Chapter 5. Risk Assessment and Hazard Analysis

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5.1 Risk Assessment Introduction

The 2023 Massachusetts State Hazard Mitigation and Climate Adaptation Plan (2023 MA SHMCAP) Risk Assessment identifies risks, consequences, and impacts associated with the hazards and climate change influences that could affect Massachusetts. It considers the existing and future long-term stressors for each hazard, along with the exposure and vulnerability of populations, geographic areas, assets, and services from each hazard. The information in the Risk Assessment includes the underlying causes of the hazards, the best available data and information for the Commonwealth, the historical context of these hazards in Massachusetts, and the projected impacts that climate change, population projections, and other trends will have on the risks posed by these hazards. The Risk Assessment provides the empirical basis for the actions and activities prioritized by the 2023 MA SHMCAP.

This introduction provides:

- An overview of the changes in the 2023 Risk Assessment compared to the 2018 Risk Assessment.
- A discussion of historical disaster occurrences in Massachusetts.
- An explanation of the approach used in each hazard section.
- A review of methodology.
- **Hazard snapshots**. These are analytical tools for comparing hazards to each other based on results of the Risk Assessment. This analysis uses information from analysis of risk and vulnerability, such as warning time and extent, to rank each hazard. Together with problem statements, hazard snapshots are a form of hazard overview:

an analysis that summarizes and allows for the comparison of vulnerabilities and consequences across hazards and provides a better understanding of Massachusetts' priorities related to addressing these hazards.

- A brief discussion of technological and human-caused hazards.

The introduction is followed by hazard profiles: two-page executive summaries that describe each hazard and provide a high-level overview of the impacts associated with it.

5.1.1 Significant Changes to the MA 2023 SHMCAP Risk Assessment

The 2023 Risk Assessment updates the 2018 Risk Assessment to advance the understanding of risk and the impact of climate change in the Commonwealth. The changes to the Risk Assessment compared to 2018 are described in the subsections below.

5.1.1.1 Integrating Analysis to Consider Future Conditions

Understanding future conditions is essential to understanding how long-term risks in Massachusetts will evolve over time. To address this, the Risk Assessment integrated new sections, analysis, and components to contribute to an improved understanding of future conditions. The Risk Assessment expanded on the 2018 analysis in the following ways:

- **Adding new hazards.** The Risk Assessment added an assessment of groundwater and includes a hazard section to profile and document risks from changes in groundwater. The inclusion of this new section required expert consultation and significant research and will support communities experiencing challenges associated with reduction, rise, and changing characteristics of groundwater.
- **Expanded assessment of existing hazards.** All hazard sections include geospatial and data analysis that had not been conducted in 2018. The analysis of invasive species includes extensive new work and research into a hazard that was flagged as a concern for multiple municipalities. To improve the understanding of earthquake risk, the Risk Assessment team used an updated Hazus analysis that included new soils data. The following hazards also incorporated recent research and data: extreme temperature, hurricanes, tsunamis, and drought.
- **Leveraging the Massachusetts Climate Change Assessment.** To leverage the findings from the 2022 Massachusetts Climate Change Assessment (MA Climate Assessment), the Risk Assessment integrated priority impacts into all hazard analysis. Projections, analysis, and findings from the MA Assessment heavily contributed to Risk Assessment sections on coastal flooding, flooding from precipitation, and extreme temperature. Section 5.1.5.1 provides detail on integration with the MA Climate Assessment.
- **Local and statewide analysis of changes in development.** To advance its understanding of future conditions, this analysis also took discrete steps to

understand changes in development. To achieve this, the team incorporated information from population projections, data that identified the location and type of planned and recently completed construction, and a review of local hazard mitigation plans and reports from the Municipal Vulnerability Preparedness program.

- **Systematically reviewing and integrating local hazard mitigation plans.** The team systematically reviewed local hazard mitigation plans chosen to be geographically representative of conditions throughout the Commonwealth. Each plan was thoroughly reviewed, analyzed, and integrated into all hazard sections, with a focus on using information from the plans to understand the local context and experience of the hazards and climate change influences, as well as mitigation and adaptation actions used at the local level to reduce risks.

Involving State Agencies Throughout the Planning Process

In addition to formal review of the Risk Assessment, state agencies and members of the Resilient MA Action Team (RMAT) had the opportunity to inform and contribute to the Risk Assessment at all periods of the analysis. Through two RMAT Working Group meetings, state agencies were invited to contribute their understanding of risk through comments, participation, and a worksheet. In connection with working group meetings, state agencies and select subject matter experts were invited to contribute with reviews and feedback to the problem statement, hazard profiles, and a preliminary version (Draft 0) of the Risk Assessment. The RMAT Working Group was also provided each section to allow for their review, comment, and recommendations.

Integrating Environmental Justice and Other Priority Populations in the Analysis

The Risk Assessment advanced the way vulnerability and risk were discussed for all hazards. For each hazard, the analysis includes a section on the understanding of environmental justice and other priority populations through multiple dimensions using both 2022 Massachusetts Environmental Justice Population data and the 2020 Census data. In evaluating vulnerability for environmental justice and other priority populations, the team drew in complementary data sources when needed and made connections to consider long-term stressors when relevant. The Risk Assessment also carried over the MA Climate Assessment's evaluation of the disproportionate distribution of impacts from climate change into all hazard analysis.

Integrating the Latest Scientific Knowledge

The 2023 Risk Assessment took steps to ensure that hazard analysis reflected the latest scientific knowledge. To understand recent and projected impacts, the team referenced papers published on or after 2018 and used the latest version of Hazus, new geospatial analysis, and updates to every hazard based on new data and information on population and growth, as well as latest science and research for each hazard.

Advancing Scientific Rigor and Replicability

The Risk Assessment includes new methodologies and approaches, applied systematically to all hazard sections, and documents methods used to increase transparency and replicability. Steps taken to advance replicability allow technical readers and municipal governments to reproduce findings and adapt methods for different contexts. Because data sources and methods are clearly listed, the transparency allows readers to use new and updated resources between SHMCAP updates. Examples of ways the Risk Assessment advances replicability include the following:

- All hazards describe the methodology used to develop maps and tables.
- Hazus information, assumptions, and inputs are clearly documented in the introduction and hazard sections.
- Citations included in text-citations are linked to reference list.

5.1.2 Identifying Hazards

In choosing hazards for inclusion in the 2023 Risk Assessment, the Commonwealth reviewed and retained all hazards from the 2018 MA SHMCAP Risk Assessment. The Commonwealth also analyzed a new hazard for 2023—groundwater changes—after reviewing anticipated future conditions and the projected impacts of climate change and determining that these changes present conditions that could result in significant hazard to the Commonwealth. Table 5.1-1 lists the 15 hazards analyzed in the Risk Assessment.

For the 2023 MA SHMCAP, the focus is on natural hazards that are influenced by anthropogenic actions such as climate change, development, pollution, environmental injustice, and other factors that are described in more detail for each hazard. While many of the phenomena discussed in the Risk Assessment are naturally occurring and, in some cases, could be beneficial in many contexts, climate change impacts, development patterns, and other human actions have increased the exposure, vulnerability, and risks associated with these hazards. The Risk Assessment also evaluated and incorporated the results of the 2019 Massachusetts *Hazard Identification and Risk Assessment* (Commonwealth of Massachusetts, 2019).

The Commonwealth assessed each hazard to determine how climate change may affect exposure, frequency, intensity, duration, vulnerability, and risks to the Commonwealth of Massachusetts. The analysis acknowledges that all hazards analyzed in the Risk Assessment have a historical and current risk component and that climate change is changing many of these hazards, expanding the extent of the geography exposed to the hazards, and increasing frequency, duration, and/or intensity.

Where climate change is known to be an influence, the hazard section includes climate projections, data, and analysis at the most downscaled geography available. A significant source of climate data and information was the *2022 Massachusetts Climate Change Assessment*, or MA Climate Assessment (Commonwealth of Massachusetts, 2022).

The MA Climate Assessment report identifies impacts from climate change to people, environments, infrastructure, economy, and governance in Massachusetts through the end of the century. Table 5.1-1 identifies the sections in the Risk Assessment that drew heavily from the analysis and results of the MA Climate Assessment.

Table 5.1-1. Hazards Included in the 2023 MA SHMCAP Risk Assessment

• Flooding from precipitation (with appendix on dam overtopping)[a] • Coastal flooding and storm surge [a] • Average and extreme temperatures [a] • Coastal Erosion • Changes in groundwater (new to 2023) • Earthquakes • Tsunamis • Landslides and mudflow	• Tornadoes • Hurricanes and tropical cyclones • Severe winter storms/nor'easters • Other severe weather • Wildfires • Invasive species • Drought (including impacts to groundwater)

[a] Draws heavily on analysis from the MA Climate Assessment

5.1.3 Historical Disaster Occurrences in Massachusetts

The 2023 MA SHMCAP identifies the frequency and historical occurrence of each hazard between 2018 and March 2023. It also includes information on the historical frequency of occurrence and the magnitude (severity and intensity) of these events before 2018, as documented in the 2018 MA SHMCAP. To identify past occurrences, the 2023 Risk Assessment considered events that resulted in federal or state disaster declarations. The historical information also includes events with notable magnitudes and impacts. Information from past events, including trends, can be used to understand future likelihood and vulnerability, and to identify areas and assets at greatest risk.

Massachusetts has experienced all the hazards included in the 2023 MA SHMCAP, some more often and some with more significant consequences to the Commonwealth. The hazards that have historically occurred more frequently and affected the greatest number of assets and populations include inland and coastal flooding, extreme temperatures, invasive species, and severe winter weather and nor'easters. Some hazards have been reported or occurred less often but have had significant localized impacts, such as coastal erosion, tornadoes, and landslides. There are also hazards that—due to climate change—are emerging and may become more significant in Massachusetts, including wildfires, drought, groundwater rise, and potential changes in hurricane exposure. Finally, there are several hazards that have occurred very infrequently in the Commonwealth, such as large earthquakes and tsunamis.

There have been four events that led to Presidentially Declared Disasters since 2018: three severe winter storm and flooding events (two in 2018 and one in 2022) and the COVID-19 pandemic. In 2011, a magnitude 5.8 earthquake centered in Mineral, Virginia, was felt throughout Massachusetts but caused no damage. This was the most significant earthquake in recent history. No new dam failures or major landslides were recorded, although these have historically occurred in Massachusetts. Between 2018 and 2022, the National Oceanographic and Atmospheric Administration (NOAA) listed the following events in Massachusetts (NOAA, 2022):

- 20 coastal flooding events
- 19 tornadoes, with eight in Worcester County alone
- 27 temperature warnings, 10 for heat and 17 for cold

In February 2023, an arctic front moved through the region with a dangerously cold airmass that stayed in place on February 3–4. The cold temperatures broke the records for the lowest recorded minimum temperature and resulted in several deaths.

Each of the Risk Assessment's hazard sections discusses the historical occurrence of the hazard and provides context on how climate change is affecting extent, frequency, duration, and severity and intensity. Appendix 5.A includes more detail on the historical hazard occurrences mentioned here, as well as significant hazards documented by the 2018 MA SHMCAP.

5.1.4 Risk Assessment Organization and Approach

The Risk Assessment is organized into hazard sections. These sections differ slightly in structure, depending on the nature of each hazard, but each section has three major components designed to convey the risk posed to the Commonwealth's populations, assets, services, and geographies. These three components are described below.

5.1.4.1 Hazard Profile

The hazard profile is an abbreviated, two-page summary of the hazard risk assessment, with information on the vulnerabilities and consequences of the hazard on all five sectors. Its goal is to provide a high-level summary of the hazard analysis—one that can be a stand-alone document, communicating the vulnerabilities and risks associated with the hazard and projected changes due to climate change. Each hazard profile identifies the most at-risk areas, the historical trends and occurrence, the secondary effects, and the projected effects of climate change. The 15 hazard profiles appear at the end of this introduction, before the 15 hazard sections.

5.1.4.2 Problem Statement

The Federal Emergency Management Agency (FEMA) defines Problem Statements as summaries that identify the location of the problem, cause and contributing factors to the problem, significance of impacts, and populations and assets most vulnerable and consequential when exposed to the hazard. A problem statement summarizes the problem that a hazard poses to Massachusetts in terms of exposure, vulnerability, and consequences. The problem statements in this Risk Assessment aim to:

- Present salient information from the analysis on assets, services, populations, and geographies most at risk
- Describe the factors that make the hazard more significant, including climate change, land use, and sensitive assets and services

5.1.4.3 Hazard Risk Assessment

This content includes an analysis and technical description of each hazard, including the probability of occurrence, the geographic extent and area exposed, assets, services and populations most affected, vulnerable characteristics of populations, and analysis of vulnerabilities and consequences for each of the five sectors—human, governance, infrastructure, natural environment, and economy. Each hazard section has several sub-categories, which are listed and described below.

5.1.4.3.1 General Background

The general background describes the hazard and its subcomponents, its severity and intensity, typical warning time, and secondary hazards caused by the hazard. When available, the general background includes examples of notable historical occurrences and broad consequences of the hazard. It contains several subsections as described below.

5.1.4.3.2 Hazard Description

Introduces the hazard, including a definition of the hazard and an overview of its historical occurrence in Massachusetts and sometimes the northeastern U.S. For some hazards, detailed historical records were available; others were reported less frequently. When available, this section includes examples of the largest or most consequential historical occurrence of the hazard in the Commonwealth.

Location

This section describes the location or geographic extent and probability of the hazard, as well as how climate change is projected to change these factors in the future.

Previous Occurences and Frequency

This section summarizes previous occurrences of the hazard in Massachusetts. Where possible, it also describes the probability of a future hazard event using the latest scientific information: probability of future occurrence and current and future frequency. For hazards that are affected by climate change, the discussion includes the latest scientific information on the impacts of climate change on vulnerability.

Severity/Intensity

This section describes the likely magnitude (or range of likely magnitudes) of the hazard. Whenever available, industry standard scales are used to describe the intensity of the hazard. For example, the National Hurricane Center's categorizations of tropical storms and hurricanes was used to define the range of hurricanes that may affect areas of Massachusetts. When no standard scale is available, a qualitative description is provided.

Warning Time

The warning time is the time available to prepare in advance of the hazard. Warning time is most often used to mean the time available to provide information to the relevant agencies and exposed assets and populations to allow them to prepare for the hazard and evacuate if warranted. The best way to reduce risk is to mitigate sources of risk ahead of time and eliminate, or reduce, reliance on warning times for critical issues that relate to life safety, environmental and public health, and lifelines.

Warning times can reduce damage, disruption, and loss of life if they are long enough to allow temporary measures—boarding up buildings, moving sensitive assets, evacuations, moving items inside or away from danger. For example, people may respond to a hurricane warning by boarding up their homes and businesses, moving sensitive items out of the flood zone, and evacuating. Some hazards (such as hurricanes, severe winter weather or nor'easters, high heat or extreme cold, and droughts) allow for hours, days, or weeks of warning time, while others (such as earthquakes, wildfires, tornadoes, and flash floods) allow for little to no warning time. The warning time for each hazard depends on the available scientific data and information for that hazard and the ability to use that information to accurately predict the timing and severity of an event.

Local Context for Hazard and Vulnerability: A Review of Local Plans

The analysis was informed by a systematic review of 37 local hazard mitigation plans to identify hazard exposure, vulnerability, damage, and other relevant local conditions. These plans were chosen to provide a range of local characteristics throughout the Commonwealth, illustrated in Figure 5.1-1 below.

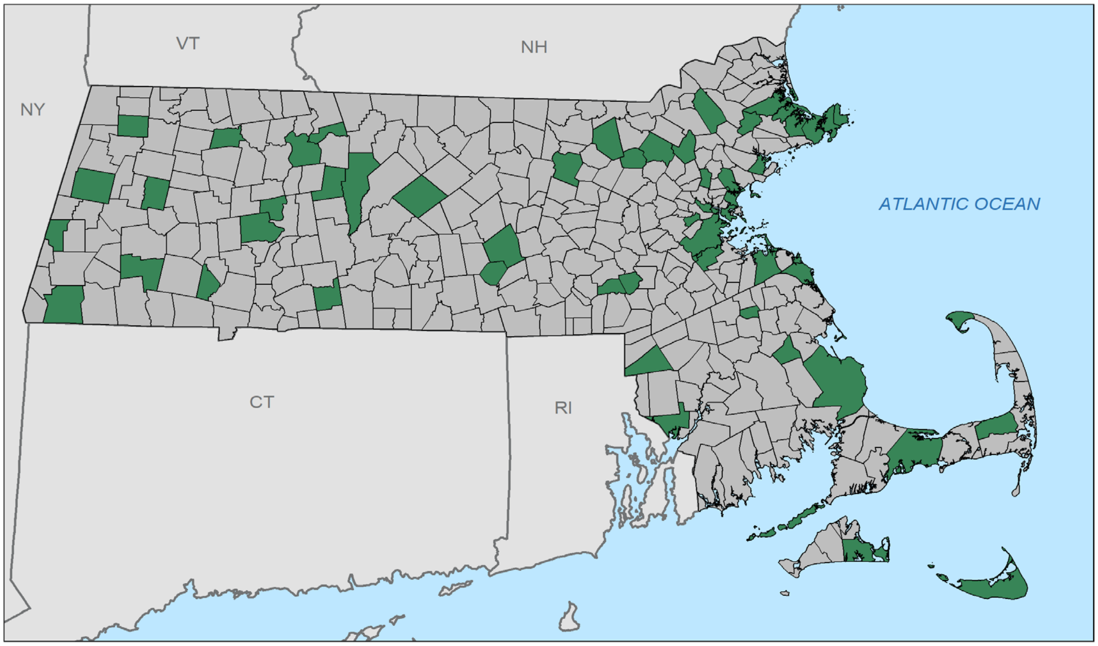


Figure 5.1-1. Map of local hazard mitigation plans included in the review.

The plans reviewed are representative of the geographic, economic, and demographic diversity of Massachusetts, as well as the diversity of current and future risks in different areas of the Commonwealth. Each plan was surveyed to collect information on the municipality's experience with each hazard, information on local conditions, vulnerability (e.g., assets and populations at risk), and actions or adaptation strategies. This information is integrated throughout each hazard section and specifically discussed in a subsection titled "Local Context for Hazard and Vulnerability." For some hazard sections, the Commonwealth reviewed additional local plans and integrated the information into the vulnerability analysis.

Secondary Hazards

A secondary hazard is a hazard whose risk increases after the primary hazard event occurs. For example, landslides and mudflows are a secondary hazard to earthquakes and extreme precipitation events. Secondary hazards are identified for each hazard based on scientific consensus and literature review. In many cases, the secondary hazards can result in as much or more damage, disruption, and loss as the primary hazard.

Sectors Assessed in Exposure and Vulnerability Analysis

The Risk Assessment analyzes the exposure and vulnerability of state assets, human populations, lifelines, critical facilities, economic activity, natural resources, and other infrastructure or resources from each hazard.

The Risk Assessment assesses vulnerability, risks, and consequences for each of the five sectors that were defined in the MA Climate Assessment (Commonwealth of Massachusetts, 2022, p. ES2). A summary of these sectors is described in Table 5.1-2.

Table 5.1-2. Exposure and Vulnerability Sectors

	**Human sector** *Impacts to people's health, welfare, and safety. Includes mortality, injury, and mental health impacts. This sector also identifies the characteristics that make populations more vulnerable to hazard exposure. To inform this sector, the Commonwealth used data from the U.S. Census, the MA environmental justice data mapping tool, and population projections, among other sources.*
	***Governance sector*** Impacts to state and municipal owned buildings, government finances, and the ability of the government to run effectively and achieve its mission and functions and provide services to its service populations. Includes damage to state- or municipality-owned buildings, reductions in tax revenue, expenses for maintenance of state- or municipality-owned transportation infrastructure and impacts to government workers.
	***Infrastructure sector*** Impacts to buildings and transportation assets and services, and to utilities infrastructure involved in providing power, communications, wastewater, stormwater, and potable water. This sector includes an assessment of community lifelines and critical assets, which enable all other aspects of society to function. Critical facilities were identified as critical assets that enable all other aspects of society to function.
	***Natural environment sector*** Impacts to ecosystems, native species, ecosystem functions, recreation assets and open spaces, and natural resources, and how plants and animals can thrive there. Assesses vulnerabilities and consequences for critical resources and conserved lands. The Risk Assessment used geospatial data and tools such as BioMap, U.S. Geological Survey data, and others.
	***Economy sector*** Impacts to people's ability to work and make a living, due to damage to buildings, infrastructure, industries, and the natural environment. Includes interruptions to workplace or regular economic activity; disruptions to specific sectors such as agriculture, fisheries, or tourism; and economic damages to individuals.

5.1.5 Risk Assessment Methods

Each hazard Risk Assessment section discusses specific methods used to assess risk for that hazard. Below, this section describes the Risk Assessment's methodology—the information and analysis used to assess past, current, and projected risks—more generally.

1. Integrating the 2022 Massachusetts Climate Change Assessment
2. Considering Vulnerability and Distribution of Impacts
3. Projected Changes in Population and Development
4. Updated Sources and Documents Reviewed
5. Expert Consultation and Review
6. Analysis of Assets at Risk and Estimated Losses
7. Conducted Regional Analysis

5.1.5.1 Integrating the 2022 Massachusetts Climate Change Assessment

The MA Climate Assessment includes an analysis of the most significant impacts that climate change poses to each of the five sectors (human health, governance, infrastructure, natural environment, and economy) in Massachusetts. This analysis identified priority impacts in each sector based on three factors: the magnitude of the hazard, the presence of disproportionate impacts on communities identified as having environmental justice concerns, and the scale of action or inaction in place to address the hazard.

