
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DPU: Facilitate a program for sharing resources between municipalities for tree maintenance.	
Greater than 5 years	Action Description:	Investigate, encourage or facilitate a program for towns, regions and utilities to work together and share information and equipment to reduce potentially hazardous trees/limbs.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Public Utilities (DPU)
	Partner(s):	Municipalities, Electric distribution companies, Community organizations
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Extreme Weather

Completion Time Frame	DPU: Review storm preparedness best practices from other regional distribution systems.	
Greater than 5 years	Action Description:	Review distribution system adaptation methods adopted in areas which have historically been subject to the types of hazards which may increase in Massachusetts (e.g. precast distribution poles near the coast, such as those used in Florida).
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Public Utilities (DPU)
	Partner(s):	Public utility commission and distribution companies in areas reviewed
	Agency Priority Score:	High
	Possible Funding Source(s):	Departmental Revenue or Other Sources
	SHMCAP Goal(s):	1, 2, 3, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DPU: Regional power grid planning and incorporation of climate change data.	
Greater than 5 years	Action Description:	Through implementation of the grid modernization docket microgrids have been identified as an area of continued research and development. Utilities could assess climate data and prioritize regional power grid improvements that will provide benefits of reduced outages, and lower long-term maintenance costs.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Department of Public Utilities (DPU)
	Partner(s):	Municipalities, Electric Distribution Companies, Community Organizations, Neighboring States, ISO-NE
	Agency Priority Score:	Medium
	Possible Funding Source(s):	Ongoing regulatory structure
	SHMCAP Goal(s):	1, 2, 3, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	DER: Develop an implementation plan to build municipal capacity to replace undersized, deteriorated culverts with larger, safer structures that are resilient to extreme storms and provide passage for fish and wildlife.	
Greater than 5 years	Action Description:	DER will provide training, tools, technical assistance, and incentive grants for municipalities to replace undersized culverts with larger, safer structures that are resilient to extreme storms, reduce roadway flooding and infrastructure damage, and provide passage for fish and wildlife.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	Municipalities; state and federal regulatory agencies; EOEEA; NOAA; U.S. Fish and Wildlife Service; National Fish and Wildlife Foundation; The Nature Conservancy; American Rivers
	Agency Priority Score:	Very High
	Possible Funding Source(s):	Federal - NOAA, U.S. Fish and Wildlife Service, Natural Resources Conservation Service, the National Fish and Wildlife Foundation, and many others. MVP grant program.
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures, Extreme Weather
Completion Time Frame	DER: Develop an implementation strategy and updated prioritization scheme to work with federal, state, and local partners and non-profit organizations to remove unwanted state-owned dams to reduce risk, increase resilience to extreme weather and climate change, and restore aquatic habitat.	
Greater than 5 years	Action Description:	DER will work with state agencies to identify, prioritize, design, permit, and guide the construction of dam removal projects that benefit public safety, build resilience to extreme weather, and restore riverine habitat.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	Office of Dam Safety at DCR; EOEEA, DFG, DCR, state and federal regulatory agencies; NOAA; U.S. Fish and Wildlife Service; NGOs
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	DER: Develop an implementation strategy for retired cranberry bog restoration for climate adaptation and habitat restoration by working with landowners, federal, state, and local partners and non-profit partners for climate resiliency, habitat quality, flood and water quality protection, and wildlife.	
Greater than 5 years	Action Description:	DER will work with landowners, federal, state, and local partners and non-profit organizations to restore retired cranberry bogs to natural wetlands, increasing habitat resilience for fish and wildlife as well as resilience to drought, improved water quality, and flood storage for communities.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	
	Agency Priority Score:	Medium
	Possible Funding Source(s):	Federal - NOAA, U.S. Fish and Wildlife Service, Natural Resources Conservation Service, the National Fish and Wildlife Foundation, and many others
	SHMCAP Goal(s):	1, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	DER: Restore streamflow to flow-stressed rivers to increase resiliency for aquatic ecosystems and for water supplies.	
Greater than 5 years	Action Description:	DER works to restore natural streamflow (the amount of water that flows through streams and rivers) in Massachusetts. DER works with partners to collect streamflow data and manages restoration projects aimed at restoring natural flow. Streamflow restoration projects increase community resilience to drought and improve aquatic habitats.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Ecological Restoration (DER)
	Partner(s):	Municipalities; watershed organizations; water suppliers; DEP; EOEEA; DCR; federal agencies; and others
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures

Completion Time Frame	MassWildlife: Identification of areas with high native aquatic biodiversity to help prioritize aquatic adaptation actions as the climate changes.	
Greater than 5 years	Action Description:	The Division of Fisheries and Wildlife is responsible for the conservation of freshwater fishes and wildlife throughout Massachusetts. Efforts (i.e. BioMap2) have been made to rigorously analyze and map rare species and natural community data in terrestrial ecosystems. These efforts identified lands critical for protecting and maintaining wildlife and plant biodiversity in Massachusetts. However, similar efforts have not been completed for the river and streams providing habitat to aquatic species (e.g., fishes, freshwater mussels) managed by MassWildlife. Identification of water bodies with high native aquatic biodiversity would provide critical information necessary for effective management and conservation of aquatic species in the state.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures, Extreme Weather

Completion Time Frame	MassWildlife: Identification of cold water climate refugia and transitional waters for protections of CFRs.	
Greater than 5 years	Action Description:	Coldwater streams are among the most vulnerable habitats to climate change. Changes in precipitation and air temperatures will alter hydrology to the detriment of many cold water streams. Some cold water streams are expected to diminish in size, permanently transition to warmer habitats, and/or go dry. However, certain watershed characteristics can buffer climate change impacts. Coldwater streams in deep canyons, poleward-facing slopes, thick canopy cover, groundwater-fed areas, and areas with fewer anthropogenic impacts, are more likely to persist as conditions change. Such areas may act as cold water refugia, providing long-term habitat to ecologically and economically important species such as brook trout (<i>Salvelinus fontinalis</i>). The efficacy of conservation strategies to protect cold water streams and the cold water-adapted species that rely on them will depend largely on understanding the potential persistence and transition of habitats. We build on existing models (SHEDS-ICE) to map stream reaches in Massachusetts that are likely to remain cold water refugia, or transition to cool- or warm water habitats, under different climate scenarios and timescales (2030-2100). Although existing mapping tools incorporate some watershed characteristics (e.g., aspect, impervious surfaces), none directly include flow management, including lake-level management and groundwater inputs, the effects of which have been shown to shape fish assemblages in Massachusetts streams. Management decisions that benefit directly from this research include prioritization of dam removal, instream flow protection, riparian vegetation management and location and timing of trout stocking.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	University of Massachusetts Amherst, Northeast Climate Adaptation Science Center, US Geological Survey, Division of Ecological Restoration
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	3
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures, Extreme Weather

Completion Time Frame	MassWildlife: Dam removals at the Merrill Ponds Wildlife Management Area.	
Greater than 5 years	Action Description:	MassWildlife owns two dams in the Merrill Ponds Wildlife Management Area (WMA), Welsh Pond Dam and Putnam Pond Dam, that have undersized outlet structures that are prone to clogging with debris. Work is needed to remove two additional dams and rehabilitate a third dam that provides significant recreational benefits. Each project will continue to improve the resiliency of the agency's resources by improving the hydraulic capacity of the roadway stream crossings, reducing solar heating of Singletary Brook.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	DER
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	4
	Primary Climate Change Interaction(s):	Precipitation Changes, Extreme Weather, Earthquake

Completion Time Frame	MassWildlife: Great Marsh Pilot Ditch Remediation Project.	
Greater than 5 years	Action Description:	At more than 10,000 acres, Great Marsh is the largest and most ecologically significant Salt Marsh in New England. In addition to providing habitat for a great diversity of fish and bird species, the Great Marsh supports a large population of Salt Marsh Sparrows a species threatened with global extinction due to rising seas. Among its many ecosystem services the marsh buffers land and infrastructure against waves, storm surges, and coastal erosion. Although salt marshes are at great risk of being destroyed by sea level rise, pilot studies are demonstrating that, with human intervention, salt marshes can accrete material and increase in elevation, increasing the ability to adapt to sea level change. Because of the significance of the marsh, cost-effective experimental pilot projects are warranted to assess the feasibility of larger-scale interventions in the future. Marsh ditching during the past century has led to partial drying and lowering of the marsh bed. In cooperation with The Trustees of Reservations (TTOR), researchers at University of New Hampshire, and other partners, we propose to fill select ditches on MassWildlife and TTOR properties with organic material and measure the effects on marsh elevation and rates of sediment trapping. Preliminary indications are that this technique may prevent further subsidence, reduce the rate of marsh loss, and possibly even gradually elevate the marsh bed through sediment trapping. The ditch remediation pilot is only the first step. Through this project we will build a coalition of partners committed to additional adaptive management, including the possibility of experimenting with thin layer deposition—another technique that is more difficult to implement and permit, but also holds the promise of gradually raising the marsh elevation, while preserving marsh grasses and other marsh life. Planning for this second phase would occur during the 5 year implementation timeline for the project.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	NGOs
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures

Completion Time Frame	MassWildlife: Mapping and control of invasive plant species.	
Greater than 5 years	Action Description:	Climate change is expected to increase the spread of non-native invasive species by increasing growth rates and providing weather-related disturbances that favor the life cycles of these species. Invasive plants are one of the greatest threats to the integrity of natural communities by decreasing the survival of many native species. As a result, the Division engages in efforts to identify the most problematic species and to manage them when and where possible. Comprehensive identification and mapping of the extent of invasive plants has not been completed on Division-owned and managed lands statewide. This information is necessary to determine the habitat quality and restoration potential of lands, as well as treatment methods for controlling or eradicating invasive species. Additionally monitoring helps with early detection and eradication efforts to control for newly introduced invaders who may be able to spread north under climate change. Once invasive plants are mapped, treatment options for eradication or control can be determined and implemented. Because of the robust nature of most invasive species, treatment to eradicate or significantly control any one existing population can take 5-8 years.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Division of Fisheries and Wildlife (MassWildlife)
	Partner(s):	DER
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	EOEEA: Accelerate implementation of priority actions identified through the Municipal Vulnerability Preparedness (MVP) program, increase municipal participation in planning program, conduct program review and revise planning and action grant program as needed.	
Greater than 5 years	Action Description:	The MVP program has now moved from its pilot stage into full implementation with the establishment of the MVP Action Grant and 156 communities enrolled in the planning process. Deployment of action grant funds will accelerate to begin implementation of priority actions, particularly those actions with multiple benefits, transferability, and nature-based solutions. EOEEA will strive to continue the high rate of enrollment so that at the end of the next four years close to 100% of the state's municipalities are MVP designated. Additionally, program review of year 1 of action and planning grants will support a more robust program going forward and help to improve and revise the MVP framework. Establishment of metrics and ongoing review will allow EOEEA to monitor program performance over time.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	MEMA, NGOs
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	EOEEA: Review habitat management, land stewardship, coastal zone management, agricultural and invasive species programs and policies to develop strategies that promote coordination among agencies and support climate change adaptation and mitigation goals.	
Greater than 5 years	Action Description:	EOEEA will facilitate multi-agency review of habitat management, forest stewardship, agricultural best practices and invasive species programs and policies to recommend updates that reflect climate change data and projections and address opportunities to increase resilience while also reducing GHG emissions or increasing carbon sequestration.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	All EOEEA Agencies
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	EOEEA: Based on results of vulnerability assessment for EOEEA properties and vulnerability assessments from other agencies, use climate change projections to develop stormwater management actions and projects.	
Greater than 5 years	Action Description:	EOEEA properties held by agencies including DCR and MassWildlife such as parkways, parking lots, and other facilities may have opportunities for decreased stormwater runoff through the use of green techniques or traditional methods. Similarly, protected green space held by agencies may be able to buffer neighboring infrastructure held by others. EOEEA will work with its agencies to examine areas with the highest potential for best practice stormwater management projects, and develop a plan to implement these management actions.
	Executive Office:	Executive Office of Energy and Environmental Affairs
	Lead Agency:	Executive Office of Energy and Environmental Affairs (EOEEA)
	Partner(s):	NGOs, MWRA, Cities and towns
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital, Federal - Grant
	SHMCAP Goal(s):	2, 4
	Primary Climate Change Interaction(s):	Precipitation Changes
Completion Time Frame	DPH: Strengthen DPH health care systems and services to prepare for climate impacts.	
Greater than 5 years	Action Description:	Includes direct health care services and licensing of healthcare facilities and professionals. Train health care professionals on responding to climate impacts. Incorporate plans to address anticipated increases in patient and client volumes, changing health demands, and delivery of critical life-saving support during climate events.
	Executive Office:	Executive Office of Health and Human Services
	Lead Agency:	Department of Public Health (DPH)
	Partner(s):	Health Care Systems, Providers
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	DPH: Strengthen environmental health programs to respond to climate-related impacts.	
Greater than 5 years	Action Description:	These programs respond to impacts on the food supply, water/air quality, recreational water quality, housing/sanitation, indoor air quality, exposure to toxins in various media, and radiation hazards. Support other state agencies and communities to conduct health impact assessments on climate.
	Executive Office:	Executive Office of Health and Human Services
	Lead Agency:	Department of Public Health (DPH)
	Partner(s):	
	Agency Priority Score:	Very High
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	DHCD: Facilitate and coordinate development of guidelines and best practices for climate change adaptation and resilience for state-aided housing development.	
Greater than 5 years	Action Description:	Facilitate and coordinate development of guidelines and best practices for climate change adaptation and resilience for state-funded housing development, including state-aided public housing and affordable housing funded by quasi-public agencies.
	Executive Office:	Executive Office of Housing and Economic Development
	Lead Agency:	Department of Housing and Community Development (DHCD)
	Partner(s):	LHA, Quasi-public authorities
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Extreme Weather

Completion Time Frame	MPRO: Review Chapter 40A and existing regulatory framework to evaluate incorporation of feasibility and practicality of climate change hazard mitigation measures.	
Greater than 5 years	Action Description:	MPRO will review Chapter 40A + Subdivision control law and regulatory framework, including standards and possible mitigation measures such as street widths (less impervious surfaces), low impact development, and natural storm water sinks/systems.
	Executive Office:	Executive Office of Housing and Economic Development
	Lead Agency:	Massachusetts Permit Regulatory Office (MPRO)
	Partner(s):	
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Operating Budget
	SHMCAP Goal(s):	2, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MEMA: Encourage state granting agencies in the Commonwealth, such as the Massachusetts Department of Housing and Community Development's review of Community Development Block Grants, to work together with MEMA to assist in providing the Non-federal cost share in Disaster Recovery and Hazard Mitigation Grants to maximize the federal funding available to the Commonwealth and its communities.	
Greater than 5 years	Action Description:	FEMA grants are typically 75% federal funding and require a 25% non-federal cost share. State funding such as Department of Housing and Community Development Community Development Block Grant (CDBG), CDBG-DR, MassWorks, Municipal Vulnerability Program, etc., can works in conjunction with FEMA funding recovery and mitigation projects in the Commonwealth. One project under this program was funded in conjunction with HMGP funding resulting in \$0 out of pocket for a small community.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	DHCD, EOEEA, DCR, EOHED, Others
	Agency Priority Score:	High
	Possible Funding Source(s):	State - Operating Budget, Federal - State Management Cost, FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MEMA: Enhance the effectiveness of 406 funding by working to further integrate mitigation into the FEMA Public Assistance Program.	
Greater than 5 years	Action Description:	Progress made. The mitigation and recovery units work collaboratively to identify areas where 406 funding can be leveraged to maximize disaster recovery funding to build back better and more resilient infrastructure. This includes working on an interagency recovery group after a disaster to maximize efficiencies and reduce duplication for communities.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	FEMA , DCR, CZM, DEP, EOEEA
	Agency Priority Score:	High
	Possible Funding Source(s):	Federal - State Management Cost, FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	1, 2, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MEMA: Work with communities to implement cost-effective, environmentally sound, and feasible mitigation projects to severe repetitive loss properties.	
Greater than 5 years	Action Description:	Progress continues; both repetitive and severe repetitive loss properties are lifted up for FMA grants each year, as well as whenever HMGP funds are available. Partners shall continue to seek other methods of funding for flood mitigation, including the use of the HUD programs, and preliminary consideration of potential new state lead partnerships to assist communities in the management of these activities. Seek to advance funding for all eligible project types that reduce risk with a particular focus on nature base solutions. In addition, the Flood Hazard Management Program will continue to assist in focusing on mitigation or SRL and RL Structures through direct property mitigation or community flood risk reduction projects. FEMA's database showed 220 SRL properties in Massachusetts. This activity must continue until all severe repetitive loss properties in the state have been acquired, relocated or mitigated. Project selection criteria will always favor properties that are designated SRL or RL.
	Executive Office:	Executive Office of Public Safety and Security
	Lead Agency:	Massachusetts Emergency Management Agency (MEMA)
	Partner(s):	Communities as Sub-grantees
	Agency Priority Score:	High
	Possible Funding Source(s):	Federal - FEMA HMA Grant Management Cost, FEMA Emergency Management Performance Grant
	SHMCAP Goal(s):	3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Extreme Weather

