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SECTION 14. SEVERE WEATHER

14.1 GENERAL BACKGROUND

14.1.1 High Winds

Wind is air in motion relative to surface of the earth. For non-tropical events over land, the NWS issues a Wind Advisory (sustained winds of 31 to 39 mph for at least 1 hour or any gusts 46 to 57 mph) or a High Wind Warning (sustained winds 40+ mph or any gusts 58+ mph). For non-tropical events over water, the NWS issues a small craft advisory (sustained winds 25-33 knots), a gale warning (sustained winds 34-47 knots), a storm warning (sustained winds 48 to 63 knots), or a hurricane force wind warning (sustained winds 64+ knots). For tropical systems, the NWS issues a tropical storm warning for any areas (inland or coastal) that are expecting sustained winds from 39 to 73 mph. A hurricane warning is issued for any areas (inland or coastal) that are expecting sustained winds of 74 mph.

Effects from high winds can include downed trees and/or power lines and damage to roofs, windows, etc. High winds can cause scattered power outages. High winds are also a hazard for the boating, shipping, and aviation industry sectors.

Massachusetts is susceptible to high wind from several types of weather events: before and after frontal systems, hurricanes and tropical storms, severe thunderstorms and tornadoes, and Nor'easters. Sometimes, wind gusts of only 40 to 45 mph can cause scattered power outages from trees and wires being downed. This is especially true after periods of prolonged drought or excessive rainfall, since both are situations which can weaken the root systems and make them more susceptible to the winds' effects. Winds measuring less than 30 mph are not considered to be hazardous under most circumstances.

14.1.2 Thunderstorms

A thunderstorm is a storm with lightning and thunder produced by a cumulonimbus cloud, usually producing gusty winds, heavy rain, and sometimes hail. Effective January 5, 2010, the NWS modified the hail size criterion to classify a thunderstorm as 'severe' when it produces damaging wind gusts in excess of 58 mph (50 knots), hail that is 1 inch in diameter or larger (quarter size), or a tornado (NWS, 2013).

Cumulonimbus clouds produce lightning, which locally heats the air to 50,000 degrees Celsius, which in turn produces an audible shock wave, known as thunder. Frequently during thunderstorm events, heavy rain and gusty winds are present. Less frequently, hail is present, which can become very large. Tornadoes can also be generated during these events.

Three basic ingredients are required for a thunderstorm to form: moisture, rising unstable air (air that keeps rising when given a nudge), and a lifting mechanism. The sun heats the surface of the earth, which warms the air above it. If this warm surface air is forced to rise—by hills or mountains, or areas where warm/cold or wet/dry air bump together can cause rising motion—it will continue to rise as long as it weighs less and stays warmer than the air around it. As the air rises, it transfers heat from the surface of the earth to the upper levels of the atmosphere (the process of convection). The water vapor it contains begins to cool, releasing the heat; and it condenses into a cloud. The cloud eventually grows upward into areas where the temperature is below freezing. Some of the water vapor turns to ice, and some of it turns into water droplets. Both have electrical charges. Ice particles usually have positive charges, and rain droplets usually have negative charges. When the charges build up enough, they are discharged in a bolt of lightning, which causes the sound waves we hear as thunder.

An average thunderstorm is 15 miles across and lasts 30 minutes; severe thunderstorms can be much larger and longer. Southern New England typically experiences 10 to 15 days per year with severe thunderstorms.

Every thunderstorm has an updraft (rising air) and a downdraft (sinking air). Sometimes strong downdrafts known as downbursts can cause tremendous wind damage, similar to that of a tornado. A small (< 2.5 mile path) downburst is known as a "microburst" and a larger downburst is called a "macro-burst." An organized, fast-moving line of microbursts traveling across large areas is known as a "derecho." These occasionally occur in Massachusetts. The strongest downburst recorded was 175 mph, in North Carolina. Winds exceeding 100 mph have been measured from downbursts in Massachusetts.

14.1.3 Tornadoes

A tornado is a narrow, violently rotating column of air that extends from the base of a cumulonimbus cloud to the ground. The visible sign of a tornado is the dust and debris that are caught in the rotating column made up of water droplets. Tornadoes are the most violent of all atmospheric storms. The following are common ingredients for tornado formation:

- Very strong winds in the mid and upper levels of the atmosphere
- Clockwise turning of the wind with height (i.e., from southeast at the surface to west aloft)
- Increasing wind speed in the lowest 10,000 feet of the atmosphere (i.e., 20 mph at the surface and 50 mph at 7,000 feet.)
- Very warm, moist air near the ground with unusually cooler air aloft
- A forcing mechanism such as a cold front or leftover weather boundary from previous shower or thunderstorm activity

Tornadoes can form from individual cells within severe thunderstorm squall lines. They can form from an isolated super-cell thunderstorm. They can be spawned by tropical cyclones or even their remnants that are passing through. And, weak tornadoes can even sometimes occur from air that is converging and spinning upward, with little more than a rain shower occurring in the vicinity.

Typically, there are 1 to 3 tornadoes somewhere in southern New England per year. Most occur in the late afternoon and evening hours, when the heating is the greatest. The most common months are June, July, and August, but the Great Barrington, MA tornado (1995) occurred in May and the Windsor Locks, CT tornado (1979) occurred in October.

Tornado damage severity is measured by the Fujita Tornado Scale, in which wind speed is not measured directly but rather estimated from the amount of damage. As of February 01, 2007, the National Weather Service began rating tornadoes using the Enhanced Fujita-scale (EF-scale). It is considerably more complicated than the original F-scale, and it allows surveyors to create more precise assessments of tornado severity. Table 14-1 and Table 14-2 illustrate the EF-scale and the damage indicators.

A waterspout is a rapidly rotating column of air extending from the cloud base (typically a cumulonimbus thunderstorm) to a water surface, such as a bay or the ocean. There are two methods of formation:

- Waterspouts can form on a clear day with the right amount of instability and wind shear. These can have wind speeds of 60 to 100 mph, but since they do not move very far, they can often be navigated around. They can become a threat to land if they drift onshore.
- A tornadic waterspout is a true tornado that is moving over water at the time that it forms. These form from the same processes that cause tornadoes (see section above).

TABLE 14-1.
THE ENHANCED F-SCALE

Fujita Scale			Derived		Operational EF Scale	
F Number	Fastest ¼ mile (mph)	3-second gust (mph)	EF Number	3-second gust (mph)	EF Number	3-second gusts (mph)
0	40-72	45-78	0	65-85	0	65-85
1	73-112	79-117	1	86-109	1	86-110
2	113-157	118-161	2	110-137	2	111-135
3	158-207	162-209	3	138-167	3	136-165
4	208-260	210-261	4	168-199	4	166-200
5	261-318	262-317	5	200-234	5	Over -200

TABLE 14-2.
ENHANCED FUJITA SCALE DAMAGE INDICATORS

No.	Damage Indicator	No.	Damage Indicator
1	Small barns, frames outbuildings	15	School – 1-story elementary (interior or exterior halls)
2	One or two-family residences	16	School – junior or senior high school
3	Single-wide mobile home	17	Low-rise (1-4 story) building
4	Double-wide mobile home	18	Mid-rise (5-20) building
5	Apt, Condo, townhouse (3 stories or less)	19	High-rise (over 20 stories
6	Motel	20	Institutional bldg. (hospital, govt. or university)
7	Masonry Apt. or motel	21	Metal building system
8	Small retail building (fast food)	22	Service station canopy
9	Small professional (Doctor office, Bank)	23	Warehouse (tilt-up walls or heavy timber)
10	Strip Mall	24	Transmission line tower
11	Large shopping mall	25	Free-standing tower
12	Large, isolated (big box) retail building	26	Free standing pole (light, flag, luminary)
13	Automobile showroom	27	Tree – hardwood
14	Automobile service building	28	Tree – softwood

The National Weather Service issues a Special Marine Warning for waterspouts over the coastal waters. The Service issues a Tornado Warning if a waterspout shows signs of moving toward land.

14.1.4 Extreme Temperatures

There is no universal definition for extreme temperatures. The term is relative to the usual weather in the region based on climatic averages. Extreme heat, for this climatic region, is usually defined as a period of three or more consecutive days above 90°F, but more generally a prolonged period of excessively hot weather, which may be accompanied by high humidity. Extreme cold, again, is relative to the normal climatic lows in a region. Temperatures that drop decidedly below normal and wind speeds that increase can cause harmful wind-chill factors. The wind chill is the apparent temperature felt on exposed skin due to the combination of air temperature and wind speed.

Massachusetts has four well-defined seasons. The seasons have several defining factors, with temperature one of the most significant. Extreme temperatures can be defined as those that are far outside the normal ranges. The average temperatures for Massachusetts are:

- Winter (Dec-Feb) Average = 27.51ºF
- Summer (Jun-Aug) Average = 68.15ºF

Criteria for issuing alerts for Massachusetts are provided on National Weather Service web pages: http://www.erh.noaa.gov/box/warningcriteria.shtml.

Extreme Cold

Extreme cold is a dangerous situation that can result in health emergencies for susceptible people, such as those without shelter or who are stranded or who live in homes that are poorly insulated or without heat. The following are some of the lowest temperatures recorded in Massachusetts for the period from 1895 to present (Source: NOAA, www.ncdc.noaa.gov.):

- Blue Hills, MA –21°F
- Boston, MA –12°F
- Worcester, MA –19°F

Extreme cold events are when temperatures drop well below normal in an area. In regions relatively unaccustomed to winter weather, near freezing temperatures are considered "extreme cold." Extreme cold temperatures are characterized by the ambient air temperature dropping to approximately 0 degrees Fahrenheit (ºF) or below.

When winter temperatures drop significantly below normal, staying warm and safe can become a challenge. Extremely cold temperatures often accompany a winter storm, which may also cause power failures and icy roads. Staying indoors as much as possible can help reduce the risk of car crashes and falls on the ice, but cold weather also can present hazards indoors. Many homes will be too cold, either due to a power failure or because the heating system is not adequate for the weather. The use of space heaters and fireplaces to stay warm, and/or generators and candles in power outages increases the risks of residential fires and carbon monoxide poisoning. Exposure to cold temperatures, whether indoors or outside, can cause other serious or life-threatening health problems. Infants and the elderly are particularly at risk, but anyone can be affected.

During cold months, carbon monoxide may be high in some areas because the colder weather makes it difficult for car emission control systems to operate effectively. Carbon monoxide levels are typically higher during cold weather because the cold temperatures make combustion less complete and cause inversions that trap pollutants close to the ground.

Another hazard of extended cold temperatures in Massachusetts is saltwater freezing in coastal bays and harbors. Coastal freezing can interfere with transportation of goods and people, plus inhibit fishing and other industries reliant on boats.

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

The NWS issues a Wind Chill Advisory if the Wind Chill Index is forecast to dip to –15ºF to –24ºF for at least 3 hours, using only the sustained winds (not gusts). The NWS issues a Wind Chill Warning if the Wind Chill Index is forecast to fall to –25ºF or colder for at least 3 hours using only the sustained wind.

On November 1, 2001, the NWS implemented a new Wind Chill Temperature Index. It was designed to more accurately calculate how cold air feels on human skin. Figure 14-1 shows the new Wind Chill

Temperature Index. The Index includes a frostbite indicator, showing points where temperature, wind speed, and exposure time will produce frostbite to humans. The chart shows three shaded areas of frostbite danger. Each shaded area shows how long a person can be exposed before frostbite develops. In Massachusetts, a wind chill warning is issued by the NWS Taunton Forecast Office when the Wind Chill Temperature Index, based on sustained wind, is –25ºF or lower for at least three hours.

Wind (mph)	Temperature (ºF)																	
Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes, 10 minutes, 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (ºF) V= Wind Speed (mph) Effective 11/01/01

Figure 14-1. Wind Chill Temperature Index and Frostbit Risk

Extreme Heat

The NWS issues a Heat Advisory when the Heat Index is forecast to reach 100-104 degrees F for 2 or more hours. The NWS issues an Excessive Heat Warning if the Heat Index is forecast to reach 105+ degrees F for 2 or more hours. The following are some of the highest temperatures recorded for the period from 1895 to present (Source: NOAA, www.ncdc.noaa.gov.):

- Blue Hills, MA 101°F
- Boston, MA 102°F
- Worcester, MA 96°F

Heat waves cause more fatalities in the U.S. than the total of all other meteorological events combined. In Boston, over 50 people die each year due to heat-related illnesses. From 1979-2012, excessive heat exposure caused in excess of 8,000 deaths in the United States. During this period, more people in this country died from extreme heat than from hurricanes, lightning, tornadoes, floods, and earthquakes combined. Because most heat-related deaths occur during the summer, people should be aware of who is at greatest risk and what actions can be taken to prevent a heat-related illness or death. At greater risk are the elderly, children, and people with certain medical conditions, such as heart disease. However, even young and healthy individuals can succumb to heat if they participate in strenuous physical activities during hot weather. Some behaviors also put people at greater risk: drinking alcohol, taking part in strenuous outdoor physical activities in hot weather, and taking medications that impair the body's ability to regulate its temperature or that inhibit perspiration.

In Massachusetts, heat warnings are issued by the NWS Taunton Forecast Office as follows (http://www.erh.noaa.gov/box/warningcriteria.shtml):

- Excessive Heat Warning: Daytime heat indices of 105°F or higher for 2 or more hours
- Heat Advisory: Daytime heat indices of 100ºF to 104ºF for 2 or more hours
- Heat Wave: Issued for non-criteria warning/advisory heat. A heat wave is defined as 3 or more days of temperatures 90ºF or above.

Temperatures that are 10ºF or more above the average high temperature for the region and last for several hours are defined as extreme heat. An extended period of extreme heat of three or more consecutive days is typically called a heat wave and is often accompanied by high humidity. There is no universal definition of a heat wave because the term is relative to the usual weather in a particular area. The term heat wave is applied both to routine weather variations and to extraordinary spells of heat which may occur only once a century. A basic definition of a heat wave implies that it is an extended period of unusually high atmosphere-related heat stress, which causes temporary modifications in lifestyle and which may have adverse health consequences for the affected population.

Based on the criteria for heat stress forecasts developed by the National Weather Service (NWS), watches or warnings are issued when thresholds of daytime high and nighttime low heat index (Hi) values are exceeded for at least two consecutive days. To determine the Heat Index, one needs to know the temperature and relative humidity. Once both values are known, the Heat Index will be the corresponding number with both values, as shown in Table 14-3. That number provides a temperature that the body feels. It is important to know that the Heat Index values are devised for shady, light wind conditions. Exposure to full sunshine can increase heat index values by up to 15°F. Also, strong winds, particularly with very hot, dry air, can be extremely hazardous.

Urbanized areas and urbanization creates an exacerbated type of risk during an extreme heat event, compared to rural and suburban areas. As defined by the U.S. Census Bureau, urban areas are classified as all territory, population, and housing units located in urbanized areas (an urban area of 50,000 or more people) and urban clusters (urban areas under 50,000 people). The U.S. Census delineates urbanized area and urban cluster boundaries to encompass densely settled territory, which generally consists of:

- A cluster of one or more block groups or census blocks each of which has a population density of at least 1,000 people per square mile at the time.
- Surrounding block groups and census blocks each of which has a population density of at least 500 people per square mile at the time.
- Less densely settled blocks that form enclaves or indentations, or are used to connect non-contiguous areas with qualifying densities (U.S. Census Bureau, 2003).

TABLE 14-3.
HEAT INDEX CHART

Relative Humidity (%)	Temperature (ºF)															
	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Category	Heat Index	Health Hazards
Extreme Danger	130 °F – Higher	Heat Stroke or Sunstroke is likely with continued exposure.
Danger	105 °F – 129 °F	Sunstroke, muscle cramps, and/or heat exhaustion possible with prolonged exposure and/or physical activity.
Extreme Caution	90 °F – 105 °F	Sunstroke, muscle cramps, and/or heat exhaustions possible with prolonged exposure and/or physical activity.
Caution	80 °F – 90 °F	Fatigue possible with prolonged exposure and/or physical activity.

Approximately 47-percent of the world's population lives in urban areas. This number is expected to increase by two-percent each year between 2000 and 2015. As these urban areas develop and change, so does the landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist are now impermeable and dry. These changes cause urban areas to become warmer than the surrounding areas. This forms an 'island' of higher temperatures – often referred to as 'heat islands'.

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

Air quality is also susceptible to impacts of extreme heat events. The Air Quality Index (AQI) is an index for reporting daily air quality that indicates how clean or polluted the air is and what associated health effects might be a concern. The AQI focuses on health effects that may be experienced within a few hours or days after breathing polluted air. The U.S. Environmental Protection Agency (EPA) calculates the AQI for five major air pollutants regulated by the Clean Air Act: ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide. For each of these pollutants, EPA has established national air quality standards to protect public health .Ground-level ozone and airborne particles are the two pollutants that pose the greatest threat to human health in this country and typically trigger air quality alerts in Massachusetts during periods of extreme heat. Daily AQI values

range from 0 to 500. The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, an AQI value of 50 represents good air quality with little potential to affect public health, while an AQI value over 300 represents hazardous air quality. An AQI value of 100 generally corresponds to the national air quality standard for the pollutant, which is the level EPA has set to protect public health. AQI values below 100 are generally thought of as satisfactory. When AQI values exceed 100, air quality is considered to be unhealthy, first for sensitive groups of people then for everyone as values get higher. National Weather Service Forecast Offices issue air quality alerts for public notification and provide recommendations for reducing risks associated with poor air quality as needed. (http://www.airnow.gov/?action=aqibasics.aqi) Daily values for AQI are posted at: http://www.epa.gov/region1/airquality/today.html.

In 2011, nationally 206 people died as a result of extreme heat, up significantly from 138 fatalities in 2010. This number is well above the 10-year average for heat related fatalities, 119. There were no heat related deaths occurring in Massachusetts during 2011. In 2011, the most dangerous place to be was in a permanent home, likely with little or no air conditioning, where a reported 119 deaths (58%) occurred. The next most dangerous identified locations were outside or in an open area, where 31 people (15%) succumbed to heat. Texas numbered the most heat victims, 46, followed by Pennsylvania, 36, and Illinois, 33. Extreme heat most strongly affected older adults aged 50+, with 170 deaths (58%). Typically, older adults are the group most affected by heat. Many more males, 133 (64%), than females, 73 (35%), were killed by heat. Those susceptible to extreme heat may suffer from dehydration, heat exhaustion, heat cramps, heat stokes or even death. Air-conditioning is the number one protective factor against heat-related illness and death.