Where available, the 2023 MA SHMCAP Risk Assessment integrates analysis from the MA Climate Assessment to understand how climate change may affect the frequency, intensity, duration, and scale or location of hazards. (The hazards that drew heavily from analysis in the MA Climate Assessment are marked in Table 5.1-1.) The MA Climate Assessment's priority impacts—including disproportionate effects and adaptation gaps—are considered in the Risk Assessment to focus actions and strategy for the 2023 SHMCAP. As relevant, these priority impacts are included in risk and vulnerability discussions in the hazard sections; impacts drawn from the MA Climate Assessment can be identified because they have an urgency ranking in parenthesis (e.g., "Most urgent," "Urgent").

Note that, in addition to information from the MA Climate Assessment, the Risk Assessment identifies additional risks and vulnerabilities for each hazard based on likelihood and magnitude of consequence.

5.1.5.2 Considering Vulnerability and Distribution of Impacts

Every hazard section includes a discussion and analysis of vulnerability factors and considers environmental justice and other priority populations and social vulnerability explicitly to indicate how populations may be disproportionately affected by a hazard and the underlying factors that drive vulnerability.

> **Environmental justice** is based on the principle that all people have a right to be protected from environmental hazards and to live in and enjoy a clean and healthful environment regardless of race, color, national origin, income, or English language proficiency. Environmental justice is the equal protection and meaningful involvement of all people and communities with respect to the development, implementation, and enforcement of energy, climate change, and environmental laws, regulations, and policies and the equitable distribution of energy and environmental benefits and burdens.
>
> —Massachusetts *Environmental Justice Policy*, 2021

Priority populations are people or communities who are disproportionately affected by climate change due to life circumstances that systematically increase their exposure to climate hazards or make it harder to respond. In addition to factors that contribute to environmental justice status (i.e., income, race, and language), other factors like physical ability, access to transportation, health, and age can indicate whether someone or their community will be disproportionately affected by climate change. This is driven by underlying contributors such as racial discrimination, economic disparities, or accessibility barriers that create vulnerability. The term "priority populations" acknowledges that the needs of people with these experiences and expertise must take precedence when developing resilience solutions to reduce vulnerability to climate change.

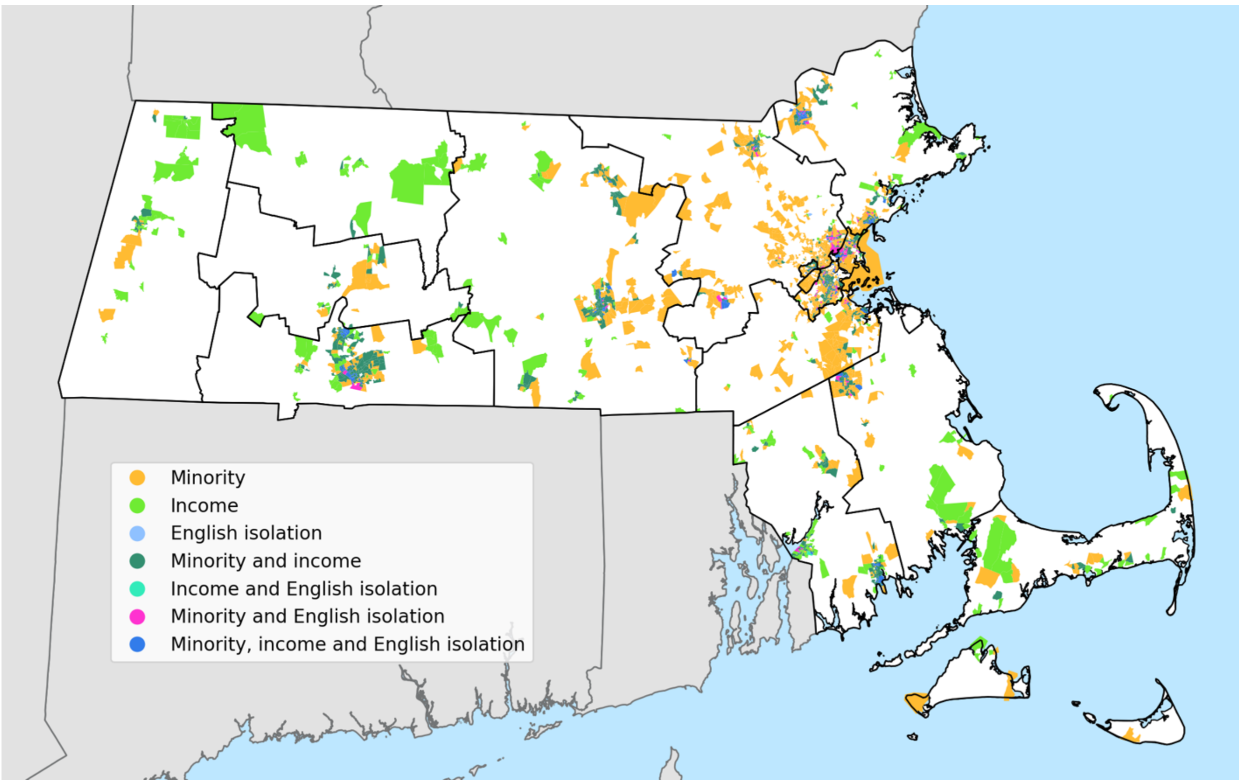
Priority populations are often exposed to pollution, impacts of climate change, and hazards while simultaneously experiencing long-term stressors. Communities experiencing these structures are referred to as environmental justice communities or communities with environmental justice concerns. Communities from minoritized identities, also referred to as "minority, including Black, Indigenous, People of Color" communities, are often exposed to conditions of disadvantage and face environmental injustice. Communities are considered disadvantaged based on several variables.

The Risk Assessment uses variables and data developed by the Executive Office of Energy and Environmental Affairs (EEA) to map communities with environmental injustice concerns by census block groups. A Census block group is identified as an environmental justice population area if it meets one or more of the following criteria:

- The annual median household income is not more than 65 percent of the statewide annual median household income.
- Individuals who identify themselves as Latino/Hispanic, Black/African American, Asian, Indigenous people, and people who otherwise identify as non-White constitute 40 percent or more of the population.
- 25 percent or more of households lack English language proficiency.
- Individuals who identify themselves as Latino/Hispanic, Black/African American, Asian, Indigenous people, and people who otherwise identify as non-White constitute 25 percent or more of the population and the annual median household income of the

municipality in which the neighborhood is located does not exceed 150 percent of the statewide annual median household income. portion of a neighborhood designated by the Secretary as an environmental justice population in accordance with the *Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy*, Chapter 8 of the Acts of 2021.

The map in Figure 5.1-2 shows the location of environmental justice populations throughout the state, as defined by Massachusetts environmental justice population data updated in 2022.



Map developed by ERG with data from Massachusetts Bureau of Geographic Information (MassGIS, 2022).

Figure 5.1-2. Map of environmental justice communities in the Commonwealth.

In addition to using the data and indicators of environmental justice and other priority populations developed by EEA, the Risk Assessment considers other indicators that could be used to identify risk and vulnerability to communities. Each hazard section addresses additional indicators based on the unique vulnerabilities and risks posed by the hazard. The following community and population characteristics were considered for each analysis and implemented depending on the relevance for the hazard:

- Low income
- Age (above 65, under five)
- Underlying health conditions

- Disabilities
- Residence in single-parent households
- Renting
- Residence in housing cost–burdened households
- Membership in an underrepresented or under-resourced community
- Transit dependency
- Linguistic isolation
- Unhoused status

In some cases, employment information was relevant to disproportionate vulnerabilities or consequences. Outdoor workers, workers in the coastal zone, emergency responders, public safety employees, and others might bear a disproportionate risk due to the location or characteristics of their employment.

5.1.5.3 Projected Changes in Population and Development

Considering future conditions of population and development is important to understand how risks from hazards and climate change can affect Massachusetts in the future. Changes in population and development can increase or decrease the number of people, buildings, and/or infrastructure at risk from a hazard event. Many of the most effective strategies to reduce risks from hazards are land use strategies that decrease the number of people and assets within high-risk areas. Additionally, to understand the risks posed from current and future hazards, it is critical to assess how population and development density and design are changing over the same timeframe. The changes to hazards due to climate change make this assessment critical, since some areas that are projected to be at risk from a hazard in the future—such as high heat, coastal flooding, wildfires, and extreme precipitation—have not historically experienced these hazards.

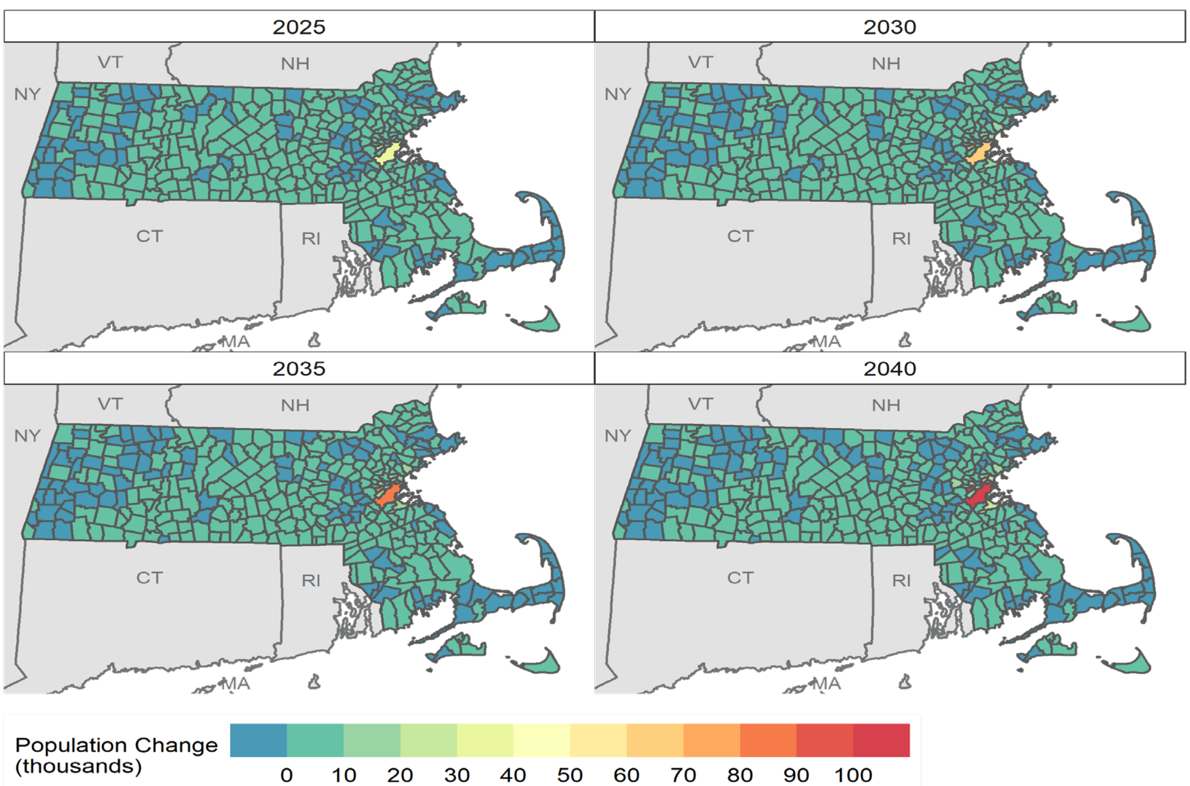
When considering changes in land use, population, and development, it is important to understand the jurisdictional authority over decisions that affect these changes. The Commonwealth of Massachusetts has granted home rule authority to municipal governance entities (i.e., cities and towns), which includes the authority to adopt ordinances and bylaws to regulate the use of land, buildings, and structures (Commonwealth of Massachusetts, 2023). Because it does not manage zoning and therefore construction permits, the Commonwealth does not have direct influence over land use decisions within Massachusetts; it can, however, support local municipalities' land use decisions by providing information on hazards and climate change risks; providing technical assistance to municipalities on actions to reduce risks; and encouraging safe and resilient development through funding support, resilient codes, and other best practices.

To assess the effect population and development characteristics on risk, the Risk Assessment team analyzed long-term changes in population, statewide construction patterns (as they bear on changes in development), and locally identified changes in development.

5.1.5.3.1 Changes in Population and Risk

Development often follows the same trends as population growth; accordingly, the Risk Assessment team used population changes as a proxy to evaluate whether recent development in hazard-prone areas could affect the Commonwealth's risk profile. Changes in population can influence demand for housing, infrastructure, and community services (e.g., schools, retail) and lead to land use change. The pace of population changes can also influence whether growth in population or decreases in population result in changes to the profile of risk for the areas experiencing changes.

Figure 5.1-3 below shows minor civil division (MCD)–level estimates of future population growth. Anticipated population changes through the Commonwealth were assessed using estimates of population growth from UMass Donahue Institute and MassDOT (UMass Donahue Institute, 2018). All hazards were assessed based on these population projections to determine if hazard exposure is growing or getting smaller.



Source: UMass Donahue Institute (2018).

MCDs shaded blue are expected to decrease in population.

Figure 5.1-3. Estimated change in population from 2020, per MCD.

To analyze how changes in population are influencing long-term risk in Massachusetts, the Risk Assessment team assessed these questions:

- Are geographic areas at current or future risk projected to grow?
- Is risk being considered when changing land uses and increasing density? Is risk being addressed through higher standards and building codes?
- Are there trends and patterns that need to be considered and described in the Risk Assessment?

Generally, the Boston Harbor region is expected to experience the most population growth in the Commonwealth, while population is expected to decline slightly in rural Massachusetts. For specific hazards, see the "Human" sector discussion in each hazard risk assessment's "Exposure and Vulnerability" section.

5.1.5.3.2 Statewide Construction Patterns

The Risk Assessment team identified one statewide resource on changes in development: the Metropolitan Area Planning Council's MassBuilds public database, which catalogues significant construction projects in Massachusetts (Metropolitan Area Planning Council, n.d.). MassBuilds collects data from participants at regional planning and other government agencies. The dataset includes locations of projects and either the year construction was completed or the projected year of completion. This information reveals which regions are experiencing more development now and in the near term.

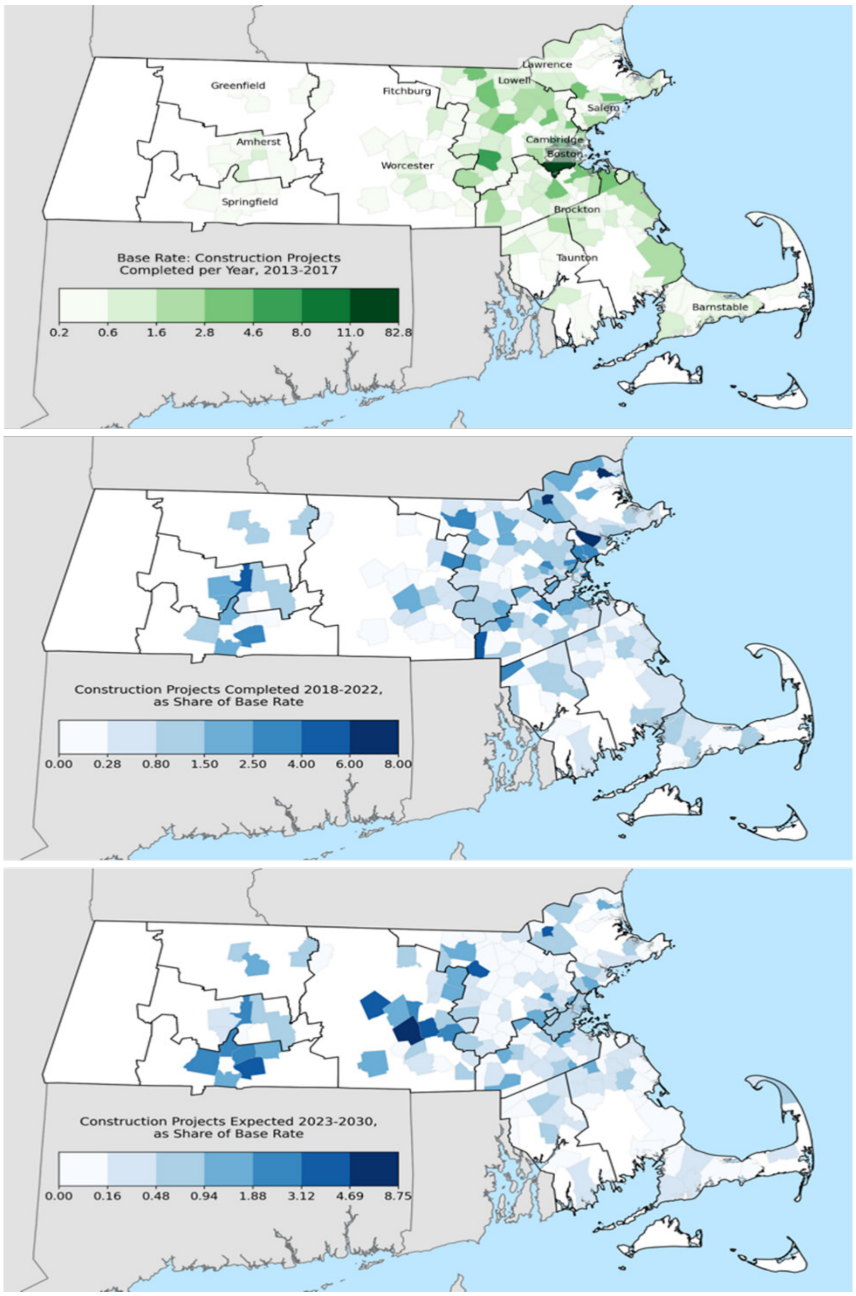
The Risk Assessment team used this dataset to assess which regions have experienced recent development and which locations are expected to experience further development. The Risk Assessment expresses both rates of recent development and projected development as shares of a "base rate," or the number of construction projects completed per year between 2013 and 2017, in Figure 5.1-4. To show the rate of recent development, it shows the number of projects completed per year between 2018 and 2022 as a share of the base rate. To show the rate of expected further development, it takes the number of projects in planning, projected, or in construction between 2023 and 2030 as a share of the base rate. Only municipalities with construction during the base period are included.

Note that MassBuilds has significant limitations. It focuses on the Greater Boston area, with far less coverage for other regions in the Commonwealth. It also focuses on large housing or commercial building projects, omitting other important types of construction such as single-family homes.

5.1.5.3.3 Locally Identified Changes in Development

Local government hazard mitigation planning can also provide insight into changes in development and population dynamics that affect risk locally. In addition to providing local context, local planning documents can provide detailed examples that illustrate patterns experienced by a region.

In collaboration with the Massachusetts Emergency Management Agency, the Risk Assessment team reviewed a representative sample of local hazard mitigation plans and extracted discussions of changes in development and land use. This review was used to gauge regional development changes. Conclusions from this exercise are included in each hazard section, in the infrastructure sector discussion under "Exposure and Vulnerability."



Maps generated using MassBuilds data.

From top to bottom, maps show base rate, recently completed, and expected construction projects.

Figure 5.1-4. Construction projects in Massachusetts.

5.1.5.3.4 Results from Analysis of Changes in Development

Recently completed projects and permitted projects with projected completion dates are key indicators for changes in development. Increases in construction are associated with growth and increased density of housing and commercial properties. While increased development in hazard-prone areas increases the number of people and buildings exposed to hazards, there are other factors in risk such as land-use decisions, construction standards and building codes, conditions and requirements that may reduce risks, and emergency management plans.

Coastal Areas

During the planning period that informed the 2018 SHMCAP, construction was concentrated in the counties around Boston Harbor, specifically Suffolk and parts of northern Norfolk, southern Essex, and eastern Middlesex counties. During this period, all coastal counties experienced construction rates higher than rates in other areas of the Commonwealth. The concentration of construction near Boston Harbor and along coastal areas exposed new buildings to coastal hazards like flooding, erosion, and storms.

Local hazard mitigation plans for governments in these regions confirm a concern with development in areas exposed to hazards, especially flooding. The Town of Hull worked with the Metropolitan Area Planning Council to evaluate areas that may be developed in the future and found that on the three parcels considered, 90 percent of the land was in a flood zone (Metropolitan Area Planning Council, 2018a). Most municipalities in and around the Boston Harbor area expressed concern over exposure to flooding but identified enough parcels outside flood zones that could be available for development (City of Boston, 2021; City of Somerville, 2022; Metropolitan Area Planning Council, 2016, 2018a, 2022). Notably, in the City of Boston, the local hazard mitigation plan estimates that nearly 19 percent of recent and future developments are in the Massachusetts Coast Flood Risk Model's (MC-FRM) projected 2070 flood zone (City of Boston, 2021). Some municipalities also expressed concern with heat associated with density and extreme heat that could be intensified by increased development (City of Somerville, 2022; Metropolitan Area Planning Council, 2016, 2022).

In 2018–2022, construction in coastal areas continued, but construction was less concentrated in the municipalities adjacent to Boston Harbor and more widely spread throughout coastal communities, with a slight concentration in Norfolk, Middlesex, and Essex. While growth was less concentrated in coastal areas, the data analyzed suggest that construction continues to take place in areas exposed to multiple hazards that affect coastal areas.