Completion Time Frame	EOTSS: Migrate Beacon, Meditech and FamilyNet to the cloud.	
Greater than 5 years	Action Description:	Migrate critical systems for the Department of Transitional Assistance (Beacon) and the Executive Office of Health and Human Services (Meditech and FamilyNet) to the cloud, removing the need to maintain and protect on premise servers for these systems.
	Executive Office:	Executive Office of Technology Services and Security
	Lead Agency:	Executive Office of Technology Services and Security (EOTSS)
	Partner(s):	EOHHS
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	EOTSS: For Registry of Motor Vehicle systems that must remain on-premises (not cloud), evaluate migration options or relocations to third party on premises.	
Greater than 5 years	Action Description:	Work with Registry to evaluate and plan relocating servers to a 3rd party location.
	Executive Office:	Executive Office of Technology Services and Security
	Lead Agency:	Executive Office of Technology Services and Security (EOTSS)
	Partner(s):	
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake

Completion Time Frame	EOTSS: Re-platform MA21 and MMIS to enable cloud migration.	
Greater than 5 years	Action Description:	Before they can be migrated to the cloud, the Executive Office of Health and Human Services' critical systems MMIS (Medicaid Management Information System) and MA21 (MassHealth's eligibility system) will need to be re-platformed. This will facilitate their future migration to the cloud, removing the need to maintain and protect on premise servers for these systems.
	Executive Office:	Executive Office of Technology Services and Security
	Lead Agency:	Executive Office of Technology Services and Security (EOTSS)
	Partner(s):	
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital Budget
	SHMCAP Goal(s):	2, 3
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	MBTA: Incorporate climate resiliency into capital planning activities.	
Greater than 5 years	Action Description:	The MBTA's Strategic Plan and Focus 40 goals explicitly address climate resiliency as a key priority for the MBTA. The overarching capital planning program will continue incorporating climate resiliency as a factor in project-level decision-making. All ongoing and new capital projects will mandate consideration of current and future extreme weather and incremental climate change related risks into design and construction of each project.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Bay Transit Authority (MBTA)
	Partner(s):	MassDOT
	Agency Priority Score:	Very High
	Possible Funding Source(s):	State Funding - Capital Budget, Federal Funding - FTA Grants
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MBTA: Complete system-wide vulnerability assessment.	
Greater than 5 years	Action Description:	Continue assessing vulnerability of MBTA systems, operations, and assets. Blue Line vulnerability assessment has been completed. Drill-down assessments of critical assets on Blue Line in-progress. Piecemeal approach will continue in FY 2019 with assessments of Red Line, Power and Communications Systems, and portions of Commuter Rail. Additional assessments and resiliency measures will occur from FY2020-onward.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Bay Transit Authority (MBTA)
	Partner(s):	Consultant support
	Agency Priority Score:	Very High
	Possible Funding Source(s):	State Funding - Capital Budget, Federal Funding - FTA Grants
	SHMCAP Goal(s):	1, 2, 3, 4, 5
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather, Earthquake
Completion Time Frame	MassDOT: Utilize the Boston Harbor Flood Risk Model and data from the vulnerability assessments to identify current and future high risk areas and strengthen emergency management with local, state and federal agencies.	
Greater than 5 years	Action Description:	MassDOT and the Federal Highway Administration co-funded a pilot project to assess the vulnerabilities of the Central Artery tunnel system in Boston to coastal storm surge for present day, 2030, and 2070. This project created the Boston Harbor Flood Risk Model (BH-FRM) and includes the effects of nor'easters, hurricanes and sea level rise. The goal of the action is encourage the use of BH-FRM data by state and local entities and begin to inform resiliency related projects.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	FHWA, Cities of Boston and Cambridge and Stakeholders
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MassDOT: Assess the feasibility of recommendations from the Commission on the Future of Transportation in the Commonwealth.	
Greater than 5 years	Action Description:	With Executive Order 579: Establishing the Commission on the Future of Transportation in Commonwealth, Governor Baker wanted to investigate 5 areas of interest one of which is Climate and Resiliency. This topic area includes greenhouse gas emission reduction, and what investments will be needed to make transportation infrastructure more resilient for the 2020-2040 timeframe. The Commission's report and recommendations are due to the Governor by December 1, 2018.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	EOEEA
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MassDOT: Capture and document institutional knowledge on vulnerabilities from staff using the Mapping Our Vulnerable Infrastructure Tool (MOVIT).	
Greater than 5 years	Action Description:	MOVIT Tool that contains data obtained from the institutional knowledge of maintenance engineers (and anyone else with pertinent knowledge) and data from the vulnerability assessments. This initiative will provide vulnerable asset data collected from districts to be used for project review and prioritization. This information will be stored in MOVIT or other databases as developed.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	Highway Division
	Agency Priority Score:	Medium
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MassDOT: Coordinate with state and federal agencies to evaluate environmental regulation and permitting processes to address current roadblocks in climate change.	
Greater than 5 years	Action Description:	Establish a regulatory working group to explore the expansion of Surface Transportation Uniform Relocation Assistance Act regarding exemptions and minor modifications.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	Regulatory Agencies
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MassDOT: Develop climate change adaptation design guidance and provide resources and training for project managers and design teams on bridge and culvert design interaction with emerging fluvial geomorphology practices.	
Greater than 5 years	Action Description:	MassDOT is developing a fluvial geomorphology based “Rivers & Roads” training program that will be initially offered to staff, including environmental analysts, project managers, bridge and hydraulic engineers, and construction and maintenance personnel. The training will eventually be offered to local government and the private consulting and construction sectors. The program will include three tiers that will increase in complexity.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department of Transportation (MassDOT)
	Partner(s):	Highway Division staff, Consultants
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Rising Temperatures, Extreme Weather

Completion Time Frame	MassDOT: Incorporate climate change adaptation into the MassDOT Highway Division Transportation Asset Management Plan and coordinate Asset Management across divisions and partner agencies.	
Greater than 5 years	Action Description:	Conduct an asset management pilot project on the vulnerability of culvert and bridge assets. This information will be stored in MAPIT and will give an alert to proponent to coordinate with Hydraulics, Bridge, and Environmental departments.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department Transportation (MassDOT)
	Partner(s):	Federal Highway Administration
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MassDOT: Incorporate resiliency review items into the Early Environmental Coordination Checklist.	
Greater than 5 years	Action Description:	Revise the Environmental Early Coordination Checklist to include resiliency review items.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department Transportation (MassDOT)
	Partner(s):	Highway and Bridge Design, Consultants
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

Completion Time Frame	MassDOT: Leverage permit granting authority and ability to influence M.G.L. Section 61 findings and mitigation.	
Greater than 5 years	Action Description:	Developers are required to evaluate a project's impacts on transportation through a Transportation Impact Analysis and to include mitigation, as necessary, in the form of highway, transit, pedestrian and bicycle accommodations. After the project is build, the proponent must submit a monitoring report. Example: ENCORE BOSTON HARBOR provided \$7.5 million to improve the transit system and ensure multimodal accommodations are effective in mitigating new trip generation. Planning is working on getting MassBike, Walk Boston and developers at the same time to evaluate performance and identify ways to enhance the transit system.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department Transportation (MassDOT)
	Partner(s):	Highway Division
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather
Completion Time Frame	MassDOT: Require a holistic evaluation of all vulnerability, environmental, transportation and social data sets in the earliest project planning phases.	
Greater than 5 years	Action Description:	Understanding a broad range of constraints and sensitive resources early in project planning ensures resilient infrastructure and helps avoid permitting issues later in the project development process. This initiative will also reduce the need to retrofit infrastructure for adaptation measures post-construction. MassDOT will vet and compile data sources including vulnerability data and leverage project planning tools such as MassDOT Project Intake Tool or MAPIT. MAPIT is a web-based GIS and project development tool that brings together transportation, safety, environmental, and vulnerability data to help arrive at the most context sensitive design.
	Executive Office:	Massachusetts Department of Transportation
	Lead Agency:	Massachusetts Department Transportation (MassDOT)
	Partner(s):	Massachusetts Department of Transportation Planning, Consultant support
	Agency Priority Score:	High
	Possible Funding Source(s):	State Funding - Capital and Operating Budget
	SHMCAP Goal(s):	1, 2, 3, 4
	Primary Climate Change Interaction(s):	Precipitation Changes, Sea Level Rise, Rising Temperatures, Extreme Weather

7.5 Strategy Development

This hazard mitigation and climate adaptation strategy was developed using the risk-based information provided in Chapter 4 to identify a wide range of vulnerabilities to natural hazards and climate change, and develop strategies to address these challenges. The strategy is also based on the capability and adaptive capacity analysis provided in *Chapter 6: State Capability and Adaptive Capacity Analysis*, which identifies strengths and opportunities to reduce risk through existing government authorities, policies, programs, staffing, and funding. The actions included in the plan were developed by participation from each Executive Office of the Commonwealth and a subset of state agencies most directly impacted by these risks. Finally, an action prioritization tool was developed by the PMT and applied by Executive Offices and state agencies to consistently evaluate and prioritize their final list of actions. This strategy serves as an initial plan for reducing losses associated with vulnerabilities identified in the risk assessment and a blueprint for development of data, tools, policies, and programs to advance hazard mitigation and climate adaptation efforts in the future.

The five primary steps outlined in FEMA’s *State Mitigation Planning Key Topics Bulletin: Mitigation Strategy* were followed in the development of this strategy (modified to include reference to climate adaptation).

1. Validating hazard mitigation and climate adaptation goals;
2. Reviewing, evaluating, and updating existing hazard mitigation and climate adaptation actions;
3. Identifying any new hazard mitigation and climate adaptation actions;
4. Prioritizing all hazard mitigation and climate adaptation actions; and
5. Identifying current and appropriate funding sources.

7.5.1 Stakeholder Engagement

This strategy was developed through an extensive stakeholder engagement process that is more fully described in Chapter 9. The stakeholder outreach and engagement process served the purpose of providing input on goals and identification of hazard mitigation and climate adaptation actions. Stakeholders included representatives from the following:

- State agencies
- Regional planning agencies
- Local government
- Nongovernment/private-sector organizations, including those representing critical infrastructure, engineering, social welfare, and economic development

- Environmental and natural resources organizations
- Public health departments and organizations

Two workshop series were held for the specific purpose of developing this strategy. The first workshop series was held in three locations in January 2018: Springfield, Framingham, and Middleborough. These workshops had the primary purpose of developing goal statements for this strategy. The second workshop series was held in April 2018 in Boston, Hopkinton, and Lanesborough to gather ideas for actions to achieve the vision of the goal statements previously developed. Additional actions were collected via the Action Proposal Worksheet. Ultimately, several hundred Action Proposal Worksheets were completed by state agencies and stakeholders across the Commonwealth. These suggested actions were considered by the relevant agencies and executive offices, and developed into a list of initial actions for implementation of the SHMCAP.

7.5.2 National Mitigation Framework

The National Mitigation Framework is one of five FEMA frameworks that comprise the National Preparedness System. All of the frameworks emphasize a whole community approach, which the PMT adopted for this planning process. This approach assumes that everyone in a community (including state agencies, nonprofit organizations, businesses, local governments, and interested citizens) can contribute to and benefit from mitigation planning efforts. The National Mitigation Framework focuses on building resiliency and creating a culture of preparedness. The PMT emphasized this throughout the planning process, and specifically added the need for improving institutional capacity to address climate change and natural hazards in the first goal statement.

The core capabilities in the National Mitigation Framework were adhered to throughout the planning process, and therefore contributed to the development of the actions the State intends to implement over the next 5 years. These capabilities are:

- **Threats and Hazards Identification.** Develop and/or gather required data in a timely and accurate manner to effectively identify threats and hazards.
- **Risk and Disaster Resilience Assessment.** Perform credible risk assessments using scientifically valid and widely used risk assessment techniques.
- **Planning.** Incorporate the findings from the assessment of risk and disaster resilience into planning processes.
- **Community Resilience.** Recognize the interdependent nature of the economy, health, and social services, housing infrastructure, and natural and cultural resources within a community.

- **Public Information and Warning.** Communicate priorities and actions identified through risk analysis and plans to stakeholders and those expected to take action to reduce risk.
- **Long-Term Vulnerability Reduction.** Develop plans and recognize that a prepared individual or family is the foundation of a resilient community.
- **Operational Coordination.** Capitalize on opportunities for mitigation actions following disasters and incidents.

7.5.3 Integration of Climate Adaptation

This plan meets FEMA requirements for a state-level hazard mitigation plan and also satisfies a key requirement of Executive Order 569 to develop a state climate adaptation plan. Integrating climate adaptation into the hazard mitigation plan update process provided an opportunity to implement a systematic approach to more fully assess the risk of natural hazards that are projected to increase in both frequency and intensity, as well as introduce new hazards in the next 50 years; and to identify adaptation strategies to reduce risk and increase resilience. Integrating hazard mitigation and climate adaptation was a strategic decision based on current science. The Climate Risk Management journal article “*Integrating climate change into hazard mitigation planning: Opportunities and examples in practice*” offers a detailed look at the benefits of this practice, and identifies opportunities for embedding climate change into hazard mitigation planning (Climate Risk Management, 2017). All of the opportunities identified in this article were used to develop this SHMCAP, including the use of climate-related stakeholders and studies in all parts of the planning process; evaluating how climate change impacts each hazard identified and assessed in the plan; and factoring climate change into the probability of future hazards. Goals for the plan were developed with climate change in mind, and climate change was part of the criteria included in the action prioritization process for this plan. As a result of this integration process, this plan uses the best available science and projections for climate change, describes the interactions of climate change and natural hazards, and then identifies adaptation strategies to reduce risk and increase resilience. As described in Section 7.4, all adaptation strategies or actions identified in the plan address at least one of four climate change interactions.

7.6 Conclusion

The result of the hazard mitigation and climate adaptation strategy is a mission statement and goal statements that represent the vision of the Commonwealth of Massachusetts for addressing vulnerabilities from climate change and natural hazards. In addition, 108 well-developed initial actions are included in this plan to reduce or eliminate long-term risk from climate change and/or natural hazards and their impacts. These actions reflect input from public and private stakeholders across the state, and extensive contributions from the Executive Offices and agencies of the Commonwealth. These actions will be further refined, assessed, and implemented

as appropriate through the ongoing SHMCAP implementation process, outlined in *Chapter 8: Plan Implementation and Maintenance*. In addition, further actions and strategies will be identified with stakeholders going forward. These actions will build the capacity of the Commonwealth to withstand future climate conditions and natural hazards.



8. Plan Implementation and Maintenance

This State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) is intended to be a living document, one that is operationalized through the continuous implementation of the actions identified in *Chapter 7: Hazard Mitigation and Climate Adaptation Strategy* and ongoing dialogue with stakeholders. It is also intended to be dynamic—changing and improving as needed through routine maintenance procedures that help to ensure the plan is reviewed, revised, and updated as conditions and information change, and with input from stakeholders. This chapter outlines more specifically how the plan will be implemented and maintained by the Commonwealth, and it describes how the public and other stakeholders will continue to be involved in the process.

The Executive Offices with the overall strategic and policy responsibility for the SHMCAP are the Executive Office of Public Safety and Security (EOPSS) and the Executive Office of Energy and Environmental Affairs (EOEEA). The state agencies with primary responsibilities for implementing, maintaining, monitoring, evaluating, enhancing, and updating the SHMCAP include the Massachusetts Emergency Management Agency (MEMA), EOEEA's Climate Change Program, and the Department of Conservation and Recreation (DCR) Flood Hazard Management Program. The Climate Change Coordinators, established through Governor Charlie Baker's *Executive Order 569 Establishing an Integrated Climate Change Strategy for the Commonwealth* and positioned within each Executive Office, will also have increased roles and responsibilities for the SHMCAP in the years ahead. These key state agencies and staff will act

through strong partnerships to lead and guide the ongoing implementation team, described below as the Resilient MA Action Team (RMAAT). Under the direction of the primary state agencies, the RMAAT will be tasked with monitoring and tracking the implementation process, making recommendations to and supporting the primary state agencies on plan updates, and facilitating coordination across State government and with stakeholders, including businesses, cities, and towns.

8.1 Plan Implementation

The most critical outcome of the SHMCAP is the effective implementation of specific hazard mitigation and climate adaptation actions, which will ensure that the Commonwealth can achieve the plan's strategic goals and overall purpose. Plan implementation will be accomplished by designing implementation strategies and establishing timelines for priority actions, and by continuing to monitor, evaluate, update, and develop actions as new information and experience becomes available. Although the RMAAT will be tasked with general monitoring and reporting on plan implementation, proposed actions have largely been assigned to a specific lead agency or Executive Office with overall responsibility and accountability for carrying the action out. Therefore, the ultimate responsibility for plan implementation falls on many state agencies and Executive Offices. Actions that are cross-cutting have also been identified, and many need to be implemented across State government, with an Executive Office or specific agency lead. These actions will be particularly important for the RMAAT to track to ensure objectives are being met at the Administration and agency scales.

Specific implementation details for each action proposed in this plan, such as the lead agency or Executive Office, potential partners, timeline for completion, funding source(s), and agency priority level are identified in Chapter 7. Although it is the responsibility of each lead agency or Executive Office to determine additional implementation needs beyond those listed in this plan, each action has been developed to be measurable and time-bounded, making these actions the most useful indicators for tracking progress in overall plan implementation. Where individual agencies find that the original prioritization framework did not provide sufficient benefit analysis to accurately prioritize certain agency-specific missions, such as natural resource protection, additional benefit analysis considering co-benefits could be conducted to reassess the action priority.