14.1.5 Drought

Drought is a temporary irregularity and differs from aridity since the latter is restricted to low rainfall regions and is a permanent feature of climate. Drought is a period characterized by long durations of below normal precipitation. Drought occurs in virtually all climatic zones yet its characteristics vary significantly from one region to another, since it is relative to the normal precipitation in that region. Drought can affect agriculture, water supply, aquatic ecology, wildlife, and plant life. There are four ways that drought can be defined or grouped:

- Meteorological drought is a measure of departure of precipitation from normal. It is defined solely on the degree of dryness. Due to climatic differences, what might be considered a drought in one location of the country may not be a drought in another location.
- Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced ground water or reservoir levels, etc. It occurs when there is not enough water available for a particular crop to grow at a particular time. Agricultural drought is defined in terms of soil moisture deficiencies relative to water demands of plant life, primarily crops.
- Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply and occurs when these water supplies are below normal. It is related to the effects of precipitation shortfalls on stream flows and reservoir, lake, and groundwater levels.
- Socioeconomic drought is associated with the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. This differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. The supply of many economic goods depends on weather (e.g., water, forage, food grains, fish, and hydroelectric power). Socioeconomic drought occurs when the demand for an economic good exceeds

supply as a result of a weather-related shortfall in water supply (National Drought Mitigation Center, 2012).

Drought can produce a range of impacts that span many sectors of an economy and can reach beyond an area experiencing physical drought. This exists because water is integral to our ability to produce goods and provide services. Direct impacts of drought include reduced crop yield, increased fire hazard, reduced water levels, and damage to wildlife and fish habitat. The consequences of these impacts illustrate indirect impacts that include: reduction in crop, rangeland, and forest productivity may result in reduced income for farmers and agribusiness, increased prices for food and timber, unemployment, reduced tax revenues due to reduced expenditures, increased crime, foreclosures, migration, and disaster relief programs. The many impacts of drought can be listed as economic, environmental, or social.

Economic impacts occur in agriculture and related sectors because of the reliance of these sectors on surface and subsurface water supplies. Environmental impacts are the result of damage to plant and animal species, wildlife habitat, and air and water quality; forest and grass fires; degradation of landscape quality; loss of biodiversity; and soil erosion. Social impacts involve public safety, health, conflicts between water users, reduced quality of life, and inequities in the distribution of impacts and disaster relief. A summary of potential impacts associated with drought are identified in Table 14-4. This table includes only some of the potential impacts of drought.

TABLE 14-4.
ECONOMIC, ENVIRONMENTAL AND SOCIAL IMPACTS OF DROUGHT

Economical	Environmental	Social
• Loss of national economic growth, slowing down of economic development • Damage to crop quality, less food production • Increase in food prices • Increased importation of food (higher costs) • Insect infestation • Plant disease • Loss from dairy and livestock production • Unavailability of water and feed for livestock which leads to high livestock mortality rates • Disruption of reproduction cycles (breeding delays or unfilled pregnancies) • Increased predation • Increased fire hazard - Range fires and Wildland fires • Damage to fish habitat, loss from fishery production • Income loss for farmers and others affected • Unemployment from production declines • Loss to recreational and tourism industry • Loss of hydroelectric power • Loss of navigability of rivers and canals	• Increased desertification - Damage to animal species • Reduction and degradation of fish and wildlife habitat • Lack of feed and drinking water • Disease • Increased vulnerability to predation. • Loss of wildlife in some areas and too many in others • Increased stress to endangered species • Damage to plant species, loss of biodiversity • Increased number and severity of fires • Wind and water erosion of soils • Loss of wetlands • Increased groundwater depletion • Water quality effects • Increased number and severity of fires • Air quality effects	• Food shortages • Loss of human life from food shortages, heat, suicides, violence • Mental and physical stress • Water user conflicts • Political conflicts • Social unrest • Public dissatisfaction with government regarding drought response • Inequity in the distribution of drought relief • Loss of cultural sites • Reduced quality of life which leads to changes in lifestyle • Increased poverty • Population migrations

The Commonwealth of Massachusetts is often considered a ‘water-rich’ state. Abundant precipitation results from frontal systems or storms that move across the continent and exit through the Northeast.

Under normal conditions, regions across the state annually receive between 44 and 47 inches of precipitation.

The Drought Management Plan was developed in 2001 as a working document and has been activated several times. This plan has been updated in consultation with the Drought Management Task Force (agencies and organizations providing technical advice on drought conditions) to reflect the lessons of past experience and to ensure a thorough and responsive approach to managing drought conditions in the future.

As part of this statewide drought management plan, data provided by the respective agencies are compiled into the "Current Water Conditions Report," a report summarizing current water resource conditions, in the Commonwealth that is prepared on a monthly basis by the Department of Conservation and Recreation (DCR) for the Water Resources Commission.

Unlike many other emergency situations, the severity of droughts develops over time allowing the opportunity to develop and implement appropriate measures as the situation worsens. Therefore, the Massachusetts Drought Management Plan defines action levels that trigger general levels of response given the severity of the situation.

Although Massachusetts is relatively small, it has a number of distinct regions that experience significantly different weather patterns and react differently to the amounts of precipitation they receive. Therefore, the Drought Management Task Force assesses drought conditions on a regional basis, rather than using a single, statewide assessment.

Because drought conditions vary due to precipitation patterns, these regions may be adjusted based on the conditions in any particular drought situation. At times, the Task Force may advise that a drought be defined on a watershed basis, if drought indices indicate that an entire watershed is affected but that watershed straddles a region that would otherwise not be considered to be affected by drought. In addition, areas served by water supplies outside of their regions have their drought conditions, as applied to their water supplies only, assessed by the capacities of their systems, rather than by the regional indices. Regional indices are used to assess drought conditions in areas served by water supplies outside of these regions. A regional approach allows customization of drought actions and conservation measures to address particular situation in each region. Because regions differ in population, density, water demand, topography, and runoff characteristics, different responses may be needed.

Drought Levels

In the Commonwealth, five levels of drought have been developed to characterize drought severity:

- Normal
- Advisory
- Watch
- Warning
- Emergency

These drought levels are based on the conditions of natural resources and are intended to provide information on the current status of water resources. The levels provide a basic framework from which to take actions to assess, communicate, and respond to drought conditions. They begin with a normal situation where date are routinely collected and distributed, move to heightened caution with increased data collection during an advisory, to increased assessment and proactive education during a watch. Water restrictions might be appropriate at the watch or warning stage, depending on the capacity of each individual water supply system. A warning level indicates a severe situation and the possibility that a

drought emergency may be necessary. A drought emergency is when a mandatory water restriction or use of emergency supplies is necessary.

The action levels specified are a general plan of action to coordinate statewide response to drought situations. However, numerous individual agencies have particular responsibilities that they are responsible for implementing on an ongoing basis. In addition, individual communities have a range of actions they can take to manage their systems during droughts.

Drought Indices

A number of drought indices are available to assess the various impacts of dry conditions. The Commonwealth uses a multi-index system to determine the severity of a drought or extended period of dry conditions.

A determination of drought level is based on seven indices: Standardized Precipitation Index, Crop Moisture Index, Keetch-Byram Drought Index (KBDI), Precipitation, Groundwater levels, Stream flow levels, and Index Reservoir levels. In the 2001 Drought Management Plan, the Palmer Drought Severity Index was included as an index, however it was found to be non-responsive to drought conditions in 1999 and 2001-2002. Thus, the Palmer Drought Index was replaced with the Standardized Precipitation Index. The 2001 Drought Management Plan also used a daily Fire Danger Index; this was replaced with the KBDI in 2010 on the recommendation of the DCR Bureau of Forest Fire Control. The KBDI gives a longer-term indication of drought conditions related to the severity of forest fire behavior (fuel moisture), that affect potential fire spread and the resources needed to extinguish fires. The KBDI is less subject to daily fluctuations than the daily fire danger rating. A detailed description of each index is provided below.

Drought level is determined monthly based on the number of indices which have reached a given drought level. A majority of the indices would need to be triggered in a region in order for a drought designation for the region to move to a more severe level. Drought levels are declared on a regional basis for each of the six regions in Massachusetts. Drought levels may also be made county by county or watershed-specific. Once a drought level of warning and emergency have been reached for the precipitation index, conditions must improve to those of the previous level before a determination is made to reduce the warning or emergency.

The NCDC's Crop Moisture Index reflects short-term soil moisture conditions for agriculture. It was developed to assess short-term crop water conditions and needs across major crop-producing regions (Palmer, W.C., 1968. *Keeping track of crop moisture conditions, nationwide: The new Crop Moisture Index*. Weatherwise 21:156–161). It is based on the concept of abnormal evapotranspiration deficit, calculated as the difference between computed actual evapotranspiration and computed potential evapotranspiration (i.e., expected or appropriate evapotranspiration). Actual evapotranspiration is based on the temperature and precipitation that occurs during the week and computed soil moisture in both the topsoil and subsoil layers. The maps are issued weekly and are posted on-line at: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/cmi.gif.

The Standardized Precipitation Index (SPI) is a probability index that considers only precipitation. It is based on the probability of recording a given amount of precipitation, and the probabilities are standardized so that an index of zero indicates the median precipitation amount (half of the historical precipitation amounts are below the median, and half are above the median). The index is negative for drought and positive for wet conditions. SPI reflects soil moisture and precipitation conditions and is calculated monthly using the Massachusetts Rainfall Database maintained by the DCR Office of Water Resources. SPI values are calculated for "look-back" periods of 1 month, 3 months, 6 months, and 12 months. The SPI values for the time periods are equivalent to the precipitation total's number of standard deviations from the normal for that time period. Drought thresholds for look-back periods of 3-month, 6-month, and 12-months are specified in the Massachusetts Drought Management Plan. The KBDI is a drought index designed for fire potential assessment. It is a number representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff and upper

soil layers. The index increases each day without rain and decreases when it rains. The scale ranges from 0 (no moisture deficit) to 800 (maximum drought possible). The range of the index is determined by assuming that there is eight inches of moisture in a saturated soil that is readily available to the vegetation. For different soil types, the depth of soil required to hold eight inches of moisture varies. A prolonged drought influences fire intensity, largely because more fuel is available for combustion. The drying of organic material in the soil can lead to increased difficulty in fire suppression. The KBDI is reported weekly from 13 Massachusetts fire districts by the DCR Bureau of Fire Control; however, these data are not available online.

The Precipitation Index is a comparison of measured precipitation amounts (in inches) to historical normal precipitation. Cumulative amounts for 3, 6, and 12-month periods are factored into the drought determination. These data are available from the DCR Office of Water Resources.

The Groundwater Level Index is based on the number of consecutive months that groundwater levels are below normal (lowest 25th percentile of period of record for the respective months). The USGS monitors groundwater levels in a network of monitoring wells throughout Massachusetts. The USGS develops monthly groundwater condition maps showing areas as above normal, normal or below normal. DCR provides a table specifying whether each Massachusetts Drought Region experienced normal, above-normal, or below-normal groundwater levels each month and includes this information in the monthly report, *Current Water Conditions in Massachusetts*.

The Stream Flow Index is based on the number of consecutive months that stream flow levels are below normal (lowest 25th percentile of period of record for the respective months). The USGS monitors stream flow in a network of gages throughout Massachusetts. The USGS develops monthly stream flow condition maps showing areas as above normal, normal or below normal. In addition, USGS provides a table that describes cumulative monthly stream flow as normal, above normal, or below normal.

The Reservoir Index is based on the water levels of small, medium, and large index reservoirs across the Commonwealth. The reservoir level relative to normal conditions for each month of the year is considered. As part of its monthly water conditions report, the DCR Office of Water Resources maintains a list of index water supply reservoirs and the percentage at which they are at capacity as well as and non-water supply index reservoir levels, as available. Reservoir data are summarized in the DCR monthly Water Conditions Reports.

Table 14-5 displays the drought thresholds for these drought indices and includes the drought level. A drought emergency will end when the conditions that led to the specific emergency have abated. For example, a critically low reservoir will need to have made significant recovery, or groundwater wells will need to have returned to normal operating capacities. If an emergency has been declared based on environmental impacts, the emergency will end when these conditions have ended.

TABLE 14-5.
DROUGHT INDICES

SPI	Crop Moisture Index*	KBDI	Precipitation	Groundwater	Stream Flow	Reservoir
Drought Level: Normal						
3-month > -1.5 or 6-month > -1.0 or 12-month > -1.0	0.0 to -1.0 Slightly dry	<200	1 month below normal	2 consecutive months below normal**	1 month below normal**	Reservoir levels at or near normal for the time of year

TABLE 14-5.
DROUGHT INDICES

SPI	Crop Moisture Index*	KBDI	Precipitation	Groundwater	Stream Flow	Reservoir
Drought Level: Advisory						
3-month > -1.5 to -2.0 or 6-month > -1.0 to -1.5 or 12-month > -1.0 to -1.5	-1.0 to -1.9 Abnormally dry	200-400	2 month cumulative below 65% of normal	3 consecutive months below normal**	At least 2 out of 3 consecutive months below normal**	Small index Reservoirs below normal
Drought Level: Watch						
3-month > -2.0 or 6-month > -1.5 to -3.0 or 12-month > -1.5 to -2.0	-2.0 to -2.9 Excessively dry	400-600	1 of the following criteria met: 3 month cum. <65% or 6 month cum. < 70% or 12 month cum. < 70%	4-5 consecutive months below normal**	At least 4 out of 5 consecutive months below normal**	Medium Index Reservoirs below normal
Drought Level: Warning						
6-month <-3.0 or 12-month -2.0 to -2.5	<-2.9 Severely dry	600-800	1 of the following criteria met: 3 month cum. <65% and 6 month cum. <65% or 6 month cum. <65% and 12 month cum. <65% or 3 month cum. <65% and 12 month cum. <65%	6-7 consecutive months below normal**	At least 6 out of 7 consecutive months below normal**	Large index reservoirs below normal
Drought Level: Emergency						
12-month <-2.5	<-2.9 Severely dry	600-800	Same criteria as warning and previous month was warning or emergency	>8 months below normal**	>7 months below normal**	Continuation of previous month's conditions

* Crop Moisture Index is subject to frequent change; the drought level for this indicator is determined based on the repeated or extended occurrence at a given level

** Below normal for groundwater and stream flow are defined as being with the lowest 25th percentile of the period of record

Drought warnings, watches, and advisories can be reduced based normal levels of precipitation returning or groundwater levels returning to the "normal" range. In order to return to normal status, groundwater levels must be in the normal range or one of two precipitation measures must be met: three months of precipitation that is cumulatively above normal; or long-term cumulative precipitation above normal.

14.2 HAZARD PROFILE

14.2.1 Location

High Winds

The entire commonwealth is vulnerable to high winds that can cause a wide range of damage. However, the coast is most frequently impacted by damage due to high wind events. The rest of this section provides more information on wind hazards, as wind is associated with other hazard events. The State Building Code has incorporated engineering standards for wind loads. Wind loads are for buildings and their components are to be designed to withstand the code-specified wind loads. Calculating wind loads is important in design of the wind force-resisting system, including structural members, components, and cladding, against shear, sliding, overturning, and uplift actions. The wind load zones for Massachusetts are shown on the Hurricane Tracks Map in Appendix 4.

Figure 14-2 indicates how the frequency and strength of windstorms impacts the U.S. and the general location of the most wind activity. This is based on 40 years of tornado history and 100 years of hurricane history, collected by FEMA. States located in Wind Zone IV have experienced the greatest number of tornadoes and the strongest tornadoes. The Commonwealth of Massachusetts is located within Wind Zone II, with speeds up to 180 mph. The entire Commonwealth is also located within the hurricane-susceptible region. The western portion of the Commonwealth is located within the special wind region. Table 14-6 describes the areas affected by the different wind zones.

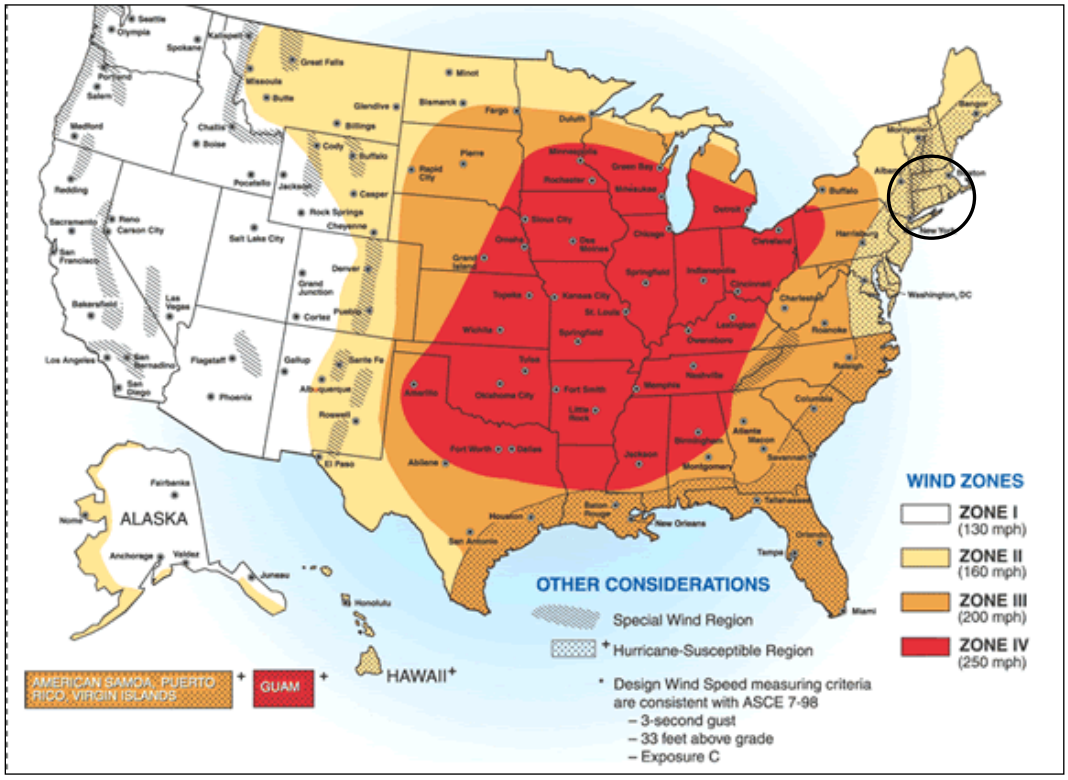

Figure 14-2. Wind Zones in the U.S.

TABLE 14-6.
WIND ZONES IN THE U.S.