Central and Western Massachusetts

A notable change in construction is occurring in central Massachusetts along the Connecticut River Valley (Franklin, Hampshire, and Hampden counties). Construction between 2018 and 2022 intensified, suggesting changes in land use toward and increases in development. The development is correlated with increased growth in the cities of Springfield and Northampton. Construction permits suggest that these development patterns are likely to continue through 2030. Permits for future construction suggest that growth is likely to increase in Worcester County, where the highest concentration of construction projects is projected between 2023 and 2030. Many municipalities' local hazard mitigation plans noted that they had less than half of their land developed and identified several new developments in the planning and permitting stages (Erving Multi-Hazard Mitigation Plan Update Committee, 2020; Metropolitan Area Planning Council, 2018b; Shutesbury Hazard Mitigation Planning Team & Franklin Regional Council of Governments, 2021). Hazards like landslides and flooding were of highest concern.

Data on construction permits suggest that the Berkshires and Hilltowns region are not projected to experience significant growth. Local hazard mitigation plans confirm that most municipalities in this regions have experienced stagnation or very low growth rates (Buckland Local Natural Hazards Mitigation Planning Committee & Franklin Regional Council of Governments, 2013; City of North Adams, 2021; Town of Otis, 2022).

5.1.5.4 Updated Sources and Documents Reviewed

The Risk Assessment used a range of documents, reports, and studies to characterize the exposure, vulnerability, and consequences for each hazard. The documents reviewed included the most recent scientific literature available in Massachusetts or the Northeast United States, statewide and regional reports, and local and multi-jurisdictional hazard mitigation and climate adaptation plans, as well as studies, analyses, and research conducted at the local level.

- **Scientific literature.** The assessment team updated literature referenced in the 2018 MA SHMCAP as applicable. The literature search was restricted to articles published in peer-reviewed journals after 2018. Older references were included if they were important or foundational work, or if they represented the most current findings on a particular topic.
- **Local hazard mitigation plans.** FEMA-approved local hazard mitigation plans were reviewed and incorporated throughout the analysis. The review and incorporation of local plans is discussed in further detail in Section 5.1.4.3.2.
- **Survey.** Representatives from state agencies were surveyed as part of the 2023 MA SHMCAP development; one of the questions asked them to identify populations at risk from hazards reviewed in the Risk Assessment. The responses to the survey were completed by agency staff and did not go through a formal review process.
- **Document review exercise.** As part of the 2023 MA SHMCAP effort, a review of state agency and local jurisdiction documents, studies, and reports was conducted. The Risk Assessment draws information from reports considered in the document review exercise.

5.1.5.5 Expert Consultation and Review

The Risk Assessment team consulted with a wide array of subject matter experts (SMEs) at important stages of the process, with several opportunities for input and rounds of review. SMEs provided feedback on drafts of the Risk Assessment before the first draft was finalized. State agencies and the RMAT had an opportunity to review and comment on hazard profiles and problem statements through working group sessions and review cycles.

State agencies also participated in a survey, which included opportunities for them to comment on the impacts of each hazard. In these surveys, SMEs provided their primary concerns for assets, services, populations served, and disproportionate impacts and recommended updates or improvements to address these concerns. Summaries of these survey responses are included in the hazard risk assessments. Additional engagement included opportunities to provide comments during three 2023 MA SHMCAP working group meetings and small group meetings with SMEs on subjects including earthquakes, soils, groundwater, wildfire, and inland flooding.

The Risk Assessment received input from over 50 SMEs representing:

- Over 30 agencies and local governments, academic institutions and non-profit organizations.

5.1.5.6 Analysis of Assets at Risk and Estimated Losses

The Risk Assessment includes a discussion of the vulnerabilities of state-owned assets as well as lifelines, critical assets, and other significant assets and service areas and the consequences they face from each hazard. To evaluate risk and exposure of state assets, the Risk Assessment used data on state-owned buildings from the Division of Capital Asset Management and Maintenance. This dataset includes an inventory of over 250 types of state-owned assets; the team identified building types of highest relevance in connection to community lifelines, critical assets, and high-consequence risks for each sector. For example, in the infrastructure sector, assets such as transportation, buildings, hospitals, dams or communications, and water utilities were included in the analysis. Critical assets were defined as assets that provide critical services to protect and maintain human and environmental health and safety and included assets with high occupancies; assets used by sensitive populations; and assets that serve a residential function, such as homes, hospitals, jails, group homes, and more.

Analysis of risk considered the exposure and likelihood of damage, disruption, or loss of assets, or increased costs or time needed to address risks to critical assets. The Risk Assessment used both quantitative and qualitative measures to identify vulnerabilities and consequences; where the data were available, it included dollar value estimates of damage and disruption, as well as cost to rebuild.

In addition to the geospatial, asset, and regional or county data and analysis, the Commonwealth updated the Risk Assessment using the 2022 updated Hazus 6.0 model to estimate risk from earthquakes and hurricanes. Level 1 probabilistic analysis was used to estimate damage from peak wind gusts using the Hazus Hurricane Model. Displacement and short-term shelter needs for each county were calculated for 10-, 50-, 100-, and 500-year hurricane events. To estimate damage from earthquakes, a Level 2 probabilistic analysis was conducted using the Hazus Earthquake Model. The Hazus analysis for earthquakes includes new data on soil classification created by researchers at Tufts University published in 2023. The soils data were based on the state's surficial geology map and considered average overburden velocity, depth to bedrock, and bedrock velocity described by Pontrelli et all. (2023). The analysis considered 100-, 500-, 1,000-, and 2,500-year mean return periods using probabilistic scenarios. Further details on the data and information used to conduct each Hazus model run are presented in the relevant hazard sections.

5.1.5.7 Regional Analysis

The Risk Assessment considered global, national, state, regional, and local geographic contexts and sought to include information at the highest resolution using the most downscaled data available for each hazard and the physical, non-physical assets, ecosystems, and populations assessed. Extensive geographic information system (GIS) data from federal, state, regional, and local sources were used.

Geospatial analysis was also used to overlay hazard data with data from all five sectors and subcategories within each sector. Based on the data available, each hazard used the most downscaled information available to support the assessment. The scale of geospatial analysis varied, depending on what level was appropriate: the Risk Assessment includes location-specific, town-level, Census Block Group–level, county-level, regional, and statewide analyses as appropriate for various sections.

The Risk Assessment includes a technical appendix that documents the data sources used and the geospatial analysis conducted for all hazards. The appendix gives technical audiences the background needed to understand the data used and how each analysis was conducted.

5.1.6 Hazard Snapshots

5.1.6.1 Snapshots: Geospatial Scale of Hazards, Magnitude of Consequences, and Likelihood of Hazard and Warning Time

As part of the risk assessment process, there is a need to consider all hazards in a summarized way that enables a discussion of risk across all hazards. To do this, the Risk Assessment includes three hazard snapshots, presented as tables below. These represent a consistent summary and comparison of all hazards, including rankings and statements across a set of consistent parameters. The Problem Statements present statements and maps, when relevant. This exercise provides a high-level overview, comparing:

- The locations and scales at which hazards are most likely to occur (Table 5.1-3)
- The likelihood that those hazards will occur (Table 5.1-4)
- The magnitude and range of anticipated/observed intensities of the hazards (Table 5.1-5)

While some hazards are more likely in the Commonwealth, all hazards identified in the 2023 MA SHMCAP come with high potential consequences, sometimes at local scales, sometimes at statewide scales. All hazards identified have a high or very high impact in at least one of three categories (human, economic, and natural environment). Some hazards are unlikely or very unlikely to occur at a significant scale (tsunamis, earthquakes), and some have primarily local impacts and consequences (landslide).

The scales used to define these relative categories are given in Section 5.1.6.2.

Table 5.1-3. Geospatial Scale of Hazards

	Impact	Consequences
Average/Extreme Temperatures	Multi-state	Multi-state
Changes in Groundwater	Statewide	Localized
Coastal Erosion	Coast-wide	Coast-wide
Coastal Flooding	Coast-wide	Statewide
Drought	Multi-state	Statewide
Earthquakes	Multi-state	Multi-state
Flooding from Precipitation	Localized	Regional
- *Dam Overtopping*	Localized	Regional
Hurricanes/Tropical Cyclones	Multi-state	Coast-wide
Invasive Species	Multi-state	Multi-state
Landslides/Mudflows	Localized	Localized
Other Severe Weather	Localized	Localized
Severe Winter Storms	Multi-state	Multi-state
Tornadoes	Multi-state	Localized
Tsunamis	Coast-wide	Statewide
Wildfires	Regional	Statewide

Table 5.1-4. Magnitude of Consequences

	Human	*Economic*	*Natural Environment*
Average/Extreme Temperatures	Very high	Medium	Very high
Changes in Groundwater	High	Medium	High
Coastal Erosion	High	Medium	High
Coastal Flooding	High	High	High
Drought	High	High	High
Earthquakes	High	Medium	Low
Flooding from Precipitation	Very high	High	Medium
- *Dam Overtopping*	High	Medium	Low
Hurricanes/Tropical Cyclones	Very high	High	Medium
Invasive Species	Medium	High	Very high
Landslides/Mudflows	High	Low	Medium
Other Severe Weather	High	Low	Low
Severe Winter Storms	Very high	Low	Low
Tornadoes	High	Medium	Medium
Tsunamis	Very high	High	Very high
Wildfires	High	Medium	Medium

Table 5.1-5. Likelihood of Hazard and Warning Time

	Likelihood	Warning Time
Average/Extreme Temperatures	Very high	1–5 days
Changes in Groundwater	High	1–5 days
Coastal Flooding	Very high	1–5 days
Coastal Erosion	Very high	More than 1 week
Drought	Medium	More than 1 week
Earthquakes	Medium	No warning
Flooding from precipitation	Very high	1–5 days
– *Dam Overtopping*	Medium	One Week
Hurricanes/Tropical Cyclones	Medium	1–5 days
Invasive Species	Very high	More than 1 week
Landslides/Mudflows	High	No warning
Other Severe Weather	Very high	1 day (24 hours)
Severe Winter Storms	High	1–5 days
Tornadoes	High	Hours
Tsunamis	Very low	Hours
Wildfires	Very high	Hours

5.1.6.2 Methods Used for Hazard Snapshots

The hazard snapshots use scales associated with aspects that affect an agency's or community's ability to prepare for, withstand, recover from, and adapt to a hazard. A stable set of factors were developed to classify hazards across dimensions that reflect location of impact, geographic scale of consequence, magnitude of consequence, likelihood of occurrence, and ability to prepare and respond. These factors are described below.

5.1.6.2.1 Location of Impact

The initial geographic reach of the hazard—that is, the locations where the hazard occurs. This ranges from multi-state to localized, as defined in Table 5.1-6 below.

Table 5.1-6. Hazard Snapshots: Geographic Scales

Multi-state	State	Regional	Coastwide	Localized
Impacts spanning several states or large regions of states	Effects on the entire state without significant overflow to other states	An area or division of the state with definable characteristics, such as counties with shared hazard-relevant conditions	One county or set of counties that experiences pronounced hazard impacts	A focused and limited area of impact

5.1.6.2.2 Geographic Scale of Consequences

The geographic reach of consequences of the hazard. This scale ranges from multi-state to localized, as defined in Table 5.1-6 above; it differs from the scale of impact in that it considers indirect consequences of the hazard. For example, if a hurricane strikes Logan Airport, thus disrupting transportation for the Northeast (and across the U.S. and the world), it has a localized scale of impact but a multi-state scale of consequences.

5.1.6.2.3 Magnitude of Consequences

The magnitude of consequence for three categories: human impacts, economic impacts, and natural environmental impacts, with a scale from very high to very low. The threshold for each ranking is provided below in Table 5.1-7.

Table 5.1-7. Hazard Snapshots: Magnitude of Consequences

	Very High	***High***	***Medium***	***Low***	***Very Low***
Human	Loss of human life	Any injuries; disruptions of emergency routes, inability to carry out daily activities	Disruption in ability to work and/or carry out daily life and activities	Limited effects, inconvenience, minor power outages	Minimal injury and/or inconvenience
Economic	National-level disruption to and long-term impacts to the state and possibly at the national economy; severe economic losses across multiple sectors	Significant long-term disruption to the state economy with repercussions across multiple sectors, likely to result in economic decline, with impacts that	Prolonged disruption to economic activity that limits or restricts growth, with risk of mid- or long-term economic decline	Economic consequences to people, state, and business conditions requiring expense and effort to overcome; long-term constraints unlikely	Economic costs and consequences do not affect economic growth; economic costs may be incurred, but they are planned and

	Very High	*High*	*Medium*	*Low*	*Very Low*
		last several years after a disaster			are sustainable expenses
Natural Environment	Irreversible loss of ecosystem and/or key organisms	Extensive damage to ecosystem and/or key organisms; unlikely to recover to pre-disaster state	Damage to ecosystems or organisms, but a likely recovery to a pre-disaster state	Some losses to individual organisms but permanent ecosystem impacts unlikely	Minimal risk of impact to individual organisms or overall ecosystems

5.1.6.3 Likelihood of Occurrence

This ranking considers likelihood that a hazard will occur and that consequences will result from the hazard occurring. The likelihood of a hazard occurring is informed by the historical record (if available) and climate projections, as well as the best available data and science for each hazard. All hazard analysis included the best available information on the likelihood of a hazard occurring. The scale below allows all hazards to be compared. The scientific knowledge available to predict or estimate an exact probability or likelihood of a hazard occurring varies significantly across hazards. As a result, the Risk Assessment team used a scale with five grades and ranked the likelihood of consequences from very high to very low using the criteria defined in Table 5.1-8. The results are illustrated in the first column of Table 5.1-5 under "Likelihood of Hazard and Warning Time".

Table 5.1-8. Hazard Snapshots: Likelihood of an Occurrence Resulting in Consequences

Very High	High	Medium	Low	Very Low
Almost certain to occur multiple times in a year	Almost certain to occur at least once in a year	Likely to occur at least once every 50 years (two or more occurrences in the next century)	Likely to occur at least once by the end of the century; some examples of historical occurrences, anticipated every 10 years	Very unlikely; minimal examples of historical occurrences

5.1.6.4 Warning Time

The time available for preparation between reliable predictions of a hazard and the onset of that hazard. The scale ranges from "no warning" to "one week or more," as defined in

Table 5.1-9 below. (For more information on warning time in relationship to risk, see Section 5.1.4.3.2.)

Table 5.1-9. Hazard Snapshots: Warning Time

No Warning	*Hours*	*1 Day (24 Hours)*	*1–5 Days*	*1 Week*	*More than 1 week (Months or Years)*
Very difficult to predict and anticipate location, severity, and onset; information available does not enable preparation	Occurs with little warning; a limited number of hours to adjust behavior or prepare	Reliable, actionable information on impact available one day (about 24 hours) allowing at least one day to prepare	Predictions of impact are accurate within one to five days before the hazard occurs	Predictions of impact are accurate enough within one week, enabling several days for preparation	Reliable, accurate prediction of hazard onset at several weeks (or significantly longer), specific enough to direct action

5.1.7 Technological and Human-Caused Hazards

The 2018 MA SHMCAP discussed technological and human-caused hazards as well as the separate hazard identification and risk assessment (HIRA) process. The inclusion of technological and human-caused hazards demonstrates that the Commonwealth's Emergency Management Program accounts for both natural and non-natural hazards to aid in maintaining the Commonwealth's Emergency Management Accreditation Program (EMAP) accreditation.

This section provides updates to the review of state emergency management plans that assess hazards in the technological and human-caused category. This HIRA undertakes an all-hazards identification, classification, and vulnerability indexing process to ensure risk analysis is comprehensive and all-encompassing.

For the purposes of the HIRA, a natural hazard is defined as an event or physical condition that has the potential to cause fatalities, injuries, property and infrastructure damage, agricultural loss, damage to the environment, interruption of business, or other types of harm or loss. In addition, a human-caused hazard includes any disastrous event caused directly and principally by one or more identifiably deliberate or negligent human actions, while a technological hazard is a hazard originating from technological or industrial conditions, including accidents, dangerous procedures, or failures.

To update the summary of mitigation plans and studies on technological and human-caused hazards, some human-caused hazards are discussed in this section, separately from the 15 main hazards in the 2023 MA SHMCAP Risk Assessment.

The following hazards are not analyzed in the Risk Assessment or action strategy because their subject matter diverges from the natural or climate change–influenced hazard categories. The 2018 SHMCAP identified the following non-natural threats. The threats in the following table are discussed in Section 6 of the 2023 Risk Assessment Introduction:

Deliberate Acts	Technological Hazards
• Cyber incident • Terrorism • Active shooter • Civil unrest • Chemical, biological, radiological, nuclear incident	• Infrastructure failure • Hazard material accident/spills • Nuclear power plant event • Major air crash • Dam failure

These threats are still relevant to the Commonwealth. Additionally, pandemics are a significant human-caused hazard that was not listed in the 2018 SHMCAP. The HIRA will act as the comprehensive all-hazards identification, assessment, and consequence analysis for the Commonwealth's Emergency Management Program.

5.1.7.1 Massachusetts THIRA/SPR

In 2018, FEMA issued updated guidelines that require the state administrative agency and urban area (as designated under the Urban Areas Security Initiative) receiving FEMA Preparedness Grant funding to complete and submit a Threat Hazard Identification and Risk Assessment (THIRA) every three years and submit annually a Stakeholder Preparedness Review (SPR) to the FEMA regional federal preparedness coordinator. The Comprehensive Preparedness Guide (CPG) 201 was issued by FEMA to provide guidance for conducting a THIRA/SPR (FEMA, 2018). The Commonwealth maintains a THIRA that is developed following CPG 201 and updated every three years; 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 involves stakeholders representing local, regional, and state government offices, the Federal Government, as well as nongovernmental organizations (NGOs) and the private sector.

The Massachusetts THIRA/SPR follows a three-step tri-annual process and a three-step annual SPR process, as described in CPG 201:

5.1.7.1.1 THIRA Three Step Process

Step 1. **Identify the Threats and Hazards of Concern.** Based on a combination of experience, forecasting, expert judgment, and other available resources, identify a list of the threats and hazards of primary concern to a community.

Step 2. **Give the Threats and Hazards Context.** Describe the threats and hazards of concern, showing how they may affect a community.

Step 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 sub steps: 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.

5.1.7.1.2 SPR Three Step Process

Step 1. **Assess Capabilities.** Based on the language from the capability targets set in THIRA Step 3, identify the community's current capability and how that capability changed over the last year, including capabilities lost, sustained, and built. Then, provide additional context to explain the reported data and its sources.

Step 2. **Identify Capability Gaps and Intended Approaches to Address Them.** Determine the causes of the capability gap between the capability target and the current capability identified in SPR Step 1. Then, describe the actions and investments needed to close the capability gap or sustain the capability.

Step 3. **Describe the Impacts of Funding Sources.** Identify how relevant funding sources, including but not limited to grant programs and the community's own resources, helped to build, or sustain the capabilities assessed by the capability targets and describe how those capabilities were used in a real-world incident(s) over the past year.

5.1.7.1.3 Comprehensive Emergency Management Plan

The Commonwealth of Massachusetts' Comprehensive Emergency Management Plan (CEMP) provides a framework for state-level emergency management activities and defines how state government interfaces with other emergency management stakeholders, including local and tribal governments, non-governmental organizations (NGOs), other states, the federal government, and the private sector during all phases of an emergency or disaster.

The CEMP describes the system that will be used by the Commonwealth of Massachusetts to prepare for, respond to, recover from, and mitigate an emergency or disaster. It also identifies and assigns specific areas of responsibility for coordinating resources to support the Commonwealth's response to an emergency or disaster. The CEMP is an all-hazards plan, developed to address the Commonwealth's unique natural, technological, and human-caused hazards.

The Commonwealth has structured its CEMP into three distinct, but interconnected volumes:

- Volume 1: Massachusetts State Hazard Mitigation and Climate Adaptation Plan
- Volume 2: Response and Short-Term Recovery Plan

- Volume 3: Long-Term Recovery Plan

Volume 1 of the State CEMP is the State Hazard Mitigation and Climate Adaption Plan (SHMCAP). The SHMCAP was approved by FEMA in September 2023. Pursuant to the requirements of 44 CFR 201.4, the SHMCAP is required to focus on natural hazards that are likely to cause a substantial impact on the state. Additionally, 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 complies with 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.

In terms of hazard mitigation activities, the Commonwealth of Massachusetts participates in federal, state, and local mitigation programs and identifies ongoing mitigation opportunities. The State takes advantage of available federal funding to implement mitigation measures at the state and local levels. Throughout the past several years, a substantial amount of funding has been directed at understanding and addressing some of the Commonwealth's most pressing hazards and their climate impacts.

Volume 2 of the CEMP, Response and Short-Term Recovery Plan is comprised of:

- The base plan
- 16 Emergency Support Function (ESF) Annexes
- Hazard-or Threat Specific Annexes
- Functional Annexes.

This Plan forms the overall framework for emergency response and short-term recovery operations in the Commonwealth. The ESF annexes describe the policies, planning assumptions, concepts of operations and responsibilities for their activities while the hazard- or threat specific and functional annexes contain specialized information and procedures required to address specific types of incidents or events. Both hazard- or threat-specific and functional annexes are maintained separately from this Plan but are incorporated by reference.

Volume 3 of the State CEMP is the Long-Term Recovery Plan. Volume 3 includes the mechanisms for utilizing long-term recovery components, including mitigation, which is provided for under the Robert T. Stafford Disaster Relief and Emergency Assistance Act. Volume 3 sets the foundation for the State's Recovery Support Functions (RSFs) designed to effectively interoperate with federal disaster recovery components as identified in the National Disaster Recovery Framework (NDRF). Volume 3 also recognizes the primacy of local governments in the implementation of long-term recovery plans and, depending on the nature and impact of the disaster, new programs that might be available to achieve full recovery.

Please see the CEMP for a list of annexes, which illustrate the extent of natural, technological, and human-caused hazards that are addressed through the CEMP.

