Section 10. Flood Hazards 10-1
10.1 General Background 10-1
10.1.1 Common Types of Floods 10-1
10.1.2 Measuring Floods 10-4
10.1.3 Floodplains 10-5
10.2 Hazard Profile 10-7
10.2.1 Location 10-7
10.2.2 Previous Occurrences 10-9
10.2.3 Probability of Future Occurrences 10-18
10.2.4 Severity 10-18
10.2.5 Warning Time 10-18
10.3 Secondary Hazards 10-18
10.4 Climate Change Impacts 10-19
10.5 Exposure 10-20
10.5.1 Population 10-23
10.5.2 State Facilities 10-23
10.5.3 Critical Facilities 10-32
10.5.4 Economy 10-36
10.6 Vulnerability 10-37
10.6.1 Population 10-37
10.6.2 State Facilities 10-38
10.6.3 Critical Facilities 10-38
10.6.4 Severe Repetitive Loss Data 10-38
10.6.5 Economy 10-41

TABLES

Table 10-1. FEMA Flood-Related Disaster Declarations (1954 to 2012) 10-10
Table 10-2. Number of Ice Events by County 10-17
Table 10-3. Data Used for Risk Assessment 10-21
Table 10-4. Estimated Population Exposed to the 1-Percent and 0.2-Percent Annual Chance Flood Events 10-23
Table 10-5. 2012 State Building Exposure to Flood Hazard by County (Building Count) 10-24
Table 10-6. 2012 State Building Exposure to Flood Hazard by County (Replacement Cost Value) 10-25
Table 10-7. 2012 State Building Exposure to Flood Hazards by Agency (Building Count) 10-26

Table 10-8. 2012 State Building Exposure to Flood Hazards by Agency (Replacement Cost Value) ..10-27
Table 10-9. State Building Exposure to Flood Hazard, 2009 to 2012 (Building Count) 10-29
Table 10-10. State Building Exposure to Flood Hazard, 2009 to 2012 (Replacement Cost Value) 10-30
Table 10-11. 2012 Estimated General Building Stock Exposure to the 1-Percent Annual Chance Flood Event 10-31
Table 10-12. 2012 Estimated General Building Stock Exposure to the 0.2-Percent Annual Chance Flood Event 10-31
Table 10-13. Summary of Critical Facility Exposure by Flood Hazard Area.....10-32
Table 10-14. POlice Stations Exposed to the Flood Hazard by County 10-32
Table 10-15. Fire Stations Exposed to the Flood Hazard by County.....10-33
Table 10-16. Emergency Operation Centers Exposed to the Flood Hazard by County.....10-33
Table 10-17. Hospitals Exposed to the Flood Hazard by County.....10-34
Table 10-18. Schools Exposed to the Flood Hazard by County 10-34
Table 10-19. Colleges Exposed to the Flood Hazard by County.....10-35
Table 10-20. Number of Bridges in the Flood Hazard Areas by County.....10-35
Table 10-21. 2012 Area Located in the Flood Hazard Boundaries.....10-37
Table 10-22. NFIP Policies, Claims, and Repetitive Loss Statistics.....10-39
Table 10-23. NFIP Repetitive Loss and Severe Repetitive Loss Data.....10-41

Figures

Figure 10-1. Typical Transect Schematic. 10-3
Figure 10-2. Special Flood Hazard Area 10-5
Figure 10-3. Watersheds of Massachusetts.....10-8
Figure 10-4. Ice Jam Events in Massachusetts (1934—2012).....10-9
Figure 10-5. Number of FEMA Flood Declared Disasters by County 10-11
Figure 10-6. FEMA Flood Map Status for the Commonwealth of Massachusetts.....10-22
Figure 10-7. FEMA Flood Hazard Areas in the Commonwealth of Massachusetts.....10-22
Figure 10-8. Risk Level of State Facilities in the FEMA Flood Hazard Areas 10-29
Figure 10-9. NFIP Repetitive Loss Areas.....10-40
Figure 10-10. NFIP Severe Repetitive Loss Areas.....10-40

SECTION 10. FLOOD HAZARDS

10.1 GENERAL BACKGROUND

Floods are among the most frequent and costly natural disasters in terms of human hardship and economic loss—75 percent of federal disaster declarations are related to flooding. Property damage from flooding totals over $5 billion in the United States each year. Flooding often coincides with spring snowmelt and can be a direct result of other frequent weather events, which in Massachusetts include nor'easters, heavy rainstorms, tropical storms, and hurricanes.

For the 2013 update, this hazard profile was significantly enhanced to incorporate updated, best available data. This was done to provide additional information that can be used by state agencies in developing mitigation strategies and by local jurisdictions as they develop mitigation plans and risk assessments. A recap of each declared event has been provided, which includes information concerning severity based on stream gage data as appropriate for the event, when available. The profile also includes a comparison between historical data and current data to demonstrate the changes that have occurred within the State, such as in the case of Repetitive Flood Claims and Severe Repetitive Losses.