Wind Zones	Areas Affected
Zone I (130 mph)	All of Washington, Oregon, California, Idaho, Utah, and Arizona. Western parts of Montana, Wyoming, Colorado, and New Mexico. Most of Alaska, except the east and south coastlines.
Zone II (160 mph)	Eastern parts of Montana, Wyoming, Colorado, and New Mexico. Most of North Dakota. Northern parts of Minnesota, Wisconsin, and Michigan. Western parts of South Dakota, Nebraska, and Texas. All New England States. Eastern parts of New York, Pennsylvania, Maryland, and Virginia. Washington, DC.
Zone III (200 mph)	Areas of Minnesota, South Dakota, Nebraska, Colorado, Kansas, Oklahoma, Texas, Louisiana, Mississippi, Alabama, Georgia, Tennessee, Kentucky, Pennsylvania, New York, Michigan, and Wisconsin. Most or all of Florida, Georgia, South Carolina, North Carolina, Virginia, West Virginia. All of American Samoa, Puerto Rico, and Virgin Islands.
Zone IV (250 mph)	Mid US including all of Iowa, Missouri, Arkansas, Illinois, Indiana, and Ohio and parts of adjoining states of Minnesota, South Dakota, Nebraska, Kansas, Oklahoma, Texas, Louisiana, Mississippi, Alabama, Georgia, Tennessee, Kentucky, Pennsylvania, Michigan, and Wisconsin. Guam.
Special Wind Region	Isolated areas in the following states: Washington, Oregon, California, Idaho, Utah, Arizona, Montana, Wyoming, Colorado, New Mexico. The borders between Vermont and New Hampshire; between New York, Massachusetts and Connecticut; between Tennessee and North Carolina.
Hurricane Susceptible Region	Southern US coastline from Gulf Coast of Texas eastward to include entire state of Florida. East Coastline from Maine to Florida, including all of Massachusetts, Connecticut, Rhode Island, Delaware, and Washington DC. All of Hawaii, Guam, American Samoa, Puerto Rico, and Virgin Islands.

Thunderstorms

Thunderstorms affect relatively small areas, rather than large regions much like winter storms and hurricane events. Thunderstorms can strike in all regions of the U.S.; however, they are most common in the central and southern states. The atmospheric conditions in these regions of the country are most ideal for generating these powerful storms. It is estimated that there are as many as 40,000 thunderstorms each day worldwide. Figure 14-3 shows the average number of thunderstorm days throughout the U.S. The most thunderstorms are seen in the southeast states, with Florida having the highest incidences (80 to over 100 thunderstorm days each year). This figure indicates that Massachusetts experiences between 10 and 30 thunderstorm days each year. Figure 14-4 shows the average number of thunderstorm days with extreme winds throughout the U.S.

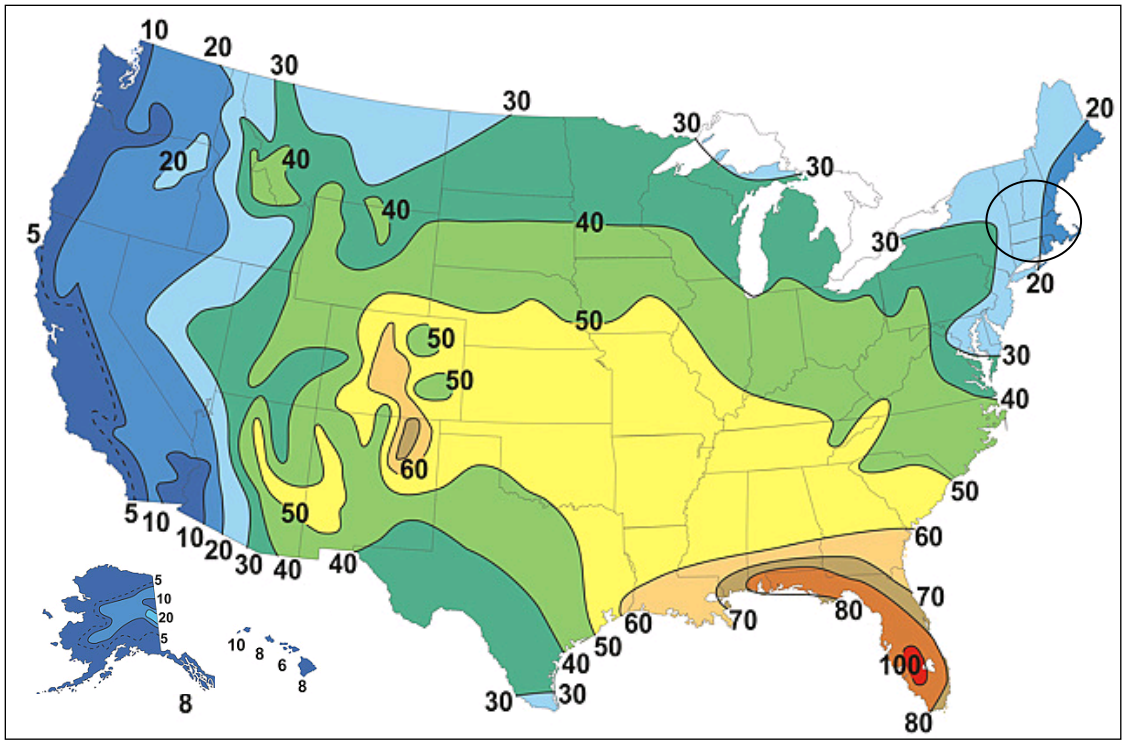

Figure 14-3. Annual Average Number of Thunderstorm Days in the U.S.

Source: MSNBC.com, 2007

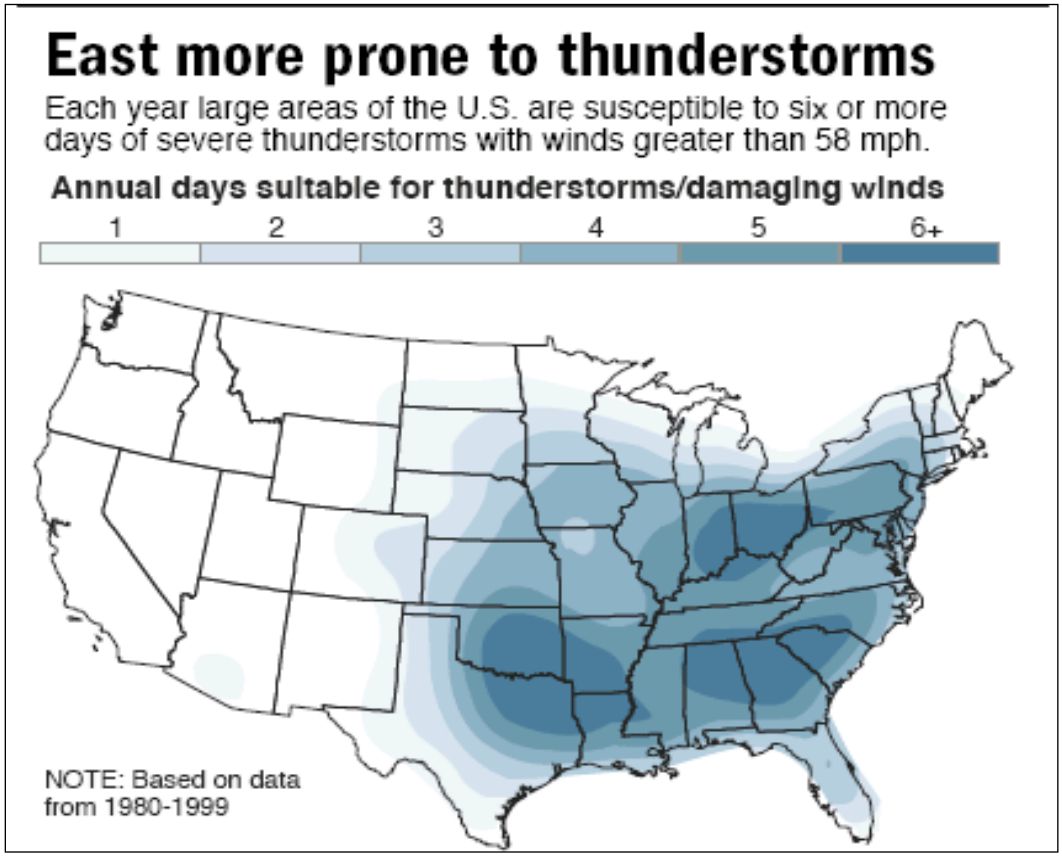

Figure 14-4. Annual Days Suitable for Thunderstorms with Extreme Winds

Tornadoes

The U.S. experiences more tornadoes than any other country. In a typical year, approximately 1,000 tornadoes affect the U.S. The peak of the tornado season is April through June, with the highest concentration of tornadoes in the central U.S. Figure 14-5 shows the annual average number of tornadoes between 1991 and 2010. Massachusetts experienced an average of one tornado event annually between 1991 and 2010.

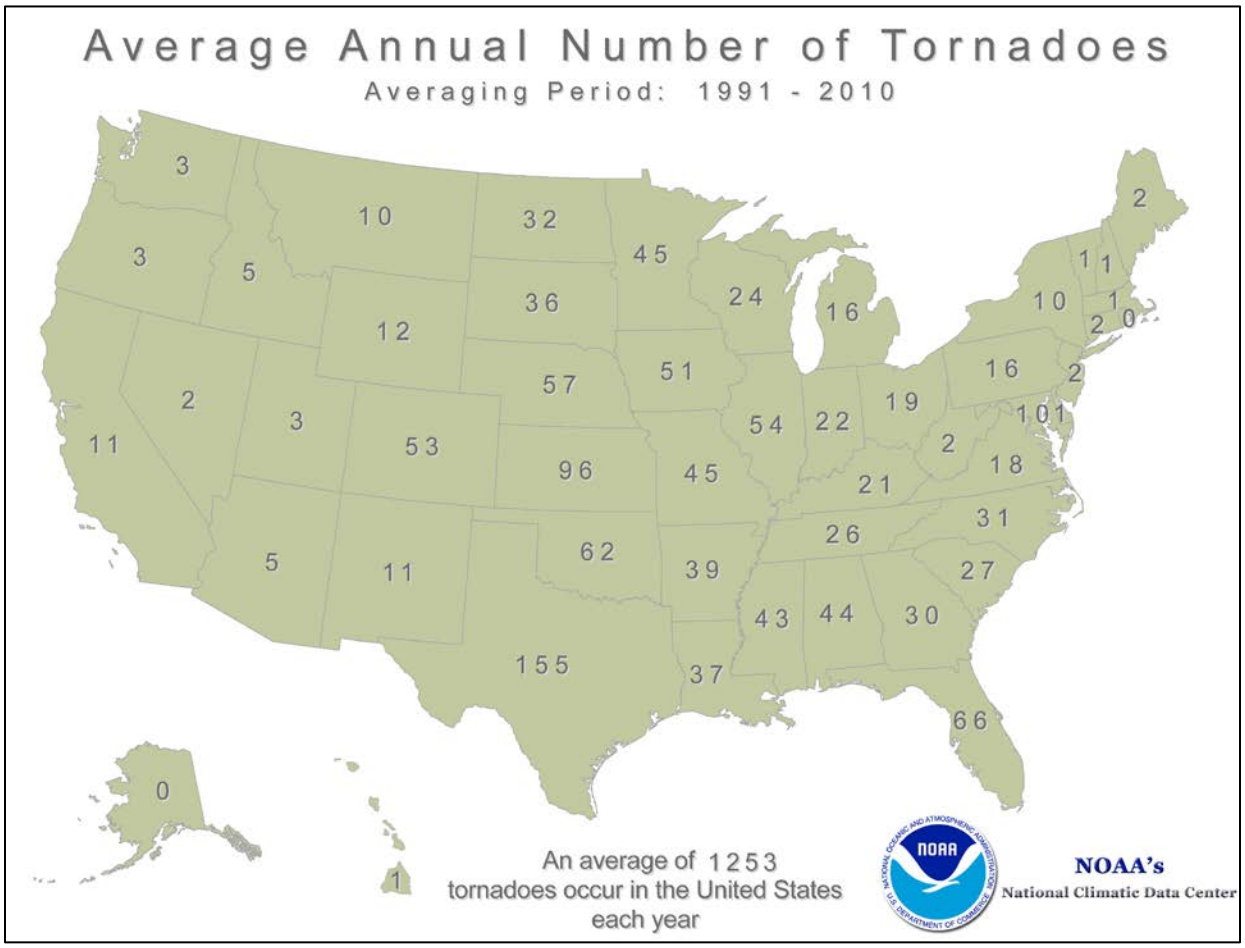

Figure 14-5. Annual Average Number of Tornadoes in the U.S., 1991 to 2010

Figure 14-6 indicates that a majority of the Commonwealth, with the exception of the southeastern section (Mid-Hudson Region), is not located within a high or highest risk tornado area. Southwest Massachusetts is located within the highest risk area of tornadoes. The remainder of the Commonwealth is not included in the high or highest risk areas. Details regarding historical tornado events are discussed in the next section (Previous Occurrences and Losses) of this profile.

Source: USGS Themes Data; information and statistical interpretations from NOAA, 2012

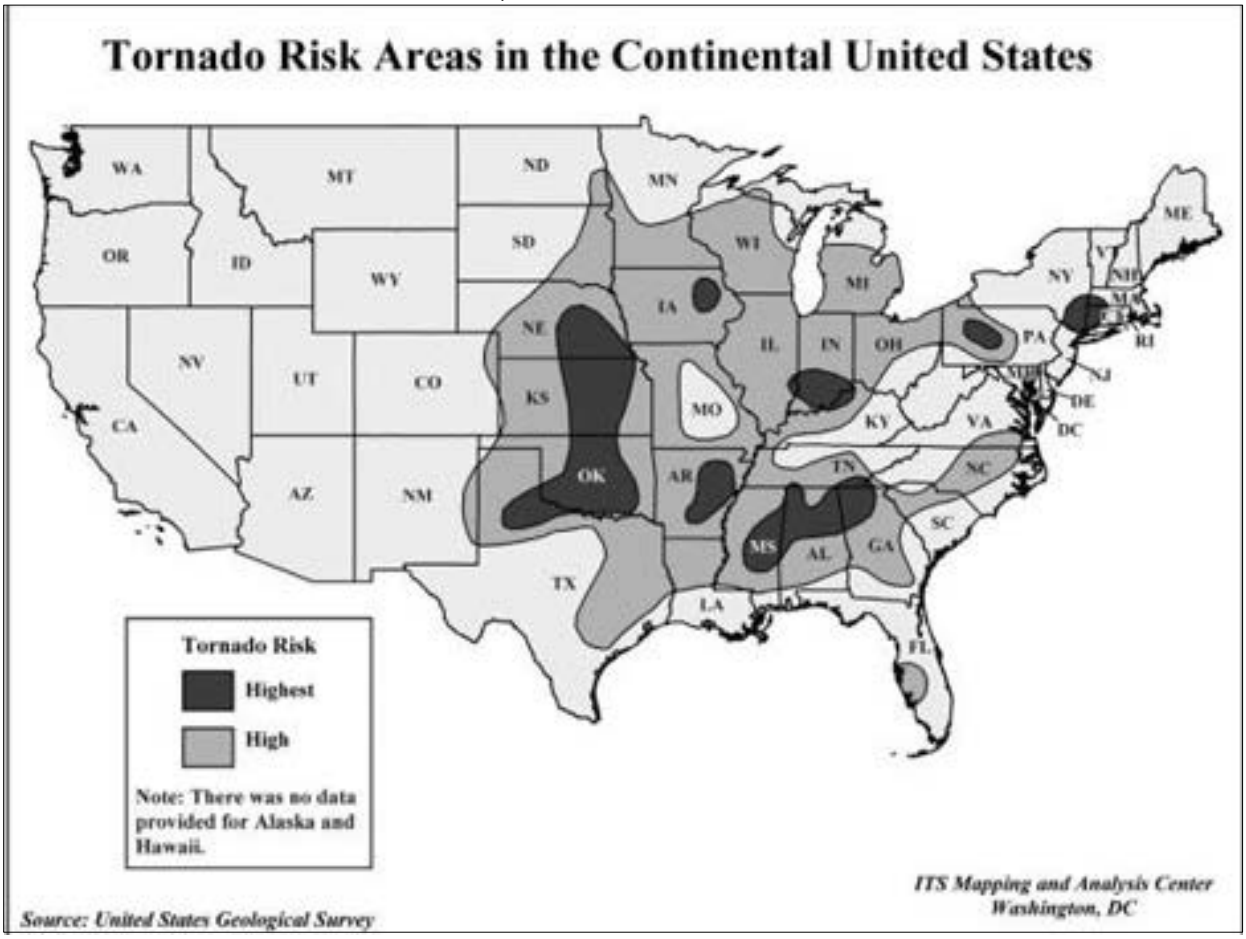

Figure 14-6. Tornado Risk in the U.S.

A study from NOAA's National Severe Storms Laboratory provided estimates of the long-term threat from tornadoes. The Laboratory used historical data to estimate the daily probability of tornado occurrences across the U.S., no matter the magnitude of the tornado. Figure 14-7 shows the estimates prepared by the Laboratory. In Massachusetts, it is estimated that the probability of a tornado occurring is 0 to 0.4 days per year. The density per 25 square miles in the map's legend indicates the probable number of tornadoes for each 25 square mile cell within the contoured zone that can be expected over a similar period of record (51 years). It should be noted that the density number does NOT indicate the number of events that can be expected across the entire zone on the map.

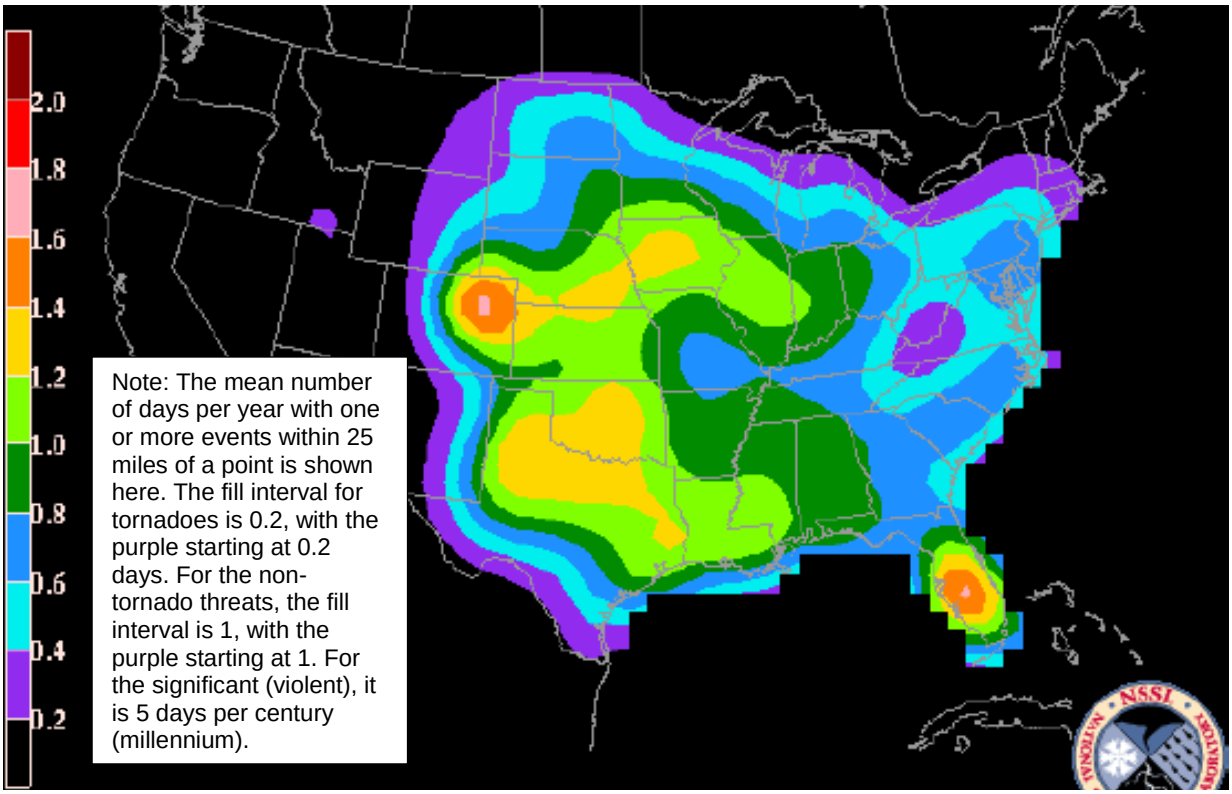

Figure 14-7. Total Annual Threat of Tornado Events in the U.S., 1980-1999

The analysis depicts point locations of initial tornado touchdown locations for the period of record using graduated symbols. These symbols depict tornado intensity based on the original Fujita Scale with thematically shaded tornado density zones derived through Arc View Spatial Analyst software and recorded tornado touchdown locations. These touchdown locations, obtained from NOAA, are based on a search radius of 50,000 square miles and the density of historical tornadoes translated to any given 20 square mile area.