8.1.1 System for Monitoring Implementation

As part of the plan implementation, the RMAAT will be charged with developing a system for monitoring and evaluating plan implementation. It is envisioned this will be through some type of action tracker—a customized spreadsheet tool for reporting progress status updates on individual actions. The action tracker will be developed by the RMAAT after this plan is

approved; serve as the primary mechanism for reporting and tracking the status updates on each action; and establish metrics to measure effectiveness.

All agencies and Executive Offices that have been assigned as the lead for an action in Chapter 7 will be required to provide annual implementation updates using the action tracker developed by the RMAAT. Lead agencies and Executive Offices will also be encouraged by their Executive Office's Climate Change Coordinator to maintain their progress tracking information for all actions on a more frequent basis. These action tracker updates include information on the specific status of the action (i.e., completed, partially completed, delayed, deferred, canceled), as well as narrative descriptions of progress made, delays incurred, problems faced, resources needed, or other details as required. In tracking these data, the action tracker will help the lead agencies and Executive Offices to evaluate the appropriateness and/or feasibility of actions as currently designed or being pursued; and when necessary, take corrective steps or adjust actions to address current conditions.

The action tracker will also be the primary tool for the RMAAT to routinely evaluate, monitor, and report on the overall implementation of the SHMCAP. Per the method and schedule for plan maintenance (described in Section 8.2), the action tracker will be used in the completion of reporting procedures that are tied to annual due dates for lead agencies, in addition to an annual summary of implementation progress. It will also be a critical tool to assist the RMAAT in completing tasks associated with regularly scheduled plan review and update processes. The State will measure and show progress toward implementation by tracking and evaluating progress of specific actions.

8.1.2 Plan Integration

At the state level, the SHMCAP serves as the Commonwealth's primary risk assessment and risk reduction strategy for natural hazards and climate change. As a result, it serves as a key document for state agencies and Executive Offices to routinely reference, and as applicable, to integrate into their own plans, budgets, policies, assessments, or strategies. Such integration will continue to be encouraged by the Office of the Governor, Executive Office of Administration and Finance (A&F), EOPSS, EOEEA, and members of the RMAAT as specific opportunities are identified. Plan integration will also be a discussion topic during regularly scheduled plan reviews, as described in Section 8.2.2.

More specifically, the SHMCAP will continue to be integrated to the maximum extent practical with state plans or programs that have already been determined to be mutually supportive; and at a minimum, in need of cross-referencing. These include, but are not limited to, the following:

- Commonwealth of Massachusetts Five-Year Capital Investment Plan, Fiscal Year 2019-2023

- Office of Coastal Zone Management (CZM) StormSmart Coasts program and Coastal Resiliency Grants
- Division of Capital Asset Management and Maintenance's (DCAMM) Statewide Resilience Master Plan
- DCR's Flood Hazard Mitigation Program
- EOEEA's Clean Energy and Climate Plan for 2030 ("2030 Plan")
- EOEEA's Division of Conservation Services land protection programs
- EOEEA's Municipal Vulnerability Preparedness program
- All EOEEA and EOEEA agency grant programs and capital spending requests
- MEMA's Comprehensive Emergency Management Plan
- MEMA's Hazard Mitigation Assistance programs
- MEMA's State Disaster Recovery Plan (under development)
- MEMA's Threat and Hazard Identification and Risk Assessment

The SHMCAP will reside on the Commonwealth's resilient MA Climate Change Clearinghouse (<http://www.resilientma.org/>), which serves as a gateway to data and information relevant to climate change adaptation and natural hazard mitigation across the state. The resilient MA site will be the home for the online version of the 2018 SHMCAP, as well as future updates to the plan; and will enable dynamic interaction with the general public, local communities, state agencies, and other stakeholders over the life of the plan. At a more local level, many state agencies routinely coordinate with municipalities and other jurisdictions, and through direct outreach will help to ensure the SHMCAP is incorporated into other relevant plans such as local or regional hazard mitigation plans and climate adaptation plans. It is expected that both state and local level planning initiatives will benefit from this coordination, because state agency staff will also be able to more easily identify ways to improve the ability of the SHMCAP to support local plans.

At a national level, the Commonwealth's participation and accreditation in the Emergency Management Accreditation Program will continue to help ensure that the SHMCAP is adequately in compliance with national standards for risk assessment, risk reduction, and other emergency or disaster management programs. The Commonwealth will also continue to seek opportunities to leverage or integrate other relevant national plans or standards with the SHMCAP as appropriate; including, but not limited to, the National Climate Assessment, the Federal Emergency Management Agency's (FEMA) Strategic Plan, the National Mitigation Framework, and the National Disaster Recovery Framework.

8.2 Plan Maintenance

The SHMCAP has been developed to be a living and public document that reflects the Commonwealth's continuing commitment to reducing risks from natural hazards and climate change. As noted above, the online version and future updates to the plan will reside on the Commonwealth's resilient MA Climate Change Clearinghouse.

This section describes how the plan will be actively maintained over time. It includes general procedures for regularly reviewing and making minor amendments, in addition to the comprehensive review, update, and adoption of the plan by the Commonwealth at least every 5 years. Per the hazard mitigation and climate adaptation strategy in Chapter 7, modifications to specific actions or action plans will be revised more frequently as needed, including if the conditions under which this plan was adopted change—such as updates to critical underlying data or new study findings, new or revised state policies or federal regulations, lessons learned from implementing the plan, or a major disaster event.

8.2.1 Roles and Responsibilities

The Executive Offices with the overall responsibility to implement, monitor, evaluate, enhance, and provide strategic policy for the SHMCAP over time are EOPSS and EOEEA, and together with the lead agencies identified above and the RMAAT, they will oversee plan maintenance. This team will also lead the following ongoing activities:

- Help ensure the current version of the SHMCAP is made readily accessible to state agencies and the public, including an online version hosted on the Commonwealth's resilient MA Climate Change Clearinghouse (<http://www.resilientma.org/>) and in other formats as needed.
- Provide clear methods for state agencies and external stakeholders to review and provide comments on the plan and/or its effectiveness, especially during any scheduled plan reviews or updates.
- Work closely with the RMAAT and other state agency staff to promote and support the SHMCAP in ways that continue to meet the needs of the Commonwealth and federal requirements for state hazard mitigation plans.
- Assist in interagency efforts for response, recovery, and hazard mitigation before and after major disaster events, including review and recommendation of Hazard Mitigation Grant Program projects.
- MEMA, working with EOPSS and EOEEA, will be responsible for the SHMCAP 5-year update, and establishing the plan update schedule, milestones, and federal requirements.

Numerous stakeholders from local, regional, state, and federal government agencies, private-sector organizations, and others will be engaged in the ongoing plan maintenance

process. The primary method to engage these stakeholders is through the RMAAT, as described below. Additional methods for stakeholder engagement and coordination in support of plan maintenance are described in Section 8.3.

Resilient MA Action Team (RMAAT) Roles and Responsibilities

The RMAAT will be established after plan adoption to include representation from each Secretariat and key state agencies. The membership is anticipated to include staff at the EOEEA (particularly in the Climate Change Program), EOPSS, MEMA, A&F, DCR, CZM, Massachusetts Department of Environmental Protection, Department of Housing and Community Development, DCAMM, Massachusetts Department of Transportation, Massachusetts Bay Transit Authority, Department of Energy Resources, Department of Fish and Game, Division of Ecological Restoration, Department of Public Health, and others. The RMAAT will be chaired by the EOPSS or their representatives at MEMA and EOEEA.

The RMAAT will also include the Climate Change Coordinator and additional staff as needed from each Executive Office, as well as other key agency staff responsible for plan oversight and implementation—including those at the director or deputy commissioner level. The role and responsibilities of the RMAAT members include, but are not limited to, the following:

- Conduct and attend quarterly meetings, annual plan reviews, post-disaster reviews, and 5-year plan review and updates as scheduled.
- Coordinate within Executive Offices to track and facilitate the completion of annual implementation updates as required for all actions included in Chapter 7 of the SHMCAP.
- Support performing tasks required for effectively completing plan review and update procedures as described in Section 8.2.2, and ensure that as new data become available, they will be incorporated into the SHMCAP. New data may include technical reports or scientific studies on hazard/climate risks; local hazard mitigation and climate adaptation plans; and completed or updated vulnerability assessments from state agencies, cities and towns, regional planning entities, private entities, educational institutions, and other sectors.
- Provide outreach, technical assistance, stakeholder engagement, and other educational services that increase general awareness and understanding of the SHMCAP.
- Help ensure the current version of the SHMCAP and Commonwealth's resilient MA Climate Change Clearinghouse (<http://www.resilientma.org/>) is well publicized and socialized in the member's own agency or Executive Office, and area of subject matter.
- Coordinate the continuous enhancement of the SHMCAP through collaborative partnerships and the active engagement of key stakeholders, including representatives from municipalities, regional planning agencies, and others who play a role in supporting plan implementation through their own plans, policies, programs, or activities.

- Support incorporation into other state plans and programs as appropriate.

8.2.2 Method and Schedule

The key components of the method and schedule for regularly maintaining the SHMCAP include an annual plan review, a post-disaster review, and a 5-year plan review and update. Effective plan maintenance will also require additional routine or recurring activities that are not necessarily bound to specific methods or schedules, such as tracking and documenting new or best practices for hazard mitigation and climate adaptation, or new policies or procedures that may affect how the SHMCAP is implemented. It is expected that many of these ongoing activities will continue to be performed by members of the RMAAT, and will be further discussed during the regularly scheduled plan reviews described below.

Annual Plan Review

The SHMCAP will be reviewed annually to evaluate the progress made on actions included in the hazard mitigation and climate adaptation strategy, and to review and potentially amend the plan to reflect significant changes that took place during the preceding year. This annual review will take place in the month of August, and will be conducted by the RMAAT under the coordination of MEMA, EOEEA, and DCR.

The following tasks may be completed by the RMAAT during the annual plan review:

- Evaluate overall progress on hazard mitigation and climate adaptation actions, especially those identified as short-term actions. The most recent status updates provided by lead agencies and Executive Offices in the action tracker (which, as noted in Section 8.1.1, will be updated on an annual basis by lead agencies and Executive Offices) shall be reviewed and discussed to measure progress.
- Identify any problems or barriers associated with plan implementation (technical, administrative, financial, political, or legal), along with any required or recommended corrective actions.
- Examine any notable changes in the Commonwealth's risks or vulnerabilities related to natural hazards and climate change based on new data and information, updated climate change projections, or lessons learned through actual hazard occurrences. Special attention should be given to technical reports or scientific studies on hazard/climate risks; local hazard mitigation and climate adaptation plans; and completed or updated vulnerability assessments from state agencies, cities and towns, regional planning entities, private entities, educational institutions, and other sectors.
- Identify any major changes to federal or state laws, authorities, regulations, funding, or other measures that may necessitate revisions or amendments to the SHMCAP.

- Prepare an internal summary of the results and findings of the above tasks, in addition to any other notable updates to the general status and implementation of the SHMCAP. The summary may also highlight any proposed additions, amendments, or improvements required for the plan to increase its overall effectiveness.

If determined necessary, the RMAAT may amend the SHMCAP to reflect significant changes in information. This may include revisions to the data or conclusions presented in the risk assessment or state capability and adaptive capacity analysis, in addition to the policies, priorities, or procedures as presented in Chapter 7, as well as this chapter. If not urgent to handle through interim/annual amendments to the plan, these changes may be documented and recommended for the next 5-year plan review and update process. Another method may be to amend the plan, as appropriate, using annexes to document changes during the current plan approval period that can be more fully integrated during the next plan update cycle. The RMAAT will decide on the best procedures for documenting and making changes.

Post-Disaster Review

After each Presidential Disaster Declaration, the RMAAT and other stakeholders will convene as necessary to review specific hazard mitigation or climate adaptation needs and opportunities related to the disaster-affected area. This may be especially important in assisting with identifying any new hazard mitigation and climate adaptation priorities for the Commonwealth, and expediting the integration of specific actions with recovery efforts in impacted areas. It will also allow the RMAAT to amend the SHMCAP to reflect lessons learned, or to address specific circumstances arising from the disaster event; including, but not limited to, the prioritization of hazard mitigation and climate adaptation actions. This post-disaster review may replace an annual plan review in any year that a major disaster occurs if so determined by the State.

Five-Year Plan Review and Update

At least once every 5 years, this plan will undergo a comprehensive review, update, and re-adoption process as required by federal regulations for state hazard mitigation plans and Executive Order 569. The plan review and update process will be managed by MEMA and EOEEA. MEMA will manage the administrative details of the plan update process, including potentially securing external funding support through FEMA, contracting with outside consultants, coordination with FEMA, and plan submission. On completion, the updated plan will be submitted to the Governor for formal adoption, and to the FEMA Regional Administrator for final federal approval.

At a minimum, the plan must be reviewed and revised to reflect changes in development, progress in statewide mitigation or adaptation efforts, and changes in priorities. It must also incorporate information learned from implementing the plan and the experiences of state agencies, municipalities, and other partners or stakeholders in assessing and responding to

natural hazard and climate change vulnerability. This includes, but is not limited to, plan amendments or updates that were identified during annual plan reviews, but not yet incorporated.

During the 5-year plan review and update, the following questions will be considered by the RMAAT as key factors for assessing the effectiveness of the plan, and for identifying the most critical improvements or enhancements to be made during the process. Additional questions may be added as appropriate.

- Are the plan's goals and actions still representative of the Commonwealth's priorities?
- Has there been meaningful progress toward achieving the goals and in implementing the actions? Has the completion of actions resulted in expected outcomes?
- If the action was completed, did it have the intended results? Did the action help achieve plan goals? What factors contributed to the action's success? Are there next steps that must be taken to ensure optimal outcomes?
- If the action was not completed, what were the barriers to implementation? Should the action remain in the strategy for the updated plan?
- How can lessons/outcomes from implementation of these actions inform development and implementation of future strategies and actions to reduce risk and vulnerability?
- Are the current capabilities and resources of state agencies adequate to implement the plan as scheduled? If not, what are the key gaps or shortfalls?
- Have there been any changes to Federal or State laws, authorities, regulations, funding, or other measures that necessitate specific revisions or amendments to the plan?
- Have the threats and hazards of concern as characterized in the risk assessment changed? Are there new data, techniques, or approaches that must be integrated into the risk assessment?
- Has there been significant new or improved development in areas susceptible or exposed to the impacts of natural hazards and/or climate change?
- Have the procedures to routinely monitor, evaluate, and enhance the plan between 5-year update cycles been effective at keeping it a living document?

The 5-year plan review and update process will entail a detailed and structured re-examination of all aspects of the original plan, followed by recommended updates. The recommendations will be presented to the RMAAT and other identified stakeholders for consideration and approval. On completion, the results and outcomes of the process will be summarized and incorporated into the relevant sections of the updated SHMCAP in accordance with the latest planning guidance or requirements from the Governor, Climate Change Coordinators, and FEMA. This includes a

comprehensive description of the plan update process, in addition to any revisions or updates to existing plan chapters as required.

Annual Consultation with FEMA

In addition to the regularly scheduled plan reviews identified above, MEMA and DCR will coordinate with FEMA to host an annual collaborative meeting to help inform updates to the SHMCAP. Per FEMA's State Mitigation Program Consultation program, the agency provides technical assistance to states in reviewing activities, plans, and programs to help ensure hazard mitigation commitments are fulfilled. The agenda and specific scheduling arrangements will be done in coordination with FEMA, with the meeting scheduled as close to the Commonwealth's annual plan reviews as possible.

After each year's consultation is completed, FEMA will prepare a State Mitigation Program Consultation summary to describe mitigation program strengths, specific challenges to advancing mitigation, and opportunities for improving mitigation capabilities.

2018-2023 Plan Maintenance Schedule

The plan maintenance methods outlined above will be conducted in accordance with the schedule in Table 8-1. The 60-month time frame will help to ensure that the 2023 SHMCAP update can be prepared, adopted, and published within the required 5-year period.

Table 8-1: General Schedule for Plan Maintenance, 2018–2023

Task	Responsibility	Month/Year
Final SHMCAP Published	MEMA, EOEEA, and DCR	September 2018
Quarterly RMAAT Meetings	RMAAT	December 2018 March 2019 June 2019 September 2019
Annual Implementation Updates (<i>Action Tracker</i>)	All Lead State Agencies	May 2019
Annual Plan Review	RMAAT	August 2019
Summary of Progress	EOEEA	September 2019
Annual Consultation with FEMA	MEMA, DCR, EOEEA, and FEMA	4 th Quarter 2019
Quarterly RMAAT Meetings	RMAAT	December 2019 March 2020 June 2020 September 2020
Annual Implementation Updates (<i>Action Tracker</i>)	All Lead State Agencies	May 2020
Annual Plan Review	RMAAT	August 2020
Summary of Progress	EOEEA	September 2020

Task	Responsibility	Month/Year
Annual Consultation with FEMA	MEMA, DCR, EOEEA, and FEMA	4 th Quarter 2020
Quarterly RMAAT Meetings	RMAAT	December 2020 March 2021 June 2021 September 2021
Annual Implementation Updates (Action Tracker)	All Lead State Agencies	May 2021
Annual Plan Review	RMAAT	August 2021
Summary of Progress	EOEEA	September 2021
Annual Consultation with FEMA	MEMA, DCR, EOEEA, and FEMA	4 th Quarter 2021
Quarterly RMAAT Meetings	RMAAT	December 2021 March 2022 June 2022 September 2022
Annual Implementation Updates (Action Tracker)	All Lead State Agencies	May 2022
5-Year Plan Review and Update	RMAAT	September 2021 – September 2023
Summary of Progress	EOEEA	September 2022
Annual Consultation with FEMA	MEMA, DCR, EOEEA, and FEMA	4 th Quarter 2022
Quarterly RMAAT Meetings	RMAAT	December 2022 March 2023 June 2023 September 2023
Final SHMCAP Update (2023) Published	RMAAT	September 2023

8.3 Stakeholder Engagement and Coordination

Active stakeholder engagement is an integral component to developing the SHMCAP, and will continue to be essential as this plan evolves and is updated over time.