5.1.7.1.4 Infectious Disease Emergency Response

The Massachusetts Department of Public Health (MDPH) Infectious Disease Emergency Response (IDER) Plan defines the MDPH's concept of operations for an infectious disease emergency response. At its core, the goal of the IDER is to mitigate the impact of a disease outbreak caused by an infectious agent or biological toxin, or to respond to other infectious disease emergencies. The Bureau of Infectious Disease and Laboratory Sciences (BIDLS) closely monitors infectious disease activity as part of their normal operating procedures. As a result of constant engagement with infectious disease experts and resources, BIDLS may receive information that suggests or indicates a potential or real public health threat. Once that information is assessed the IDER may be activated if needed.

This emergency response plan may be activated for an outbreak of an existing reportable condition, emerging infectious disease, pandemic, or suspected bioterrorism event that threatens the public's health. An infectious disease emergency will require timely and effective use of public health and medical resources, including facilities, personnel, equipment, mental and behavioral health services, and pharmaceutical and other supplies. The need for resources during an infectious disease emergency may exceed routine operations and overwhelm resources available at the local, tribal, regional, and state levels.

5.1.7.2 Nuclear Plans

The Pilgrim Nuclear Power Station ("Pilgrim") is in Plymouth, Massachusetts. Pilgrim permanently ceased power generation operations on May 31, 2019, and is currently being decommissioned. The Massachusetts Emergency Management Agency (MEMA) communicates radiological emergency response plans and standard operating procedures for communities and facilities falling within the Massachusetts portion of the Seabrook Nuclear Power Emergency Planning Zone. The information is communicated through the Emergency Public Information for Seabrook Nuclear Power Station.[1]

5.1.8 Hazard Profiles

The 15 hazard profiles on the following pages provide high-level summaries of the hazard risk assessments, able to serve as a stand-alone document. For more information on their content and purpose, see Section 5.1.4.1.

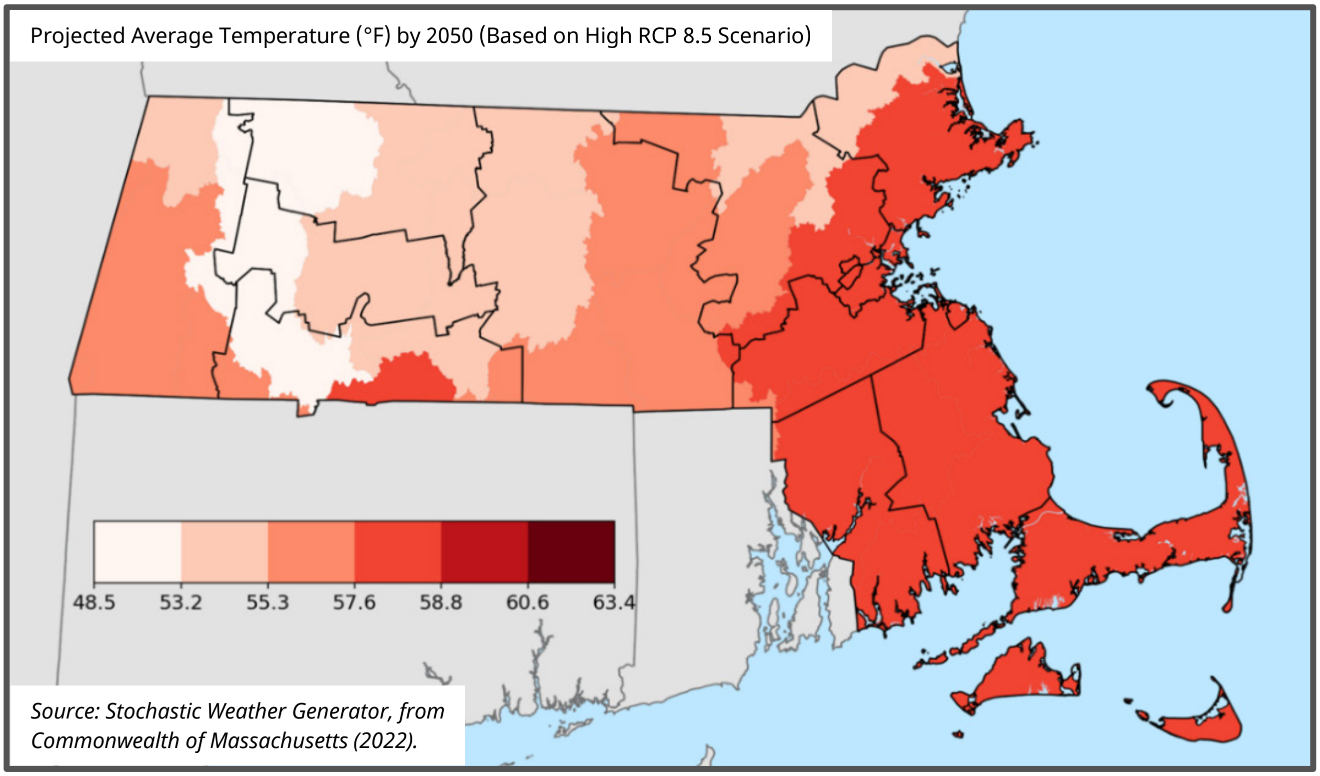
Appendix 5.C includes detailed information on the risk assessment and hazard analysis of the 15 hazards presented in the 2023 MA SHMCAP.

[1] Emergency Public Information for Seabrook Nuclear Power Station information is available at the following link: https://www.mass.gov/info-details/seabrook-nuclear-power-station#seabrook-emergency-planning-zone-(epz)-

Average/Extreme Temperatures Hazard Profile

Temperatures vary across Massachusetts, with higher temperatures typical in the southeast and colder ones in the northwest. The *2022 Massachusetts Climate Change Assessment* predicts that temperatures are almost certain to rise across the Commonwealth. Humidity will rise as well, causing hot days to feel even hotter. These changes could have significant consequences for human and ecosystem health, as human populations and ecosystems in Massachusuetts are not adapted or accustomed to these temperatures. Projections show that inland areas are very likely to warm more and experience more extreme heat than coastal areas.

Projected Average Temperature (°F) by 2050 (Based on High RCP 8.5 Scenario)



Source: Stochastic Weather Generator, from Commonwealth of Massachusetts (2022).

Most At-Risk Areas

Inland areas are very likely to experience extreme temperatures more often than coastal areas, as they are not moderated by the Atlantic Ocean. Urban areas experience greater temperatures due to the urban heat island effect.

Cause

Temperature variations occur due to several atmospheric phenomena. Increased greenhouse gas emissions from human activities are contributing to an increase in the earth's surface temperature, causing more extreme temperatures.

Historical Frequency and Recent Trends

2022 was one of the hottest and driest summers on record in Massachusetts. Over the last century, annual air temperatures increased at an average rate of 0.5ºF per decade. Massachusetts' hottest recorded temperature was 107ºF in August 1975. Its coldest was -35ºF in February 1943.

Projected Effects of Climate Change

Climate change is already contributing to increasing average temperatures and more extreme temperatures and is virtually certain to continue doing so. Climate change in the near term is also likely to contribute more severe winter storms, bringing colder temperatures, even if the winter season overall is shorter.

Secondary Hazards from Temperature:

- Severe weather events such as hurricanes, increases in precipitation intensity (e.g., inches/hour) and amount (e.g., inches), and more severe winter storms.
- Longer, more severe droughts and a longer, more severe wildfire season.
- Invasive species, habitat shifts, and surface water warming.

Average/Extreme Temperatures Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Extreme temperature is the leading cause of weather-related mortality in the U.S.
- Reductions in air quality can lead to lung and respiratory diseases and require medical visits and costly prescriptions, in addition to resulting in death. Currently, one in eight children in Massachusetts suffers from asthma.
- Age and chronic health conditions can also increase susceptibility to heat-related illnesses.
- Environmental justice populations are particularly at risk from extreme temperature–related health effects because they reside in temperature hotspots. Linguistically isolated populations are most disproportionately exposed to this hazard.
- Black and African American people are 40% more likely to live in areas with high childhood asthma rates.
- The majority of extreme heat impacts fall in the Eastern Inland and Boston Harbor regions.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage to roads and loss of road service.
- Damage to rail and loss of rail/transit service.
- Damage to electric transmission and utility distribution infrastructure.
- Pipes freezing and bursting due to extreme cold, leading to flooding and water damage/mold inside homes and buildings.
- Loss of urban tree cover.
- Potential impacts to critical facilities, such as water infrastructure and emergency response infrastructure.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Reduced ability to work.
- Decrease in marine fisheries and aquaculture productivity.
- Decrease in agricultural productivity.
- Increased possible cost for water and electricity, caused by higher demand.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Increased demand for state and municipal government services. All state-owned buildings are exposed to extreme temperatures, increasing government expenditures for energy and maintenance.
- Increase in government expenditures to coordinate between state agencies and municipalities for adaptation efforts.
- Health risks and reduced productivity for state employees who work outdoors.

Natural Environment

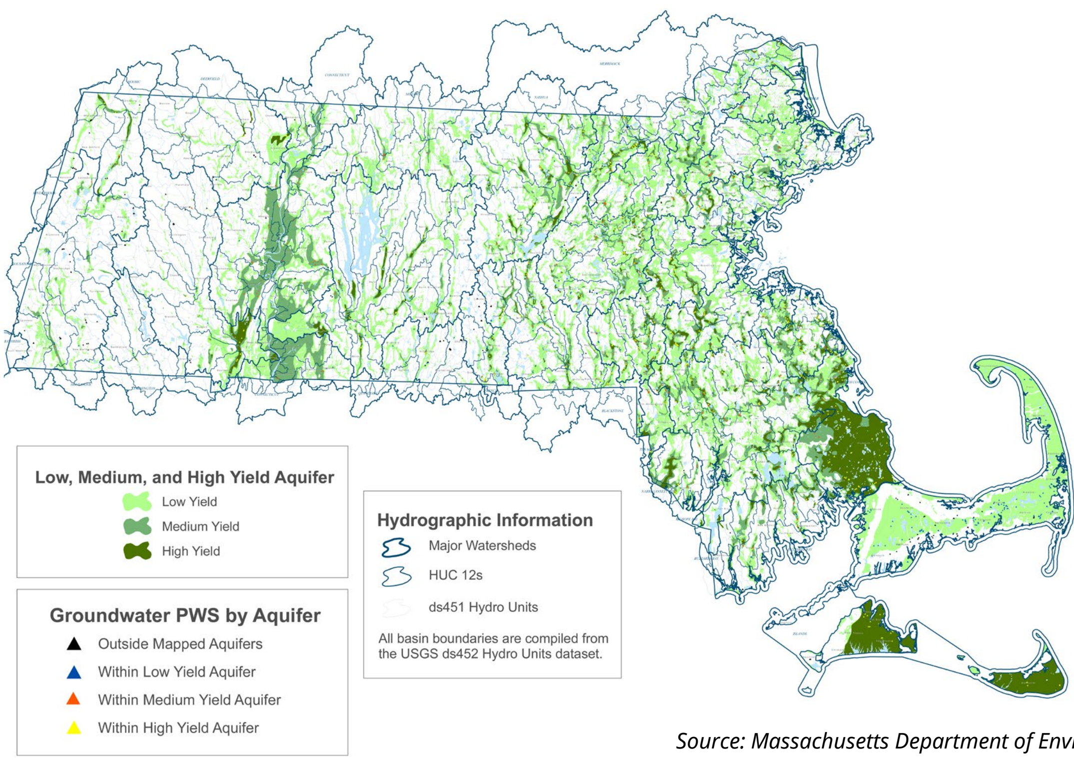
Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Shifting distribution of native and invasive species.
- Negative impacts on the Commonwealth's natural resources—such as wetland, cold-water, marine, and forested ecosystems; agricultural resources; and open space—due to temperature increases.
- Reduced ecosystem services, such as carbon sequestration and storage in forests or water filtering in coastal wetlands, due to ecosystem stress.
- Stress to ecosystems from secondary hazards associated with increased temperatures such as drought, invasive species, wildfire, and more varied intensity and frequency of rainfall.

Changes in Groundwater Hazard Profile

There are three primary risks associated with groundwater in Massachusetts: increase in groundwater levels, groundwater resource depletion, and contamination of groundwater by pollution and salinity changes from sea level rise and flooding. Shallow, unconstrained, unconfined aquifers are likely to interact with the surface and can affect local temperatures. Groundwater recharge depends on precipitation, water evaporation from the land surface and vegetation, snowpack and timing of snowmelt, hydrologic connectivity zones, and geological features that influence permeability and water flow. Issues associated with groundwater vary by region, season, and topography and are influenced by hazards such as sea level rise, flooding, heat, drought, and extreme precipitation as well as development patterns and flood management measures that reduce permeability of soils.

Map of Aquifers (Low, Medium, and High Yield)



Source: Massachusetts Department of Environmental Protection, using USGS 100k Hydro units dataset.

Most At-Risk Areas

Changes in groundwater affect the entire state. They can lead to flooding, instability in structures, and effects on drinking water availability.

Cause

Above-average increases or decreases in groundwater create risk. They are a result of changes in the water cycle. Sea level rise affects groundwater in coastal areas.

Historical Frequency and Recent Trends

There are no published data on historical frequency or recent trend data associated with groundwater hazards. There are historical trends and projections for seasonal groundwater recharge in Massachusetts.

Projected Effects of Climate Change

Sea level rise, extreme heat, drought, extreme precipitation, and a reduction in snow are all climate change impacts that will affect groundwater. Risks will vary by season and location and type of change.

Secondary Hazards from Changes in Groundwater:

- Depleted groundwater reserves can increase drought, affecting the environment and communities.
- Groundwater rise can lead to coastal and inland flooding. Contamination can mobilize during flooding events, with impacts to waters, soils, ecosystems, and communities.
- Shallow aquifers are likely to interact with the surface and experience increases in temperature, amplifying heat island effects.

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Reduced access to and increased cost of freshwater for drinking and other uses (e.g., agriculture) from saltwater intrusion, contaminants, or depleted aquifers.
- Flooding and damage to basements and below-grade living spaces, creating risk of contamination, mold, and injury.
- Damage and disruption to water, sewer, stormwater, or power service from flooding that affects below-grade utilities and infrastructure.
- Salinity intrusion, caused by sea level rise, that affects salt-sensitive components of people's homes and other assets.
- Septic system failure leading to water quality degradation in nearby waterways and increased bacterial exposure.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage, disruption, or loss to below-grade buildings and foundations of buildings due to flooding or unstable soils.
- Damage, disruption, or loss to below-grade or at-grade utilities, infrastructure, roads, and transit (including power, heat, water, sewer, and stormwater services) due to flooding or unstable soils.
- Damage to building foundations, as well as salt-sensitive infrastructure and utilities, from salinity intrusion.
- Mobilization of contaminants.
- Cost to repair or relocate due to flood damage.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Costs to businesses and industries, particularly small businesses and water-related and -dependent businesses, due to increased flooding or reduced water supply.
- Increased costs for alternative sources of water such as desalination.
- Disruption of utility and infrastructure creating travel delays or lack of water, power, or sewer service.
- Flooding impacts on at-grade roads and infrastructure. (Government facilities with basements and below-ground areas are most heavily affected.)
- Cost of damage from flooding, especially in areas of repetitive loss.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Increased demand for state and municipal government services and resources to conduct studies, run programs, develop policies, and engage locally to better understand the risks and mitigate the impacts.
- Flooding or salinity intrusion to state-owned assets including structures, parks, trails, natural areas, and others.
- Cost to repair or relocate state-owned assets at risk from or damaged by groundwater rise.
- Cost to identify alternative water sources for state-owned assets if supplies are depleted or (due to saltwater intrusion or groundwater rise) contaminated.

Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Damage to habitats, natural areas, and wetlands due to reduced freshwater supplies from groundwater recharge.
- Saltwater intrusion and inundation of aquifers, wetlands, and ecosystems that cannot adapt to new conditions due to sea level rise.
- Mobilization of contaminants into habitats, vegetation, and wetlands.
- Higher risk of wildfires, invasive species, and reduced health of native species, caused by drought and heat resulting from less groundwater in the ecosystem.
- Changes to groundwater temperature in urban environments, which can amplify heat island effects and stress vegetation and urban trees.

Coastal Erosion Hazard Profile

Coastal erosion affects populations, structures, and the environment along the coastline of the Commonwealth. High-risk areas include communities and ecosystems near developed barrier beaches, dunes, and coastal banks. Climate change impacts such as sea level rise and the increased intensity and frequency of coastal storms also contribute to increased coastal erosion. The combination of human activity along the shoreline and climate impacts can result in a net loss of coastal land. Massachusetts has 1,500 miles of coastline that includes a range of coastal landforms, habitats, developed lands, and infrastructure and utilities that are susceptible to coastal erosion.

Most At-Risk Areas

Most of the coastline is eroding. Urban shorelines with failing seawalls and no dry beach are the most susceptible to damage.

Cause

Coastal erosion is caused by many processes including waves, tides, storms, sea level rise, development, and shoreline armoring.

Historical Frequency and Recent Trends

Coastal erosion can be constant and episodic. Accelerated sea level rise will increase rates of erosion where change is already occurring. Storm intensity associated with climate change may contribute to episodic erosion.

Projected Effects of Climate Change

Sea level rise will increase the coastal areas exposed to wave and tidal action and reduce natural shoreline buffers. The changing intensity, frequency, and duration of coastal storms, including Nor'easters and hurricanes, will increase the rate of coastal erosion in areas already experiencing it. Research is needed to understand climate change impacts on the location, speed, and profile of erosion.

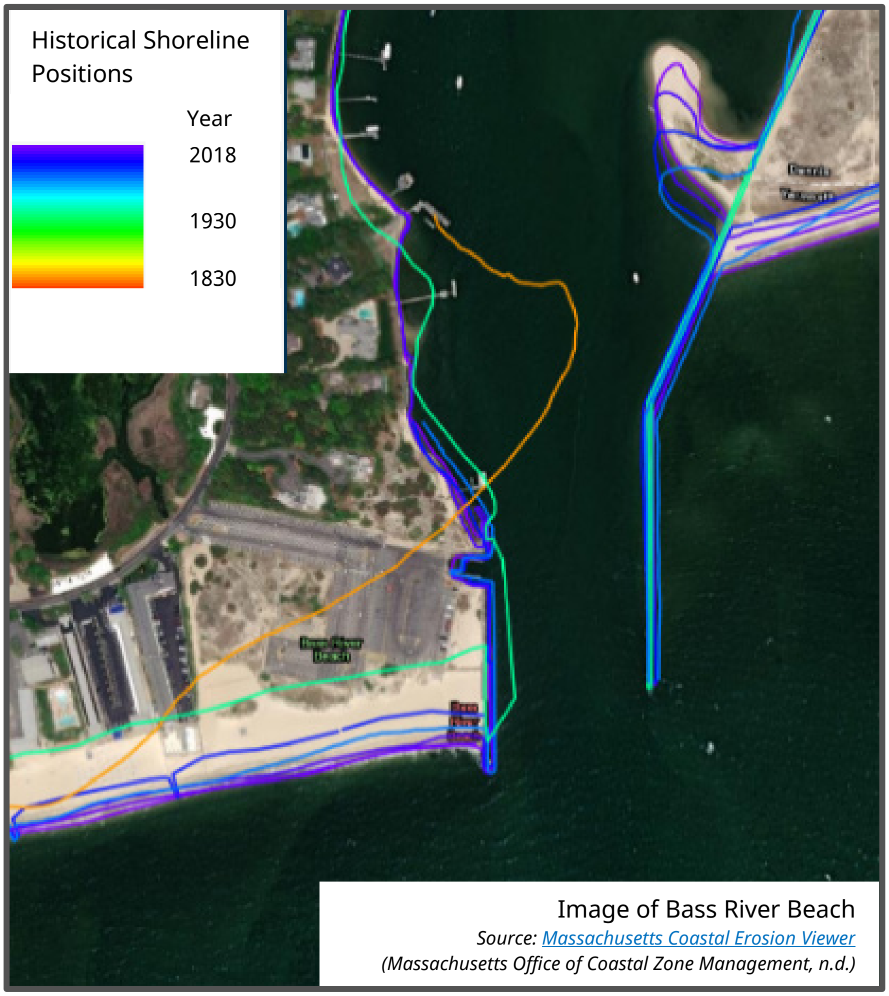


Image of Bass River Beach
Source: Massachusetts Coastal Erosion Viewer
(Massachusetts Office of Coastal Zone Management, n.d.)

Secondary Hazards from Coastal Erosion:

- Landslides and loss of sediment and vegetation, with impacts to native species.
- Profile steepening or flattening, resulting in changes to flood risk.
- Changes in areal extent exposed to flooding, with resulting changes in land use.
- Mobilization of contaminants into water sources and the environment.