The Enhanced F-scale is a set of wind estimates (not measurements) based on damage. Its uses three-second gusts estimated at the point of damage based on a judgment of 8 levels of damage to the 28 indicators listed in Table 14-2. These estimates vary with height and exposure. Important: The 3-second gust is not the same wind as in standard surface observations. Standard measurements are taken by weather stations in open exposures (http://www.spc.noaa.gov/faq/tornado/ef-scale.html, April 2007).

A tornado may happen anywhere in Massachusetts given the right atmospheric conditions. The Reported Tornado Occurrences Map depicts the tornado risk based on probability of occurrence based past events. The density per 25 square miles indicates the probable number of tornado touchdowns for each 25 square mile cell within the contoured zone that can be expected over a similar period of record (approximately 50 years). It should be noted that the density number does NOT indicate the number of events that can be expected across the entire zone, but the percent probability of occurrence in the given area. The analysis indicated that the area at greatest risk for a tornado touchdown runs from central to northeastern Massachusetts.

Massachusetts does not fall within Tornado Alley. However, tornadoes can occur at any time and in any area. Since Massachusetts experiences far fewer tornadoes than other parts of the country, residents may be less prepared to react to a tornado.

Extreme Temperatures

Climate divisions are regions within a state that are climatically homogeneous. NOAA has divided the U.S. into 359 climate divisions. The boundaries of these divisions typically coincide with the county boundaries, except in the western U.S., where they are based largely on drainage basins (U.S. Energy Information Administration, Date Unknown).

According to NOAA, Massachusetts is made up of three climate divisions: Western, Central, and Coastal (NOAA, 2012). Figure 14-8 shows the climate divisions throughout the U.S. and Figure 14-9 shows the climate divisions of Massachusetts.

Source: NOAA, 2012

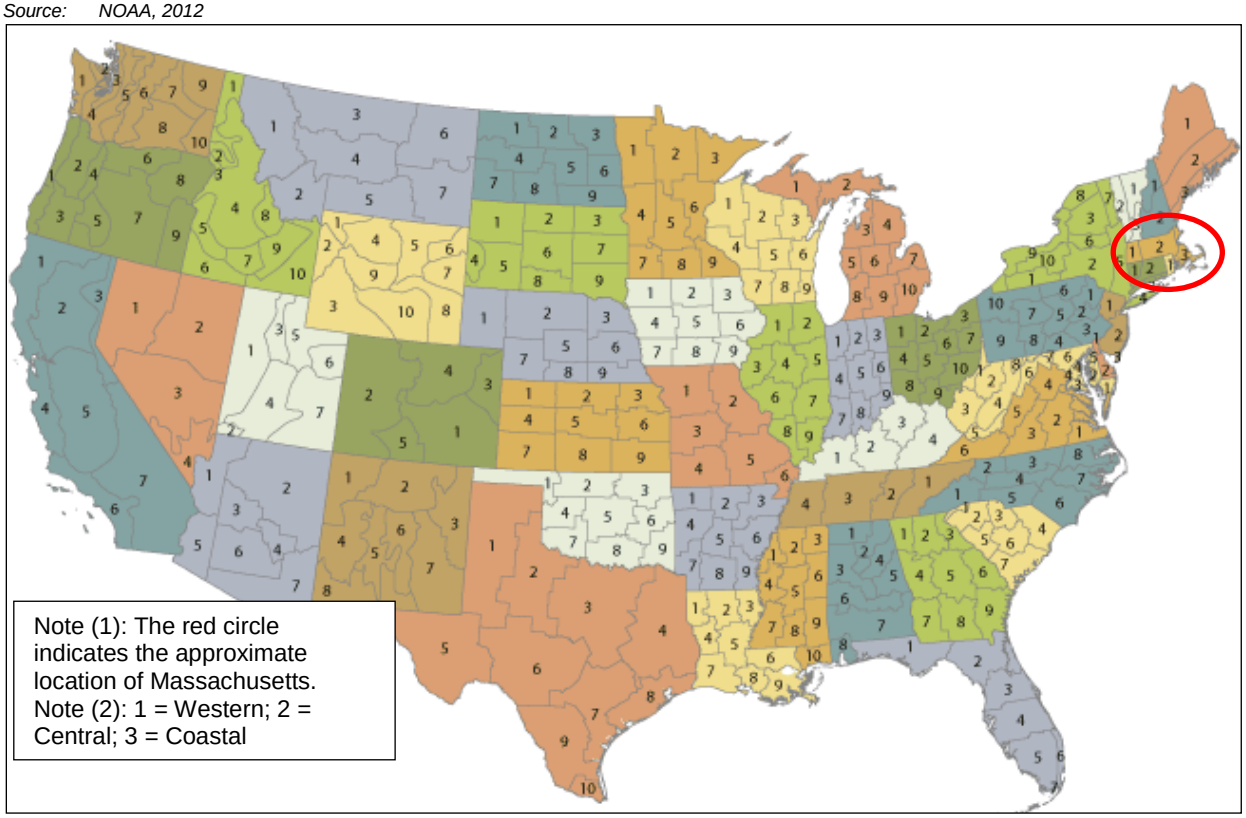

Figure 14-8. Climate Divisions of the United States

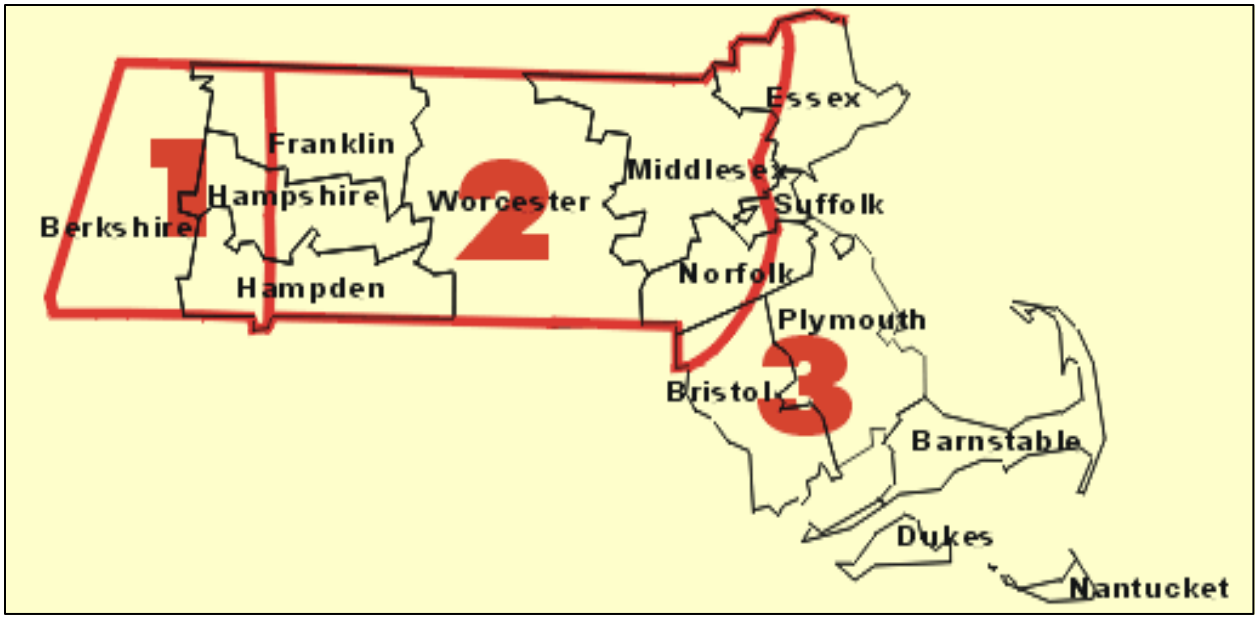

Figure 14-9. Climate Divisions of Massachusetts

Temperature extremes can occur throughout the entire Commonwealth of Massachusetts. Areas that are more prone to heat include inland urban areas. Boston is susceptible to the stresses of heat waves for two reasons. First, the City has a large population of residents considered to be vulnerable during extreme heat (elderly and low-income). Second, the City's dark colored infrastructure in combination with the lack of vegetation creates the urban heat island effect.

Colder temperatures and extremes are more common in the higher elevations. The coastal areas also have lower daily averages that the inlands parts of the Commonwealth, but do not carry the same extreme temperature records.

According to the National Weather Service and the Centers for Disease Control, extreme heat events are the most common cause of weather-related deaths in the United States, causing more deaths annually than hurricanes, lightning, tornadoes, floods, and earthquakes combined. However, in 2011, tornado was the top weather fatality event, with 553 deaths and then heat events with 206 deaths.

Drought

Based on past events and current criteria outlined in the Massachusetts Drought Management Plan, it appears that western Massachusetts may be more vulnerable than eastern Massachusetts to severe drought conditions. However, many factors, such as water supply sources, population, economic factors (i.e., agriculture based economy), and infrastructure, may affect the severity and length of a drought event. The Massachusetts Drought Management Plan takes into account regional responses to such conditions.

The DCR precipitation index divides the Commonwealth into six regions: Western, Central, Connecticut River Valley, Northeast, Southeast, and Cape and Islands (see Figure 14-10).

Figure 14-11 illustrates the watershed extents for all surface water supplies including active, inactive, emergency, sources outside of Massachusetts.

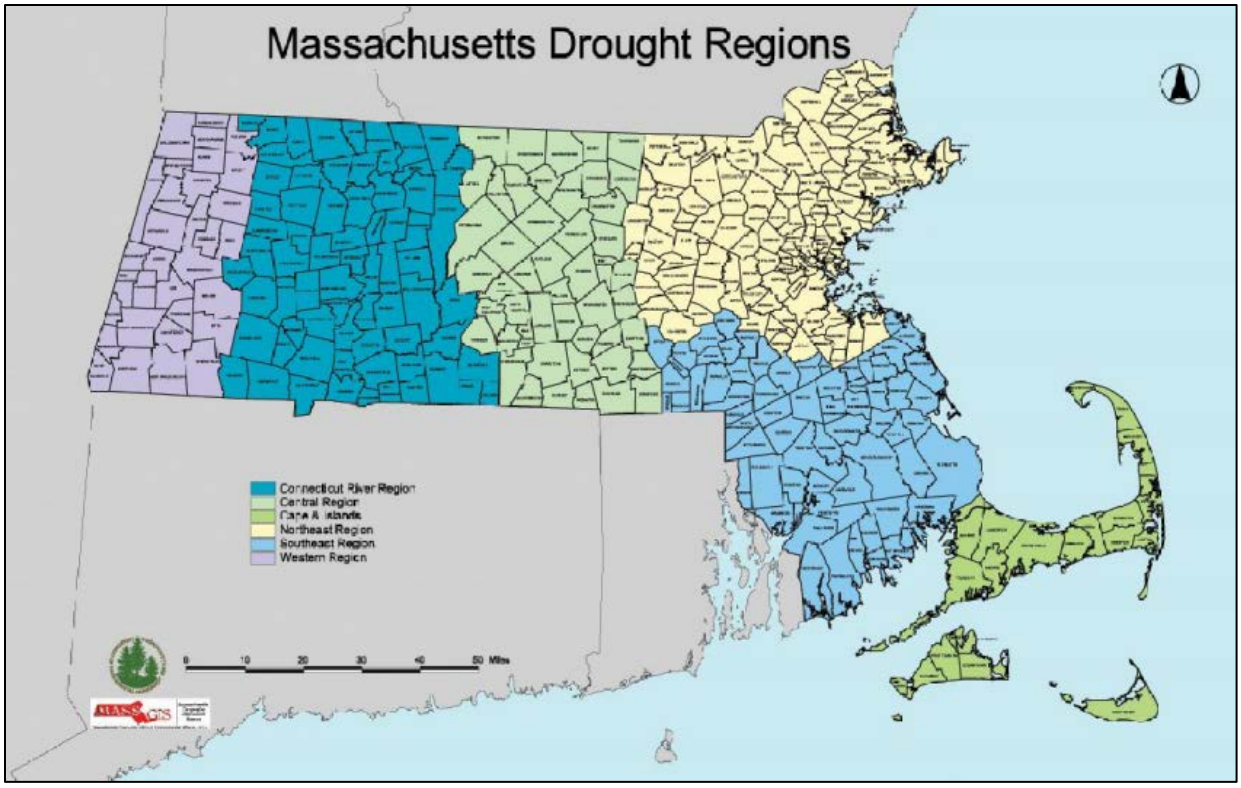

Figure 14-10. Drought Regions of Massachusetts

Source: MassGIS

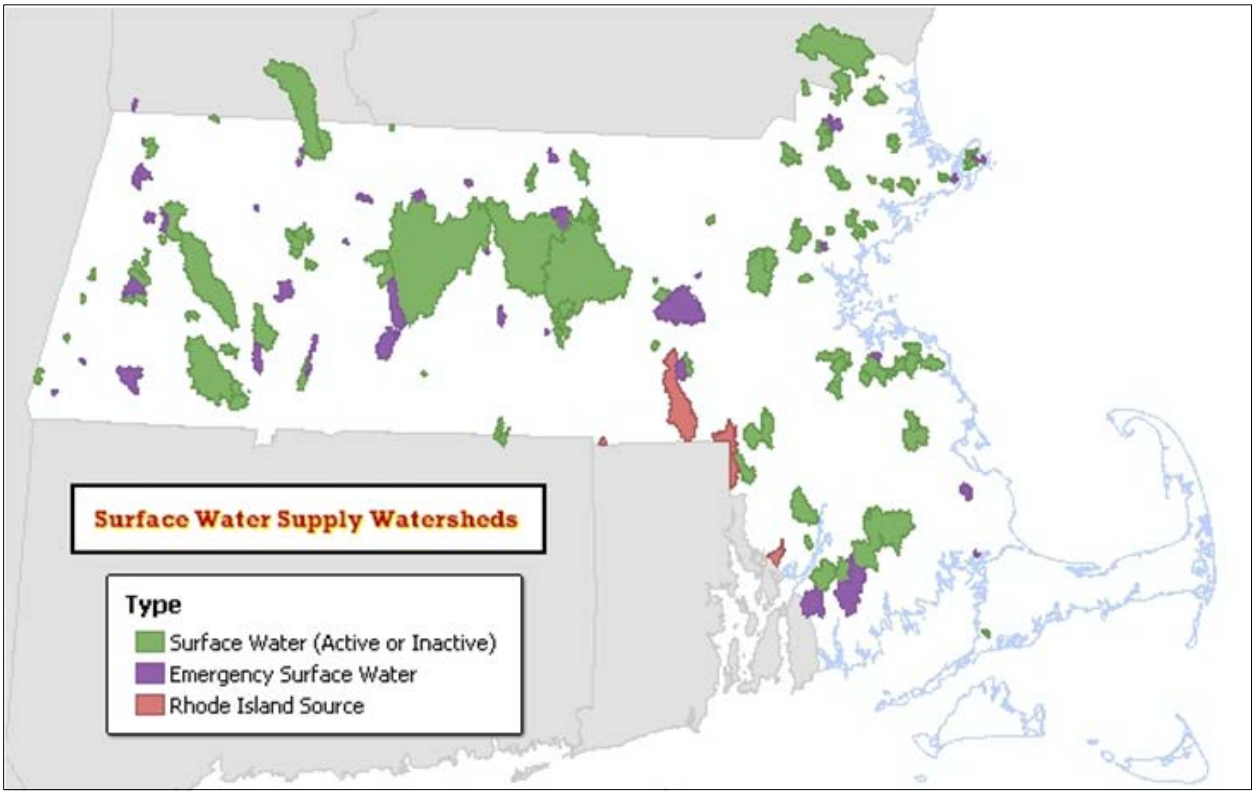

Figure 14-11. Watersheds with Surface Water Intakes for Drinking Water

14.2.2 Previous Occurrences

FEMA Declarations

Based on all sources researched, known severe weather events that have affected Massachusetts and were declared a FEMA disaster are identified in Table 14-7, which provides detailed information concerning the FEMA declarations for the Commonwealth. Figure 14-12 illustrates the number of disasters per County. Specific event types are described in the following sections.