The most appropriate and meaningful opportunities for stakeholders to be involved in the maintenance and implementation of the plan occur during the 5-year plan review and update process. Stakeholders can play a role in helping to identify pathways for implementation of the plan, including opportunities for public-private partnerships, access to new data and techniques, and other catalysts that can speed implementation. Stakeholder engagement in this process will be solicited by members of the RMAAT through multiple means, and as similarly done for development of the plan, as resources permit. As demonstrated in *Chapter 9: Planning Process*, the Commonwealth has been proactive in seeking widespread stakeholder involvement through multiple methods, including numerous public meetings and workshops throughout the process that involve a cross-section of representatives from across the state. Future methods and opportunities to continue or enhance this engagement will be explored and determined by the RMAAT as part of the 5-year plan review.

In addition, while the 5-year plan review and update process represents the greatest opportunity for continued engagement, additional efforts to involve stakeholders in the plan maintenance process will continue to be developed and refined as necessary. These efforts may include, but are not limited to, the following:

- Maintaining and publicizing the availability of the SHMCAP for review through multiple methods, including the ability to submit comments or questions regarding the plan at any time using the online plan platform on the resilient MA website. This website will make the SHMCAP available as a downloadable PDF, but will be enhanced over the next 5 years for a more dynamic user experience.
- Advertising regularly scheduled meetings of the RMAAT with the potential of accommodating additional guests, providing speaking or presentation opportunities, or other means of participation.
- Creating a SHMCAP listserv for stakeholders who express an interest in keeping up with relevant news as it pertains to the implementation and maintenance of the plan.
- Delivering formal updates or presentations on the status of the SHMCAP at relevant professional conferences, seminars, or other forums of exchange.
- Developing active partnerships with municipalities, regional planning agencies, academic institutions, businesses, non-profit organizations, and other entities who share a mutual interest in advocating for and implementing effective hazard mitigation and climate adaptation strategies.

- Hosting an annual “Resilient MA Summit” or similar event to share updates and gather input from stakeholders on the implementation of the SHMCAP and other related initiatives of the Commonwealth. This event could be used to bring together a cross-section of representatives from various sectors to assist the RMAAT in identifying potential plan updates and enhancements. Attendance should be broad and inclusive to representatives from state agencies, municipalities, regional planning agencies, businesses, universities, non-profit organizations, FEMA, and other federal agencies. In addition to helping to improve the SHMCAP, such an event could benefit these other stakeholder organizations as their representatives return, and bring with them plan knowledge and tools to update their own resiliency plans or activities.

In summary, although the 2018 SHMCAP will be submitted and adopted in the fall of 2018, the planning process itself is continuous, and focused on plan implementation, maintenance, and iteration, which largely will occur in the period between September 2018 and the next 5-year plan update, due September 2023.

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9. Planning Process

This chapter provides a summary of the process used to develop this State Hazard Mitigation and Climate Adaptation Plan (SHMCAP), including how it was prepared and who was involved. It also describes the stakeholder outreach and engagement strategy that was developed and implemented for the SHMCAP, and provides an overview of the state agency vulnerability assessment process that was integrated into the plan. Note that state agency program integration is more fully addressed in *Chapter 6: State Capability and Adaptive Capacity Analysis*.

9.1 Overview

The Massachusetts Emergency Management Agency (MEMA) of the Executive Office of Public Safety and Security, in partnership with the Executive Office of Energy and Environmental Affairs (EOEEA), issued a Request for Response in December 2016 to secure a vendor to support development of an integrated SHMCAP. A consulting team led by AECOM won the competitive procurement and was hired by the Commonwealth in March 2017. Although there have been efforts at the municipal level to embed climate adaptation considerations into local hazard mitigation plans, the Commonwealth is the first state to officially integrate these two types of plans at a statewide level. This new planning framework will allow the Commonwealth to address climate change and natural hazards together in a comprehensive way, while charting a course that municipalities and other states can follow.

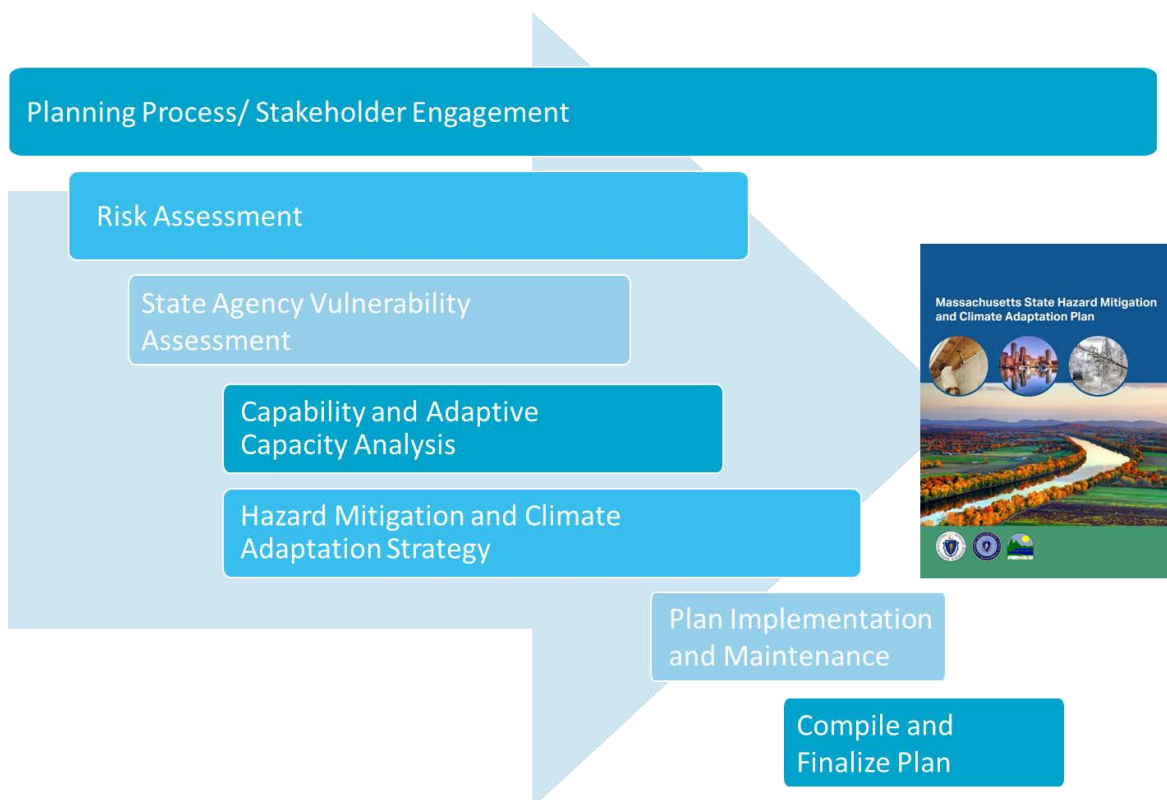
The AECOM consulting team was tasked to work closely with MEMA and EOEEA in preparation of a plan that is in full compliance with current Federal Emergency Management Agency (FEMA) planning requirements, per the following rules, regulations, and guidance:

- Robert T. Stafford Disaster Relief and Emergency Assistance Act (Public Law 93-288), as amended by the Disaster Mitigation Act of 2000
- Code of Federal Regulations – Title 44, Part 201 (§201.4 Standard State Mitigation Plans)
- FEMA State Mitigation Plan Review Guide (FP 302-094-2, March 2016)

This plan was also developed to be compliant with Executive Order 569 *Establishing an Integrated Climate Change Strategy for the Commonwealth*, which was issued by Governor Charlie Baker in September 2016. One of the Executive Order 569 requirements is to develop and publish a statewide Climate Adaptation Plan, which this SHMCAP satisfies.

Furthermore, the SHMCAP was prepared to satisfy applicable Emergency Management Accreditation Program standards, including *Standard 4.1 Hazard Identification, Risk Assessment, and Consequence Analysis* and *Standard 4.2 Hazard Mitigation*.

The Commonwealth's planning process included the completion of seven key tasks over the course of approximately 18 months (March 2017 to September 2018), as illustrated on Figure 9-1. A detailed project schedule is included in Appendix E. The completion of each key task resulted in critical outcomes and products that collectively were incorporated into the SHMCAP. Several of these tasks are summarized and included as separate chapters of the plan, each of which is introduced and further described in *Chapter 1: Introduction and Assurances*.

Figure 9-1: State Hazard Mitigation and Climate Adaptation Planning Process

On March 30, 2017, the Commonwealth held a SHMCAP kickoff meeting with its consulting team to discuss the goals and objectives of the project; review roles and responsibilities of the Project Management Team (PMT) and other key stakeholders; and review the scope of work and overall project approach and schedule. Input received from this kickoff meeting was incorporated into the Final Project Work Plan, which served as a guide for the project and the overall planning process.



One of the earliest tasks completed in support of the planning process was the creation of a Project Management Team (PMT) to help guide and inform the plan throughout its development. A SHMCAP kickoff meeting with the PMT and consulting team was held on March 30, 2017.

9.2 Project Management Team

One of the earliest tasks completed in support of the planning process was the creation of a PMT to help guide and inform the plan throughout its development. The PMT was co-chaired by the MEMA State Hazard Mitigation Officer and Massachusetts EOEEA Assistant Secretary of Climate Change, and it included representatives from numerous state agencies to allow representation of a variety of State interests and perspectives on hazard mitigation and climate adaptation. Throughout the planning process, PMT members were asked to provide their input and expertise, including any information, ideas, or resources that would contribute to the quality and effectiveness of the plan. A complete listing of all SHMCAP members is provided in Table 9-1.

In addition to helping shape and guide the development of the plan, the PMT members were invited and asked to provide support to the planning process through the following key roles and responsibilities:

- Attend multiple PMT meetings (in-person meetings, as well as conference calls).
- Support stakeholder outreach and engagement efforts.
- Identify opportunities to increase awareness and integrate the SHMCAP into other State planning efforts.
- Provide supporting data and information.
- Assist in the evaluation and prioritization of hazard mitigation and climate adaptation actions.
- Review and comment on draft plan deliverables.
- Endorse final draft plan prior to submission to FEMA.

Table 9-1: Massachusetts State Hazard Mitigation and Climate Adaptation Project Management Team (PMT)

Name	Affiliation
Jeremy Caron	Division of Capital Asset Management and Maintenance
Brian Domoretsky	Executive Office of Public Safety and Security
Beth Dubrawski	Massachusetts Emergency Management Agency
Joy Duperault	Department of Conservation and Recreation (Flood Hazard Management)
Kurt Gaertner	Executive Office of Energy and Environmental Affairs
Marybeth Groff	Massachusetts Emergency Management Agency
Julia Knisel	Office of Coastal Zone Management
Will Lauwers	Department of Energy Resources
Thad Leugemors	Massachusetts Emergency Management Agency
Margot Mansfield	Office of Coastal Zone Management
Sally Miller	Division of Capital Asset Management and Maintenance
Steve Miller	Massachusetts Department of Transportation
Shelly O'Toole	Massachusetts Emergency Management Agency
Kristen Patneau	Department of Energy Resources
Marybeth Riley-Gilbert	Massachusetts Bay Transportation Authority
Margaret Round	Department of Public Health
Shannon Sullivan	Executive Office of Public Safety and Security
Katie Theoharides (Co-Chair)	Executive Office of Energy and Environmental Affairs
Sarah White (Co-Chair)	Massachusetts Emergency Management Agency

A secure SHMCAP SharePoint site was established for the project. All PMT members were provided access to this site, which was used as a clearinghouse to facilitate data sharing and coordinate review of key draft project deliverables. Over the course of the project, biweekly project management conference calls were conducted between the PMT Co-Chairs and the consulting team to track the project schedule and deliverables, and identify PMT support needs, and weekly project status reports were submitted to the PMT Co-Chairs to document project progress and identify information needs.

9.3 Secretariat Climate Change Coordinators

In addition to the PMT, Secretariat “Climate Change Coordinators” were established early in the planning process, in response to Executive Order 569, to further facilitate strong inter-agency coordination and contributions to the SHMCAP. A Climate Change Coordinator was identified for each Executive Office that oversees the programs and services offered by the state agencies. Table 9-2 lists the Executive Offices and the respective Climate Change Coordinators.

Table 9-2: Secretariat Climate Change Coordinators

Executive Office	Climate Change Coordinator
Executive Office of Administration and Finance	Jennifer Sullivan
Executive Office of Education	B. Kim
Executive Office of Energy and Environmental Affairs	Katie Theoharides
Executive Office of Health and Human Services	Michael Kelleher and Robert Jones
Executive Office of Housing and Economic Development	Genevieve McLaughlin
Executive Office of Labor and Workforce Development	William McKinney
Executive Office of Public Safety and Security	Brian Domoretsky and Shannon Sullivan
Massachusetts Department of Transportation	Katherine Fichter
Executive Office of Technology Services and Security	Laurie Pessah

The Climate Change Coordinators served as the primary conduits for information exchange with state agencies during the project, and aided in coordination of draft deliverable reviews and executive-level approvals for final plan content. They were also tasked with signing off on the state agency vulnerability assessments conducted as part of the SHMCAP (see Section 9.5 for additional information).

9.4 Stakeholder Outreach and Engagement

The SHMCAP planning process included a robust stakeholder outreach and engagement strategy that was designed to generate project interest and input from a variety of stakeholders, including and beyond State government (general public, local and regional government, nonprofit, private sector, academia, institutional, and others). These stakeholders represented various sectors across the Commonwealth, including emergency management, economic development, land use and development, housing, health and social services, infrastructure and utilities, and natural and cultural resources.

The stakeholder outreach and engagement strategy was designed to solicit meaningful input and feedback during the plan development process; and ultimately, a broad and diverse audience was involved in the creation of the Commonwealth's first SHMCAP. A list of organizations, agencies, and other stakeholders involved and engaged in the planning process is provided in Appendix E. This strategy included specific opportunities and methods for stakeholders to participate at various points in the planning process. Table 9-3 summarizes several meetings, trainings, and workshops that were conducted as part of the stakeholder outreach and engagement strategy; and Figure 9-2 identifies the locations of these events across the Commonwealth. Appendix E provides additional supporting documentation, including a sample

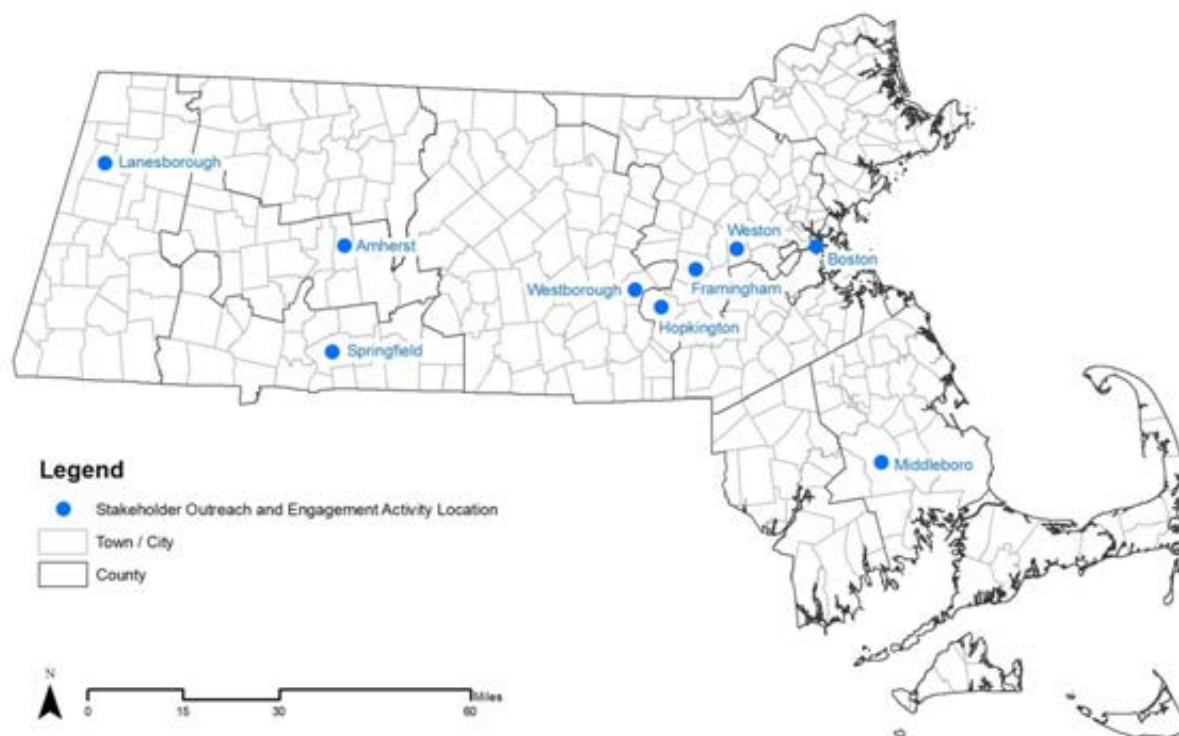
presentation and a detailed project schedule. The Commonwealth has retained supporting documentation of meeting sign-in sheets, notes, and other materials as a permanent record.