Coastal Erosion Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Loss of life or injury may result from episodic and dramatic events of coastal erosion resulting from landslides and flooding.
- Property, homes, community assets, and neighborhoods may be lost to erosion and associated increased flood risk.
- Community assets and services such as parks, schools, businesses, roadways, and utilities are at risk of being damaged, disrupted, or lost.
- Cultural and archaeological resources are at risk of damage, disruption, and loss.
- Damage to sewer infrastructure and septic systems may lead to degradation of water quality: sewer leaks may release bacteria, red tides may result in gastrointestinal infections, and contaminated water may cause water-borne illness.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage, disruption, or loss of coastal homes.
- Damage, disruption, or loss of utilities and infrastructure, particularly underground, linear infrastructure including water supply, sewers, power, roadways, rail, and recreational areas including trails.
- Damage or loss of shoreline flood management infrastructure.
- Damage, disruption, or loss of infrastructure to support water-dependent and water-related uses such as maritime, fisheries, and other industries.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Damage, disruption, or loss of businesses in coastal areas, particularly small businesses and water-related and -dependent businesses.
- Loss or disruption of visitors and tourism spending.
- Loss or disruption to jobs and workforce.
- Disruption of utility and infrastructure that creates travel delays or lack of water, power, or sewer services.
- Erosion damage to 130 state-owned assets within 50 feet of the coast in at-risk areas in Barnstable, Bristol, Essex, Middlesex, Plymouth, and Suffolk counties.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Increased demand for state and municipal government services and resources to conduct studies, run programs, develop policies, and engage locally.
- Demand for public safety and first responder services in preparation for incidents that may result in rapid episodes of coastal erosion.
- Loss of, disruption of, or damage to state-owned assets including structures, parks, trails, and natural areas. Increased cost to repair or relocate state-owned assets at risk from or damaged by coastal erosion.

Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Potential loss of uplands that support native species and provide wetland–upland transition zones.
- Loss of wetland and salt marsh shoreline functions, including habitat for native species, filtering pollutants, trapping and retaining sediment, and buffering the shoreline from wave energy and storms.
- Coastal erosion can accelerate impacts from sea level rise like saltwater intrusion and inundation, putting pressure on habitats and ecosystems that cannot quickly adapt to new conditions.
- Loss of biodiversity, natural resources, and state-owned natural areas, as well as disruption to ecosystem function along the coast.

Coastal Flooding Hazard Profile

Coastal regions of Massachusetts are increasingly susceptible to the risks of coastal flooding which are exhasterbated by to climate change impacts such as sea level rise and increased intensity of coastal storms. Coastal flooding results from a several factors, including waves, high astronomical tides, storm surges, and rising sea levels. Storm surges occur during hurricanes and nor'easters, when low barometic pressures and wind-driven water combine to push coastal water landward. Sea level rise is expected to accelerate and storm surge and coastal windstorm intensity are also expected to intensify as global temperatures rise. These conditions further increasing risks of damaging flood episodes.

Most At-Risk Areas

All coastal regions are at risk. However, the Boston Harbor region currently experiences about half of the average annual statewide impact from coastal flooding.

Cause

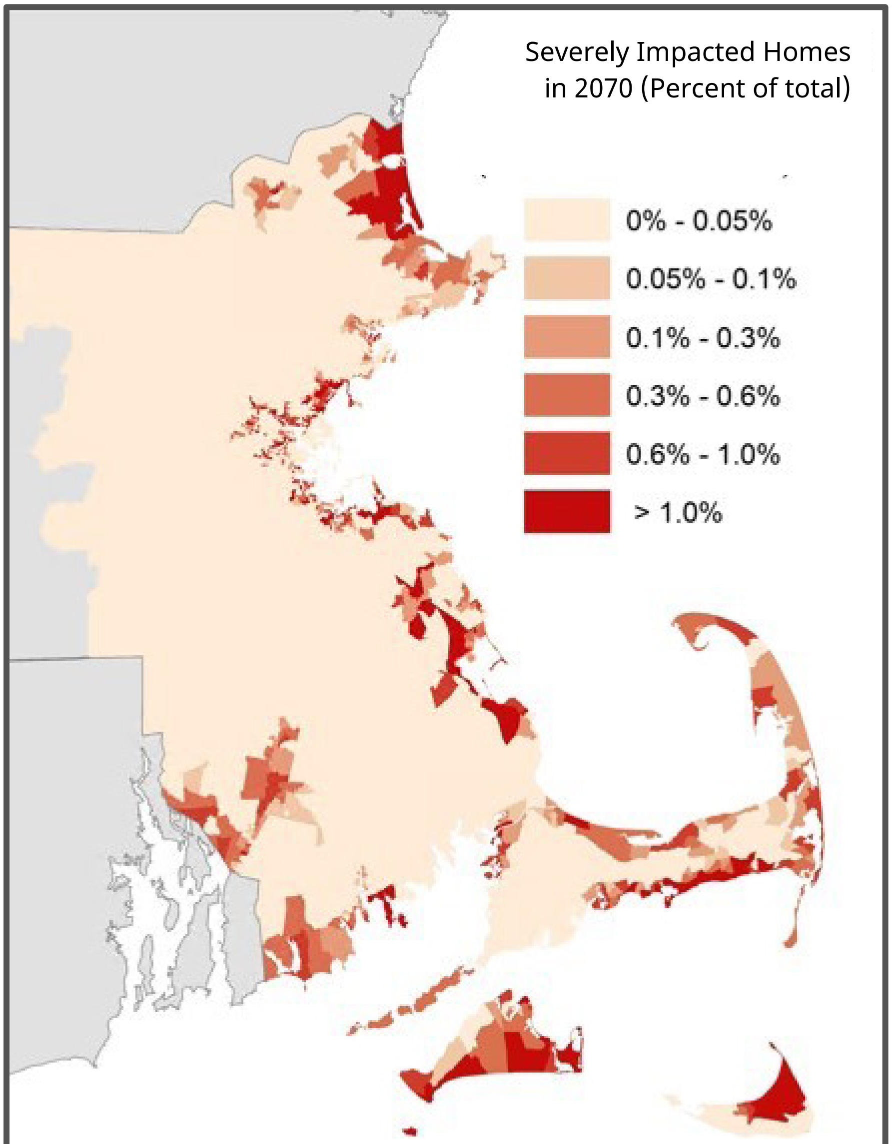
Coastal flooding is caused primarily by wind-driven waves combined with low barometric pressure during coastal storms, but is worsened by sea level rise, as is king tide flooding.

Historical Frequency and Recent Trends

The rate of sea level rise (SLR) could accelerate to 6.0 mm/year by mid- to late century. Boston Harbor tide gauge data show SLR at a current rate of 2.9 (+/- 0.15) mm/year. Coastal flooding could generate annual damages between $150 and $200 million (current storm activity, 2008 sea-levels).

Projected Effects of Climate Change

Rising temperatures accelerate thermal expansion and ice sheet melting, accelerating sea level rise—which in turn elevates daily and seasonal high tides, causing high-tide flooding. Rising temperatures also increase the frequency and severity of hurricanes and nor'easters, which could result in increased coastal flooding.



Source: MA Climate Assessment analysis of MC-FRM results using methods from Neumann et al. (2021).

Secondary Hazards from Coastal Flooding:

- Disruption, damage to or destruction of power, gas, water, broadband, and oil transmission infrastructure. Shutdown of mass transit, airports, roads, bridges, and other transportation systems.
- Indirect effects from damage to ports and marinas, including supply chain interruptions.
- Saltwater intrusion in to drinking water resources.
- Loss of jobs, wages, business revenue and childcare facilities.

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Coastal flooding affects populations who cannot evacuate quickly (e.g., people aged over 65 or under five, people with mobility limitations), as well as residents in rural areas with limited access to services.
- Extreme coastal storms can cause direct health impacts in the form of injuries or fatalities.
- Coastal flooding increases building moisture and exposure to mold, leading to respiratory health effects.
- Coastal storms can increase rates of food spoilage and bacterial infection during power outages.
- Contact with flood waters may lead to bacterial and/or toxic chemical exposure.
- Coastal flooding can cause loss of housing (permanently or temporarily) and subsequent physical displacement and financial burden to flood victims.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Coastal flooding and higher seas inundate land and structures, erode beaches, and lead to more damaging storm surges, which can cause devastating episodic flooding.
- Coastal storms can damage roads, bridges, and culverts. This can cause loss or blockage of evacuation routes.
- The total value of structures within the floodplain for the current 100-year return period coastal storm is about $55 billion, of which about $40 billion is residential, $12 billion is industrial, and $2.5 billion is commercial. The number of vulnerable infrastructure assets and anticipated loss will grow over time as rising seas expand the coastal floodplain.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- High-tide flooding, exacerbated by rising seas, leads to traffic delays that affect people's ability to work.
- Coastal flooding can cause losses in revenue due to flood-induced business interruptions, damage to port infrastructure relied on for commercial fishing, and a decrease in beach tourism.
- Massachusetts is second in the nation in the percentage of federally subsidized affordable housing units vulnerable to coastal flood risk. Risks by 2050 are largest in Boston (3,189 units exposed per year), Quincy (668 units), Cambridge (510 units), and Revere (266 units).
- Massachusetts state-subsidized public housing accounts for 47 developments of housing at high risk for coastal flooding.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Loss of coastal property threatens the property tax base and possible loss of tax revenue in coastal cities and towns.
- Annual expected loss of or damage to state-owned buildings and infrastructure is estimated at $8 million currently and may grow to $36 million by 2050.
- The largest risks to state-owned buildings and infrastructure are in the Cape/Islands/South Coast and the Boston Harbor regions.

Natural Environment

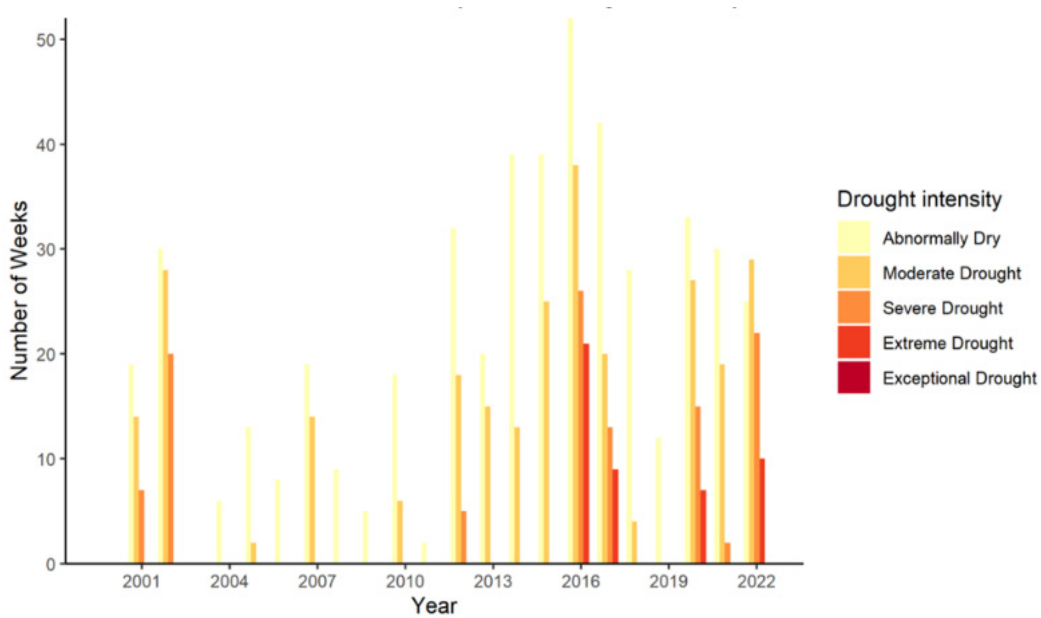
Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Intensified coastal flooding threatens the viability of coastal wetlands, where natural processes of accretion cannot keep up with accelerating rates of change in sea levels.
- Modeling of the effect of higher sea levels on marshes concludes that roughly half of today's total salt marsh area in the Commonwealth could be lost by 2100.
- Loss of salt marshes and other shoreline habitats due to sea level rise and sea level rise–induced accelerated coastal erosion results in negative impacts to species dependent on these habitats (e.g., waterfowl, wading and coastal shorebirds, juvenile marine fish).

Drought Hazard Profile

More than 6 million Massachusetts residents receive their water from public water suppliers, while over 500,000 residents rely on their own private groundwater wells. In addition to impacting residential, commercial, and industrial water supply, droughts across Massachusetts can have implications on public health, agricultural crops, recreation, and natural resources. Approximately 10 percent (500,000 of 4.9 million acres) of Massachusetts is agricultural land, located primarily in Franklin County, Plymouth County, and Hampshire County. There are about 3 million acres of core habitat and critical natural landscape in the Commonwealth that support native and rare species, maintain ecological connectivity, and provide recreational value.

Number of Weeks in Drought Conditions (2001–2022)



Source: Massachusetts Executive Office of Energy and Environmental Affairs & Massachusetts Emergency Management Agency

Most At-Risk Areas

The entire Commonwealth is exposed to drought. The most at-risk assets include agriculture, natural lands and waters, and groundwater and aquifers. From 2001 to 2017, the Connecticut River Valley region and Central region experienced extreme drought.

Cause

Droughts are caused by low precipitation and high evapotranspiration. Land use change, the existence of dams, and water supply withdrawals or diversions also contribute to drought conditions.

Historical Frequency and Recent Trends

Disaster-level drought is infrequent in Massachusetts. As of 2022, the Commonwealth has not received a drought-related Presidentially Declared Disaster. The 2016–2017 drought was the most significant drought in recent years.

Projected Effects of Climate Change

Rising temperatures and changes in precipitation patterns are expected to increase the length, frequency, and intensity of droughts. Reduced snowpack will affect the ability of groundwater supplies to recharge and the availability of water for the growing period.

Secondary Hazards from Drought:

- Reduced quantity and quality of streamflow, groundwater, and surface water stored in lakes and ponds.
- Potential impairment to wetlands bordering rivers and streams, or loss of riverfront areas in headwaters.
- Increased susceptibility of urban tree cover and forest health to wildfire and invasive pests.
- Reduced bank stability from dry soil in root zones, potentially leading to increased erosion.
- Increased contamination of freshwater ecosystems (i.e., harmful algal blooms) during drought conditions.

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Decrease in yields or dry wells for residents with private water supplies.
- Increase in prices and water rationing for people who receive water through a public provider.
- Reduction in food safety and security.
- Increase in mental health stressors.
- Increase in health effects from aeroallergens and mold.
- Increase in vector-borne diseases and bacterial infections.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Reduction in clean water supply.
- Increased strain on public water utilities.
- Need for alternate supplies, such as emergency backup water supplies.
- Impacts on energy generation that requires water for cooling.
- Loss of urban tree cover.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Decrease in agricultural productivity.
- Increase in food prices due to recued yield or loss of crops and the need to purchase water.
- Loss of income for farms and farm workers.
- Disproportionate impacts on water-dependent industries such as nurseries and hydroelectric power generation.

Governance

Impacts to state and local government-owned buildings, government finances, and the ability of the government to run effectively.

- Increased demand for state and municipal government services.
- Impacts to wildfire firefighting due to water shortages.
- Disruption in landscaping at parks and natural areas.

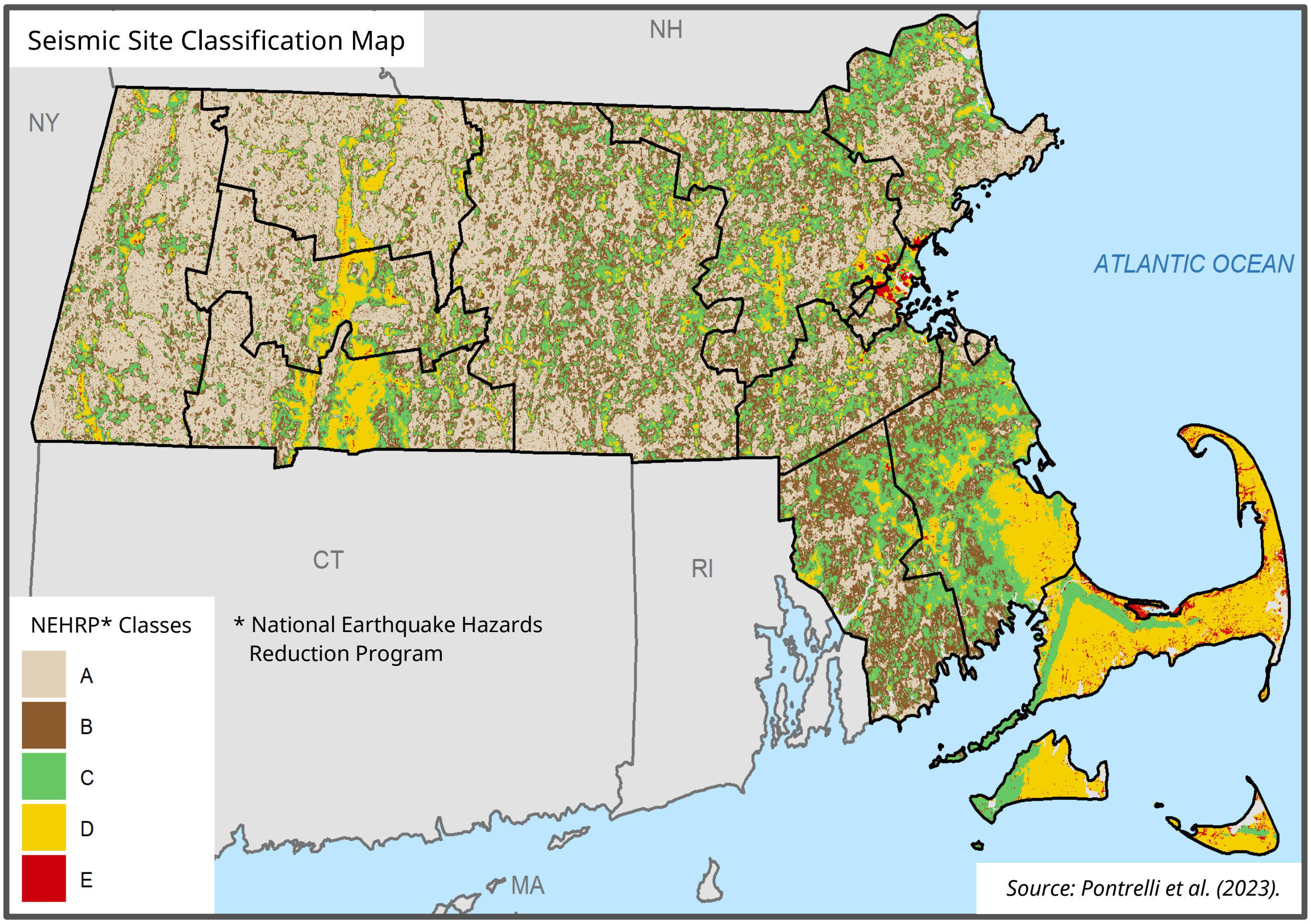
Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Decline in groundwater recharge to aquifers and reduced streamflow.
- Freshwater ecosystem degradation.
- Forest health degradation.
- Coastal wetland degradation.
- Shifting distribution of native and invasive species.
- Increased incidence of wildfires.

Earthquakes Hazard Profile

Massachusetts is not near tectonic plate boundaries, but it is still susceptible to earthquakes that can occur within the interior North American Plate. Earthquakes centered in other parts of New England or Canada could also affect the Commonwealth. Building and land use characteristics increase the risk of local damage. Unreinforced masonry buildings that are common in Boston are especially vulnerable to being damaged by ground shaking. Softer soil types amplify and magnify ground shaking relative to nearby bedrock, which may increase building damage and losses. Liquefaction poses an additional risk in areas with water-saturated sands, silts, or gravelly soils that lose their strength in an earthquake.



Source: Pontrelli et al. (2023).

Most At-Risk Areas

Greater Boston, Cape Cod, and the Connecticut River Valley have softer soils that can amplify shaking. Boston's many unreinforced masonry buildings and areas of filled land place the city at higher risk of earthquake damage.

Cause

An earthquake is the vibration of the Earth's surface that follows a release of energy in the Earth's crust. Risk is related to how the ground shaking interacts with people, buildings, and natural features.

Historical Frequency and Recent Trends

The 1755 Cape Ann earthquake (magnitude 6.2) is the most significant event recorded. The probability of a magnitude 5.0 or greater earthquake centered in New England in a 10-year period is about 10–15%.

Projected Effects of Climate Change

Research does not identify effects of climate change on the earthquake hazard in Massachusetts.

Secondary Hazards from Earthquakes:

- Fires in buildings, communities, or ecosystems, which can cause injury or loss of life.
- Soil liquefaction in certain soil types. Slope failure and landslides; tsunamis.
- Potential release of hazardous materials.

Earthquakes Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Elderly and low-income populations, and people living in substandard housing, are more vulnerable to the impacts of earthquakes.
- Emergency service response delays and evacuation disruptions.
- Direct health risks include trauma-related injuries and deaths. Access to hospitals and medical intervention may be limited following severe earthquakes.
- Hazus estimates fewer than five people may be injured in a 100-year mean return period (MRP) earthquake. Between 1,200 and 3,200 casualties could result from a 2,500-year MRP earthquake, depending on what time it occurs.
- About six households may be temporarily displaced in a 100-year MRP earthquake, and 9,100 households may be displaced in a 2,500 MRP earthquake.
- Earthquakes can damage cultural resources.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage to roads and loss of road service.
- Damage to rails and loss of rail/transit service.
- Damage to or limited emergency communications.
- Damage and disruption to electric transmission and utility distribution infrastructure.
- Reduction in clean water supply.
- Potential release of hazardous materials into the environment from damage to production or storage facilities.
- Damage to unreinforced masonry buildings and structures built on soils that are susceptible to liquefaction. (These are especially vulnerable to shaking.)
- Estimated transportation and utility losses of nearly $10.1 million from a 100-year MRP earthquake and over $1.3 billion from a 2,500-year MRP earthquake.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Economic losses from commercial structural damage and business interruptions.
- Building-related economic losses estimated at around $10.7 million for a 100-year MRP earthquake and over $18.4 billion for a 2,500-year MRP earthquake.
- Costs of debris management and removal.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- All government buildings in Massachusetts are exposed to potential earthquakes.
- Earthquakes may damage public safety infrastructure.
- Increased service demands of first responders during earthquake response and recovery.