TABLE 14-7.
FEMA SEVERE WEATHER-RELATED DISASTER DECLARATIONS (1954 TO 2012)

Disaster #	Disaster Type	Declaration Date	Incident Period	Barnstable	Berkshire	Bristol	Dukes	Essex	Franklin	Hampden	Hampshire	Middlesex	Nantucket	Norfolk	Plymouth	Suffolk	Worcester	**Number of Counties Impacted**
DR-325	Severe Storms, Flooding	03/06/72	03/06/72					X						X	X	X		**4**
DR-790	Severe Storms, Flooding	04/18/87	3/30/87 - 4/13/87		X			X	X	X	X	X		X			X	**8**
DR-1142	Severe Storms/Flooding	10/25/96	10/20/96 - 10/25/96					X				X		X	X	X		**5**
DR-1224	Heavy Rain and Flooding	06/23/98	6/13/98 - 7/6/98			X		X				X		X	X	X	X	**7**
DR-1364	Severe Storms & Flooding	04/10/01	3/5/01 - 4/16/01			X		X				X		X	X	X	X	**7**
DR-1614	Severe Storms and Flooding	11/10/05	10/7/05 - 10/16/05		X	X			X	X	X	X		X	X		X	**9**
DR-1642	Severe Storms and Flooding	05/25/06	5/12/06 - 5/23/06					X				X				X		**3**
DR-1701	Severe Storms and Inland and Coastal Flooding	05/16/07	4/15/07 - 4/25/07	X	X		X	X	X	X	X				X			**8**
DR-1895	Severe Storm and Flooding	03/29/10	3/12/10 - 4/26/10			X		X				X		X	X	X	X	**7**
DR-1994	Severe Storms and Tornadoes	06/15/11	06/01/11							X							X	**2**
DR-4051	Severe Storm and Snowstorm	01/06/12	10/29/11 - 10/30/11		X				X	X	X	X					X	**6**
Total				**1**	**4**	**4**	**1**	**8**	**4**	**5**	**4**	**8**	**0**	**7**	**7**	**6**	**7**	**66**

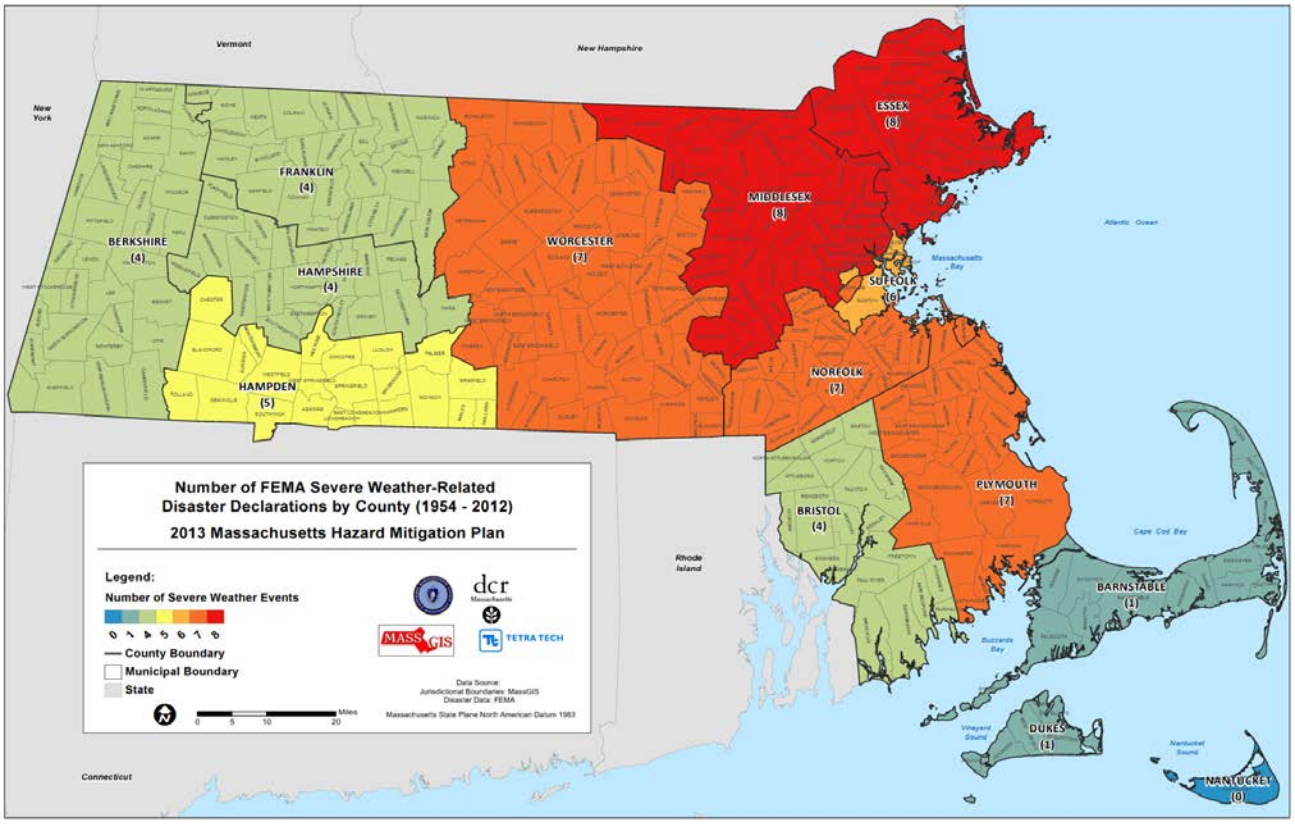

Figure 14-12. Number of FEMA Severe Weather-Related Disaster Declarations (1954 to 2012)

High Winds

The Storm Prediction Center maintains a severe weather database that contains information regarding hail, tornado, and damaging events. The damaging wind reports include data from 1955 to 2011. For the purpose of this plan, the last 20 years of data was inspected. According to the Storm Prediction Center database, over the course of the last 20 years, the Commonwealth has experienced 1,443 damaging wind events, with an annual frequency of 72.15 per year. The events from the past 20 years caused over $29.4 million in property losses and $1.25 million in crop losses. Along with the monetary losses, these damaging wind events caused 88 injuries and three fatalities.

Thunderstorms

There have been several damaging thunderstorms in Massachusetts.

- The **March 1972** storm event resulted in a federal disaster declaration (FEMA DR-325); however, detailed information regarding this event was not available.
- A pair of spring storms occurring within a few days of one another in **March and April 1987** combined with snowmelt to produce record flooding in Massachusetts, Maine, and New Hampshire. The events brought over 8 inches of rainfall to some areas of Massachusetts and combined with already high river conditions to produce major flooding in the Connecticut and Merrimack River basins. In addition, several of the Corps of Engineers dams recorded record pool levels (NOAA, date unknown). This March-April 1987 event resulted in a federal disaster declaration (FEMA DR-790).
- On **October 19 through October 20, 1996**, a slow-moving system produced record-breaking rainfall in northeast Massachusetts. This event also brought strong winds with gusts of over 45 mph and a peak gust of 63 mph. Rainfall totals were nearly eight inches and resulted in

widespread small stream and tributary flooding. In Essex County (Newburyport), 13.03 inches of rain was reported. There was widespread urban flooding in Boston. Major roadways were flooded. Many basements of homes were flooded and homes were severely damaged. This event resulted in a federal disaster declaration (FEMA DR-1142). Damage was estimated at over $10 million.

- In **June 1998**, a very slow moving and complex storm system moved through southeast New England. The combination of its slow movement and presence of tropical moisture across the region produced rainfall of 6 to 12 inches over much of eastern Massachusetts. This led to widespread urban, small stream, and river flooding. As a result, the counties of Suffolk, Essex, Middlesex, Norfolk, and Bristol received a presidential disaster declaration for the Individual Household Program (Individual Assistance) on June 23, 1998. The counties of Plymouth and Worcester were added to the initial declaration on July 3, 1998. This 1998 storm caused more than $7 million in personal property damage (FEMA DR-1224).
- A series of storm events occurred in Massachusetts between **March 5 and April 16, 2001**. These events included a major winter storm, heavy rainfall, and melting snow. On March 5, a major winter storm impacted Massachusetts with near-blizzard conditions, high winds, and coastal flooding. Over two feet of snow fell across the interior portion of the Commonwealth. Approximately 80,000 people were without power and businesses and schools were closed for several days. Snowfall totals ranged between two and 30 inches across Massachusetts. During this storm event, high tides ran two to three feet above normal, resulting in widespread coastal flooding along the entire east-facing coastline. Beachfront homes and roadways were flooded and sea walls were damaged. Between March 22 and March 31, a series of flooding events occurred throughout Massachusetts as a result of melting snow and heavy rainfall. The most severe flooding occurred in the Merrimack Valley. Another event occurred on March 30, bringing heavy snow to parts of interior Massachusetts and heavy rain and strong winds to the coastal communities, causing flooding along rivers and streams in the eastern portion. Over six inches of rain fell in some areas. This series of flooding events resulted in a federal disaster declaration (FEMA DR-1364).
- On **October 9, 2005**, the remnants of Tropical Storm Tammy produced significant rain and flooding across western Massachusetts. It was reported that between nine and 11 inches of rain fell. The heavy rainfall washed out many roads in Hampshire and Franklin Counties. The Green River flooded a mobile home park. Several people had to be evacuated from their homes. On October 15, a low-pressure system, combined with tropical moisture, resulted in heavy rain and flooding across Massachusetts. Approximately 1,000 evacuations occurred due to severe urban flooding and near record flooding along the Blackstone and Quinebaug Rivers. Many streets were flooded and shut down, including state and interstate highways. This series of storms resulted in a federal disaster declaration (FEMA DR-1614) and Massachusetts received over $13 million in individual and public assistance.
- Between **May 13 and 15, 2006**, heavy rain caused widespread flooding across much of eastern Massachusetts. Rainfall totals ranged between eight and 12 inches, with some areas receiving over 12 inches of rain. Small streams and main stem rivers flooded, some experienced major flooding. Some areas experienced the worst flooding since the 1938 hurricane and the floods of March 1936. A state of emergency was declared by the governor and this event resulted in a FEMA disaster declaration (FEMA DR-1642). This severe storm and flooding event caused two fatalities and the Commonwealth received over $56 million in individual and public assistance.
- An intense coastal storm (**April 15-16, 2007**) brought wet snow, sleet, and rain to parts of western Massachusetts. Snowmelt and heavy rain between three and six inches led to

moderate flooding of small streams and creeks in parts of the Commonwealth , particularly in the lower Merrimack River Basin/mainstream and tributaries. This event resulted in a federal disaster declaration (FEMA DR-1701). Those counties included in this disaster received over $8 million in public assistance from FEMA. The storm was primarily a rain event due to warmer temperatures; however, higher elevations experienced significant snow and ice accumulations.

- On **May 24, 2009** Bristol, Plymouth, Norfolk, and Worcester Counties experienced an intense thunderstorm causing minor flooding, winds exceeding 70 mph, and quarter sized to golf-ball sized hail.
- A series of severe storms and flooding events occurred throughout Massachusetts between **March 10 and April 26, 2010**. These storms brought widespread rainfall, causing small streams to rise above their flood stages. River flooding, coupled with heavy rain and poor drainage flooding resulted in a federal disaster declaration (FEMA DR-1895). This series of storms and flooding caused three injuries and over $145 million was received in individual and public assistance.
- On **July 26, 2011**, a strong cold front moved across southern New England in which severe thunderstorms developed. These storms produced large hail and damaging winds. The strong winds knocked down many trees and power lines in Berkshire, Hampden, and Hampshire Counties. Hail sizes were from quarter-size to ping-pong-ball-size. A microburst occurred will Wilbraham that resulted in significant tree damage. Hundreds of trees were downed. Many roads were closed. Based on tree damage, the strongest winds were estimated to have been between 90 and 100 mph in Wilbraham. The affected areas had over $1.5 million in property damage.
- Between **August 19 and 21, 2011**, Berkshire, Hampshire, Essex, Middlesex, Suffolk, Franklin, Norfolk, and Worcester Counties experienced severe thunderstorms that produced quarter sized hail and damaging winds. The strong winds knocked down numerous trees and power lines in the affected areas, causing nearly $100,000 in property damage.
- A rare October Nor'easter brought heavy snow to portions of southern New England on **October 29, 2011**. Snowfall accumulations of one to two feet were common in the Monadnocks, Berkshires, Connecticut Valley, and higher elevations in central Massachusetts. Up to 31 inches of snow was reported in Plainfield, MA. The accumulation of the heavy, wet snow on trees and power lines resulted in widespread tree damage and power outages across central and western Massachusetts. At the peak, approximately 665,000 customers in Massachusetts were without power. Seventy-seven shelters were opened and housed over 2,000 residents. Governor Patrick declared a state of emergency on October 29. Six fatalities occurred during and in the aftermath of the storm. The Commonwealth had approximately $300,000 in property damage from this Nor'easter event. This event resulted in a federal disaster declaration (FEMA DR-4051) for the following counties: Berkshire, Franklin, Hampden, Hampshire, Middlesex, and Worcester.

Tornadoes

Over the course of the last 20 years, the Commonwealth has experienced 52 tornadoes, with an annual frequency of 2.6 per year. Table 14-8 lists all recorded tornado events in the Commonwealth since 1950.

TABLE 14-8.
TORNADO EVENTS BETWEEN 1950 AND 2011

Date	F-Scale	Fatalities	Injuries	Date	F-Scale	Fatalities	Injuries
8/21/1951	2	0	0	8/17/1970	1	0	0
12/18/1951	2	0	0	8/28/1970	2	0	0
6/9/1953	4	90	1228	10/3/1970	1	0	0
6/9/1953	3	0	17	10/3/1970	3	1	0
7/14/1954	1	0	0	7/1/1971	1	0	1
8/16/1954	1	0	0	7/1/1971	1	0	2
7/5/1955	2	0	0	7/17/1971	1	0	0
7/12/1955	2	0	0	9/13/1971	3	0	0
10/24/1955	1	0	0	11/7/1971	1	0	0
10/24/1955	1	0	0	11/7/1971	1	0	0
6/1/1956	1	0	0	7/3/1972	1	0	0
6/1/1956	1	0	0	7/3/1972	1	0	0
6/1/1956	1	0	0	7/21/1972	2	0	4
6/1/1956	1	0	14	7/21/1972	1	0	0
6/13/1956	1	0	0	8/9/1972	1	0	0
9/12/1956	1	0	0	8/9/1972	2	0	1
11/21/1956	2	0	0	8/9/1972	1	1	6
11/21/1956	2	0	0	8/27/1972	2	0	0
11/21/1956	2	0	0	9/14/1972	1	0	0
12/18/1956	1	0	0	9/14/1972	0	0	0
5/10/1957	-9	0	0	8/2/1973	0	0	0
5/10/1957	1	0	0	8/28/1973	4	4	36
6/19/1957	1	0	0	9/6/1973	1	0	0
6/19/1957	1	0	0	9/29/1974	3	0	1
6/19/1957	1	0	0	7/13/1975	2	0	0
7/5/1957	1	0	0	7/24/1975	2	0	0
7/5/1957	2	0	0	5/3/1976	1	0	0
6/26/1958	1	0	0	6/29/1977	1	0	0
7/11/1958	2	0	0	8/22/1977	1	0	2
7/11/1958	1	0	0	7/27/1978	0	0	0
7/11/1958	1	0	0	8/10/1979	2	2	2
7/11/1958	2	0	0	8/10/1979	1	0	1
7/16/1958	1	0	1	6/22/1981	3	0	3
7/29/1958	1	0	0	7/18/1983	0	0	0
8/13/1958	1	0	0	8/1/1983	0	0	0
8/14/1958	2	0	0	7/5/1984	1	0	0
8/25/1958	2	0	0	7/5/1984	1	0	0
9/7/1958	0	0	0	7/11/1984	1	0	0
9/7/1958	0	1	1	9/27/1985	1	0	0
7/13/1960	0	0	0	8/7/1986	1	0	0
7/2/1961	0	0	0	8/8/1986	1	0	0

TABLE 14-8.
TORNADO EVENTS BETWEEN 1950 AND 2011

Date	F-Scale	Fatalities	Injuries	Date	F-Scale	Fatalities	Injuries
7/3/1961	0	0	0	9/16/1986	1	0	0
7/21/1961	2	0	0	7/10/1989	1	0	0
7/21/1962	1	0	3	7/10/1989	1	0	0
10/12/1962	2	0	0	7/10/1989	1	0	0
5/20/1963	2	0	0	7/10/1989	1	0	0
5/20/1963	2	0	0	7/10/1989	0	0	0
5/20/1963	2	0	0	7/10/1989	1	0	1
5/20/1963	2	0	0	7/10/1989	0	0	0
7/18/1963	1	0	0	5/18/1990	0	0	0
7/21/1963	0	0	0	5/18/1990	0	0	0
9/12/1963	1	0	0	8/10/1990	0	0	0
10/3/1963	1	0	0	8/15/1991	1	0	0
5/19/1964	0	0	0	6/24/1992	0	0	0
5/19/1964	1	0	0	6/27/1992	0	0	4
7/4/1964	1	0	0	5/29/1995	4	3	24
7/29/1964	0	0	0	7/3/1997	1	0	0
7/29/1964	1	0	0	7/3/1997	1	0	0
5/27/1965	1	0	0	7/3/1997	2	0	0
6/9/1965	0	0	0	7/3/1997	2	0	0
8/10/1965	1	0	0	7/3/1997	1	0	0
8/28/1965	2	0	0	7/3/1997	2	0	0
3/1/1966	2	0	0	8/6/1997	0	0	0
8/11/1966	2	0	0	8/20/1997	0	0	0
8/11/1966	2	0	0	6/2/2000	1	0	0
8/31/1966	2	0	0	6/17/2001	1	0	0
8/31/1966	0	0	1	6/30/2001	0	0	0
11/18/1967	2	0	0	7/23/2002	1	0	0
7/1/1968	1	0	1	8/20/2004	0	0	0
7/17/1968	1	0	0	8/21/2004	1	0	0
7/19/1968	0	0	0	6/29/2005	0	0	0
8/9/1968	1	0	4	7/11/2006	2	0	0
8/9/1968	1	0	0	7/19/2007	0	0	0
8/9/1968	1	0	0	7/23/2008	0	0	0
5/29/1969	1	0	0	6/1/2011	3	3	200
6/18/1970	1	0	0	6/1/2011	1	0	0
7/11/1970	1	0	0	6/1/2011	0	0	0
8/2/1970	1	0	0	6/1/2011	0	0	0

The most destructive tornado in New England history was the Worcester tornado of June 9, 1953. The F4 tornado hit at about 3:30 p.m. The funnel quickly intensified, carving a 46-mile path of death and destruction as it moved through seven towns. The twister tore through Barre, Rutland, Holden, Worcester,

Shrewsbury, Westborough, and Southborough. It killed 94 people and left approximately 1,300 people injured. The National Storm Prediction Center has ranked this as one of the deadliest tornadoes in the nation's history. With wind speeds between 200 to 260 mph, the force of the tornado carried debris miles away and into the Atlantic Ocean. A music box and a 3-foot aluminum trap door were found about 35 miles away, according to NOAA. Further, frozen mattresses fell into Boston Harbor, after having been carried aloft by the tornado.

On August 15, 1991, an F1 tornado touched down in Georgetown (Essex County) at the north end of Rock Pond and then skipped along, moving from northwest to southeast, across Route 97. It then touched down near the south-southeast shore of Pentucket Pond where it caused the greatest damage. A number of large trees were snapped off 20 feet above the ground. A car was crushed by a falling tree and a modular home had its roof blown off. The tornado continued approximately one-quarter mile southeast and then disappeared. Width of the damage path varied from 300 yards to as narrow as 50 yards.

Based on the extent of destruction, the Worcester tornado may have been an EF5 – the most severe on the Enhanced Fujita Tornado Scale. Two other deadly tornadoes occurred later – the May 29, 1995 Great Barrington tornado, an EF4, which claimed 3 lives and injured 24; and the August 28, 1973 West Stockbridge tornado, a EF4, which killed 4 and injured 36.