Table 9-3: Summary of Stakeholder Engagement Events

Activity	Date	Location	Description	Estimated Attendance
Stakeholder Workshop Series #1: SHMCAP Kickoff	August 2, 2017 August 25, 2017	Westborough, MA Amherst, MA	Engaged stakeholders from several disciplines to provide an overview of the plan and to describe the planning process. Included plenary sessions, as well as small group engagement sessions where facilitators encouraged participants to identify issues and objectives that should be considered in the planning process.	158
State Agency Vulnerability Assessment Training	October 25, 2017	Framingham, MA	Provided training to state agencies on completion of the vulnerability assessment survey that was prepared as part of the SHMCAP.	55
Earthquake Stakeholder Meeting	November 15, 2017	Weston, MA	Provided an overview of the SHMCAP earthquake risk assessment and discussion of possible mitigation actions.	11
Massachusetts Ecosystem Climate Adaptation Network (MassECAN) Conference	November 30, 2017	Westborough, MA	The MassECAN network was launched at this conference. Attendees participated in a module that provided natural resources feedback to be incorporated into the SHMCAP plan.	More than 100
Stakeholder Workshop Series #2: Summary of Draft Risk Assessment and Hazard Mitigation and Climate Adaptation Goal Development	January 9-11, 2018	Springfield, MA Framingham, MA Middleboro, MA	Presented results of the Draft Risk Assessment and solicited input for development of goal statements for the SHMCAP Hazard Mitigation and Climate Adaptation Strategy.	112
State Agency Action and Strategy Development Workshop	April 5, 2018	Boston, MA	Presented a summary of draft results from the State Agency Vulnerability Assessments and State Capacity and Adaptive Capacity Analysis. Also presented the draft goal statements and solicited input on state agency actions to include in the SHMCAP.	67
Stakeholder Workshop Series #3: Hazard Mitigation and Climate Adaptation Action Development	April 9, 2018 April 12-13, 2018	Boston, MA Hopkinton, MA Lanesborough, MA	Presented the draft goal statements and solicited input on state agency actions to include in the SHMCAP.	125
State Agency	May 15,	Boston, MA	Provided training to state agencies on	15

Activity	Date	Location	Description	Estimated Attendance
Vulnerability Assessment Training	2018		completion of the vulnerability assessment survey that was prepared as part of the SHMCAP.	
In-Person State Agency Vulnerability Assessment Support	May 16-17, 2018 May 22, 2018	Boston, MA	Offered in-person consultations with the SHMCAP consulting team to state agencies to answer questions and assist in completion of the online State Agency Vulnerability Assessment Survey and resulting report.	9

Figure 9-2: Geographic Locations of Key Stakeholder Outreach and Engagement Events



In addition to capturing input and feedback on the SHMCAP, the Commonwealth's stakeholder outreach and engagement strategy also sought to increase general awareness of the plan development process, and integrate it with other State planning efforts. This was done by sharing regular updates on the process with the Governor's Office, state agencies, and state legislators, in addition to providing informative reports or presentations as opportunities were identified by the PMT. Table 9-4 summarizes events where formal SHMCAP presentations were made at a variety of other meetings and conferences across the state.

Table 9-4: Summary of State Hazard Mitigation and Climate Adaptation Plan Presentations

Event	Date	Estimated Attendance
National Association for Industrial and Office Parks (NAIOP) Climate Change Panel	February 2017	More than 150
Endicott College Sustainability Conference	March 17, 2017	50
Cape Cod Climate Change Commission Meeting	March 22, 2017	10
Society of Civil Engineers Spring Meeting	March 25, 2017	More than 200
Woods Hole Research Institute Meeting	May 8, 2017	10
Northeast Climate Change Science Center Regional Meeting	May 16, 2017	More than 200
Massachusetts Silver Jackets Meeting	May 17, 2017	23
EOEEA Environmental Stakeholders Meeting	June 21, 2017	15
Using Green Infrastructure to Improve Drought Resilience Workshop	June 26, 2017	50
Climate Resiliency and Utilities Meeting (National Grid)	August 3, 2017	NA
Climate Week / Municipal Vulnerability Preparedness Announcement with Governor Baker	September 12, 2017	More than 150
EOEEA Environmental Stakeholders Meeting	October 12, 2017	NA
Massachusetts All Hazards Emergency Preparedness Conference	November 1, 2017	More than 100
Great Marsh Symposium	November 9, 2017	More than 150
Climate Change Council / City of Cambridge	November 28, 2017	NA
Environmental Business Council / University of Massachusetts Climate Change Adaptation Forum	January 17, 2018	More than 200
Massachusetts Bays Management Committee	January 24, 2018	25
Plymouth Southern Pine Barrens Meeting	March 19, 2018	25
Central Massachusetts Regional Planning Commission Spring Legislative Affairs Breakfast	May 18, 2018	NA
Martha's Vineyard Coastal Conference	June 6, 2018	150
Mystic Watershed Steering Committee Meeting	June 14, 2018	30

The following sections provide detail on two key elements of the SHMCAP stakeholder outreach and engagement strategy: the project website, and the stakeholder workshop series.

9.4.1 Project Website

At the beginning of the planning process, the PMT worked closely with the consulting team to develop a project website, which was launched in May 2017 as <https://resilientma.com/>. The main objectives of the website included:

- Serve as the online home for all public-facing project-related materials.
- Communicate key project updates and important workshop dates to stakeholders.
- Broadcast draft deliverables available for public review and comment.
- Direct stakeholders to online surveys and worksheets developed to solicit input for the SHMCAP.
- Provide resources for state agencies completing a vulnerability assessment as part of the project.

The project website was publicized at all stakeholder events, and the web address was included in presentations and handout materials to enable easy access. It was well-received and frequently used by stakeholders to keep informed about the SHMCAP project progress. As of August 2018, the project website had received approximately 13,900 views from more than 3,900 visitors.

The project website will be closed at the end of the SHMCAP project in September 2018, and the final plan materials will be hosted on the Commonwealth's resilient MA Climate Change Clearinghouse (<http://www.resilientma.org/>), which serves as a gateway to data and information relevant to climate change adaptation and mitigation and natural hazard



The SHMCAP project website served as the main online presence for the project, and was an integral part of the stakeholder outreach and engagement program. As of August 2018, the project website received approximately **13,900 views** from more than **3,900 visitors**.



The Final SHMCAP and future updates of the plan will be hosted on the Commonwealth's resilient MA Climate Change Clearinghouse, which serves as a gateway to data and information relevant to climate change adaptation and mitigation across the state.

mitigation across the state. The resilient MA website will be the home for the online version of the 2018 SHMCAP, as well as future updates to the plan.

9.4.2 Stakeholder Workshop Series

A key component of the 2018 SHMCAP stakeholder outreach and engagement program was the development and implementation of three stakeholder workshop series to inform stakeholders about the project and to solicit input at key stages of the planning process to inform the plan development. The workshops were designed and facilitated by the PMT and the consulting team, and were conducted at multiple locations across the Commonwealth to engage stakeholders from a variety of geographic areas and interest groups (see Table 9-3 and Figure 9-2). Descriptions of the three workshop series are provided in the following sections.

Stakeholder Workshop Series #1: SHMCAP Kickoff

The first stakeholder workshop series was conducted in August 2017 in Westborough, Massachusetts, and Amherst, Massachusetts, and served as the official public kickoff for the plan. This workshop series was organized to accomplish two main objectives over the course of a 3-hour workshop: (1) introduce stakeholders to the SHMCAP project and related efforts, and (2) obtain early stakeholder feedback on important issues to address in the plan. Matthew Beaton, EOEEA Secretary, provided introductory remarks, and the following topics were presented:

- Executive Order 569 Overview and Status Update (Katie Theoharides, EOEEA)
- Overview of the SHMCAP (Sarah White, MEMA)
- Climate Change Projections for Massachusetts (Ambarish Karmalkar and Richard Palmer, Northeast Climate Adaptation Science Center – University of Massachusetts Amherst)

Small group engagement sessions were then conducted on the following topics to obtain feedback and suggestions from the stakeholders:

- Group 1: State Capabilities and Adaptive Capacity – Identify important policies, programs, regulations, and other issues to review for the state capability and adaptive capacity analysis portion of the SHMCAP.



The first stakeholder workshop series was attended by almost 160 diverse stakeholders and yielded key input early in the planning process to guide development of the SHMCAP.

- Group 2: Extreme Weather Events and Other Hazards – Identify the major issues, as well as the data and information that managers and decision-makers need, and how these hazards interact with climate change.
- Group 3: Man-made Hazards – Discuss how to best account for man-made hazards in the SHMCAP.
- Group 4: Climate Change Variables (Temperature and Precipitation) – Obtain feedback on these key climate variables and parameters.
- Group 5: Inland Flooding and Precipitation – Identify the major issues and what data and information managers and decision-makers need for these variables.
- Group 6: Coastal Flooding and Sea Level Rise – Identify the major issues and what data and information managers and decision-makers need for these variables.
- Group 7: Public Health Stressors – Obtain input on how to incorporate public health risks into the SHMCAP.
- Group 8: Environmental Stressors – Obtain input on how to incorporate environmental stressors, such as toxics, invasive species, and habitat loss, into the SHMCAP; and examine the intersecting role of environmental stressors and climate change.

[Stakeholder Workshop Series #2: Summary of Draft Risk Assessment and Hazard Mitigation and Climate Adaptation Goal Development](#)

The second workshop series was held in three locations in January 2018: Springfield, Framingham, and Middleborough. The primary purpose of this workshop series was to seek input from stakeholders to aid in the development of goal statements for the SHMCAP's hazard mitigation and climate adaptation strategy. Preliminary results of the risk assessment conducted for the plan were also presented to provide context for goal development. The workshop format included two breakout group sessions: the first identifying key concepts for goal statements; and the second developing the goal statements. For the first breakout group session, key concepts for goal statements were gathered in the following four categories (these categories represent FEMA's hazard mitigation action categories):

1. Institutional Capacity, Plans and Regulations
2. Structure and Infrastructure
3. Natural Systems Protection
4. Education and Awareness Programs

Participants were organized into five stakeholder groups (aligning with the five main sectors evaluated in the SHMCAP's risk assessment) according to their expertise:

1. Government
2. Built Environment
3. Natural Systems/Environment
4. Vulnerable Populations
5. Economy

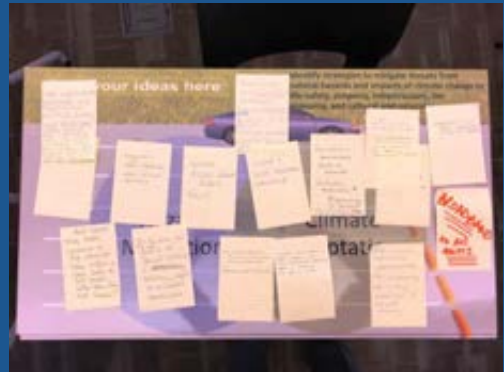
Each stakeholder group developed key concepts for goal statements for the four action categories.

The second breakout group session mixed participants from the different stakeholder groups, which led to the development of goal statements in each of FEMA’s hazard mitigation action categories. In addition, “Parking Lot Bulletin Boards” were used, where participants could leave their ideas for specific strategies for mitigating threats from natural hazards and impacts of climate change to life safety, property, infrastructure, the economy, and cultural and natural resources.

Following the workshops, the consulting team and the PMT evaluated the proposed goal statements; and over several weeks, consolidated them into the five goal statements presented in this plan. Ideas were gathered from diverse geographic locations and from a diverse group of stakeholders.

Stakeholder Workshop Series #3: Hazard Mitigation and Climate Adaptation Action Development

The third workshop series was held in April 2018 in Boston, Hopkinton, and Lanesborough. The purpose of this series was to present updated findings on the risk assessment that was conducted as part of the SHMCAP, and to gather actions to meet the vision of the goal statements that were previously developed based on input from Stakeholder Workshop Series #2 and the PMT. Actions were developed in one breakout group session at each workshop using Action Proposal Worksheets and risk assessment conclusions to guide conversation. Information requested on the Action Proposal Worksheet included title and description of action, hazards addressed, potential cost and funding source, and lead state agency.



The second stakeholder workshop series resulted in feedback that was crafted into the SHMCAP goal statements, as well as early ideas for strategies and actions to respond to identified risks and vulnerabilities.

The Action Proposal Worksheet was also provided as a Google Form. The link to the online version of the worksheet was advertised with the workshops and made available on the project website as another method for stakeholders to contribute action ideas, even if they could not attend the workshops. Following this workshop series, content from the hard copies of completed worksheets was entered into the Google Form and downloaded to a master SHMCAP Proposed Actions Google Sheet. Ultimately, several hundred Action Proposal Worksheets were completed by state agencies and stakeholders across the Commonwealth.

A version of this workshop was conducted for state agencies in Boston on April 5, 2018, which was attended by almost 70 representatives from a variety of state agencies from different Executive Offices. In addition to the hazard mitigation and climate adaptation action development activity, findings from the state agency vulnerability assessment survey (Section 9.5) and an overview of the state capability and adaptive capacity analysis (Chapter 6) were presented.



The third stakeholder workshop series was focused on development of proposed hazard mitigation and climate adaptation actions to be considered for inclusion in the SHMCAP. Several hundred actions were proposed by state agencies and stakeholders across the Commonwealth.

9.5 State Agency Vulnerability Assessment Survey

Executive Order 569 directs the Executive Branch to lead by example to combat and prepare for the impacts of climate change. A key requirement of Executive Order 569 is completing state agency vulnerability assessments that will identify vulnerabilities to climate change and natural hazards. The assessments are intended to provide the basis for the development of agency-specific priority actions so that the Commonwealth can lead by example in strengthening its resiliency and preparedness to climate change and extreme events.

To aid in satisfying this requirement, a State Agency Vulnerability Assessment Survey Tool was developed as part of the SHMCAP project. The tool was designed by the consulting team in coordination with the PMT to help state agencies identify vulnerabilities to climate change and natural hazards, and it includes five key sections:

1. An overview of the agency's mission, along with a summary of its critical assets, functions (i.e., programs or services), and population groups served;

2. Identification and agency confirmation of natural hazards and climate change impacts that will affect its critical items;
3. Assessment of the agency's sensitivity to anticipated future climate conditions;
4. Assessment of the agency's adaptive capacity to natural hazards and climate change; and
5. Assessment of the agency's vulnerability to climate change and natural hazards.

The tool was in the form of an online survey, and incorporated a login function for security purposes.

In-person state agency vulnerability assessment survey training sessions were conducted by the PMT and consulting team on October 25, 2017 and May 15, 2018 in Framingham and Boston, respectively, to provide detailed instructions and a demonstration of how to use the survey tool. The training was recorded and shared online for subsequent use by state agencies. Additional opportunities for in-person and remote consultations with the consulting team were also offered to aid agencies in completion of their survey. Some agencies conducted their own internal workshops and trainings for staff as part of the process. Resources such as maps, climate change data, and a Microsoft Word version of the survey were provided to agencies to facilitate their assessments, and made available on the project website. The Microsoft Word version of the survey is provided in Appendix E.

The survey process required the Secretariat Climate Change Coordinators to identify and work with agency points-of-contact to facilitate survey distribution and to obtain a broad representation of answers from various divisions/offices. Each agency was also asked to review natural hazard and climate change primer material provided by the PMT and consulting team to become familiar with current/future climate change impacts, and to consider how these may impact their assets and mission. Following completion of each agency assessment, the respective Secretariat Climate Change Coordinators were asked to review the assessment for quality and completeness prior to submittal of the survey.

A predefined vulnerability assessment report was generated for each state agency that completed the online survey, using the responses that were submitted by the agency. These reports summarize an agency's mission; priority concerns regarding natural hazards and climate change;

The image shows a screenshot of the 'Massachusetts Agency Vulnerability Assessment Survey' form. The form is titled 'Section I: General Agency Information' and includes instructions for identifying critical assets. It contains several numbered sections with input fields and checkboxes:

- 6. Critical Physical/ Non-Physical Assets**: A text input field for listing up to 10 critical assets.
- 7. Reason for criticality**: A dropdown menu with options: 'Number of people served', 'Length of time an asset/function can be inoperable without consequences', 'Provides critical services', 'Supports critical infrastructure', and 'Impacts vulnerable population'.
- 8. If known, identify any critical threshold(s)**: A text input field for identifying thresholds that could disrupt normal operations.
- 9. Street address if available, or lat/long coordinates**: A text input field.
- 10. Municipality**: A text input field.
- 11. Who owns / manages the asset?**: A text input field.
- 12. If another agency, provide the point of contact**: A text input field.
- 13. Do you want to add another asset?**: Radio buttons for 'Yes' and 'No'.

Below the form, a progress bar indicates the survey is approximately 25% complete.