Natural Environment

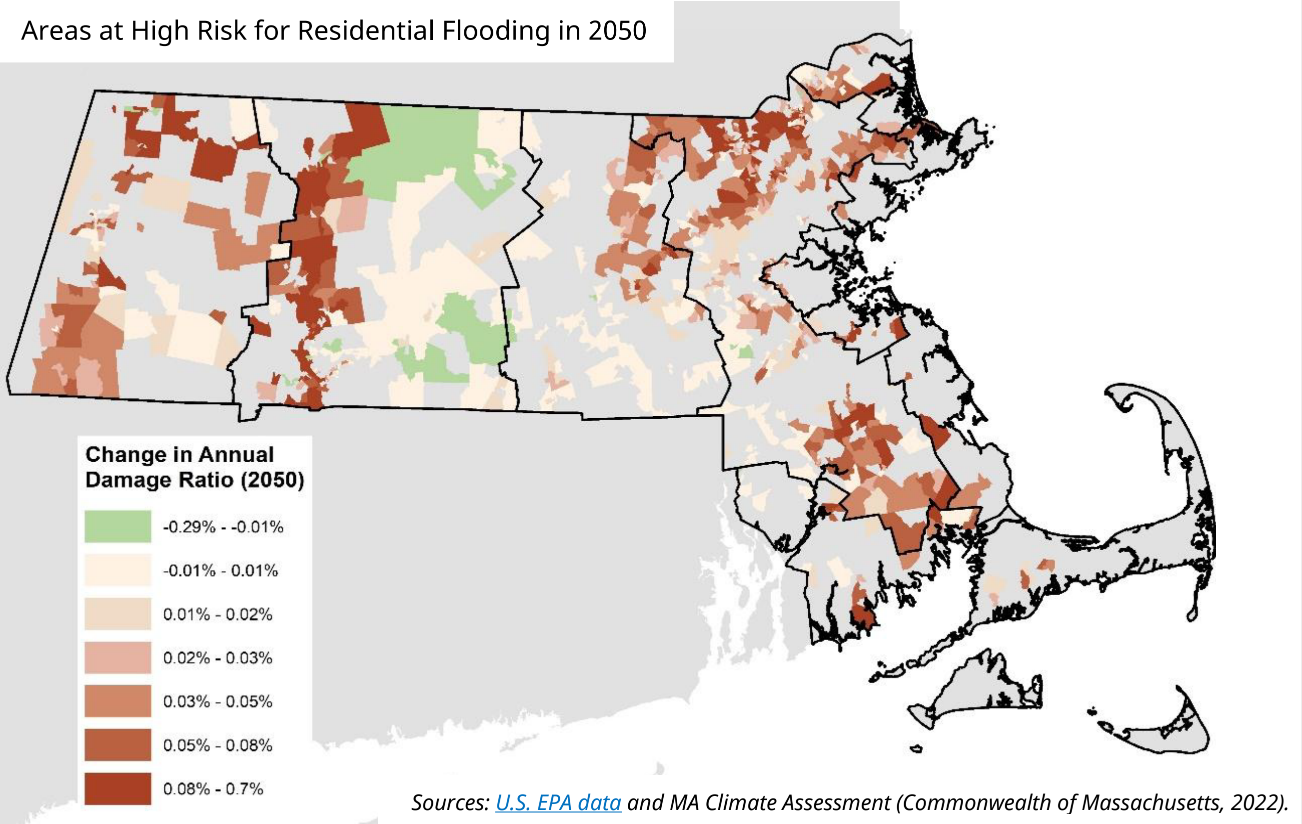
Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Physical changes to an ecosystem from an earthquake can disrupt species balance and leave an area more vulnerable to the spread of invasive species.
- Secondary impacts (flooding, liquefaction, landslide, fire) may cause localized species loss.
- Damaged infrastructure may leak hazardous materials into the local environment or watershed.

Flooding from Precipitation Hazard Profile

Changes in development and population density, connected to changes in the frequency and intensity of precipitation patterns in Massachusetts, increase the risk from flooding from precipitation. The increase in impervious surfaces due to changes in development limits infiltration during heavy rainfall, resulting in greater runoff and demands on drainage systems. Existing infrastructure is not designed to respond to current precipitation and is increasingly strained as climate change increases the intensity and duration, as well as possibly the frequency, of precipitation. As systems experience demand to move water beyond their designed capacity, precipitation-related flooding is likely to occur more often.

Areas at High Risk for Residential Flooding in 2050



Sources: U.S. EPA data and MA Climate Assessment (Commonwealth of Massachusetts, 2022).

Most At-Risk Areas

Areas with strained drainage system capacity face the most risk. Riverine flood risk is high near current and historical wetlands and river systems, especially along the Connecticut River Valley and coastal watersheds.

Cause

Inland riverine flooding results when a high rainfall event exceeds the capacity of natural drainage systems. Risk can be amplified when land cover has a high percentage of impermeable surface.

Historical Frequency and Recent Trends

Climate change is projected to increase the variability of precipitation events within a year, including the potential for extreme precipitation events. Instances of inland flooding, river overflows, and pressure on dams may result.

Projected Effects of Climate Change

Projected changes in precipitation patterns in all seasons, as well as higher frequency of extreme weather (including hurricanes and nor'easters), will change patterns of river flow and increase the frequency and severity of inland riverine flooding.

Secondary Hazards from Flooding from Precipitation

- Reservoir or waterway contamination due to high river flow, re-suspension of contaminated sediment, and transport of that sediment downstream.
- Stress on ecosystems that could increase the risk of invasive species.
- Damage or increased degradation of critical infrastructure and habitats, including residences, that increases vulnerability and risk to other hazards.

Flooding from Precipitation Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Physical injury and premature death—the most serious and acute health impacts during a flood.
- Increase in mental health stressors.
- Health effects from aeroallergens and mold, especially for people with existing respiratory conditions.
- Increase in vector-borne disease incidence and bacterial infections; elevated rates of emergency room visits for gastrointestinal illness.
- Emergency service response delays and evacuation disruptions.
- Loss of or damage to cultural resources.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage to electric transmission and utility distribution infrastructure.
- Reduction in clean water supply.
- Damage to roads and loss of road services.
- Bridge support scour caused by high river flow events. (Up to 25 percent of bridges in New England may be vulnerable to this effect.)
- Increased risk of dam overtopping or failure.
- Disruption of water resources, including waste management (sewage) and water supply, caused by dam failure.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Economic losses from commercial structure damage and business interruptions, with potential for cascading supply chain disruptions.
- Reduced availability of affordably priced housing, which disproportionately affects low-income populations.
- Reduced ability to work and loss of wages.
- Dam overtopping or failure can lead to economic impact due to initial loss of structures, loss of businesses and homes, damage to land, and cost of debris cleanup.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Demand for state and municipal government services could increase.
- Fewer than 10 state-owned major facilities are in areas expected to experience significant riverine flooding by the end of the century. As a result, it appears that current facility siting decisions are adequately addressing the risk of riverine flooding—but many of these buildings (the exact number is currently unknown) may be subject to stormwater drainage flooding.
- State-owned parks, roads, and minor facilities could experience disruptions or damage due to heavy rainfall and flooding.
- 159 state and 469 municipality–owned and operated dams are at a high or significant hazard level and therefore at risk of damage or destruction.

Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Freshwater ecosystem degradation and water quality issues due to increased sediment, nutrient, and contaminant delivery from stormwater runoff and combined sewer overflows.
- Alteration and contamination of coastal ecosystems due to increased freshwater flow to estuaries.
- Soil erosion affecting local ecological functions.
- Forest health degradation.

Hurricanes/Tropical Cyclones

Massachusetts has over 1,500 miles of coastline, which is home to more than 1,900 beaches, boat ramps, trails, and other public access sites. Many houses, businesses, ports, critical infrastructure sites, and utilities also share the Massachusetts coast, and 74 percent of the Commonwealth's population resides in coastal counties. Hurricanes and tropical storms reach Massachusetts after traveling up the Atlantic Ocean, leaving areas near the coast most vulnerable to damage from these storms. Tropical storms lose strength once they move inland; however, all regions of the Commonwealth may experience strong winds and heavy rainfall from a storm moving inland and significant hurricane impacts have occurred in western Massachusetts in recent years. Stronger storms may lead to increased wind damage and flooding, which in turn may produce power outages, structural damage to homes and critical assets, business damage and disruption, human health and public safety impacts, and ecosystem damage and loss. As sea levels rise, storm surge and coastal flooding from tropical storms and hurricanes will have impacts further inland.

Most At-Risk Areas

Coastal populations, infrastructure, and ecosystems are most vulnerable. Historically, south-facing shores have been the hardest hit.

Cause

Tropical cyclones form over warm ocean waters, as moisture evaporates and rises into enormous amounts of heated, moist air twisted high in the atmosphere.

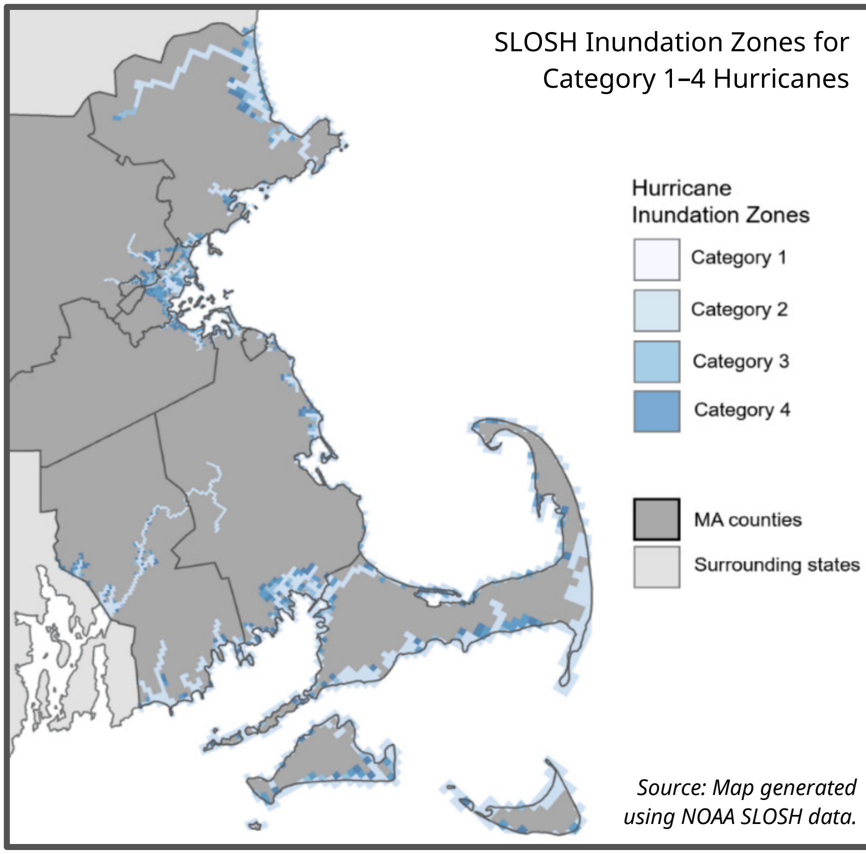
Historical Frequency and Recent Trends

97 hurricanes or tropical storms occurred near Massachusetts from 1842 to 2022, averaging one storm every two years. Four have occurred between 2020 and 2022.

Projected Effects of Climate Change

Warming ocean and air temperatures are expected to contribute to the increased intensity of hurricanes and tropical storms. There may be a related increase in the frequency of Atlantic tropical cyclones as well.

SLOSH Inundation Zones for Category 1–4 Hurricanes



Source: Map generated using NOAA SLOSH data.

Secondary Hazards from Hurricanes/Tropical Cyclones:

- Possibility of tornado generation.
- Coastal and riverine erosion.
- Increased risk of landslides.
- Contamination of water supplies and flooding of sewage treatment facilities.

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Health effects of extreme storms and power outages, including injury, carbon monoxide poisoning, and medical device failure.
- Health effects from mold due to flooding and water damage, which may disproportionately affect people who live in substandard housing, live in flood-prone areas, or have existing respiratory illness.
- Flood-related injury or fatality. First responders and utility workers are especially vulnerable to high water, swift currents, and submerged debris.
- Impaired public safety response due to infrastructure and transportation damage.
- Higher difficulty in preparing for, evacuating from, and recovering from extreme events for minority, language-isolated, low-income, elderly, and disabled populations.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage to electric transmission and utility distribution infrastructure.
- Damage to coastal buildings and ports.
- Damage to critical facilities. (Storm surge in a Category 1 hurricane could inundate 190 critical facilities, including 15 energy facilities. Suffolk County has the highest concentration of affected critical facilities.)
- Inundation of roads. (Over 1,800 miles of road are in coastal hazard areas for a Category 1 storm; nearly 3,000 miles of road could be inundated in a Category 3 storm. Barnstable County has the highest road exposure to hurricane storm surge inundation.)

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Economic losses from commercial structure damage and business interruptions, especially in flood-prone areas.
- Decrease in agricultural productivity where field crops or tree products are damaged by flooding or wind.
- Damage to tourist attractions and recreation amenities (e.g., beaches, coastal hotels, rental homes) and disruptions to travel.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Increase in costs of responding to climate migration, and of coordination between sending (coastal) and receiving (inland) communities.
- Increase in costs associated with public safety agency responses, caused by a higher magnitude and frequency of events.
- Loss of or damage to state-owned buildings and infrastructure. (732 state-owned buildings are in Storm surge inundation zones for a Category 1 hurricane. The highest concentration of these buildings is in Suffolk County.)

Natural Environment

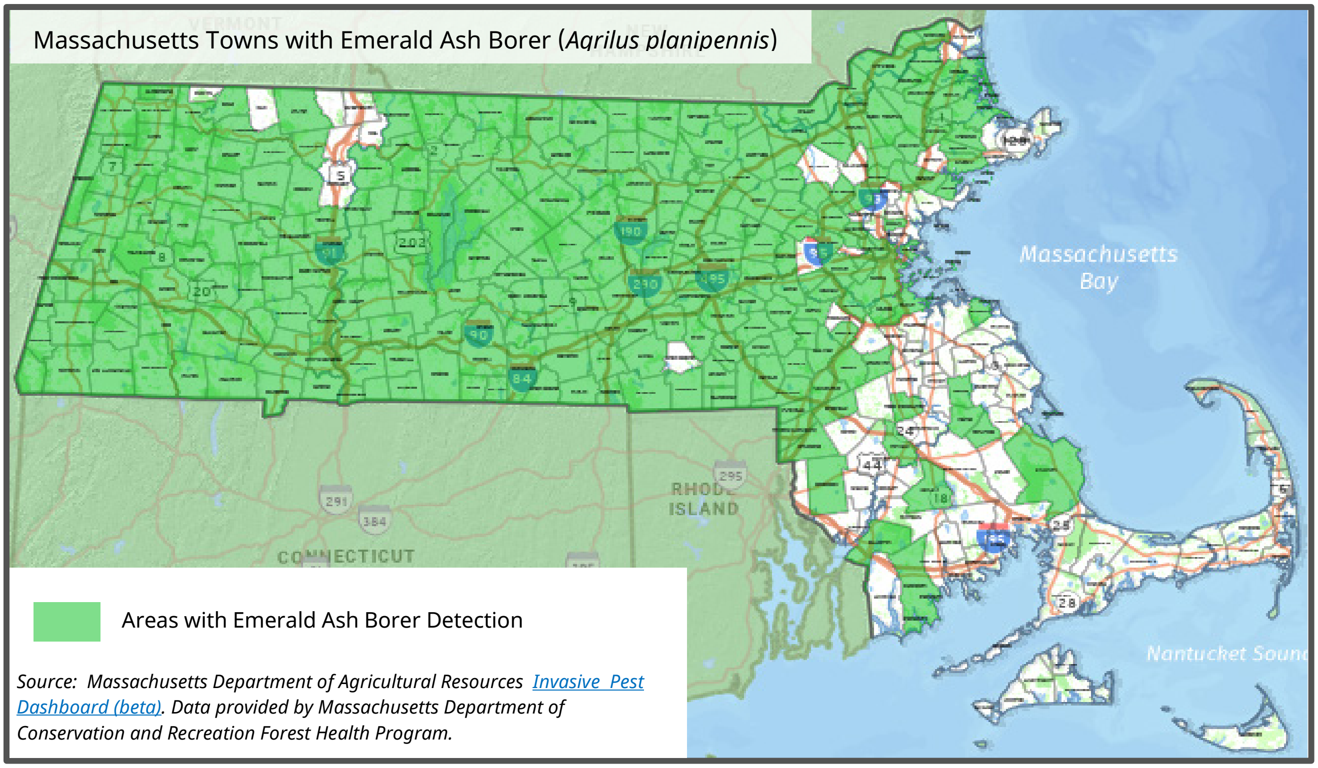
Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- A storm can cause short-term disruptions to normal ecosystem function.
- Estuarine habitats and species are vulnerable to coastal storm surge and changing salinity of their water.
- Storms can have longer-term impacts related to physical structure of ecosystems, such as riverbed erosion and tree loss.
- Exposure to pollutants spread by storm-damaged infrastructure may cause widespread and long-term population impacts on species in the area.
- Out of the 528 Massachusetts Department of Conservation and Recreation sites assessed, 96 have moderate vulnerability to coastal flooding (which hurricanes and tropical storms can cause) and 47 have increased or high vulnerability to coastal flooding.

Invasive Species Hazard Profile

All of Massachusetts is susceptible to effects from invasive species. Invasive species threaten biodiversity and natural resources and have significant economic impacts. Specific costs associated with invasive species include control and management activities, prevention and early detection, and rapid response programs, as well as funding for research, public outreach campaigns, and removal and restoration programs. In Massachusetts, aquatic invasive species threaten water quality, fish and wildlife habitat, coastal infrastructure, and economically important fisheries. Invasive species can damage and disrupt the existing ecosystem, outcompete native flora and fauna, eradicate native species, and in some cases increase wildfire risk.

Massachusetts Towns with Emerald Ash Borer (*Agrilus planipennis*)



Source: Massachusetts Department of Agricultural Resources [Invasive Pest Dashboard (beta)](). Data provided by Massachusetts Department of Conservation and Recreation Forest Health Program.

Most At-Risk Areas

Invasive species are a threat to ecosystems across the Commonwealth. The emerald ash borer can kill an ash tree in just three years. Some marine species can structurally change native ecosystems, while others (like the green crab) prey on native species.

Cause

Human activity intentionally or unintentionally introduces invasive species into native ecosystems.

Historical Frequency and Recent Trends

Increased global trade created new pathways for the spread of invasive species. Global climate change has contributed to introduction of invasive species. In 2008, an outbreak of Asian long-horned beetles in Worcester destroyed nearly 30,000 trees.

Projected Effects of Climate Change

Climate change is predicted to increase the abundance of invasive species and expand their habitat ranges. Species hierarchies in ecosystems are also expected to change, and ecosystems that are stressed (due to climate-change associated drought, increased temperatures, wildfires, etc.) will be more susceptible to invasive species.

Secondary Hazards from Invasive Species:

- Increased heat island effect from tree mortality, damage to agriculture crops.
- Tree damage and die-offs that can result in increased wildfire risk and erosion.
- Stress from changes (increase, decrease) on ecosystems can make them more susceptible to invasive species.

Invasive Species Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Invasive species can bring new diseases or aggravate existing health problems (e.g., it may increase arbovirus risk for humans).
- People with compromised immune systems or pre-existing health conditions, children under five, and people over 65 might be particularly vulnerable to new diseases or aggravated health problems.
- The dinoflagellate *Alexandrium minutum* contributes to red tide outbreaks, which produce toxins that accumulate in shellfish and can be toxic to humans who ingest them.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Facilities that rely on biodiversity or the health of surrounding ecosystems, such as outdoor recreation areas or agricultural/forestry operations, could be vulnerable to impacts from invasive species.
- Japanese knotweed is known to decrease streambank stability and contribute to topsoil erosion, which can contribute to flood damage. Japanese knotweed also grows on roadways, sometimes growing large enough to impair sightlines and growing over guardrails; this can contribute to maintenance and safety issues.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Invasive species are one of the costliest natural hazards in the U.S. given the widespread nature of the hazard; the cost of ongoing control efforts; and economic impacts from loss of crops, aquaculture, and public goods such as water quality. Invasive species such as the European green crab have significant impacts to the shellfish industry: a 1999 study estimated that this species caused a loss of $44 million per year in New England and Canadian shellfish industries.
- The Commonwealth spends over $95,000 per year on invasive species on control at state properties and over $290,000 annually for control efforts in over 290 infested lakes.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- State-managed water bodies are vulnerable to invasive species such as zebra mussels.
- State-managed wildlife areas and state forests face impacts now and are vulnerable to future impacts.
- Invasive species throughout the Commonwealth pose a cost and management burden to government agencies tasked with preventing or controlling the spread of these plants, animals, and fungi. The cost of restoration due to damage from invasive species can be significant.