A National Weather Service Damage Survey Team concluded that an EF1 Tornado and/or Waterspout occurred in a portion of Eastern Rhode Island and Southeast Massachusetts on July 23, 2008 at 4:05 PM. What began as a waterspout just off of Rumstick Point in Barrington, Rhode Island quickly moved onto land over the southern portion of Warren, Rhode Island. It then continued eastward into southeastern Massachusetts. Most of the damage had a rating of EF0 on the Enhanced Fujita Scale with wind speeds of 65 to 75 mph. However, there was one small section of Warren, RI that demonstrated EF1 damage, where wind speeds were estimated at 90 mph. The tornado path length was 4.2 miles and very narrow with a path width of only 40 yards. No injuries were reported. The majority of the damage was to trees, some of which fell onto power lines and houses.

An EF2 tornado moving north-northeast from Rockingham County New Hampshire into Merrimack County New Hampshire on July 24, 2008. Although this event did not fall within the Massachusetts borders, the touchdown occurred about 35 miles north of the state line. Homes and buildings in the Tornadoes path sustained damage along the path, which was up to a half-mile wide and 50 miles long. The tornado traveled through 5 counties, resulting in 1 fatality and damage to over 100 structures some of which were completely destroyed.

The most recent tornado occurred June 1, 2011, impacting Hampden and Worcester Counties. Thunderstorms developed during the morning of June 1 and entered western Massachusetts in the form of supercells. A supercell eventually produced a tornado that entered Hampden County from the Berkshires. The cell produced an EF3 tornado, touching down in Westfield and continued on a 38-mile-long path through West Springfield, Springfield, Wilbraham, Monson, Brimfield, and Sturbridge. The tornado was on the ground for approximately 70 minutes. Two hours later, another supercell tracked north of the path of the EF3 tornado. It produced brief tornadoes in Wilbraham, North Brimfield, and Sturbridge. This series of tornadoes caused extensive property damage (over $227 million). This event resulted in a FEMA disaster declaration (FEMA DR-1994).

Extreme Temperatures

Since 1994, there have been 19 cold weather events within the Commonwealth, ranging from Cold/Wind Chill to Extreme Cold/Wind Chill events. Since 1995, there have been 43 warm weather events, ranging from Record Warmth/Heat to Excessive Heat events. Detailed information regarding most of these extreme temperature events was not available.

In June 2008, temperatures across Massachusetts were recorded above 90 degrees for a period of four days, breaking records in some areas. The high of 94 degrees in Worcester was three degrees hotter than a

1984 record and the high of 96 degrees in Providence, two degrees above a 1974 record. As a result of days of heat public schools in Taunton and Fall River were dismissed early. While in other towns children's attendance was optional.

In 2012, Massachusetts experienced 27 broken heat records. Most of these records were broken between June 20 and June 22, 2012. June 2012 was the first major heat wave of the summer to hit the east coast, including Massachusetts.

Table 14-9 and Table 14-10 summarize historical cold-weather and warm-weather events.

TABLE 14-9.
NOTABLE COLD WEATHER EVENTS

Date	Type	Date	Type
1/15/1994	Cold	2/3/2007	Extreme Cold/Wind Chill
1/18/1994	Cold	1/1/2009	Cold/Wind Chill
1/19/1994	Cold	1/16/2009	Cold/Wind Chill
1/27/1994	Cold	4/29/2009	Frost/Freeze
1/17/2000	Extreme Cold	5/19/2009	Frost/Freeze
5/20/2002	Freeze	6/1/2009	Frost/Freeze
5/22/2002	Freeze	5/9/2010	Frost/Freeze
10/15/2002	Freeze	5/13/2010	Frost/Freeze
1/15/2004	Extreme Cold/Wind Chill	1/23/2011	Extreme Cold/Wind Chill
1/25/2007	Cold/Wind Chill		

TABLE 14-10.
NOTABLE WARM WEATHER EVENTS

Date	Type	Date	Type
1/13/1995	Record Warmth	7/16/1999	Record Warmth
7/13/1995	Record Heat	7/17/1999	Record Warmth
2/22/1997	Record Warmth	7/18/1999	Record Warmth
1/3/1998	Record Warmth	9/7/1999	Record Warmth
3/27/1998	Record Warmth	3/8/2000	Record Warmth
3/28/1998	Record Warmth	5/8/2000	Record Heat
3/31/1998	Record Warmth	5/9/2000	Record Heat
9/27/1998	Record Heat	10/14/2000	Record Warmth
12/2/1998	Record Warmth	12/17/2000	Record Warmth
12/7/1998	Record Warmth	4/24/2001	Record Heat
1/24/1999	Record Warmth	5/2/2001	Record Heat
2/12/1999	Record Warmth	5/3/2001	Record Heat
3/18/1999	Record Warmth	5/4/2001	Record Heat
6/7/1999	Excessive Heat	5/12/2001	Record Heat

TABLE 14-10.
NOTABLE WARM WEATHER EVENTS

Date	Type	Date	Type
6/7/1999	Record Heat	7/6/2010	Excessive Heat
7/4/1999	Excessive Heat	7/21/2011	Excessive Heat
7/5/1999	Record Heat		

Drought

Most droughts in Massachusetts have started with dry winters, rather than a dry summer. During the summer of 2002, one-third of the country, including Massachusetts, experienced drought conditions. Massachusetts has experienced multi-year drought periods in 1879-83, 1908-12, 1929-32, 1939-44, 1961-69, and 1980- 83. The most severe drought on record in the northeastern United States was during 1961-69. Water supplies and agriculture were affected because of the severity and long duration of the drought. Precipitation was less than average beginning in 1960 in western Massachusetts and beginning in 1962 in eastern Massachusetts. Table 14-11 summarizes estimated historical droughts in the Commonwealth based on the SPI.

TABLE 14-11.
ESTIMATED DROUGHTS BASED ON THE MASSACHUSETTS STANDARDIZED PRECIPITATION INDEX

Year(s)	Duration (months)	Lowest SPI Statistic	Lowest SPI value for Statistic	Month of Lowest SPI Statistic	Estimated Drought Level
1924-1925	13	12-month	-2.28	August-25	Warning
1930-1931	12	12-month	-2.52	September-30	Emergency
1934-1935	15	12-month	-2.10	March-35	Warning
1944	11	12-month	-1.95	October-44	Watch
1949-1950	15	12-month	-1.92	May-50	Watch
1957-1958	12	12-month	-2.23	July-57	Warning
1964-1967	36	12-month	-3.26	April-66	Emergency
1971	8	12-month	-1.90	February-72	Watch
1980-1981	13	12-month	-1.84	March-81	Watch
1985	7	12-month	-1.94	July-85	Watch
1988-1989	11	12-month	-1.73	February-89	Watch
1990-1991	9	12-month	-1.54	July-91	Watch
2001-2002	13	12-month	-1.63	August-02	Watch

The summer of 1999 was a very dry summer with high temperatures. The eastern U.S. experienced most of this drought/heat wave and had extensive agricultural losses. Overall, this event caused $1 billion in the U.S. and resulted in 502 deaths.

March 2007 was the second driest March on record, increasing fire danger. August 2010 found stream flow in western and central Massachusetts was below normal levels from August into September. Record daily lows were recorded in early September in areas of western Massachusetts. Reservoir supply in the Northeast and Central Regions were also below normal.

The 2012 drought/heat wave was the most extensive drought to affect the U.S. since the 1930s. Drought conditions affected more than half the county for the majority of 2012. Drought impacts were most costly across the central agricultural states, resulting in widespread harvest failure for corn, sorghum, and soybean crops. The summer heat wave associated with this drought caused 123 direct deaths. In Massachusetts, January 2012 through March 2012 was the driest start to any year on record, with only 6 inches of total precipitation. Most areas in southern New England typically were running 6 to 8 inches below normal. April 2012 again found much of the Commonwealth under drought conditions, lasting until May 2012.

An analysis of historical rainfall data indicated that based on this index alone, between 1850 and 2012, the Commonwealth experienced drought emergency conditions in 1883, 1911, 1941, 1957, and 1965-1966. The 1965-1966 drought period is viewed as the most severe and longest duration drought to have occurred in Massachusetts. On a monthly basis, there is a 1-percent chance of the Commonwealth being in a drought emergency. Drought warning conditions not associated with drought emergencies occurred in 1894, 1915, 1930, and 1985. On a monthly basis, there is a 2-percent chance of the Massachusetts being in a drought warning level. Drought watch conditions not associated with higher levels of drought would have typically occurred in three to four years per decade between 1850 and 1950. The drought emergency dominated the 1960s. There were no drought watch conditions or above in the 1970s. In the 1980s, there was a drought watch level of precipitation between 1980 and 1981, followed by a drought warning in 1985. A frequency of drought watch conditions, at a rate of three years per decade, occurred in 1995, 1998, and 1999. In the 2000s, drought watches occurred in 2001 and 2002. The overall frequency of the Commonwealth being in a drought watch is 8-percent each month.

Agriculture-related drought disasters are quite common. One-half to two-thirds of the counties in the U.S. have been designated as disaster areas in each of the past several years. The Secretary of Agriculture is authorized to designate counties as disaster areas to make emergency loans to producers suffering losses in those counties and in counties that are contiguous to a designated county. Table 14-12 presents USDA declared drought and excessive heat events impacting the Commonwealth.

TABLE 14-12.
DROUGHT AND EXTREME HEAT EVENTS DECLARED BY USDA

Incidence Period	Event Type	USDA Designation Number	Counties Included in Disaster	Losses / Impacts
November 4, 2010	Drought and Excessive Heat	S3049	Franklin	N/A
December 17, 2010	Drought	S3072	Berkshire	N/A
January 18, 2011	Excessive Heat	S3091	Barnstable, Bristol, Dukes, Norfolk, Plymouth	N/A

Source: USDA, 2012
S = Secretarial National Disaster Determination

14.2.3 Severity

Many forms of severe weather can lead to injury and death as well as property damage. Figure 14-13 shows national fatality statistics associated with severe weather for 2011 and the preceding 10- and 30-year periods. The following sections describe severity of specific weather types.

High Winds

Windstorms have been known to cause damage to utilities. The predicted wind speed given in wind warnings issued by the National Weather Service is for a one-minute average; gusts may be 25 to 30 percent higher.

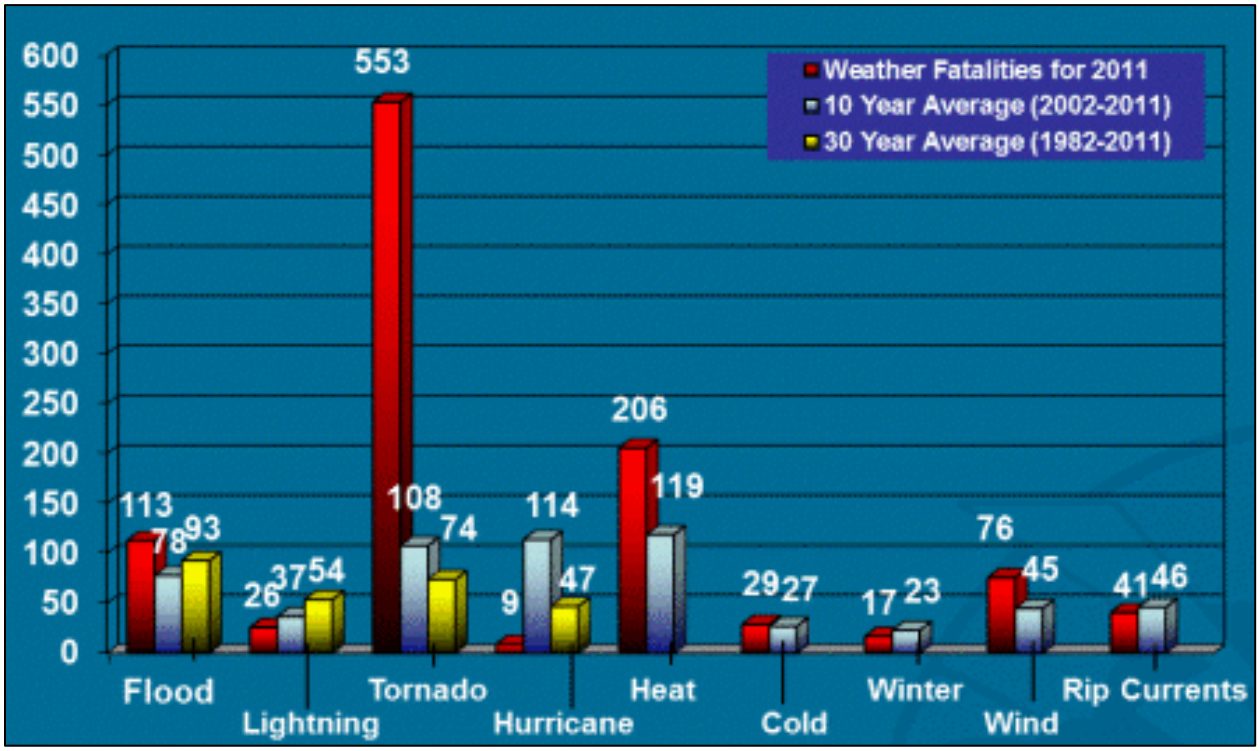

Figure 14-13. National Fatalities from Weather Events

Thunderstorms

The most common problems associated with severe storms are immobility and loss of utilities. Fatalities are uncommon, but can occur. Roads may become impassable due to flooding, downed trees, ice or snow, or a landslide. Power lines may be downed due to high winds or ice accumulation, and services such as water or phone may not be able to operate without power. Lightning can cause severe damage and injury. Windstorms can be a frequent problem and have been known to cause damage to utilities. The predicted wind speed given in wind advisories or high wind warnings issued by the National Weather Service is for a one-minute average; gusts may be 25 to 30 percent higher.

Tornadoes

Tornadoes are potentially the most dangerous of local storms. If a major tornado were to strike within the populated areas of the Commonwealth, damage could be widespread. Businesses could be forced to close for an extended period or permanently, fatalities could be high, many people could be homeless for an extended period, and routine services such as telephone or power could be disrupted. Buildings may be damaged or destroyed. Massachusetts ranks 35th among states for frequency of tornadoes, 14th for the frequency of tornadoes per square mile, 21st for injuries, and 12th for cost of damage.

Extreme Temperature

The severity of extreme cold temperatures is generally measured through the Wind Chill Temperature Index. Wind Chill Temperature is the temperature that people and animals feel when outside and it is based on the rate of heat loss from exposed skin by the effects of wind and cold. As the wind increases, the body is cooled at a faster rate causing the skin's temperature to drop. The severity of extreme heat temperatures are generally measured through the Heat Index. The Heat Index can be used to determine what effects the temperature and humidity can have on the population. Detailed information regarding the Wind Chill Temperature Index and Heat Index is found in Section 0.

Drought

The severity of a drought depends on the degree of moisture deficiency, the duration, and the size and location of the affected area. The longer the duration of the drought and the larger the area impacted, the more severe the potential impacts. Droughts are not usually associated with immediate impacts on people or property, but they can have significant impacts on agriculture, which can impact people indirectly. When measuring the severity of droughts, analysts typically look at economic impacts on a planning area.

Unlike most disasters, droughts normally occur slowly but may last a long time. On average, the nationwide annual impacts of drought are greater than the impacts of any other natural hazard. They are estimated to be between $6 billion and $8 billion annually in the United States and occur primarily in the agriculture, transportation, recreation and tourism, forestry, and energy sectors. Social and environmental impacts are also significant, although it is difficult to put a precise cost on these impacts.

Drought affects both groundwater sources and smaller surface water reservoir supplies. Reduced precipitation during a drought means that water supplies are not replenished at a normal rate. This can lead to a reduction in groundwater levels and problems such as reduced pumping capacity or wells going dry. Shallow wells are more susceptible than deep wells. Reduced replenishment of groundwater affects streams. Much of the flow in streams comes from groundwater, especially during the summer when there is more evapotranspiration (plant uptake of water) and less rainfall infiltration. Reduced groundwater levels mean that even less water will enter streams when steam flows are lowest. This can contribute to warmer stream temperatures and decreased dissolved oxygen availability for aquatic organisms, in addition to diminished aquatic habitat. In terms of public water supply impacts of drought, ground water sources may develop water quality problems. Suppliers may struggle to meet system demands while maintaining adequate water supply pressure for fire suppression requirements. Private well supplies may dry up and need to either be deepened or supplemented with water from outside sources. In some cases, potable water may need to be supplied via distribution centers for residents.

A drought directly or indirectly impacts all people in affected areas. A drought can result in farmers not being able to plant crops or the failure of planted crops. This results in loss of work for farm workers and those in related food processing jobs. Other water-dependent industries are commonly forced to shut down all or a portion of their facilities, resulting in further layoffs. A drought can harm recreational companies that use water (e.g., swimming pools, water parks, and river rafting companies) as well as landscape and nursery businesses because people will not invest in new plants if water is not available to sustain them.

14.2.4 Warning Time

High Winds and Thunderstorms

Meteorologists can often predict the likelihood of a severe thunderstorm outbreak with several days of lead time. However, they can only pin this down to portions of states and cannot predict the exact time of onset or severity of individual events. Some events may develop quickly and have only a few minutes of advance warning time...such as "pulse" type / "popcorn" afternoon thunderstorms. Other storms, such as a well-organized squall line, can yield lead times of up to an hour (from the time a Severe Thunderstorm

Warning is issued to the time that severe criteria are observed). Tornadoes have the least amount of lead time. Doppler radar and a dense network of spotters and amateur radio operators across the region have helped increase warning lead time across southern New England.

Tornadoes

Tornado watches and warnings are issued by the local NWS office. A tornado watch is released when tornadoes are possible in an area. A tornado warning means a tornado has been sighted or indicated by weather radar. The current average lead-time for tornado warnings is 13 minutes. Occasionally, tornadoes develop so rapidly, that little, if any, advance warning is possible.

Extreme Temperatures

Meteorologists can accurately forecast extreme temperature event development and the severity of the associated conditions with several days lead time. These forecasts provide an opportunity for public health and other officials to notify vulnerable populations. For heat events, the NWS issues excessive heat outlooks when the potential exists for an excessive heat event in the next three to seven days. Watches are issued when conditions are favorable for an excessive heat event in the next 24 to 72 hours. Excessive heat warning/advisories are issued when an excessive heat event is expected in the next 36 hours. Winter temperatures may fall to extreme cold readings with no wind occurring. Currently, the only way to headline very cold temperatures is with the use of the Wind Chill Advisory or Warning products.