The state agency vulnerability assessment process used a custom online survey developed as part of the SHMCAP project. Approximately 80 state agencies completed the survey by the time the 2018 SHMCAP was finalized.

critical assets, functions, and population groups for an agency; capability and adaptive capacity related to hazard mitigation and climate change adaptation; and vulnerability scores for each critical item that was self-assessed to aid in prioritization of agency initiatives going forward.

Aligning the state agency vulnerability assessment requirement with development of the SHMCAP resulted in extensive coordination with most of the Commonwealth's state agencies, and direct integration of the assessment results into several elements of the plan, including the government sector of the risk assessment, state capability and adaptive capacity analysis, and hazard mitigation and climate adaptation strategy.



10. Coordination of Local Hazard Mitigation and Climate Adaptation Planning

10.1 Funding and Technical Assistance

10.1.1 Local Hazard Mitigation Planning

For more than 2 decades, the Massachusetts State Hazard Mitigation Team (SHMT) has provided grant funding and technical assistance to support the development of local mitigation plans and a comprehensive mitigation program that includes mitigation project grants.

MITIGATION PLAN PREPARATION

The Commonwealth provides funding to municipalities and regional planning agencies (RPAs) through federal planning grants for the preparation of local and multi-jurisdictional hazard mitigation plans.

Most communities in Massachusetts do not have the capacity to develop hazard mitigation plans without funding or technical assistance, and therefore, the SHMT developed a strategy consistent with the Disaster Mitigation Act of 2000 (DMA 2000) to fund RPAs through the Pre-Disaster Mitigation (PDM) grant program and post-disaster funding available for hazard mitigation planning through the Hazard Mitigation Grant Program (HMGP). The RPAs have professional planners on staff with extensive knowledge of the communities in their regions. Although most communities engage the RPAs to prepare their hazard mitigation plans, some communities apply through the State to the Federal Emergency Management Agency (FEMA) for funding to conduct their own planning process, or to hire a contractor to assist with plan preparation. Communities may also develop mitigation plans using other internal or external sources of funding. The SHMT works with these communities to assist them through the planning process. Plans are integrated with any multi-jurisdictional or regional mitigation plan in place to remain consistent across the state.

TECHNICAL ASSISTANCE

Mitigation Plan Preparation

The Commonwealth has a full-time mitigation planner who provides technical assistance to municipalities and RPAs that are developing hazard mitigation plans. In addition to receiving technical assistance from the Massachusetts Emergency Management Agency (MEMA), the RPAs provide direct assistance to municipalities. The mitigation planner is responsible for coordinating the update of the State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) in accordance with DMA 2000 requirements.

In support of enhanced planning initiatives statewide, MEMA and Department of Conservation and Recreation (DCR) staff provide local communities with varying types of technical assistance across mitigation planning areas. This assistance includes site visits and meetings, workshops and trainings, and templates and resources. The State provides technical assistance throughout the process in a range of both process-related and content-related mitigation planning areas. At the beginning of a plan development or update, MEMA and DCR staff provide templates and information to assist each jurisdiction. Providing samples of previously approved annexes, plans, and templates has proven to be effective for many jurisdictions, especially those who were new to planning. Providing regular, diverse technical assistance and educational opportunities enables staff to reach a broad audience and increases awareness and understanding of mitigation planning. The State also uses social media to increase public awareness of trainings and events. Tables 10-1 and 10-2 list the types and areas of technical assistance the Commonwealth provides for mitigation planning.

Table 10-1: Types of Technical Assistance provided by the Commonwealth for Mitigation Planning

Type of Technical Assistance	
<ul style="list-style-type: none"> • Site visits—one-on-one or planning teams • Workshops and trainings, such as G318 mitigation planning and Hazus training • Attendance at kickoff meetings • Phone and conference calls • Web-based meetings • Emails and other written correspondence • Written correspondence 	<ul style="list-style-type: none"> • Classroom settings • Attendance at public meetings and workshops • Samples and templates provided at the beginning of the plan development or update process, including the plan review guide, STAPLEE worksheets, Resolution for adoption, National Flood Insurance Program (NFIP) guidelines/requirements, public meeting notice, and newspaper ads announcing community meetings • Publications, such as MEMA's info bulletins and newsletters, which are distributed regularly

Table 10-2: Areas of Technical Assistance provided by the Commonwealth for Mitigation Planning

Mitigation Planning Area	
<ul style="list-style-type: none"> • Community Rating System (CRS) and Insurance Services Office (ISO) support and interface • Update versus new plan—Differences between the two, and what is needed? • Kickoff meetings—Detailed process involved • Public meetings—what fulfills this requirement? • Meeting with local planning teams to assist with issue resolution • Mitigation strategy development • Gaining public input and participation • Risk analysis • Capabilities assessment • Hazus development • Flood Mitigation Assistance program to develop local flood mitigation plans 	<ul style="list-style-type: none"> • Data gathering, sources • Geographic information system mapping • Benefit-cost analysis development/training • Planning team development—who should be involved? • NFIP requirements • Repetitive Loss and Severe Repetitive Loss properties • Funding sources • Coordination with local planning mechanisms—what should be included? • Review of plan drafts under development to handle any issues the jurisdiction experiences immediately, rather than waiting until the plan is completed

MEMA Mitigation Planning and All Hazards Planning Units are working together to develop a new risk ranking concept that will standardize risk terminology across planning efforts. This will entail training by MEMA staff in a workshop-type session. MEMA has compiled a list of man-made hazards and cross-checked this with multiple plans to ensure common language across plans. MEMA is currently in the process of assisting with the Threat and Hazard Identification and Risk Assessment update, which is due in December of 2018.

The Commonwealth has developed a number of new hazard-specific studies, such as a landslide study, Division of Capital Asset Management and Maintenance master plan, Office of Coastal Zone Management erosion maps, and a fluvial geomorphic assessment to identify areas prone to fluvial erosion. This information will become available for future local and state-level plan updates.

Another concept that MEMA has considered is the development of a hazard mitigation user's group that would meet quarterly, and be led by the Commonwealth's Hazard Mitigation Planning Coordinator. The meetings would be an exchange for best-practice discussions among partners developing plans. The intent behind this user's group concept is to exchange information concerning areas of difficulty where planners have developed innovative ideas, or to gain information on how to address specific plan areas with which they are having difficulties.

The Municipal Vulnerability Preparedness (MVP) program, described below, is one example of new technical assistance offered by the State. The MVP program has a strong focus on generating local buy-in, interest, and capacity. This program is increasing MEMA's ability to reach communities through Hazard Mitigation Program assistance.

Municipal Vulnerability Preparedness Program

The Commonwealth's MVP grant program provides support for cities and towns in Massachusetts to plan for resiliency to respond to and mitigate the impacts of climate change, and to implement key climate change adaptation actions.

Community Resilience Building is a unique, "anywhere at any scale," community-driven process, rich with information, experience, and dialogue, where participants identify top hazards, current challenges, strengths, and priority actions to improve community resilience to all hazards today, and in the future (CommunityResilienceBuilding.org)

Funding is available to all cities and towns in the Commonwealth to support the completion of climate change vulnerability assessments and resiliency planning using the Community Resilience Building (CRB) workshop guide developed by The Nature Conservancy, now used in well over 200 communities across the country. The program provides access to MVP-certified providers, a standardized toolkit for assessing vulnerability and developing strategies, and the best available statewide climate projections and data. Grants are awarded to municipalities who wish to prepare for climate change impacts, build community resilience, and receive designation from the Executive Office of Energy and Environmental Affairs (EOEEA) as a Climate MVP Community. This designation leads to increased standing in other state grant programs, and eligibility to apply for MVP Action grants that support implementation of key priorities identified through the planning process.

The program helps communities to do the following:

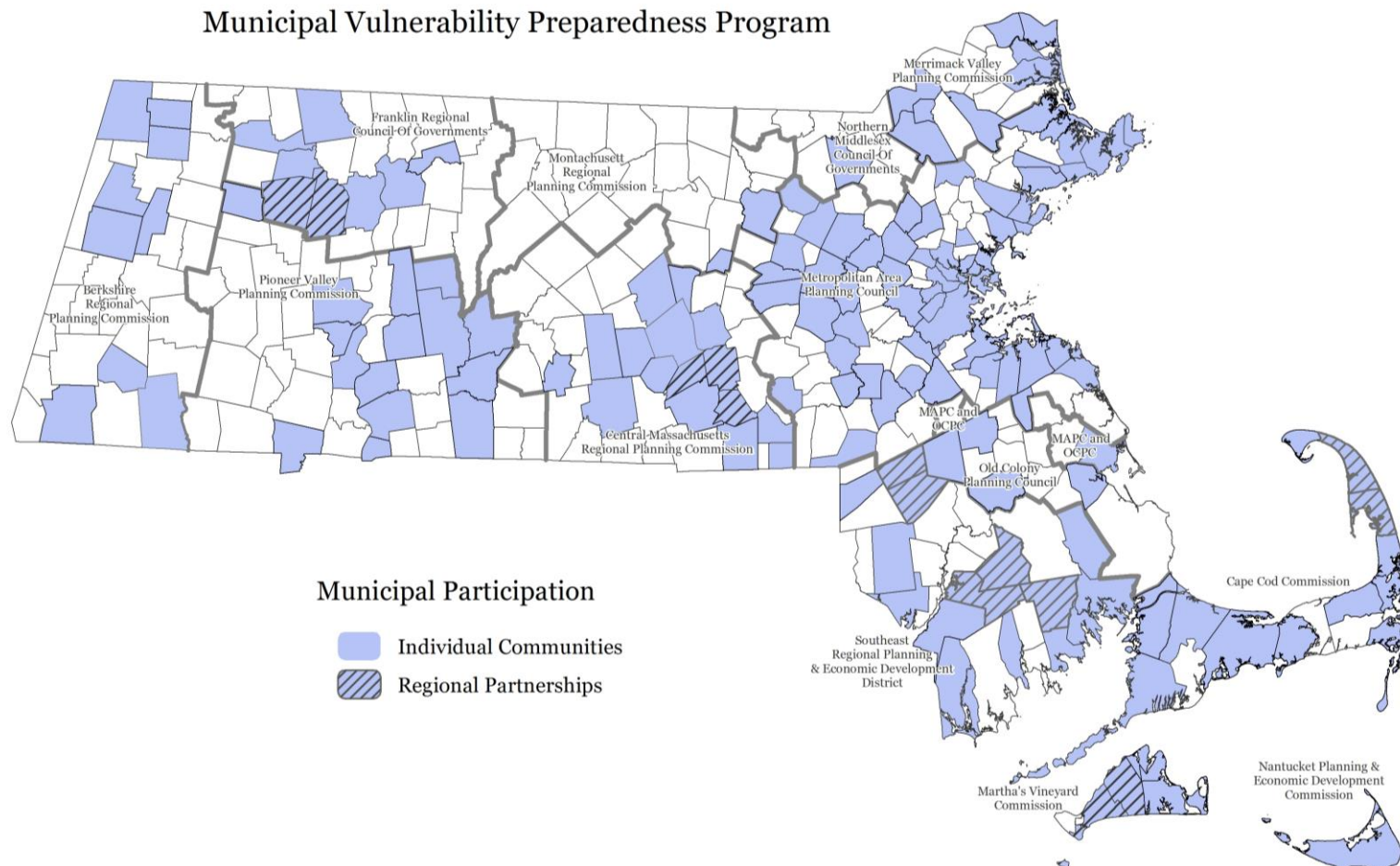
- Understand extreme weather and natural and climate-related hazards.
- Understand how their community may be impacted by climate change with a Massachusetts-specific [Climate Change Clearinghouse](http://resilientMA.org) (resilientMA.org) that has the latest science and data produced by the Northeast Climate Adaptation Science Center at the University of Massachusetts Amherst.
- Identify existing and future vulnerabilities and strengths.

- Develop and prioritize actions for the community.
- Identify opportunities to take action to reduce risk and build resilience.
- Implement key actions identified through the planning process.

Just as the Commonwealth has integrated its Hazard Mitigation and Climate Change Adaptation plans, there are many similarities between the MVP planning process and the steps required to complete a local hazard mitigation plan. The CRB process can satisfy specific elements of the FEMA Regulatory Checklist for Local Mitigation Plans. A [crosswalk](#) highlighting elements of the CRB process that can be used to catalyze and fulfill certain requirements of local hazard mitigation plan preparation has been developed to aid communities in using the grant process to develop their plan, and the Commonwealth encourages cities and towns to synchronize the planning processes.

As of June 2018, there are 156 MVP communities in the state, as shown on Figure 10-1. A number of these communities have been awarded additional funding to update their local hazard mitigation plan, to complete a local hazard mitigation plan for the first time, or to better incorporate climate change into an existing plan. EOEEA and MEMA will continue to collaborate on grant development, review, and implementation to ensure local governments are able to plan for climate change and natural hazards in the most efficient way possible.

Figure 10-1: Map of Municipal Vulnerability Preparedness Communities



10.1.2 Hazard Mitigation Assistance Projects

Massachusetts has had a FEMA-approved Hazard Mitigation Grant Program (HMGP) Administrative Plan since 1986. This plan was last updated in June 2015, and is provided as Annex 1.

The HMGP Administrative Plan describes eligible projects for pre-disaster and post-disaster hazard mitigation funding in Massachusetts. This includes the project's consistency with the SHMCAP and the goals of the community's FEMA-approved Local Hazard Mitigation Plan; compliance with local, State, and Federal laws and regulations; cost-effectiveness; and the project's ability to provide or contribute to a solution to a problem.

Massachusetts uses its Hazard Mitigation Grants Administrative Plan to guide the process for prioritizing post-disaster mitigation funding of local mitigation projects. It has used similar criteria to prioritize local PDM grant applications. It is likely that available federal funds for pre-disaster and post-disaster mitigation assistance will not be sufficient to support all eligible project applications. The State aims to award grants to the maximum number of eligible projects, and to equitably distribute HMGP grant awards across the state. Emphasis is placed on ensuring that mitigation measures provide more protection to life and property than what existed prior to the disaster event, and that they do not merely replace what is damaged.

As described in the Administrative Plan, project proposals are evaluated and prioritized by the State Mitigation Interagency Committee (SHMIC) and the SHMT according to the following criteria. These are ranking criteria; individual projects are not required to meet all criteria, and extra "points" are awarded to applications that mitigate repetitive loss and severe repetitive loss structures.

1. If the project is not implemented, there will likely be a detrimental impact, such as potential loss of life, loss of essential services, damage to critical facilities and infrastructure, and/or economic hardship (Statement of Need).
2. The project mitigation adequately mitigates current hazards and anticipates future ones. The level of protection that will exist after the project is implemented is clearly defined. (How does your project solve the problem?)
3. The project clearly describes the solution by providing a detailed scope of work.
4. The project budget is detailed.
5. The application describes how the proposed project will provide long-term hazard mitigation benefits. A well-defined Benefit-Cost Analysis is provided with relevant supporting documentation. For projects where a Benefit-Cost Ratio is not required, a qualitative analysis of the project benefits will be used.

6. The application demonstrates through a clear work schedule the capability of the applicant to implement and complete the project in a timely manner. This includes a plan for obtaining all required State and local environmental permitting.
7. The application commitment to complete the project is substantiated by providing documentation of the non-Federal cost match, signed support by the chief administrative official, and a description of the decision-making process.
8. The application details how the proposed mitigation activity is consistent with the FEMA-approved hazard mitigation plan for the state and/or local jurisdiction
9. The project is consistent with local and regional priority protection and priority development areas (e.g., Smart Growth Principles, comprehensive land use plans, and capital improvement plans), and the application provides these details.
10. The project promotes resiliency and sustainability, and provides environmental benefits.
11. The project mitigates the type of hazard that caused the Presidentially Declared Event.
12. The project is in the Presidentially Declared Disaster area.

In areas that are experiencing greater population growth and development pressure, the potential that detrimental impacts may occur if a project is not implemented is likely greater. Additional information about project ranking is included in the HMGP Administrative Plan (Annex 1). After projects are reviewed, the Director of MEMA and the Commissioner of DCR, under the advisement of the SHMIC, recommends projects for funding to FEMA Region I. FEMA determines the final selection of grants to be awarded.

Table 10-3 displays the number of Hazard Mitigation Assistance grant applications that have been awarded in the last 5 years. Several additional applications are awaiting award or are currently wait-listed.

Table 10-3: Mitigation Projects Awarded Funding

Year of Obligation Date	Projects Awarded Funding (#)	Counties Represented (#)
2013	11	8
2014	38	9
2015	26	8
2016	25	11
2017	7	5

Source: MEMA, 2018

In addition to supporting mitigation planning, MEMA and DCR have provided significant technical assistance to state agencies, local jurisdictions, and Tribes during the process of submitting PDM and HMGP applications following presidential disaster declarations. In 2013-2017, the State provided more than 200 individuals with training to complete a successful application. The MEMA Mitigation Unit has five staff who coordinate hazard mitigation grants, conduct grant briefings, meet informally with communities, host meetings throughout the state to discuss projects, visit sub-applicants on site, and provide targeted outreach to state agencies, eligible nonprofit organizations, and professional associations. These grant briefings and technical assistance meetings increase the visibility of mitigation programs throughout the Commonwealth and enhance sub-applicants' knowledge of program requirements. The outcomes of these efforts include improved grant applications; and ultimately, more cost-effective projects that address and reduce vulnerability to hazards.