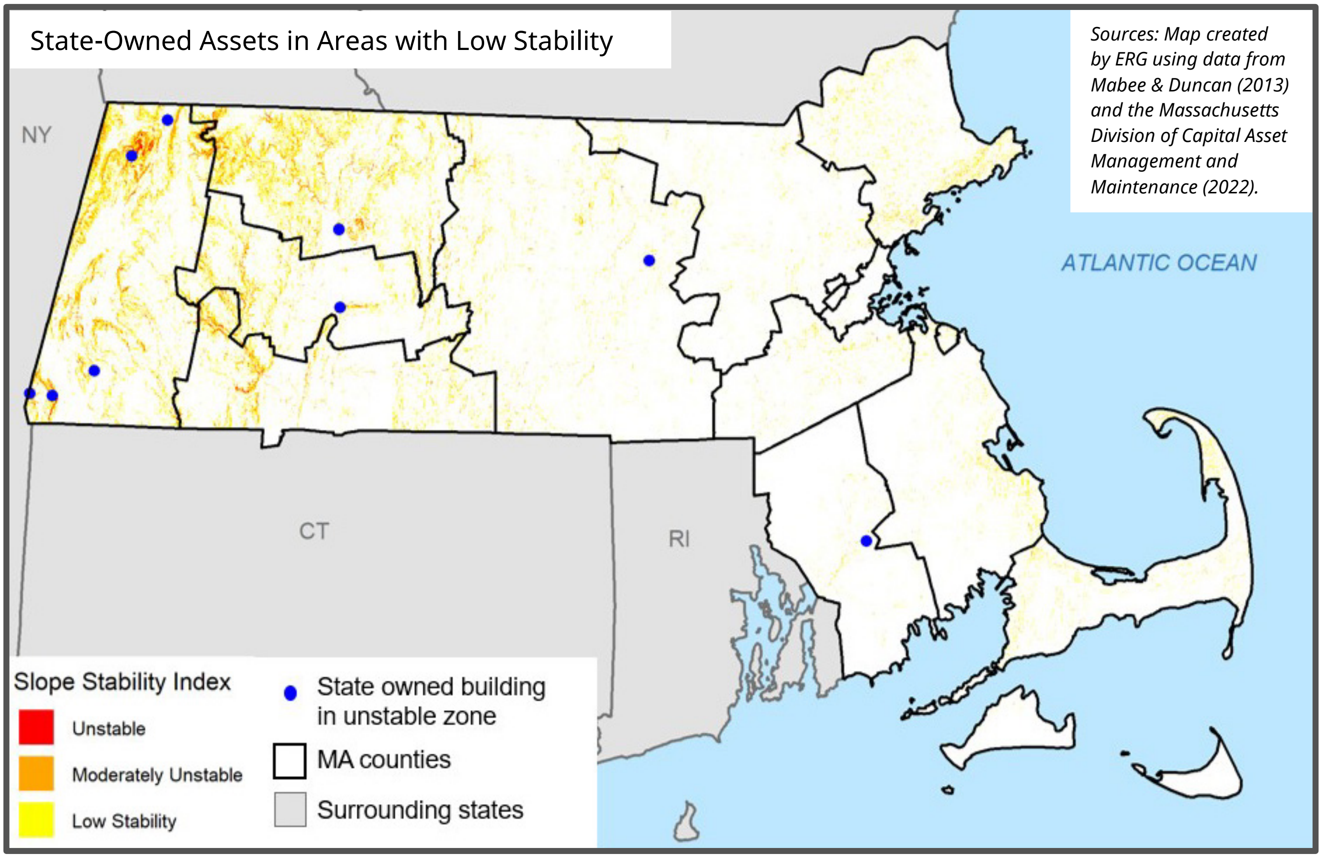
Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Invasive species spread quickly, rapidly taking over an area. Native species are likely unable to resist the invasive species, which often outcompete them.
- Native species are pressured by the spread of invasive insects and disease. For example, native species such as the American elm have essentially been eradicated due to Dutch elm disease and native shellfish are preyed upon by European green crabs.
- Some invasive plant species are capable of changing ecosystem conditions such as soil chemistry and intensity of wildfires. Invasive species that are not fire-adapted may take over fire-prone grassland or forest areas, thereby increasing wildfire risk.
- Japanese knotweed can contribute to streambank destabilization and erosion. *Phragmites australis* invade wetlands and can form thick, dense stands that displace native species and reduce habitat for native wildlife.
- In the U.S., an estimated 4,600 acres of land are invaded by invasive plants daily. This can result in loss of vulnerable species, species of concern, or endangered species.

Landslides/Mudflows Hazard Profile

Landslide and mudflow risk is higher in the western portion of the Commonwealth. Landslides and mudflows tend to be isolated in size and location and have localized impacts that pose threats to highways, rail, and other linear networks and systems. Additionally, communities and development on unstable slopes or in areas of high fire and flood risk are at risk from localized damage and loss of infrastructure from landslides and mudflows. Data are limited on the full extent of landslide and mudflow events across the Commonwealth, as they may occur in remote areas. As development expands across Massachusetts, land use changes may contribute to an increase in landslides and mudflows or introduce development into areas already at risk from these hazards.



Sources: Map created by ERG using data from Mabee & Duncan (2013) and the Massachusetts Division of Capital Asset Management and Maintenance (2022).

Most At-Risk Areas

Mount Greylock and the nearby portion of the Deerfield Park, the U.S. Highway 20 corridor near Chester, and the main branches of the Westfield River are most at risk.

Cause

Most landslides and mudflows in Massachusetts are caused by a combination of unfavorable geological conditions, steep slopes, and/or excessive soil moisture.

Historical Frequency and Recent Trends

Reported landslides and mudflows occur every other year. Many landslides occur unobserved in remote areas, meaning that the actual rate of occurrence is higher than the rate of observed and reported events.

Projected Effects of Climate Change

More frequent and intense storms will result in soil saturation, leading to more frequent landslides and mudflows. The projected increased risk of frequency and intensity of drought and wildfires will reduce the vegetation cover in the Commonwealth, which leads to loss of soil stability and an increase the probability of landslides.

Secondary Hazards from Landslides/Mudflows:

- Damage to vegetation on steep slopes weakens soils contributing to increased runoff and sediment in runoff that affects water quality of downstream water bodies.
- Contamination of reservoirs or waterways from to soil/sediment flow and susceptibility to invasive species.

Landslides/Mudflows Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- People living or traveling in areas with steep slopes and unstable soils.
- Populations who cannot evacuate quickly (people aged over 65 or under 5), populations with mobility limitations, residents in rural areas with limited access to services.
- Potential loss of life for people living in landslide and mudflow hazard areas.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage and disruption to roads and buildings in the western regions of Massachusetts. Potential loss or blockage of evacuation routes and for areas with limited or single point of access.
- Damage and disruption to electric transmission and utility distribution infrastructure.
- Loss of energy production and resources.
- Reduced potability of water due to organic materials entering streams.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Loss of or damage to buildings, properties, and infrastructure, including communications in areas with steep slopes in the western portion of the Commonwealth where there are limited and non-redundant services.
- Interruption to businesses and loss of productivity due to road closures and utility damage, particularly for small businesses and movement of time-sensitive or perishable goods.
- Loss of tax revenues and reduced property values.
- Cost of cleanup, debris removal, and restoration of affected areas.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Increased demand for state and municipal government services.
- Increased need to prepare for and respond to damage and disruption from landslides and mudflows.
- Loss of or damage to state-owned buildings and infrastructure, including communications in areas with steep slopes.
- Impacts on 14 state-owned facilities in landslide and mudflow hazard areas, including Bash Bish Falls State Park (2), East Mountain State Forest, Freetown-Fall River State Forest, Mount Everett State Reservation (2), Mount Greylock Reservation, Mount Sugarloaf Reservation (3), Natural Bridge State Park, Joseph Allen Skinner State Park (2), and the Wachusett Reservoir.

Natural Environment

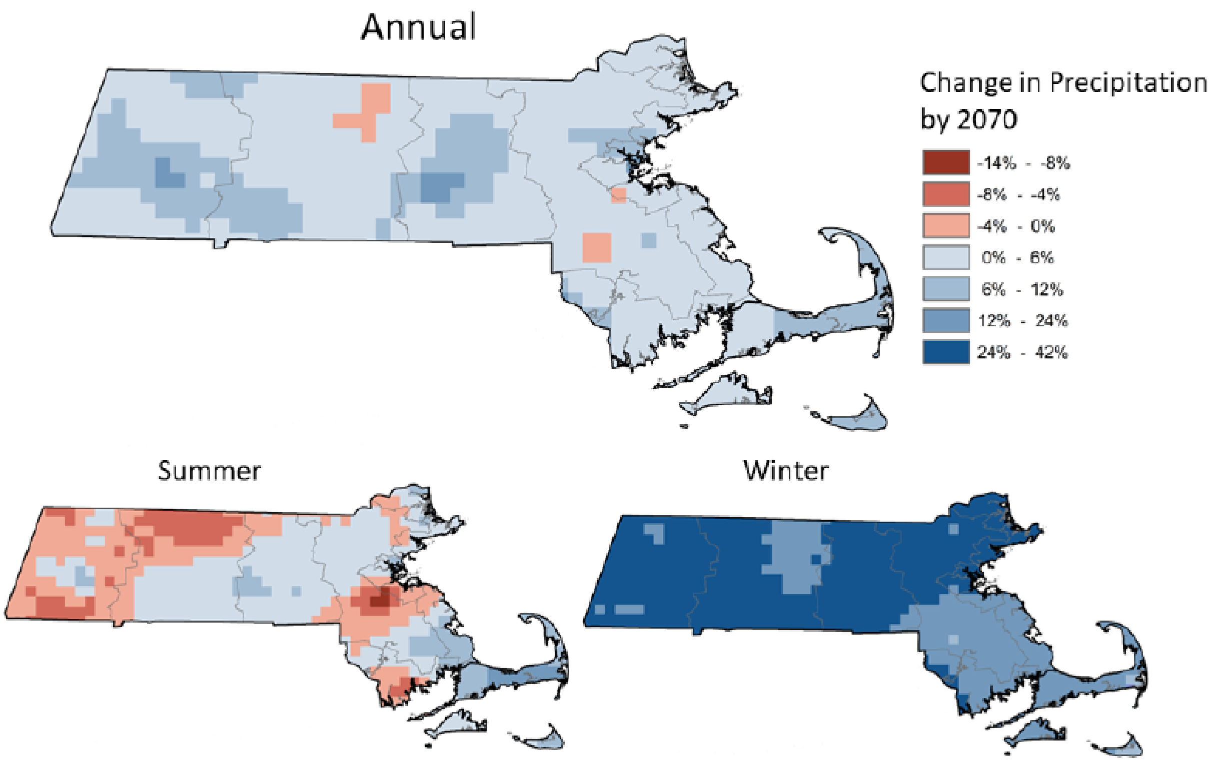
Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- When landslides or mudflows make physical changes to the landscape, the lack of topsoil limits the ability of flora to re-establish.
- Mass movement of soil can uproot trees and understory, degrading forest health.
- Streams and waterbodies near landslide or mudflow hazard areas have the highest risk of pollution, and excess sediment in them can create dams. This can affect both water quality and fish habitat.

Other Severe Weather Hazard Profile

Several frequent natural hazards in Massachusetts—such as strong winds and extreme precipitation events—occur outside of notable storm events (e.g., hurricanes, nor'easters, snowstorms). The entire Commonwealth is susceptible to these severe weather events. While high winds can affect the entire Commonwealth, the coast is most at risk of exposure to high-wind events and damage. The Commonwealth is also located within a region that is susceptible to hurricanes, and the western portion is located within the special wind region, in which wind-speed anomalies are present and additional consideration of wind hazards is warranted.

Predicted Change in Annual, Summer, and Winter Season Precipitation in 2070 Compared to Current Climate



Source: Commonwealth of Massachusetts (2022); data from Localized Constructed Analogs repository.

Most At-Risk Areas

The coastal zone is most at risk from high-wind events. This includes Dukes, Nantucket, Suffolk, and Barnstable Counties, as well as areas of Bristol, Plymouth, Suffolk, and Essex Counties.

Cause

Thunderstorms form when there is rising unstable air, moisture, and a lifting mechanism. Wind is caused by differences in atmospheric pressure and the Coriolis Effect.

Historical Frequency and Recent Trends

Precipitation volume from the heaviest storms in the Northeast has increased by 55 percent since 1958. Massachusetts experiences an average of 10 to 15 days per year with severe thunderstorms.

Projected Effects of Climate Change

Higher temperatures due to climate change will increase the atmosphere's capacity to hold moisture, increasing the intensity of extreme precipitation events. The number of days of precipitation are expected to be more variable.

Secondary Hazards from Other Severe Weather:

- Heavy rain can overwhelm artificial and natural drainage systems, causing overflows and property damage.
- Soil on slopes can oversaturate from extreme precipitation, causing landslides and floods.
- More frequent lightning can spark fires, even when accompanied by heavy rains.
- Lightning can cause severe damage, injury, and death.

Other Severe Weather Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Increased vulnerability to extreme weather impacts, particularly lightning strikes, for populations living outdoors. An estimated 18,400 people in Massachusetts experience homelessness, and an estimated 830 are unsheltered.
- Challenges to large-scale emergency response to transport or assist impacted populations.
- Health effects, such as gastrointestinal illness, from extreme rainfall events, which degrade water quality by introducing bacteriological contaminants.
- Delayed access to emergency care and impacts to electricity-dependent medical equipment due to power outages.
- Health and financial impacts from increased inland flooding, which may flood basements and increase exposure to mold.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage to electric transmission and utility distribution infrastructure, resulting in power outages.
- Damage to roads, culverts, and transportation infrastructure.
- Potential loss or blockage of evacuation routes and long-term transportation needs, which disproportionately impacts people who rely on public transportation.
- Damage to roads for emergency response teams.
- Impacts to seven critical facilities, including five residential facilities, located in the highest wind load zone. The highest concentration of critical facilities in this hazard area is in Nantucket County.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Disrupted business operations and loss of revenue due to utility damage; this disproportionately impacts small businesses.
- Damage to and loss of homes, which impacts people's ability to work and consumers' spending power.
- Damage to agricultural crops, equipment, and infrastructure from high winds.
- Damage to crops from intense rains; changes in precipitation patterns can delay planting for corn and vegetables or reduce yields.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Increased demand for state and municipal government services to address damage from extreme weather events and implement pre-disaster preparations, including warning systems and evacuation procedures.
- Loss of or damage to state-owned buildings and infrastructure, including communications located in high-wind zones.
- Impacts to 11 state-owned buildings located in the highest wind load zone, all of which are in Nantucket County.

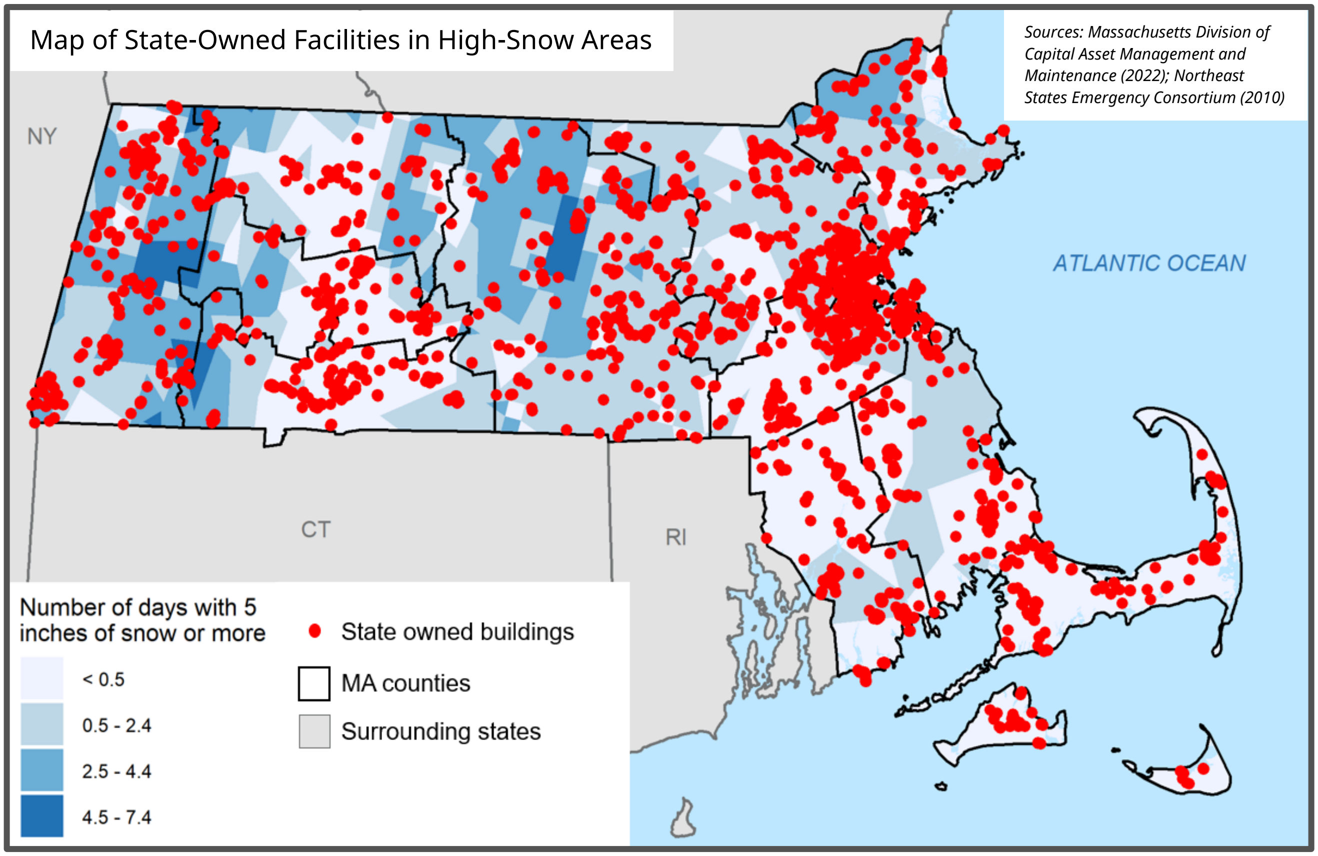
Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Defoliation of forest canopies can degrade forest health, which could lead to loss of biodiversity and structural ecosystem changes.
- Extreme precipitation events can disrupt some species' mating behaviors, causing population decline.
- Direct damage to plants from uprooting or destruction of trees can increase wildfire risk.
- Extreme precipitation events can cause harmful algal blooms and associated aquatic neurotoxins.
- Widespread winds can uproot watershed forests and create serious water quality disturbances, damaging public drinking water reservoirs.

Severe Winter Storms Hazard Profile

Severe winter storms, which include ice storms, nor'easters, heavy snow, blowing snow, and other extreme forms of winter precipitation, occur regularly in Massachusetts. Coastal communities are particularly vulnerable to impacts from nor'easters due to the combination of high winds, waves, and tidal surge. Rural populations are more at risk from service and access issues because heavy snow conditions can block roads and often result in downed power and communication lines. As coastal development increases and sea levels continue to rise, nor'easters will lead to more substantial damage due to high water levels, higher coastal populations, and increased land use in current and future risk zones.



Most At-Risk Areas

North- and east-facing coastal areas are the most exposed to nor'easter winds and storm surge. Rural populations in central and western Massachusetts are most exposed to severe snow fall.

Cause

Severe winter storms are types of extratropical cyclones, which are formed when a cold mass of air meets with a warm mass of air and create a front. They can have weak or strong winds.

Historical Frequency and Recent Trends

On average, Massachusetts experiences one to two nor'easters per year. In the past 10 years (2013–2022), there have been 63 heavy snow days, 12 blizzard days, and two ice storm days in Massachusetts.

Projected Effects of Climate Change

Sea level rise, warming ocean temperatures, and changing atmospheric circulation patterns are likely to increase the frequency and severity of winter storms. Warmer temperatures indicate that more precipitation will fall as rain rather than snow throughout the 21st century.

Secondary Hazards from Severe Winter Storms:

- Large amounts of precipitation cause flooding or levee and dam failure. Flooding can increase incidents of mold and mildew, and release of hazardous materials.
- Snow and ice melt runoff can destabilize slopes leading to landslides.
- Storm surge can increase coastal erosion and flooding.

Severe Winter Storms Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Increased risks to the 14,000 people living in high-snow areas.
- Exposure to higher winds and storm surge for the 5.2 million people living in the coastal zone.
- Disrupted and delayed public transit.
- Increased risk of hypothermia and frostbite to populations without access to housing or sufficient heat, including the estimated 18,400 people in Massachusetts experiencing homelessness.
- Isolation of rural populations due to storm debris, blocked roadways, and power outages.
- Increased risk of carbon monoxide poisoning from inappropriate use of combustion heaters, cooking appliances, and generators during power outages.
- Injury and loss of life from automobile accidents, overexertion, and exposure.
- Increased risk to public safety personnel and increased response times.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage to roofs and structures due to the weight of snow and ice.
- Damage to coastal infrastructure and ports.
- Damage or destruction of power, gas, water, broadband, and oil transmission lines.
- Damage to roads and culverts. Potential blockage of emergency response vehicles and evacuation routes.
- Increased risk to the 33 critical facilities—including 17 residential and four water resource facilities—located in high-snow zones. The highest concentration of critical facilities in this hazard area are in Worcester and Berkshire Counties.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Significant economic impacts and revenue losses due to building damage and disruption in telecommunications, electricity, and transportation systems.
- Revenue losses from reduced snow cover in the winter recreation and tourism industries.
- Impacts to aquaculture and marine fisheries from damage to ports and processing facilities, which may prevent fisher's ability to process, land, and sell catches.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Loss of or damage to state-owned buildings and infrastructure, including communications facilities located in coastal flood zones.
- Increased demand and cost for state and municipal government services for storm preparation, response, and recovery.
- Increased risks to 90 state-owned buildings in high-snow zones. These buildings are most concentrated in Berkshire and Worcester Counties.