Drought

Droughts are climatic patterns that occur over long periods of time. Only generalized warning can take place due to the numerous variables that scientists have not pieced together well enough to make accurate and precise predictions. Drought levels are established at gradual levels to alert the public to conditions that, if continued, could result in more serious degrees of drought. Initial drought levels include Advisory and Watch levels. Voluntary water conservation efforts are advised during early stages of drought conditions. Increasing conservation requirements are expected when Drought Warning and Emergency conditions develop. These higher levels of drought require months of dry conditions to be reached. Therefore, there is a lot of lead time as drought conditions progress.

Empirical studies conducted over the past century have shown that meteorological drought is never the result of a single cause. It is the result of many causes, often synergistic in nature; these include global weather patterns that produce persistent, upper-level high-pressure systems along the West Coast with warm, dry air resulting in less precipitation.

Scientists at this time do not know how to predict drought more than a month in advance for most locations. Predicting drought depends on the ability to forecast precipitation and temperature. Anomalies of precipitation and temperature may last from several months to several decades. How long they last depends on interactions between the atmosphere and the oceans, soil moisture and land surface processes, topography, internal dynamics, and the accumulated influence of weather systems on the global scale.

Products produced by the National Drought Mitigation Center include a weekly Drought Monitor map for the United States (http://droughtmonitor.unl.edu/). The National Climate Prediction Center publishes a monthly U.S. Seasonal Drought Outlook that can be used to preview the potential for developing drought conditions (http://www.cpc.ncep.noaa.gov/products/expert_assessment/seasonal_drought.html).

14.2.5 Frequency of Occurrences

The Massachusetts Drought Management Plan (2013) has determined drought occurrence and frequency in the Commonwealth. Figure 14-14 summarizes statewide drought levels using the Standard Precipitation Index (SPI) parameter.

Review of EOEEA data demonstrates that on a monthly basis, the Commonwealth has been in a Drought Watch to Emergency condition 11-percent of the time between 1850 and 2012. On a monthly basis, there is a one-percent chance of being in a drought Emergency status, and a two-percent chance of being in a drought Warning.

Source: EOEEA and MEMA, 2013

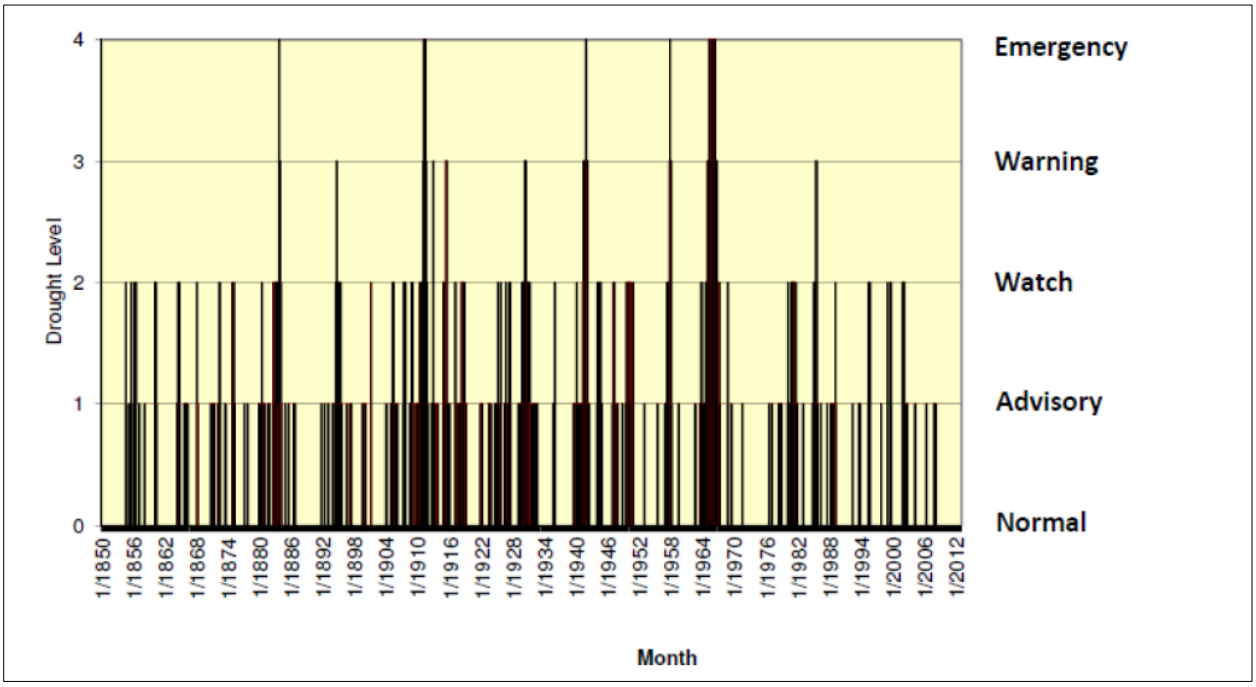

Figure 14-14. Statewide Drought Levels using SPI Thresholds from 1850 to 2012

Drought Watches not associated with higher levels of drought generally would have occurred three to four years per decade between 1850 and 1950. While drought Emergencies dominated the 1960s, there were no drought Watches or above during the 1970s. However, during the 1980s, there was a lengthy drought Watch level of precipitation between 1980 and 1981, followed by a drought Warning in 1985. A frequency of drought Watches at a rate of 3 years per decade resumed in the 1990s (1995, 1998, 1999). In the 2000s, Drought Watches occurred in 2001 and 2002. The overall frequency of being in a drought Watch is 8 percent in a month (EOEEA and MEMA, 2013).

14.3 SECONDARY HAZARDS

The most significant secondary hazards associated with severe local storms are floods, falling and downed trees, landslides, and downed power lines. Rapidly melting snow combined with heavy rain can overwhelm both natural and man-made drainage systems, causing overflow and property destruction. Landslides occur when the soil on slopes becomes oversaturated and fails.

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

14.4 CLIMATE CHANGE IMPACTS

Climate change presents a significant challenge for risk management associated with severe weather. The frequency of severe weather events has increased steadily over the last century. The number of weather-related disasters during the 1990s was four times that of the 1950s, and cost 14 times as much in economic losses. Historical data show that the probability for severe weather events increases in a warmer climate (see Figure 14-15). The changing hydrograph caused by climate change could have a significant

impact on the intensity, duration, and frequency of storm events. All of these impacts could have significant economic consequences.

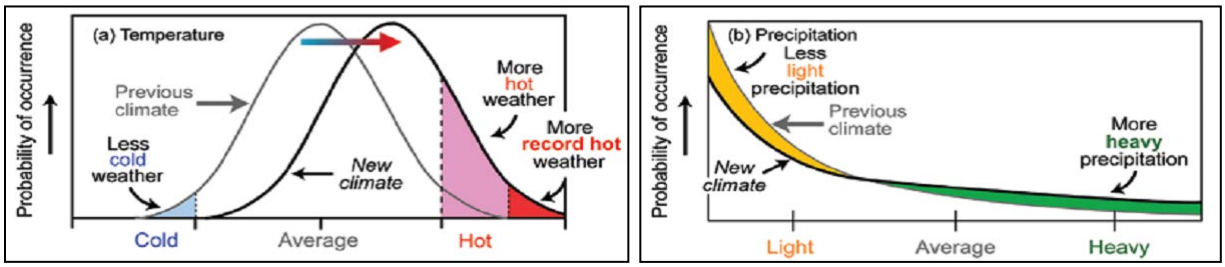

Figure 14-15. Severe Weather Probabilities in Warmer Climates

With a warmer climate, droughts could become more frequent, more severe, and longer-lasting. From 1987 to 1989, losses from drought in the U.S. totaled $39 billion (OTA, 1993). More frequent extreme events such as droughts could end up being more cause for concern than the long-term change in temperature and precipitation averages.

Extreme temperatures are among the most dangerous impacts associated with climate change. Additional impacts pose serious threats to the safety of urban areas, including droughts, rising sea level, and decrease biodiversity, but extreme heat is among the most harmful to public health and safety. It is expected that climate change will cause temperatures to increase, but it is difficult to predict by how much or at what rate.

14.5 EXPOSURE

To understand risk, the assets exposed to the hazard areas are identified. For the severe weather hazard the entire Commonwealth of Massachusetts is exposed. The following discusses the Commonwealth of Massachusetts' exposure to the severe weather hazard including:

- Population
- State facilities
- Critical facilities
- Economy

14.5.1 Population

For the purposes of this Plan, the entire population of the Commonwealth of Massachusetts is exposed to severe weather events. Certain areas are more vulnerable to specific severe weather events than others, due to geographic location and local weather patterns.

Residents may be displaced or require temporary to long-term sheltering due to severe weather events. In addition, downed trees, damaged buildings, and debris carried by high winds can lead to injury or loss of life. Socially vulnerable populations are most susceptible, based on a number of factors including their physical and financial ability to react or respond during a hazard and the location and construction quality of their housing.

14.5.2 State Facilities

High Winds and Thunderstorms

Damage to buildings is dependent upon several factors including wind speed, storm duration, path of the storm track or tornado, distance from the tornado funnel and building construction. According to Hazus-MH's wind model, direct wind-induced damage (wind pressures and windborne debris) to buildings is dependent upon the performance of components and cladding, including roof covering (shingles, tiles,

membrane), roof sheathing (wood frame construction only), windows and doors and is modeled as such. Structural wall failures can occur for masonry and wood frame walls and uplift of whole roof systems due to failure at the roof/wall connections. Foundation failures (i.e., sliding, overturning, and uplift) can potentially take place for manufactured homes.

Impacts to transportation lifelines affect both short-term (e.g., evacuation activities) and long-term (e.g., day-to-day commuting) transportation needs. Utility infrastructure (power lines, gas lines, electrical systems) could suffer damage and impacts can result in the loss of power, which can impact business operations and can impact heating or cooling provision to citizens (including the young and elderly, who are particularly vulnerable to temperature-related health impacts). Post-event, there is a risk of fire, electrocution or an explosion.

Massachusetts is divided into four wind zones, the limits of which are defined by the Massachusetts State Building Code (Seventh Edition). National wind data prepared by the American Society of Civil Engineers serve as the basis of these wind zones ("Minimum Design Loads for Buildings and Other Structures," ASCE-7). Generally speaking, structures should be designed to withstand the total wind load of the zone in which they are located. Refer to the State Building Code for appropriate reference wind pressures, wind forces on roofs, etc.

Using ArcMap GIS software, these data were overlaid with the DCAMM facility data; the appropriate wind load zone determination was assigned to each facility, as summarized in Table 14-13. Figure 14-16 illustrates the wind load zones.

TABLE 14-13.
NUMBER OF STATE-OWNED AND LEASED BUILDINGS IN WIND LOAD ZONES

	< 90 mph		90 mph		100 mph		110 mph		
County	Lease	Own	Lease	Own	Lease	Own	Lease	Own	Total
Barnstable	—	—	—	—	—	—	12	297	309
Berkshire	20	292	—	46	—	—	—	—	358
Bristol	—	—	—	—	18	205	33	226	482
Dukes	—	—	—	—	3	10	—	—	13
Essex	—	—	13	52	26	447	—	—	538
Franklin	6	75	1	129	—	—	—	—	211
Hampden	—	—	36	430	—	—	—	—	466
Hampshire	—	2	16	544	—	—	—	—	562
Middlesex	—	—	11	335	53	708	—	—	1,107
Nantucket	—	—	—	—	—	—	2	3	5
Norfolk	—	—	—	—	26	654	—	—	680
Plymouth	—	—	—	—	18	340	16	168	542
Suffolk	—	—	—	—	73	326	—	—	399
Worcester	—	—	44	837	5	207	—	—	1,093
Total	**26**	**369**	**121**	**2,373**	**222**	**2,897**	**63**	**694**	**6,765**

Source: DCAMM, 2012
Note: Building data are updated as agencies change or modify. State-owned building information is current as of October 3, 2012, and the state-leased building information is current as of October 10, 2010, with a total of 6,765 buildings.

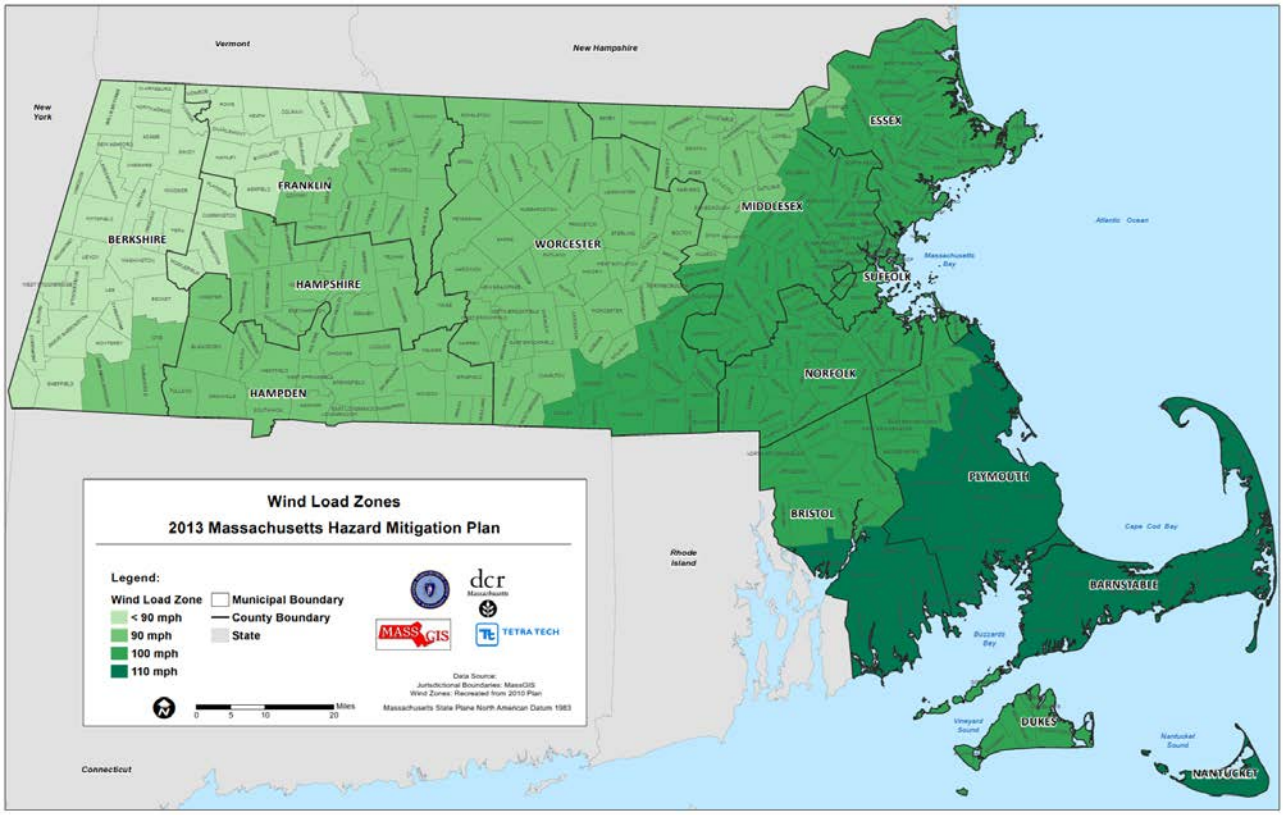

Figure 14-16. Wind Load Zones in the Commonwealth of Massachusetts

Tornadoes

Figure 14-17 illustrates the reported tornado occurrences, based on initial touch-down locations across the Commonwealth. The number of historical tornado touch-downs in 25 miles was updated using the NOAA Storm Prediction Center's dataset through 2011 (2012 data were not available at the time of the 2013 Plan update). To calculate density, the ArcGIS kernel density tool was used.

As was conducted in the 2010 SHMP, tornado risk for the 2013 update is based on probability of occurrence of past events. The density per 25 square miles indicates the probable number of tornado touchdowns for each 25 square mile cell within the contoured zone that can be expected over a similar period of record (approximately 60 years). It should be noted that the density number does not indicate the number of events that can be expected across the entire zone, but the percent probability of occurrence in the given area. The analysis indicated that the area at greatest risk for a tornado touchdown runs from central to northeastern Massachusetts, with the greatest historical touch-down density located in Hampden and Hampshire Counties.

To analyze how tornadoes could impact state facilities, DCAMM data were overlaid with the states area of greatest historical tornado density (0.011 to 0.014). There are over 397 state-owned and leased structures in this zone. The remaining 6,368 state facilities are in low tornado probability areas (<0.011).

Extreme Temperatures

All of the state-owned and leased buildings are exposed to the extreme temperature hazard. Extreme heat generally does not impact buildings. Losses may be associated with the overheating of HVAC systems. Extreme cold temperature events can damage buildings through freezing/bursting pipes and freeze/thaw cycles. Additionally, manufactured homes (mobile homes) and antiquated or poorly constructed facilities may have inadequate capabilities to withstand extreme temperatures.

Drought

No structures are anticipated to be directly affected by a drought, and all are expected to be operational during a drought event. However, droughts contribute to conditions conducive to wildfires. Risk to life and property is greatest in those areas where forested areas adjoin urbanized areas (high density residential, commercial, and industrial), also known as the wildland-urban interface. Therefore, all state facilities in and adjacent to the wildland-urban interface are considered vulnerable to wildfire. See Section 9 regarding the wildland fire hazard in the Commonwealth.