After a grant is received, a mitigation contract specialist conducts an in-person training with every grant recipient at a kickoff meeting. This meeting offers assistance with quarterly performance and financial reporting, records retention, 2 Code of Federal Regulations 200, budget concerns, and time extensions. These educational efforts result in an enhanced ability to effectively and efficiently manage the grants. The combined efforts of the HMGP coordinators and contract specialists provide communities with an opportunity to ask for guidance on the entire process, from application to final close-out. This increased participation helps sub-applicants better understand the process and have greater ease in navigating the reimbursement and close-out.

RISK MAP PROGRAM

The Commonwealth's comprehensive approach to hazard mitigation planning goes beyond supporting the development of hazard mitigation plans. To ensure continued compliance with the National Flood Insurance Program (NFIP), and in coordination with the Risk Mapping, Assessment, and Planning (Risk MAP) program, the DCR Flood Hazard Management Program assists with and updates floodplain bylaws and ordinances. DCR also conducts NFIP Community Assistance Visits, Community Assistance Contacts, and Community Information System updates. DCR provided technical assistance for State General Law update, including the development of the 9th Edition of the Massachusetts State Building Code. State agencies also conduct a range of outreach sessions and presentations for various interest groups.

10.2 Local Hazard Mitigation Plans

As of June 2018, the Commonwealth has 229 approved local mitigation plans, including 100 single jurisdiction plans. An additional 74 plans are in the process of being developed, reviewed, and approved (see Table 10-4). Thirty-seven plans have expired, and 18 communities

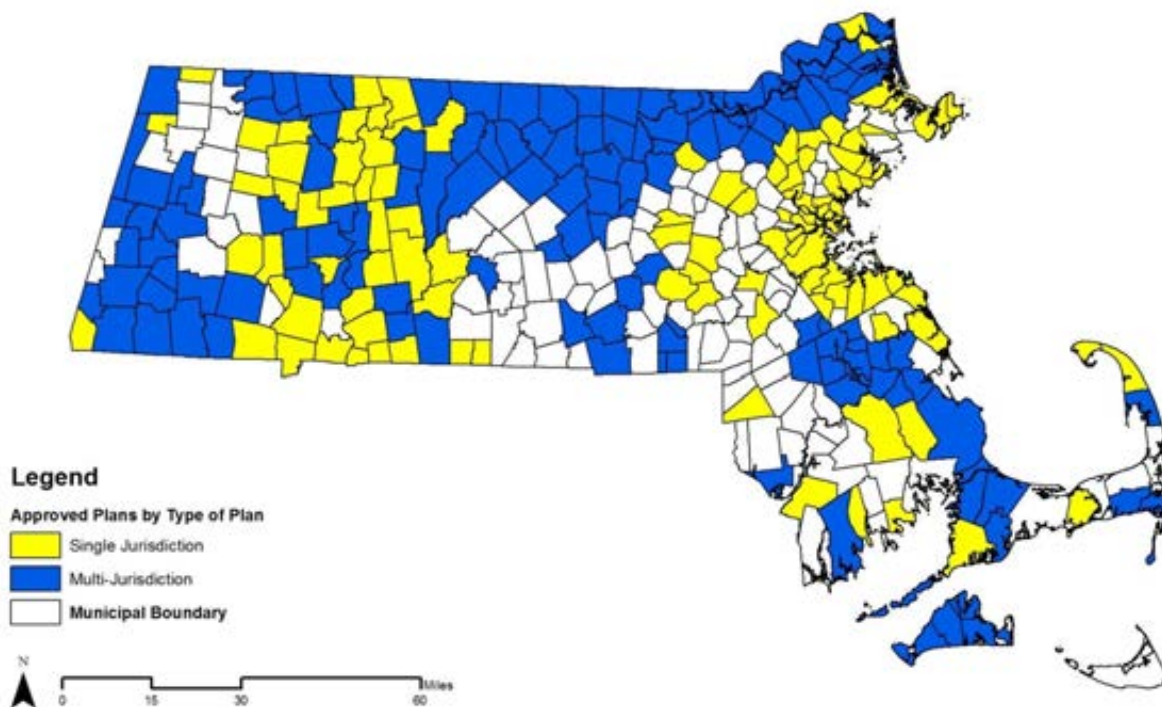
do not have a plan. Several other entities have plans in place, including University of Massachusetts Amherst, multiple University of Massachusetts campuses (Boston, Dartmouth, Lowell, Systems Office), University of Massachusetts Medical School, and Tufts University. Figure 10-2 displays jurisdictions with approved plans as of June 5, 2018.

Table 10-4: Local and Multi-Jurisdiction Hazard Mitigation Plan Status

Plan Status	Number
Approval Pending Adoption	3
Approved	229
Undergoing Local Development	56
Undergoing Local Revisions	10
Undergoing MEMA Review	2
Undergoing FEMA Review	3
Expired	37
None	18

Source: MEMA, June 5, 2018

Figure 10-2: Map of Communities and Regions with Approved Plans as of June 5, 2018



Source: MassGIS; MEMA, 2018

The local mitigation planning process is coordinated by MEMA. MEMA sends a letter to remind communities of the upcoming expiration of their plan 3.5 years after the approval. MEMA also provides communities with information about funding to prepare the plans. From this time, communities have 1.5 years to complete a plan update, undergo the State and Federal review process, and formally adopt their plan prior to the plan expiration. The average time to develop the mitigation plan is 12 months. The state plan review process is typically initiated within 45 days of receiving the plan from a community. It is recommended that plans are submitted to FEMA for review 60 days prior to expiration of the plan to avoid a lapse in the time a community has an approved plan on record.

MEMA's mitigation planner records plans in the MEMA Mitigation Plan Database the day they are received. Figure 10-3 summarizes the State's procedure for reviewing plans that have been submitted to MEMA for review. The State reviews local plans to ensure they align with State mitigation priorities. These local plan reviews also help inform the routine evaluation and amendment of the mitigation goals, strategies, and actions included in the SHMCAP.

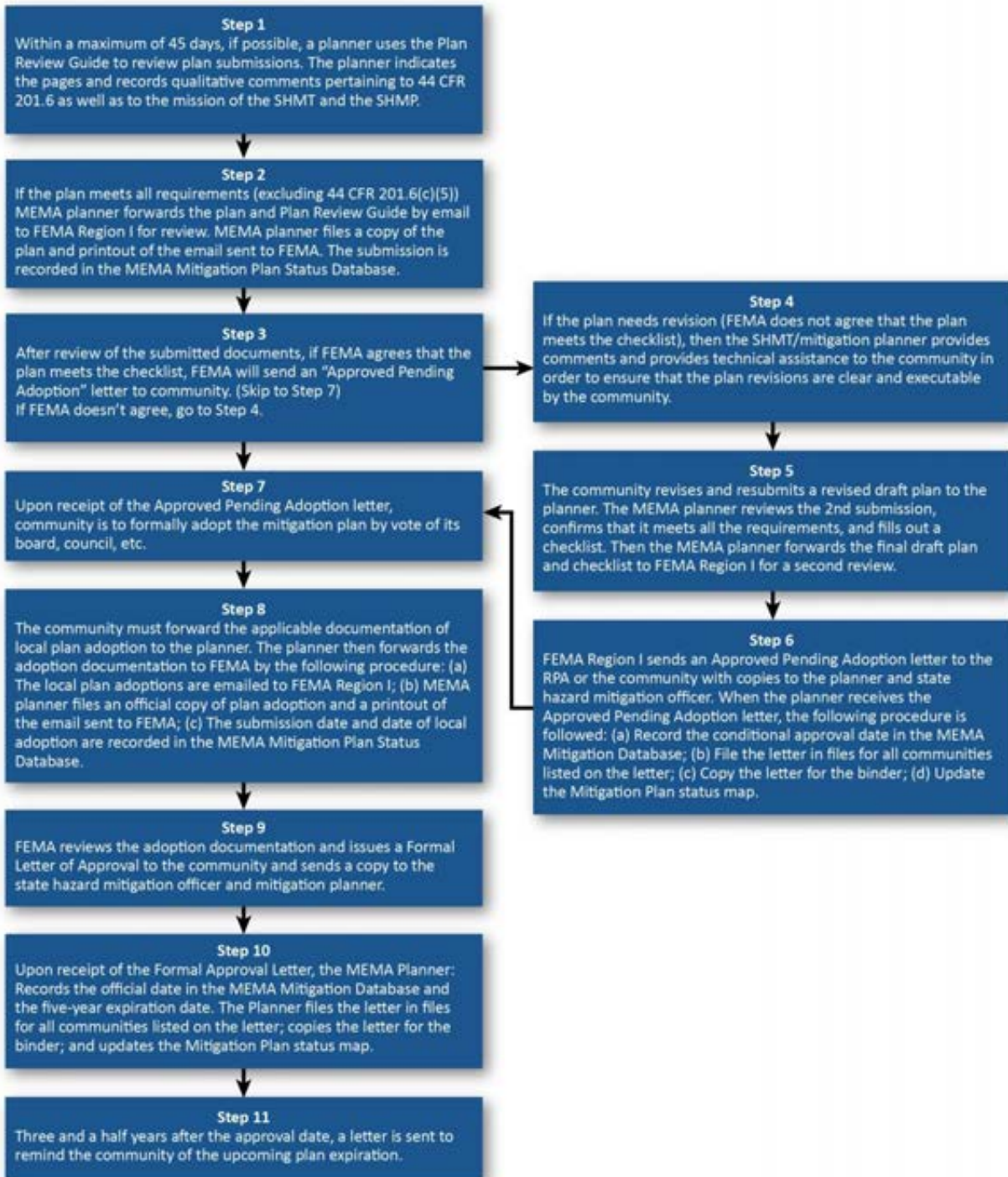
As local and multi-jurisdictional plans are approved, the hazard mitigation measures (and other elements) are entered into the Local/Regional Database, which is later incorporated into this section of the plan. For this update, measures were reviewed and analyzed by the SHMT to identify any trends and issues. Depending on future funding, the Commonwealth will provide participating RPAs and communities with technical assistance as needed to implement cost-effective hazard mitigation measures.

The greatest challenges to developing, updating, adopting, and implementing local mitigation plans is local buy-in, interest, and capacity. Hazard mitigation plans are often developed or updated without the active participation or leadership of local planning and community development staff. The State guidance includes helping local communities inform and engage local leadership, staff, and stakeholders. The State also helps communities identify key players, and builds support for hazard mitigation integration. This includes helping to establish channels for interdepartmental or interagency communication and cooperation.

Local land use planners are less willing to embrace hazard mitigation planning as falling within their professional purview. To address this challenge, the State helps local planners and stakeholders to become familiar with the risks facing their communities, and assesses communities' capacity to plan and implement mitigation activities. The State helps to review existing hazard mitigation plans and local planning policies, regulations, and programs to identify areas of overlap or gaps where integration is needed.

Another challenge is that hazard mitigation plans often include mitigation strategies or actions that are focused on a disconnected series of emergency services, structure or infrastructure protection projects, and public outreach initiatives, with less emphasis on nonstructural measures

Figure 10-3: Steps in the MEMA and FEMA Plan Review Process



available through local land use planning or policy alternatives. In response, the State educates the planning team on land use policies that can build community resilience by taking into consideration information on the location, frequency, and severity of hazards and setting forth recommendations that influence development in a way that does not increase risks to life and property.

Further, hazard mitigation plans are typically completed as stand-alone documents that cover multiple jurisdictions. It is relatively uncommon for them to be directly linked or integrated with other community-specific planning tools, such as comprehensive land use plans and development regulations. The State provides guidance to overcome this barrier by helping local communities identify ways to use current projects, future initiatives, or potential funding opportunities as vehicles for implementing aspects of their hazard mitigation plan or other resilient community principles.

10.3 Local Climate Adaptation Plans

Across the state, several local and regional climate action and climate adaptation plans have been adopted and are in various stages of implementation.

A screening of these local plans was completed as part of the preparation of this SHMCAP. Appendix F includes this preliminary list of local climate action and climate adaptation plans.

Excerpt from Town of Milford Hazard Mitigation Plan: Climate Change Impacts

Climate change is a long-term change in the Earth's climate and encompasses increases in ambient temperature, sea level rise, and shifting seasonal and weather patterns. Climate change is not a hazard in and of itself, but it can impact the severity, duration, frequency, and probability of occurrence of other natural hazards.

According to the Massachusetts Climate Change Adaptation Report, "By the end of the century, under the high emissions scenario of the Intergovernmental Panel on Climate Change (IPCC), Massachusetts is set to experience a 3° to 5°C (5° to 10°F) increase in average ambient temperature, with several more days of extreme heat during the summer months. Days with temperatures greater than 32°C (90°F) are predicted to increase from 5 to 20 days annually that Massachusetts experiences today to between 30 to 60 days annually; while up to 28 days annually are predicted to reach above 38°C (100°F), compared to up to two days annually today (Frumhoff et al., 2006, 2007). Sea surface temperatures are also predicted to increase by 4°C (8°F) (Dutil and Brander, 2003; Frumhoff et al., 2007; Nixon et al., 2004), while winter precipitation—mostly in the form of rain—is expected to increase by 12 to 30 percent. The number of snow events is predicted to decrease from five each month to one to three each month (Hayhoe et al., 2006)" (EOE0EEA, September 2011).

Of the hazards discussed in this section, climate change is expected to impact flood hazards, severe weather, and fire most significantly. Winter precipitation is expected to increase by 20 to 30 percent, and could occur more as rain than as snow. Heavy rainfall is likely to occur more frequently and more intensely, and likely to result in more frequent and more severe floods. Precipitation patterns may shift to prolonged wet and dry periods, leading to increased frequency of short-term droughts (Union of Concerned Scientists, 2017). Brush and other outside fires may be more likely to occur in waves that crest every 2 to 3 years, mostly due to the dry and hot weather patterns in the spring and summer that allow for an increased vulnerability of vegetation to brush fires (Ostroskey, 2014).

Massachusetts communities are increasingly incorporating climate change impacts into their hazard mitigation plans. The extent to which climate change has been incorporated into local hazard mitigation plans varies across jurisdictions. The Town of Brookfield’s 2018 Hazard Mitigation Plan, for example, discusses how climate change is expected to exacerbate many of the hazards described in the community’s Hazard Mitigation Plan, and identifies the impacts that a changing climate may have on Brookfield’s hazard risk profile in the future. In its Hazard Mitigation Plan, the Town of Milford summarizes climate projections and identifies hazards that are expected to be most impacted by climate change.

Following the completion of the 2018 SHMCAP, the State will continue to encourage and support the inclusion of climate adaptation in local mitigation plans. The State’s Climate Change Clearinghouse, [resilient MA](#), is a key resource that has been developed and will be maintained to provide the public, municipal decision-makers, and other stakeholders with user-friendly, scientific information on climate change projections and impacts. The website provides guidance and resources for climate change planning, including identifying impacts and risks, and assessing vulnerability.

The MVP program, described in Section 10.1.1, is another resource and tool that the State will continue to use to support the inclusion of climate adaptation planning in local hazard mitigation plans. An example of how the State supports communities through the MVP program is provided in the following callout.

Throughout Franklin County, Massachusetts, communities are experiencing more extreme weather events—especially heavy rains and flooding—along with higher temperatures and other climate-related conditions. These types of conditions are predicted to increase as a result of climate change.

In the face of these and other changes, municipalities have more of a sense of urgency to increase their resilience and adapt to extreme weather events and mounting natural hazards. Relatively recent events in Franklin County, such as Tropical Storm Irene and “Snow-tober,” have reinforced this sense of urgency and compelled communities like the Town of Colrain to proactively plan and mitigate potential risks. This type of planning will reduce the vulnerability of Colrain’s people, infrastructure, and natural resources; and will empower Colrain’s officials and citizens alike to take steps to protect themselves and their community.

In the spring of 2018, with funding from the Massachusetts Executive Office of Energy and Environmental Affairs, the Franklin Regional Council of Governments (FRCOG) offered the Town of Colrain technical assistance in completing their Community Resilience Building Workshop to achieve designation as a Municipal Vulnerability Preparedness Community or “MVP” Community. As a State-certified MVP Provider, the FRCOG helped the Town of Colrain engage in a community-driven process that brought together climate change information and local knowledge to conduct the workshop, whose central objectives were to:

- Define top local natural and climate-related hazards of concern;
- Identify existing and future strengths and vulnerabilities;
- Develop prioritized actions for the community; and
- Identify immediate opportunities to collaboratively advance actions to increase resilience.

10.4 Local Plan Integration

The SHMT reviews each multi-jurisdictional or local mitigation plan according to Stafford Act guidelines and applicable FEMA guidance, and completes a checklist. During this review, the Commonwealth confirms that the plan is consistent with the SHMP/SHMCAP. The State Hazard Mitigation Planning Coordinator, who is a member of the SHMT, manages this review and analysis. The State works with the local governments, planning teams, and RPAs to ensure that their plans are revised to reflect changes in development and progress in local mitigation efforts, and also to demonstrate that the community has revised the plan to reflect changes in their mitigation priorities and measures.

The Hazard Mitigation Planner reviews a wide array of plans across the Commonwealth to incorporate best practices from the cities and towns to present an all-inclusive / all-hazards approach to mitigation planning that fully encompasses all of the potential hazards that may affect the Commonwealth. In turn, this all-inclusive approach provides information about current mitigation strategies from the Berkshires to the coast of the Atlantic that informs the development of the state plan, and better prepares Massachusetts for future disasters.