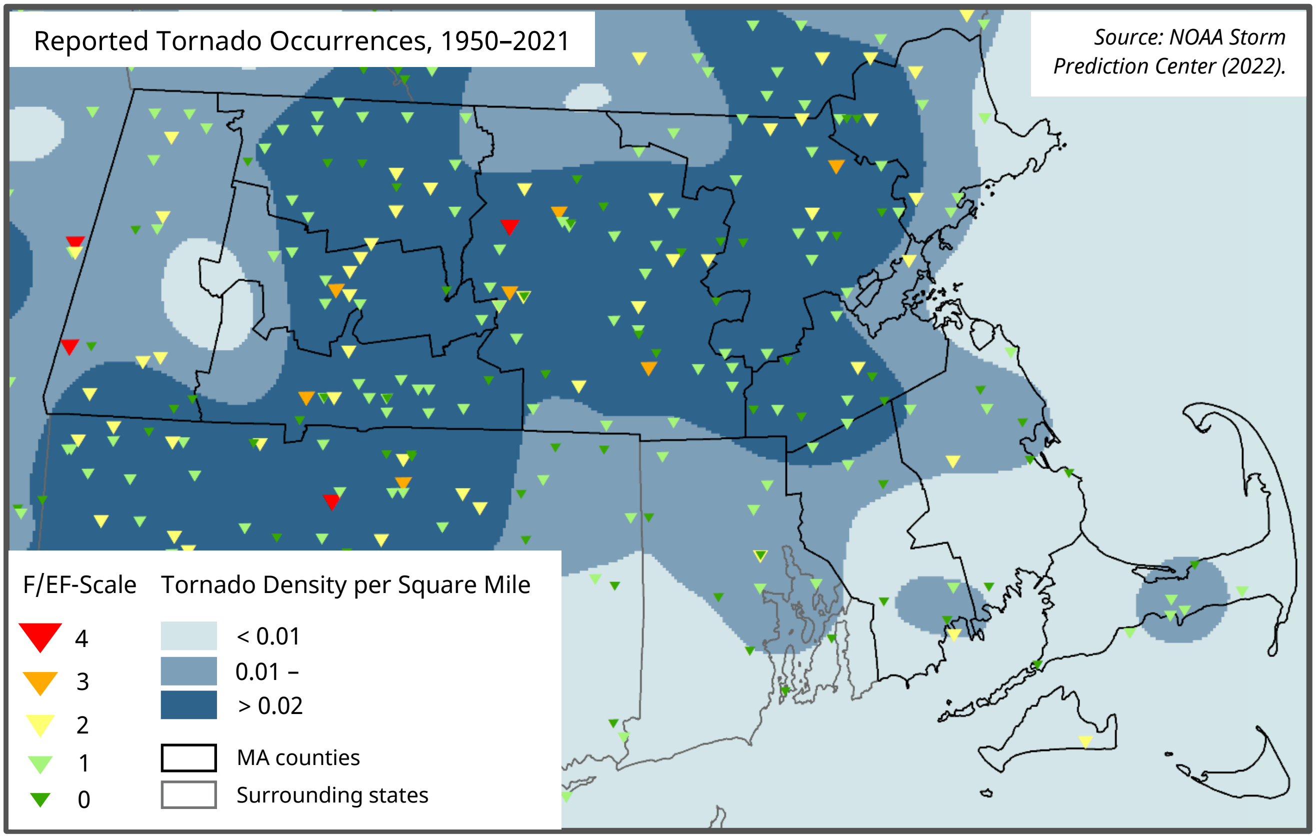
Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Damaged salt marshes and wetlands from severe winds, flooding, and decreased water quality, which can reduce coastal protection of natural systems during subsequent storms.
- Damaged forests from loss of tree cover, poor water quality, increased soil erosion, and changes in nutrient pathways from flooding.
- Decreased water quality from coastal erosion; landslides; and damage to wastewater facilities, overburdened stormwater systems, and sewers.
- Decreased spring river flows for aquatic ecosystems due to less spring snow melt.
- Increased vulnerability of 96 Massachusetts Department of Conservation and Recreation sites (out of 528 assessed) to coastal flooding from storms.

Tornadoes Hazard Profile

Massachusetts experiences an average of two to five tornadoes per year, compared with the average 1,200 tornadoes the United States experiences annually. Because tornadoes are relatively rare in the Commonwealth, residents are less likely to be prepared. Populations in manufactured housing such as mobile homes are more at risk. Tornadoes can affect all sectors and populations, and their primary effect is damage from high winds to structures and the environment. Any structure located in a tornado zone or path is at risk.



Most At-Risk Areas

All of Massachusetts is at risk for tornadoes. However, the greatest risk area for tornado touchdowns runs from south-central to northeastern Massachusetts (Hampden County through Worcester, Middlesex, and part of Essex County).

Cause

Thunderstorms have the potential to produce tornadoes. However, the type of storm that most commonly produces tornadoes is supercells: severe, long-lived thunderstorms. Approximately 20 percent of supercells produce tornadoes.

Historical Frequency and Recent Trends

Massachusetts averages two to five tornadoes per year. Only two tornadoes (1953 and 2011) received disaster declarations. Massachusetts has experienced 12 tornadoes since 2018 (EF0 to EF1). Massachusetts experienced six tornadoes in 2021 (EF0), causing under $50,000 in property damage.

Projected Effects of Climate Change

Current climate models predict an increase in severe thunderstorms, which have the potential to produce tornadoes. However, it is unclear if tornado frequency will increase with climate change. Some studies suggest there will be a decrease in the number of tornado days, but an increase in the number of tornadoes per day.

Secondary Hazards from Tornadoes:

Due to the high winds and subsequent damage from tornadoes, secondary hazards include:

- Significant areas of falling and downed trees and broader ecosystem damage.
- Spread of invasive species.
- Hail, which commonly accompanies tornadoes; heavy rain accompanies supercell storms and tornadoes.

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- The entire population of Massachusetts is exposed to tornado hazard, and 3,563,721 people live in high tornado density zones. The largest number of people in a high tornado density zone is 1,359,837 in Middlesex County (1,632,002 residents in the county total).
- Populations who might have difficulty evacuating, individuals over the age of 65, households with young children, and people who reside in old or less stable housing are at risk.
- First responders responsible for evacuation and fire and medical response units are at risk. Hospital facilities and nursing homes are vulnerable.
- Individuals with limited internet or phone access or low English proficiency may not be aware of tornado warnings. People living in mobile homes, homes with aboveground foundations, or homes without basements are particularly vulnerable.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- All critical facilities and infrastructure are exposed to tornado events.
- Hail, rain, and wind can create flying debris and contribute to flash flooding, which can damage water infrastructure. Power lines are likely to be damaged in a tornado area.
- Flying debris can cause structural damage and severe injuries.
- There are 1,511 critical facilities in the high-hazard zone across 11 counties, with the highest numbers in Middlesex (367 critical facilities) and Worcester (335 critical facilities) Counties.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- All government buildings in Massachusetts are exposed to tornado events.
- There are 4,483 government buildings in the high-intensity tornado zone, 2,949 government buildings in the medium-intensity tornado zone, and 1,330 in the low-intensity tornado zone.
- The total replacement value of government buildings in the high-intensity tornado zone is over $34 billion.
- Tornadoes can impact emergency response coordinated by first responders, law enforcement and national guard. They can compromise the ability of first responders to provide shelter, food, and medical attention in the aftermath of a major event.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Tornado events are typically localized and can have significant economic impacts, such as loss of business function, damage to inventory, wage loss, rental income loss, and loss of or damage to homes and communities.
- Recovery and clean-up costs can be significant. The total cost of property damage from tornadoes in Massachusetts was $49,000 in 2021.

Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- High winds, heavy rains, and hail can uproot or down trees and significantly damage other large plants. A tornado-impacted neighborhood in Springfield went from 40 percent tree cover to 1 percent cover. Temperature increases of 4°F have been observed in tornado-affected neighborhoods due to tree loss.
- Heavy winds from tornadoes can transport hazardous materials and introduce them into the atmosphere or water supplies. High winds can also transport invasive species.
- Disturbances from high winds may impact biodiversity and the composition of forests. Disruptions to the ecosystem and biodiversity can allow for invasive plant species to establish in disrupted areas.

Tsunamis Hazard Profile

Coastal areas of Massachusetts are exposed to the threat of tsunamis; however, the probability of a tsunami occurring is relatively low compared to the Pacific Coast of the United States. Over 74 percent (5.2 million of 7.0 million) of Massachusetts residents live along the coastline. In the event of a local tsunami generated in or near the Commonwealth, there would be little warning time to evacuate to higher ground. Tsunami exposure along the Commonwealth's coast is unlikely; however, were an event to occur, it could have extensive and prolonged impacts to the economy, coastal ecosystems, and residents living along the coastline.

Most At-Risk Areas

All coastal areas of the Commonwealth are exposed to the threat of tsunamis. However, the probability of a tsunami is very low in Massachusetts.

Cause

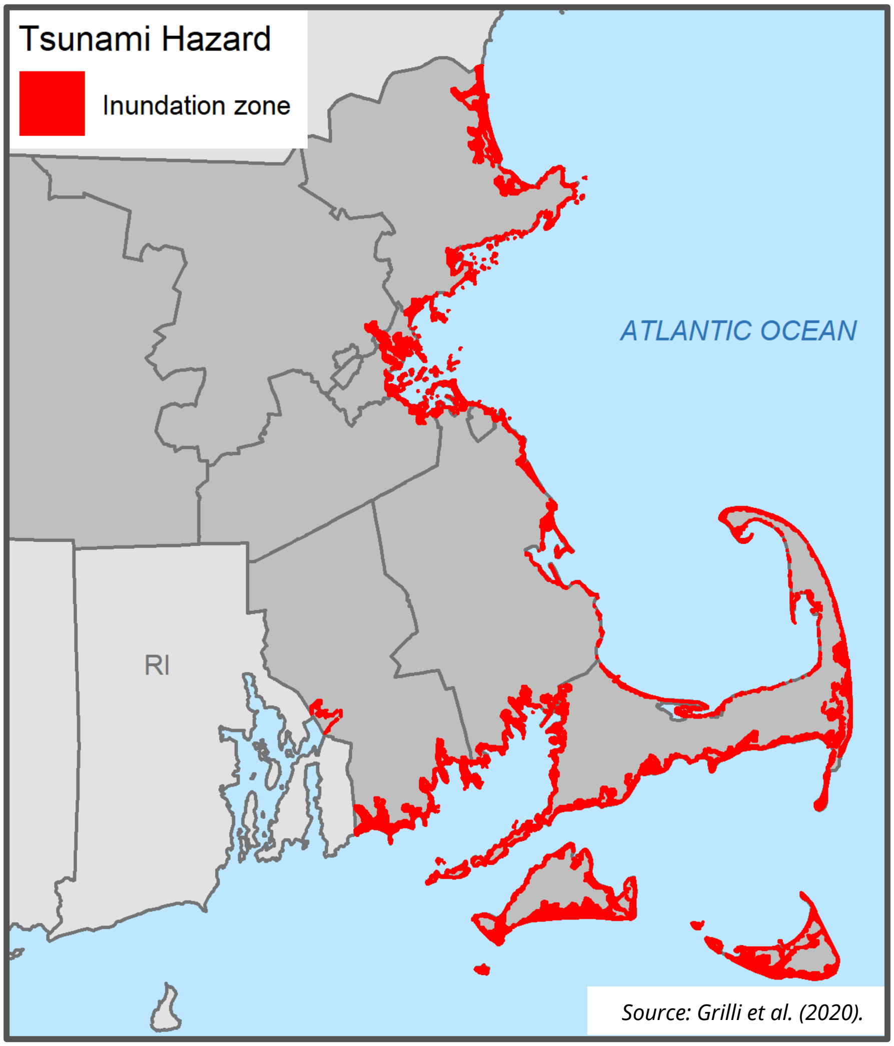
Tsunamis are caused by water displacement triggered by earthquakes, volcanic eruptions, landslides, glacier calving, or meteorite impacts.

Historical Frequency and Recent Trends

No significant tsunami has ever struck the Massachusetts coast. Historically, the frequency of tsunami or run-up events on the East Coast of the United States is approximately one event for every 29 years.

Projected Effects of Climate Change

Sea level rise and rising temperatures will accelerate ice melts and collapse of glaciers across the world, which may cause massive landslides (or glacial earthquakes) that may trigger tsunamis.



Secondary Hazards from Tsunamis:

- Episodes of coastal erosion.
- Widespread flooding along coastal areas.
- Increases in the propagation of invasive species along impacted ecosystems.

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- Increased risks to people, infrastructure, and buildings within a 1-mile buffer of the coast.
- Increased risks to populations who are unable to evacuate quickly (people aged over 65 or under five), populations with mobility limitations, and rural residents with limited access to services.
- Potential loss of life for first responders and people living in the 1-mile buffer of the coast.
- Mental health impacts due to trauma and displacement.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Damage to electric transmission and utility distribution infrastructure.
- Loss of energy production and resources.
- Damage to bridges, roads, and culverts. Potential loss or blockage of evacuation routes.
- Damages to rail and/or transit, potentially resulting in loss of service.
- Saltwater inundation in drinking water supplies and overburdening of stormwater and wastewater systems.
- Increased risks to the 149 critical facilities in tsunami hazard areas. The highest concentration of critical facilities at risk are in Plymouth County (50) and Suffolk County (48).

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, our natural environment, or people's health.

- Business interruption and closure.
- Port closure.
- Loss of tourism and tax base.
- Loss of or damage to general building stock and infrastructure, including communications located within 1 mile of the coast.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Increased demand for state and municipal government services.
- Loss of or damage to state-owned buildings and infrastructure, including communications located within 1 mile of the coast.
- Increased risks to the 737 state-owned buildings in tsunami hazard areas. The highest concentration of these buildings is in Suffolk County (274) and Plymouth County (148).

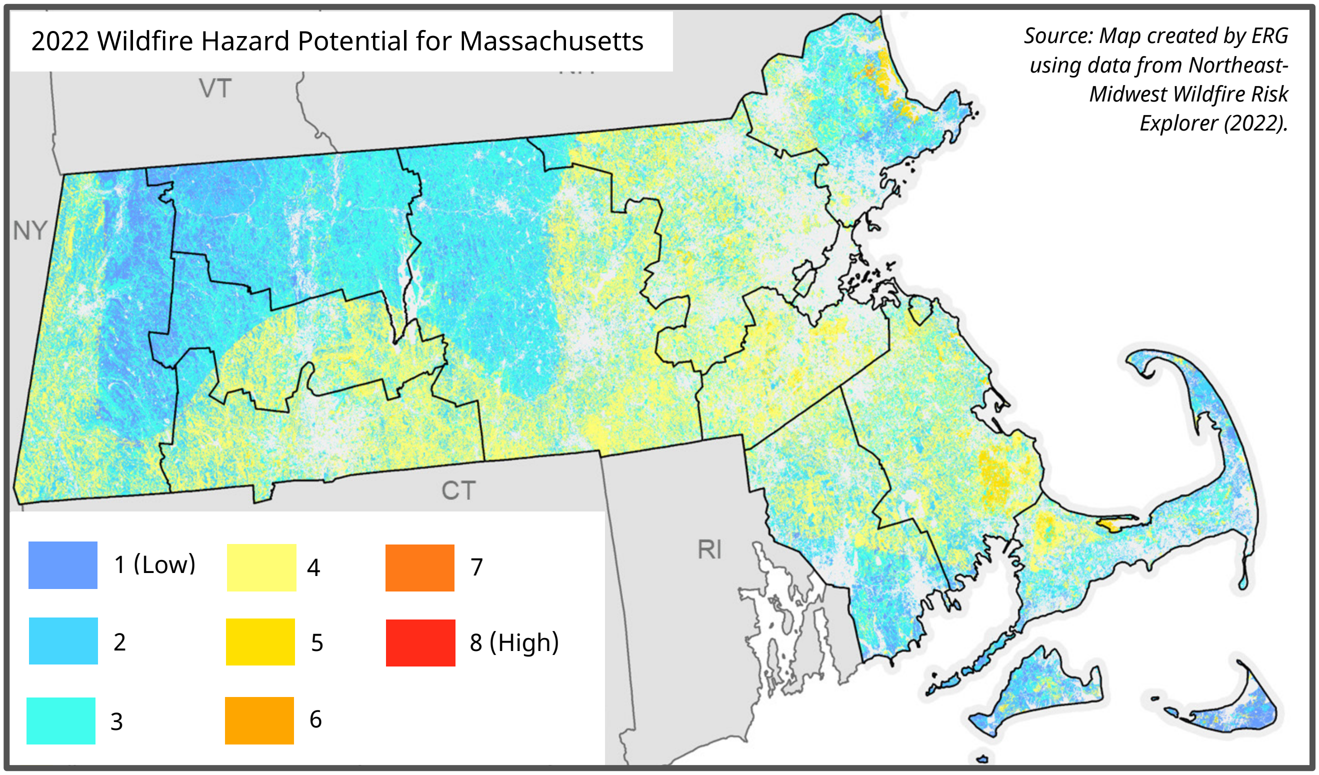
Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Inundation of typically dry areas, which can reshape the topography by scouring existing sediment and depositing sediment from other locations.
- Habitat loss and direct mortality to animals in affected areas.
- Core habitats and critical natural landscapes located along the coastline in the tsunami hazard zone, such as the wetlands of Cape Cod National Seashore, which can act as protective buffers and enhance resilience, may be significantly damaged by a tsunami.

Wildfire Hazard Profile

As demonstrated by the 2022 fire season, prolonged periods of severe drought, combined with multiple high-heat days with low dewpoints, increase the likelihood and intensity of wildfires and wildfire—a pattern that is predicted to continue. Fire-adapted ecosystems that cannot adapt to increased fire frequency, duration, or intensity that may result from climate change impacts (e.g., more frequent, or prolonged droughts, high heat) will be impacted, as well as timber harvest and production, recreation, and residents living near forested areas. Future fires in the Commonwealth will have negative impacts on ecosystems that aren't adapted to fires.



Most At-Risk Areas

Barnstable, Essex, Plymouth, Hampshire, Norfolk, and Hampden counties. Pitch pine and scrub oak communities are the most fire prone compared to other tree species in the state because they rely on fire to reproduce.

Cause

Wildfires can be caused by natural events (e.g., lightning), drought, extreme heat, forest management practices, invasive species, and human activity (e.g., smoking, campfires). In the Commonwealth, 98% of wildfires are human caused.

Historical Frequency & Recent Trends

Historical average of fewer than 50 fires per month during a regular fire season. As of November 28, 2022, 1,027 fires had burned 2,716 acres in 2022. Significant increase in acres burned in the U.S. from 1992 (around 2 million acres) to 2020 (over 10 million acres).

Projected Effects of Climate Change

Precipitation changes, prolonged drought, rising temperatures, and increased frequency of lightning are expected to contribute to increased frequency and severity of wildfire. As droughts become more frequent and severe, forest types that do not usually burn and are not fire adapted will be more likely to burn. Wildfires are projected to increase worldwide by 14% by 2030, 30% by 2050, and 50% 2100.

Secondary Hazards from Wildfire:

- Contamination of reservoirs due to ash and debris.
- Insect outbreaks in pine forest systems following a fire.

Wildfire Hazard Profile

Impacts to Sectors:

Human

Impacts to people's health, welfare, and safety.

- People living at the wildland-urban interface (WUI) or intermix hazard areas, as well as infrastructure and buildings located in these areas, are most at risk. In the Commonwealth, 1,076,472 people live in majority moderate wildfire hazard zones.
- Populations who are unable to evacuate quickly (people aged over 65 or under five), populations with mobility limitations, and residents in rural areas with limited access to services.
- People lacking fire insurance or resources to repair and replace damaged structures.
- Health impacts due to poor air quality from smoke. Potential loss of life for first responders and people living in the WUI or intermix areas.

Infrastructure

Impacts to buildings, transportation systems, and electricity and water systems.

- Loss of energy production and resources. Damage or destruction to energy and communication transmission lines.
- Damage to roads, culverts, and potentially bridges. Potential loss or blockage of evacuation routes, which could challenge emergency personnel response.
- Out of 406 critical facilities in moderate wildfire hazard areas, there are 37 energy facilities, 25 waste management facilities, and 112 water resource facilities.
- The highest concentration of critical facilities in a majority moderate wildfire hazard area is in Norfolk County.

Economy

Impacts to people's ability to work and make a living due to damage to infrastructure, the natural environment, or people's health.

- Loss of or damage to state-owned buildings and infrastructure, including communications, located in the WUI or intermix area.
- Disruptions to the timber industry and its workers.
- Damage to and loss of homes and infrastructure.
- Costs associated with cleaning up and restoring natural and recreational areas. Costs of debris management and removal.
- 1,251 state-owned buildings are in moderate wildfire hazard areas. The total replacement value is $644,928,289.

Governance

Impacts to state and local government–owned buildings, government finances, and the ability of the government to run effectively.

- Increased demand for state and municipal government services to address impacts from loss and damage.
- Public safety personnel and equipment costs associated with wildfire preparation and response.
- Loss of or damage to state-owned buildings and infrastructure, including communications, located in the WUI or intermix area.
- 1,251 state-owned buildings are in moderate wildfire hazard areas. The highest concentration of these buildings is in Middlesex County (189 buildings).

Natural Environment

Impacts to ecosystems and natural resources, and how plants and animals can thrive there.

- Fire is important in maintaining the ecosystems of pitch pine, scrub oak, and oak forests in sandy, low-nutrient soil areas. However, drought, high heat, land use, and non-native species may increase the risk of high-intensity wildfires that can threaten these and other forest types.
- Forest health degradation due to increased frequency of wildfires in ecosystems not adapted to fire.
- The Massachusetts Department of Conservation and Recreation has 169 sites (out of 528 assessed) with moderate vulnerability and 32 sites with high vulnerability.