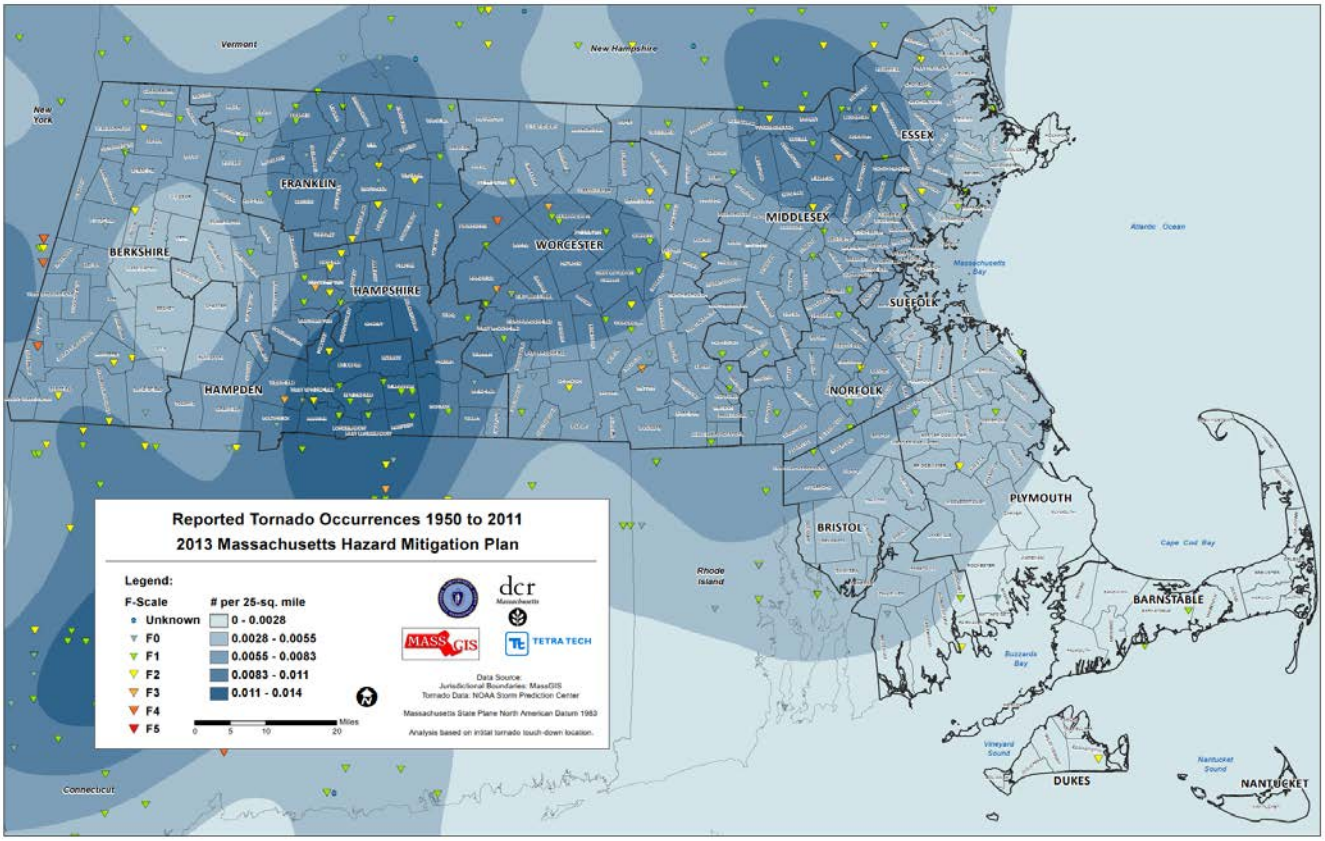

Figure 14-17. Reported Tornado Occurrences from 1950 to 2011

14.5.3 Critical Facilities

High Winds and Thunderstorms

All critical facilities are exposed to severe weather events such as high winds and thunderstorms. The most common problem associated with severe weather is loss of utilities. Downed power lines can cause blackouts, leaving large areas isolated. Phone, water, and sewer systems may not function. Roads may become impassable due to flash or urban flooding. As discussed earlier, there are four wind load zones in the Commonwealth. Table 14-14 summarizes the number of critical facilities within each wind load zone.

Tornadoes

All critical facilities and infrastructure are exposed to tornado events. Similar to the analysis conducted for state facilities, the number of critical facilities and bridges located within the greatest historical tornado touch-down area (density of 0.011 – 0.014), or area of highest probability of occurrence, are listed in Table 14-15. There are a total of 300 bridges in the 0.011-0.014 density zone.

TABLE 14-14.
NUMBER OF CRITICAL FACILITIES LOCATED IN EACH WIND LOAD ZONE

Wind Zone	Police	Fire	Emergency Operation Centers	Hospitals	Schools (pre-K-grade 12)	Colleges
< 90 mph	46	59	0	5	99	7
90 mph	137	240	1	22	830	46
100 mph	200	384	1	47	1,529	137
110 mph	54	106	0	8	309	15

Source: MassGIS, 2012

TABLE 14-15.
NUMBER OF CRITICAL FACILITIES IN THE TORNADO PROBABILITY ZONES

Density	Police	Fire	Emergency Operation Centers	Hospitals	Schools (pre-K-grade 12)	Colleges
0.011 to 0.014	20	41	1	5	215	16
< 0.011	417	748	1	77	2,552	189

Source: MassGIS, 2012

Extreme Temperatures

All critical facilities are exposed to the extreme temperature hazard. Extreme heat generally does not impact buildings. Losses may be associated with the overheating of HVAC systems. Extreme cold temperature events can damage buildings through freezing/bursting pipes and freeze/thaw cycles. Additionally, manufactured homes (mobile homes) and antiquated or poorly constructed facilities may have inadequate capabilities to withstand extreme temperatures.

Drought

No critical facilities are anticipated to be directly affected by a drought, and all are expected to be operational during a drought event. However, droughts contribute to conditions conducive to wildfires. All critical facilities in and adjacent to the wildland-urban interface are considered vulnerable to wildfire. See Section 9 regarding the wildland fire hazard in the Commonwealth.

14.5.4 Economy

High Winds, Thunderstorms and Tornadoes

Wind storms, thunderstorms, and tornado events may impact the economy, including loss of business function, water supply system damage, damage to inventory, relocation costs, wage loss, and rental loss due to the repair/replacement of buildings. Recovery and clean-up costs can also be costly and impact the economy as well. Tornado events are typically localized, whereas high wind and thunderstorm events can be more widespread. The impacts of high winds, thunderstorms, and tornadoes on the environment may include severe damage to plant species. This includes uprooting or total destruction of trees and increased threat of wildfire in areas of tree debris. Public drinking water reservoirs may also be damaged by widespread wind damage uprooting watershed forests and creating serious water quality disturbances.

Extreme Temperatures and Drought

Extreme temperature events also have impacts on the economy, including loss of business function and damage/loss of inventory. Business-owners may be faced with increased financial burdens due to unexpected repairs caused to the building (e.g., pipes bursting), higher than normal utility bills or business interruption due to power failure (i.e., loss of electricity, telecommunications).

The agricultural industry is most at risk in terms of economic impact and damage due to extreme temperature and drought events. Extreme heat can result in drought and dry conditions and directly impact livestock and crop production.

In 2007, there were 7,691 farms in the Commonwealth, with a total land area of 517,879 acres. The average size of a farm was 67 acres. According to the 2007 Census of Agriculture, approximately 3,688 farm operators reported farming as their primary occupation. Refer to Section 4 for additional information regarding the agricultural industry per County.

14.6 VULNERABILITY

14.6.1 Population

In general, vulnerable populations include the elderly, low income or linguistically isolated populations, people with life-threatening illnesses, and residents living in areas that are isolated from major roads. Power outages can be life threatening to those dependent on electricity for life support. Isolation of these populations is a significant concern. These populations face isolation and exposure during severe weather events and could suffer more secondary effects of the hazard.

High Winds and Thunderstorms

The entire population of the Commonwealth is considered exposed to high wind and thunderstorm events. Downed trees, damaged buildings, and debris carried by high winds can lead to injury or loss of life. Socially vulnerable populations are most susceptible, based on a number of factors including their physical and financial ability to react or respond during a hazard and the location and construction quality of their housing.

Lightning strikes primarily occur during the summer months. According to NOAA, there has been one fatality and 43 injuries as a result of lightning events from 1993 and 2012 in the Commonwealth (NCDC, 2012). Populations located outdoors are considered at risk and more vulnerable to a lightning strike compared to being inside a shelter. Moving to a lower risk location will decrease a person's vulnerability.

Tornadoes

The impact of tornado or high wind events on life, health, and safety depends on factors including the severity of the event and whether adequate warning time was provided. Unfortunately some tornadoes strike with little or no warning and residents must act quickly. The following populations are more vulnerable to a tornado or other type of wind or severe storm event: 1) population located in communities without or have ineffective early warning systems; 2) population with functional needs and/or over the age of 65 because they may have more difficulty evacuating or seeking shelter; 3) economically disadvantaged populations because they are likely to evaluate their risk and make decisions based on the major economic impact to their family and may not have funds to evacuate; 4) population with a language barrier unable to following warning messages; 5) population in mobile homes; and 5) population in automobiles at the time of a tornado. The elderly and functional needs populations are considered most vulnerable because they require extra time or outside assistance to seek shelter and are more likely to seek or need medical attention which may not be available due to isolation during and/or after an event.

Extreme Temperatures

According to the Centers for Disease Control and Prevention, populations most at risk to extreme cold and heat events include the following: 1) the elderly, who are less able to withstand temperatures extremes due to their age, health conditions, and limited mobility to access shelters; 2) infants and children up to four years of age; 3) individuals who are physically ill (e.g., heart disease or high blood pressure), 4) low-income persons who cannot afford proper heating and cooling; and 5) the general public who may overexert during work or exercise during extreme heat events or experience hypothermia during extreme cold events.

Meteorologists can accurately forecast extreme heat event development and the severity of the associated conditions with several days lead time. These forecasts provide an opportunity for public health and other officials to notify vulnerable populations, implement short-term emergency response actions, and focus on surveillance and relief efforts on those at greatest risk. Adhering to extreme temperature warnings can significantly reduce the risk of temperature-related deaths.

Drought

Drought conditions can cause a shortage of water for human consumption and reduce local firefighting capabilities. Populations which rely upon groundwater sources and surface water intakes for drinking water are more vulnerable to the drought hazard. Social impacts of a drought include mental and physical stress, public safety (increased threat from forest/grass fires), health, conflicts between water users, reduced quality of life, and inequities in the distribution of impacts and disaster relief. Impacts on the economy and environment may have social implications as well.

14.6.2 State Facilities

High Winds

Using ArcMap, GIS software, the wind load zones discussed earlier were overlaid with the DCAMM facilities; the appropriate wind load zone determination was assigned to each facility. Table 14-16 summarizes the replacement cost values (structure only) of the state-owned and leased facilities within each wind load zone.

TABLE 14-16.
ESTIMATED REPLACEMENT COST VALUE OF STATE-OWNED AND LEASED FACILITIES IN WIND LOAD ZONES (STRUCTURE ONLY)

	Replacement Cost Value of State Facilities, by Wind Zone				
County	< 90 mph	90 mph	100 mph	110 mph	Total
Barnstable					**$573,157,181**
Lease	—	—	—	$8,590,637	
Own	—	—	—	$564,566,544	
Berkshire					**$926,000,416**
Lease	$20,719,316		—	—	
Own	$898,331,435	$6,949,665	—	—	
Bristol					**$1,506,105,175**
Lease	—	—	$22,946,411	$51,885,878	
Own	—	—	$485,514,336	$945,758,550	
Dukes					**$8,112,024**
Lease	—	—	$3,129,480	—	
Own	—	—	$4,982,544	—	
Essex					**$2,236,600,714**
Lease	—	$22,058,887	$46,374,475	—	
Own	—	$116,974,057	$2,051,193,295	—	

TABLE 14-16.
ESTIMATED REPLACEMENT COST VALUE OF STATE-OWNED AND LEASED FACILITIES IN WIND LOAD ZONES (STRUCTURE ONLY)

	Replacement Cost Value of State Facilities, by Wind Zone				
County	< 90 mph	90 mph	100 mph	110 mph	Total
Franklin					**$406,618,464**
Lease	$9,844,613	$2,236,564	—	—	
Own	$248,444,666	$146,092,622	—	—	
Hampden					**$2,525,825,124**
Lease	—	$77,791,722	—	—	
Own	—	$2,448,033,402	—	—	
Hampshire					**$2,343,693,926**
Lease	—	$16,521,098	—	—	
Own	$67,597	$2,327,105,231	—	—	
Middlesex					**$4,940,998,327**
Lease	—	$30,099,561	$132,885,318	—	
Own	—	$1,947,910,576	$2,830,102,873	—	
Nantucket					**$15,690,622**
Lease	—	—	—	$470,593	
Own	—	—	—	$15,220,029	
Norfolk					**$2,570,915,628**
Lease	—	—	$73,911,176	—	
Own	—	—	$2,497,004,452	—	
Plymouth					**$1,591,202,077**
Lease	—	—	$25,132,602	$21,359,191	
Own	—	—	$1,190,279,233	$354,431,050	
Suffolk					**$4,141,536,865**
Lease	—	—	$243,913,967	—	
Own	—	—	$3,897,622,898	—	
Worcester					**$4,722,349,497**
Lease		$103,759,546	$5,157,862	—	
Own		$3,988,649,389	$624,782,701	—	
Total					**$28,508,806,041**
Lease	$30,563,929	$252,467,378	$553,451,291	$82,306,299	
Own	$1,146,843,697	$10,981,714,942	$13,581,482,332	$1,879,976,172	

Source: DCAMM, 2012

Thunderstorms

According to NOAA's Technical Paper on Lightning Fatalities, Injuries, and Damage Reports in the United States from 1959 - 1994, monetary losses for lightning events range from less than $50 to greater than $5 Million (the larger losses are associated with forest fires, with homes destroyed, and crop loss) (NOAA, 1997). Lightning can be responsible for damage to buildings; can cause electrical, forest and/or wildfires; and can damage infrastructure such as power transmission lines and communication towers. The total replacement cost value of all state-owned and leased facilities in the Commonwealth is $57 Billion (structure and contents).

Tornadoes

To estimate the potential losses to state-owned and leased structures, the exposure analysis methodology was used. As discussed, there are 6,765 state-owned/leased structures in the Commonwealth. Table 14-17

identifies the replacement cost value of the state-owned and leased buildings located in the defined tornado high hazard area. This figure assumes 100-percent loss to each structure and its contents.

TABLE 14-17.
STATE-OWNED AND LEASED BUILDINGS IN HISTORICAL TORNADO DENSITY ZONES

Density	Own	Lease	Total
High (0.011 to 0.014)	$4,351,752,095	$141,141,012	$4,492,893,107
Low (< 0.011)	$50,828,282,192	$1,696,436,782	$52,524,718,974

Source: DCAMM, 2012

Extreme Temperatures and Drought

Extreme heat and drought events generally do not impact buildings. Losses may be associated with the overheating of HVAC systems. Extreme cold temperature events can damage buildings through freezing/bursting pipes and freeze/thaw cycles. Additionally, manufactured homes (mobile homes) and antiquated or poorly constructed facilities may have inadequate capabilities to withstand extreme temperatures. Additionally, it is essential that certain state facilities remain operational during natural hazard events. Extreme heat events can sometimes cause short periods of utility failure commonly referred to as brown-outs, due to increased usage from air conditioners, appliances, etc. Similarly, heavy snowfall and ice storms, associated with extreme cold temperature events, can cause power interruption as well. Backup power is recommended for critical facilities and infrastructure.

14.6.3 Critical Facilities

The replacement cost values for critical facilities were not available for this planning effort. A total risk exposure would equal to the full replacement value of each critical facility exposed.

Incapacity and loss of roads are the primary transportation failures resulting from severe weather, mostly associated with secondary hazards such as landslide events. Landslides caused by heavy prolonged rains can block roads. High winds can cause significant damage to trees and power lines, blocking roads with debris, incapacitating transportation, isolating population, and disrupting ingress and egress. Of particular concern are roads providing access to isolated areas and to the elderly.

Prolonged obstruction of major routes due to secondary hazards such as landslides, debris, or floodwaters can disrupt the shipment of goods and other commerce. Large, prolonged storms can have negative economic impacts for an entire region.

Severe windstorms causing downed trees can create serious impacts on power and above-ground communication lines. Freezing of power and communication lines can cause them to break, disrupting electricity and communication. Loss of electricity and phone connection would leave certain populations isolated because residents would be unable to call for assistance.

14.6.4 Economy

High Winds, Thunderstorms and Tornadoes

Economic losses include direct building losses, or the estimated costs to repair or replace the damage caused to the building. Agricultural losses can be devastating due to lightning and resulting fires.

Because of differences in building construction, residential structures are generally more susceptible to wind damage than commercial and industrial structures. Wood and masonry buildings in general, regardless of their occupancy class, tend to experience more damage than concrete or steel buildings. High-rise buildings are also very vulnerable structures. Mobile homes are the most vulnerable to damage, even if tied down, and offer little protection to people inside. Table 14-18 summarizes the replacement cost value of the residential general building stock (structure only) for the Commonwealth by County. The total structural replacement cost value for residential buildings in the Commonwealth is greater than $426 Billion or approximately 70-percent of all occupancy classes. Refer to Section 11 (Hurricanes/Tropical Storms), which includes estimated potential losses to the Commonwealth's general building stock due to high wind speeds associated with historical tropical storm and hurricane events.

TABLE 14-18.
RESIDENTIAL GENERAL BUILDING STOCK REPLACEMENT COST VALUE FOR THE COMMONWEALTH

County	Total (All Occupancies) Replacement Cost Value	Residential Replacement Cost Value	% of Total
Barnstable	$29,472,545,000	$23,858,042,000	81.0
Berkshire	$12,320,794,000	$9,021,345,000	73.2
Bristol	$44,744,005,000	$32,571,342,000	72.8
Dukes	$3,037,454,000	$2,458,850,000	81.0
Essex	$61,243,002,000	$44,561,352,000	72.8
Franklin	$6,049,044,000	$4,371,893,000	72.3
Hampden	$39,337,031,000	$26,881,407,000	68.3
Hampshire	$12,609,441,000	$9,444,897,000	74.9
Middlesex	$143,825,613,000	$102,752,128,000	71.4
Nantucket	$2,225,512,000	$1,731,180,000	77.8
Norfolk	$66,668,319,000	$48,205,584,000	72.3
Plymouth	$42,892,528,000	$32,612,565,000	76.0
Suffolk	$65,816,336,000	$40,215,170,000	61.1
Worcester	$66,832,305,000	$47,390,524,000	70.9
Total	**$597,073,929,000**	**$426,076,279,000**	**71.4**

Source: Hazus-MH v. 2.1

Extreme Temperatures and Drought

Extreme temperature events also have impacts on the economy, including loss of business function and damage/loss of inventory. Business-owners may be faced with increased financial burdens due to unexpected repairs caused to the building (e.g., pipes bursting), higher than normal utility bills or business interruption due to power failure (i.e., loss of electricity, telecommunications). Increased demand for water and electricity may result in shortages and a higher cost for these resources. Industries that rely on water for business may be impacted the hardest (e.g., landscaping businesses). Even though most businesses will still be operational, they may be impacted aesthetically. These aesthetic impacts are most significant to the recreation and tourism industry.

The agricultural industry is most at risk in terms of economic impact and damage due to extreme temperature and drought events. Extreme heat events can result in drought and dry conditions and directly impact livestock and crop production.

In 2007, there were 7,691 farms in the Commonwealth, with a total land area of 517,879 acres. The average size of a farm was 67 acres. According to the 2007 Census of Agriculture, approximately 3,688 farm operators reported farming as their primary occupation. The market value of agricultural products sold from all farms in the Commonwealth total over $489.8 million, with total sales averaging $63,687. Crop sales, including nursery and greenhouse, accounted for over $364.4 million (74.4%) of total sales and livestock, poultry and their products accounted for over $125.3 million (25.5%) of total sales. The lead agricultural products sold were nursery, greenhouse, floriculture and sod ($169.1 million); fruits, tree nuts, and berries ($100.6 million); and vegetables, melons, potatoes, and sweet potatoes ($15.7 million) (U.S. Department of Agriculture National Agricultural Statistics Service, 2007).

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