As part of the SHMCAP planning process, MEMA undertook a review of more than 20 local hazard mitigation plans that had been approved in the last 12 months. MEMA identified and synthesized common vulnerabilities from these plans for each hazard recognized in the SHMCAP. Several actions and mitigation strategies were developed for each hazard. These commonalities and the steps taken to mitigate adverse effects of hazards on communities are summarized in Table 10-5. This summary of local risk assessments and mitigation strategies, in addition to the SHMT's familiarity and knowledge of Massachusetts communities and their existing hazard mitigation plans, helped to inform the development of the risk assessment and risk reduction actions identified in the SHMCAP.

Table 10-5: Common Vulnerabilities across Local Jurisdictions in Local Hazard Mitigation Plans

Hazard	Common Vulnerabilities	Actions and Mitigation Strategies
Inland Flooding	<ul style="list-style-type: none"> • The impact of flooding on life, health, and safety is dependent on several factors, including the severity of the event, and whether or not adequate warning time is provided to residents. Exposure includes the population living in or near floodplain areas that could be impacted should a flood event occur. Additionally, exposure should not be limited to those who reside in a defined hazard zone, but should consider everyone who may be affected by a hazard event (e.g., risk while traveling in flooded areas or compromised access to emergency services during an event). The degree of such impacts will vary, and is not strictly measurable. Of the population exposed, the most vulnerable include the economically disadvantaged and population over the age of 65. Those over the age of 65 are vulnerable because they are more likely to seek or need medical attention, which may not be available due to isolation during a flood event. They also may have more difficulty evacuating. • If evacuation routes and critical facilities are flooded, emergency response or evacuations could be hampered. 	<ul style="list-style-type: none"> • Improve maintenance for culverts, trenches, and drainage systems. • Implement green infrastructure for stormwater management. • Land Acquisition: The towns, in conjunction with other public/private entities, should continue efforts to acquire parcels of land subject to flooding. • Drainage system maintenance and repair. Street sweeping and catch basin cleaning.
Drought	<ul style="list-style-type: none"> • Long-term drought can have moderate to high-risk effects on both the environment and the economy. • Reduced water levels also cause loss of landscape due to restrictions on outdoor watering, and therefore less crop production and loss of business revenues. • Under a severe long-term drought, communities could be vulnerable to restrictions on water supply. Potential damages of a severe drought could include losses of landscaped areas if outdoor watering is restricted, and potential loss of business revenues if water supplies are severely restricted for a prolonged period. • Because of this hazard's regional nature, a drought would likely impact the entire community, resulting in reduced crop, rangeland, and forest productivity; increased fire hazard; reduced water levels; increased livestock and wildlife mortality rates; and damage to wildlife and fish habitat. 	<ul style="list-style-type: none"> • Promote drought-tolerant and site design measures. • Establish bylaws to enforce water conservation. • Reduce outdoor watering to ensure adequate supply during water supply emergencies. • Promote drought-tolerant landscaping and site design measures.
Landslide	<ul style="list-style-type: none"> • The effects of a landslide are localized. • Vulnerable communities tend to be communities that are more inland and in close proximity to Mount Greylock. • Impacts include localized road closure and sustained structural damage. • Transportation and ability of emergency support agencies to respond are concerns. • It is difficult to determine demographics of populations vulnerable to landslides. • Should a landslide occur in the future, the type and degree of impacts would be highly localized. The town's vulnerabilities could include damage to structures, damage to transportation and other infrastructure, and localized road closures. Injuries and 	<ul style="list-style-type: none"> • Increase efficiency of debris removal and demolition. • Coordinate debris management with Regional Emergency Planning Committees. A debris management plan would include information on the amount, type, and disposal of demolition debris, storm debris, and hazardous waste; and identify sites for sorting, chipping, and transporting the debris after the hazard event.

Hazard	Common Vulnerabilities	Actions and Mitigation Strategies
	casualties, while possible, would be unlikely, given the low extent and impact of landslides in the Commonwealth.	
Coastal Flooding	<ul style="list-style-type: none"> Specific populations that required increased assistance are people over age 65 and the economically disadvantaged, due to an increased need for timely evacuation notice, transportation, and medical support. 	<ul style="list-style-type: none"> Improve maintenance for culverts, trenches, and drainage systems. Implement green infrastructure for stormwater management.
Coastal Erosion	None identified	None identified
Tsunami	<ul style="list-style-type: none"> A tsunami has the capability of affecting any town/county within the “buffer zone,” which encompasses any land 1 mile from the coastline. These are only predictions of the geographical extent of a tsunami’s effect because of the lack of experience/occurrences of tsunamis on the east coast. It is difficult to determine demographics of populations vulnerable to a tsunami. 	<ul style="list-style-type: none"> Coordinate with debris management agencies to create a plan that determines specific procedures in which disposal of storm debris, hazardous waste, and demolition debris will be handled. Coordinate debris management with Regional Emergency Planning Committees.
Average/ Extreme Temperature	None identified	<ul style="list-style-type: none"> Promote green building and cool roof design. Designate a local cooling center, and identify staffing protocol for mid-week and weekend servicing of the facility.
Wildfires	<ul style="list-style-type: none"> Increased risk and rate of wildfires combined with the reduced water levels can cause heightened mortality of both wildlife and livestock. 	None identified
Invasive Species	None identified	None identified
Hurricane/ Tropical Storm	<ul style="list-style-type: none"> The impact of a hurricane or tropical storm on life, health, and safety is dependent on several factors, including the severity of the event and whether or not residents received adequate warning time. It is assumed that the entire Commonwealth’s population is exposed to this hazard. Residents may be displaced, or require temporary to long-term sheltering. In addition, downed trees, damaged buildings, and debris carried by high winds can lead to injury or loss of life. Socially vulnerable populations are most susceptible, based on a number of factors, including their physical and financial ability to react or respond during a hazard, and the location and construction quality of their housing. Of the population exposed, the most vulnerable include the economically disadvantaged and population over the age of 65. Those over the age of 65 are vulnerable because they are more likely to seek or need medical attention, which may not be available due to isolation during a flood event. They also may have more difficulty evacuating. Hurricanes typically have regional impacts beyond their immediate tracks. Falling trees and branches are a significant problem because they can result in power outages 	<ul style="list-style-type: none"> Assess and inspect public buildings to withstand wind loads to diminish loss of life. Conduct regular tree trimming to avoid communication line damage. Coordinate a debris management plan prior to a disaster. Assess public buildings for ability to withstand wind loads. Purchase Barriers and Signage: The towns should seek funds to purchase additional barricades (jersey barriers) and signage to aid in the blockade and evacuation of hazard areas during a storm event. The Tree Department and local electric company, National Grid, conducts regular tree trimming.

Hazard	Common Vulnerabilities	Actions and Mitigation Strategies
	<p>when they fall on power lines or block traffic and emergency routes.</p> <ul style="list-style-type: none"> • Hurricanes have the capability to displace citizens in direct impacts zones to long-term sheltering facilities, and can cause severe injuries and death due to infrastructure damage, debris, and downed trees. • Towns in the direct impact zone of hurricanes (coastal towns) are taking steps to improve their preparedness and response to hurricanes. 	<p>The towns respond to downed tree limbs caused by winds, lightning strike reports, and other weather-related incidents.</p> <ul style="list-style-type: none"> • Coordinate debris management with Regional Emergency Planning Committees. A debris management plan would include information on the amount, type, and disposal of demolition debris, storm debris, and hazardous waste; and would also identify sites for sorting, chipping, and transporting the debris after the hazard event. • Improve drainage.
Severe Winter Storm/ Nor'easter	<ul style="list-style-type: none"> • The impact of a nor'easter on life, health, and safety is dependent on several factors, including the severity of the event, and whether or not residents received adequate warning time. It is assumed that the entire Commonwealth's population is exposed to this hazard (wind and rain/snow). Of the population exposed, the most vulnerable include the economically disadvantaged and population over the age of 65. Those over the age of 65 are vulnerable because they are more likely to seek or need medical attention, which may not be available due to isolation during a flood event. They also may have more difficulty evacuating. • The Commonwealth is vulnerable to both the wind and precipitation that accompany nor'easters. High winds can cause damage to structures, fallen trees, and downed power lines leading to power outages. Intense rainfall can overwhelm drainage systems, causing localized flooding of rivers and streams, as well as urban stormwater ponding and localized flooding. Fallen tree limbs, as well as heavy snow accumulation and intense rainfall, can impede local transportation corridors and block access for emergency vehicles. • Deaths are primarily attributed to automobile accidents, exhaustion, and exposure; and these situations are exacerbated due to physical isolation of communities caused by falling debris. • Debris impedes emergency services from reaching populations in need, such as the elderly or homeless. • Falling trees/branches can also damage power lines, causing communication isolation among communities. • According to the National Oceanic and Atmospheric Agency's National Severe Storms Laboratory, winter weather indirectly and deceptively kills hundreds of people in the United States every year, primarily from automobile accidents, overexertion, and exposure. Winter storms are often accompanied by strong winds, creating blizzard 	<ul style="list-style-type: none"> • Assess municipal structures for susceptibility to snow loads. • Improve drainage structure; for example, by maintaining culverts and trenches. • Coordinate debris management with Regional Emergency Planning Committees.

Hazard	Common Vulnerabilities	Actions and Mitigation Strategies
	<p>conditions with blinding wind-driven snow, drifting snow, and extreme cold temperatures with dangerous wind chills. These storms are considered deceptive killers, because most deaths and other impacts or losses are indirectly related to the storm. Injuries and fatalities may occur due to traffic accidents on icy roads, heart attacks while shoveling snow, or hypothermia from prolonged exposure to cold. Heavy snow can immobilize a region and paralyze a town, shutting down its transportation network, stopping the flow of supplies, and disrupting medical and emergency services. The elderly are considered most susceptible due to their increased risk of injury and death from falls and overexertion, and/or hypothermia from attempts to clear snow and ice, or related to power failures. In addition, severe winter weather events can reduce the ability of these populations to access emergency services. Residents with low incomes may not have access to housing, or their housing may be less able to withstand cold temperatures (e.g., homes with poor insulation and heating supply).</p> <ul style="list-style-type: none"> • The conditions created by freezing rain can make driving particularly dangerous, and emergency response more difficult. The weight of ice on tree branches can also lead to falling branches damaging electric lines. 	
Tornadoes	<ul style="list-style-type: none"> • High winds are capable of launching debris, which can lead to loss of life if proper shelter is not taken. • High winds can impede emergency response agencies from responding to those affected by the natural disaster. 	<ul style="list-style-type: none"> • Coordinate with other agencies prior to the severe weather to determine a “debris management plan.” • Identify staffing protocol to ensure the facility is always able to offer their services.
Other Severe Weather	<ul style="list-style-type: none"> • High winds are capable of launching debris, which can lead to loss of life if proper shelter is not taken. • High winds can impede emergency response agencies from responding to those affected by the natural disaster. • The entire population of Massachusetts is exposed to severe weather events. Residents may be displaced, or require temporary to long-term sheltering due to severe weather events. In addition, downed trees, damaged buildings, and debris carried by high winds can lead to injury or loss of life. Socially vulnerable populations are most susceptible, based on a number of factors, including their physical and financial ability to react or respond during a hazard, and the location and construction quality of their housing. In general, vulnerable populations include the elderly, low-income or linguistically isolated populations, people with life-threatening illnesses, and residents living in areas that are isolated from major roads. Power outages can be life-threatening to those dependent on electricity for life support. Isolation of these populations is a significant concern. These populations face isolation and exposure 	<ul style="list-style-type: none"> • Coordinate debris management with Regional Emergency Planning Committees. A debris management plan would include information on the amount, type, and disposal of demolition debris, storm debris, and hazardous waste,; and identify sites for sorting, chipping, and transporting the debris after the hazard event. • Trim trees.

Hazard	Common Vulnerabilities	Actions and Mitigation Strategies
	<p>during severe weather events, and could suffer more secondary effects of the hazard.</p> <ul style="list-style-type: none"> • Tree damage during high winds has the potential to be a significant hazard in Sharon. Trees can knock out power lines and block major roadways, which hinders emergency response. 	
Earthquake	<ul style="list-style-type: none"> • The entire population of Massachusetts is potentially exposed to direct and indirect impacts from earthquakes. The degree of exposure is dependent on many factors, including the age and construction type of dwelling structures, soil types in which homes are constructed, and proximity to fault locations. Furthermore, the time of day also exposes different sectors of the community to the hazard. • Earthquakes are a hazard with multiple impacts beyond the obvious building collapse. Buildings may suffer structural damage that may or may not be readily apparent. Earthquakes can cause major damage to roadways, making emergency response difficult. Water lines and gas lines can break, causing flooding and fires. Another potential vulnerability is equipment inside structures. For example, a hospital may be structurally engineered to withstand an earthquake, but if the equipment inside the building is not properly secured, the operations at the hospital could be severely impacted during an earthquake. Earthquakes can also trigger landslides. • Earthquakes have the capacity to affect the entire Commonwealth, but can have varying effects depending on each region. • Structural damage is an imminent hazard, because it can cause serious injury and loss of life. • Other vulnerabilities include damage to equipment in hospitals and other major facilities that are in constant demand. • Damage to hospital equipment can both hinder medical professionals' ability to serve the needed populations, as well slow emergency response medical attention in off-site areas. 	<ul style="list-style-type: none"> • Assess public buildings for earthquake resistance. • Properly manage and protect crucial equipment. • Provide education about what to do in the event of an earthquake. • Assess public buildings for earthquake resistance. • Coordinate debris management with Regional Emergency Planning Committees. A debris management plan would include information on the amount, type, and disposal of demolition debris and hazardous waste; and identify sites for sorting, chipping, and transporting the debris after the hazard event.

10.5 Ecosystem Scale Planning for Nature-Based Solutions

Effective hazard mitigation and climate adaptation planning and implementation need to be done at a larger, regional scale. Nature-based solutions (NBS) in particular should be considered at an ecosystem scale to prioritize the most effective solutions and locations. For example, flooding is best considered at a watershed scale, while land protection priorities can be considered at a regional or watershed level. Ecosystem scales do not align with municipal boundaries, and regionalization among communities should be encouraged. There are several groups that can be employed to assist municipalities in improving resilience. This section helps define the roles and responsibilities for local and regional governments and groups.

10.5.1 Municipal Roles and Responsibilities

Municipal governments have primary control over their local land use, which has an enormous effect on the amount of impervious surfaces; which in turn affects local temperature, stormwater runoff, flooding, and drought. To improve local resilience, communities can take certain actions to encourage NBS and focus on smart growth that balances the needs of both development and conservation in their planning boards, conservation commissions, open space committees, public works departments, and others.

As described in *Chapter 6: State Capability and Adaptive Capacity Analysis*, municipalities should consider changing local land use planning tools such as zoning bylaws and ordinances and subdivision rules and regulations that encourage NBS that manage stormwater and reduce urban heat island effects while providing additional co-benefits. Communities can use a bylaw review tool developed by Mass Audubon to comprehensively consider how to do this, based on the State's smart growth toolkit and other tools.

Similarly, while updating zoning and codes, communities should consider updating their development standards in terms of anticipated increased precipitation, and in terms of how they describe and plan around floodplains. Although the 100-year floodplain has historically been used to consider hazards, and mostly does not consider the 500-year floodplain, changes in precipitation and storm events have altered the frequency of 100-year events, so that they have become more frequent. By adjusting planning guidance to consider use of the 500-year floodplain, communities can be more proactive about not siting infrastructure in a frequently flooded area.

10.5.2 Regional Roles and Responsibilities

Communities perform much of their larger-scale planning through RPAs. These organizations assist communities to consider regional priorities and actions, such as through technical assistance or through the MVP program (described earlier). Additionally, watershed associations,

land trusts, and other nonprofit organizations that work at state and regional levels may assist communities to prioritize NBS to optimize resilience and benefits at multiple scales.

10.5.3 Private-Sector Roles and Responsibilities

The private sector has a need for general technical assistance, as well as help with conducting vulnerability assessments, adopting resilience standards, and developing action plans—all of which should incorporate current climate change projections. Finance, insurance, and real estate industry associations should promote information about risks and vulnerability, and also resilient building techniques and the establishment of standards. Finance and insurance sectors should monetize the value of investments by responding, for example, to resilience investments with adjusted rates.

The private sector should collaborate with policymakers to encourage a series of voluntary actions and policy and code changes. Collaboration should also advance resilience in the private sector by providing a suite of tools that includes science, standards, technical assistance, public funding, and regulations (and associated compliance and enforcement).

The private sector should promote awareness among developers, realtors, property owners, and tenants; leverage support from the financial and insurance sectors; and monetize economic externalities for which the private sector is not accounting.

10.6 Concluding Statement

This chapter concludes the 2018 SHMCAP, which has identified risks and vulnerabilities associated with natural disasters and climate change, and presented long-term strategies for protecting people and property from future hazard events and climate change impacts. The plan is intended to help the Commonwealth and its residents to better understand when, where, why, and how natural hazards occur; how natural hazards are expected to be affected by climate change; how to reduce the cost of recovery and rebuilding through making a more resilient Commonwealth; and how preparedness and adaptation planning can reduce health impacts.

As stated elsewhere, this plan is a living document that will reside on the Massachusetts Climate Change Clearinghouse (resilientma.org), and be operationalized through the continuous implementation of actions identified in the plan. The plan will also be improved as needed through routine maintenance procedures that help to ensure the plan is reviewed, updated, and enhanced as conditions change, and with input from stakeholders.

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