10.1.1 Common Types of Floods

The flood-related hazards most likely to affect Massachusetts are riverine (inland) flooding, coastal flooding, and flooding associated with ice jams. Each is described below, along with the sub-categories associated with each hazard type.

Riverine (Inland) Flooding

Riverine or inland flooding often occurs after heavy rain. Areas of the state with high slopes and minimal soil cover (such as found in western Massachusetts) are particularly susceptible to flash flooding caused by rapid runoff that occurs in heavy precipitation events, and in combination with spring snowmelt. Frozen ground conditions can also contribute to low rainfall infiltration and high runoff events that may result in river flooding. Some of the worst riverine flooding in Massachusetts occurred without snowmelt and as a result of strong nor'easter storms and tropical storms. Tropical storms can produce very high rainfall rates and volumes of rain that can generate high runoff when soil infiltration rates are exceeded. Inland flooding in Massachusetts is forecast and classified by the National Weather Service's Northeast River Forecast Center as minor, moderate, or severe based upon the types of impacts that occur. Minor flooding is considered a "nuisance only" degree of flooding that causes impacts such as road closures and flooding of recreational areas and farmland. Moderate flooding can involve land with structures becoming inundated. Major flooding is a widespread, life-threatening event. River forecasts are made at many locations in the state containing USGS river gages, with established flood elevations and levels corresponding to each of the degrees of flooding.

Urban Drainage Flooding

Urban drainage flooding entails floods caused by increased water runoff due to urban development and drainage systems. Drainage systems are designed to remove surface water from developed areas as quickly as possible to prevent localized flooding on streets and other urban areas. They make use of a closed conveyance system that channels water away from an urban area to surrounding streams, bypassing natural processes of water infiltration into the ground, groundwater storage, and evapotranspiration (plant water uptake and respiration). Since drainage systems reduce the amount of time the surface water takes to reach surrounding streams, flooding can occur more quickly and reach greater depths than if there were no urban development at all (Wright, 2008).

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

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

Coastal Flooding

Coastal flooding generally occurs along the coasts of oceans, bays, estuaries, coastal rivers and large lakes. Coastal floods are the submersion of land areas along the ocean coast and other inland waters caused by seawater over and above normal tide action. Coastal flooding is a result of the storm surge where local sea levels rise often resulting in weakening or destruction of coastal structures. Hurricanes and severe storms, including nor'easters, cause most coastal flooding. Nor'easters are severe storms that occur in the Atlantic basin that are extra-tropical in nature with winds out of the northeast (FEMA, Date Unknown). Coastal flooding not only results in the many problems identified for riverine flooding but could also include additional problems such as beach erosion, loss or submergence of wetlands and other coastal ecosystems, saltwater intrusion, high water tables, loss of coastal recreation areas, beaches, protective sand dunes, parks and open space, and loss of coastal structures (sea walls, piers, bulkheads, bridges, or buildings).

According to the 2011 Coastal Construction Manual, FEMA P-55, Zone V identifies the Coastal High Hazard Area, which is the portion of the special flood hazard area (SFHA) that extends from offshore to the inland limit of a primary frontal dune along an open coast and any other portion of the SFHA that is subject to high-velocity wave action from storms or seismic sources. The boundary of Zone V is generally based on wave heights (3 feet or greater) or wave run-up depths (3 feet or greater). Zone V can also be mapped based on the wave overtopping rate (when waves run up and over a dune or barrier). Zone A or AE, identify portions of the SFHA that are not within the Coastal High Hazard Area. These zones are used to designate both coastal and non-coastal SFHAs. Regulatory requirements of the National Flood Insurance Program (NFIP) for buildings located in Zone A are the same for both coastal and riverine flooding hazards. Zone AE in coastal areas is divided by the limit of moderate wave action (LiMWA). The LiMWA represents the landward limit of the 1.5-foot wave.

The area between the LiMWA and the Zone V limit is known as the Coastal A Zone for building codes and standard purposes and as the Moderate Wave Action area by FEMA flood mappers. This area is subject to wave heights between 1.5 and 3 feet during the base flood. The area between the LiMWA and the landward limit of Zone A due to coastal flooding is known as the Minimal Wave Action area, and is subject to wave heights less than 1.5 feet during the base flood (FEMA P-55, 2011). Figure 10-1 is a typical transect illustrating Zone V, the Coastal A Zone and Zone A, and the effects of energy dissipation and regeneration of a wave as it moves inland. Wave elevations are decreased by obstructions such as vegetation and rising ground elevation.

Source: FEMA P-55, 2011

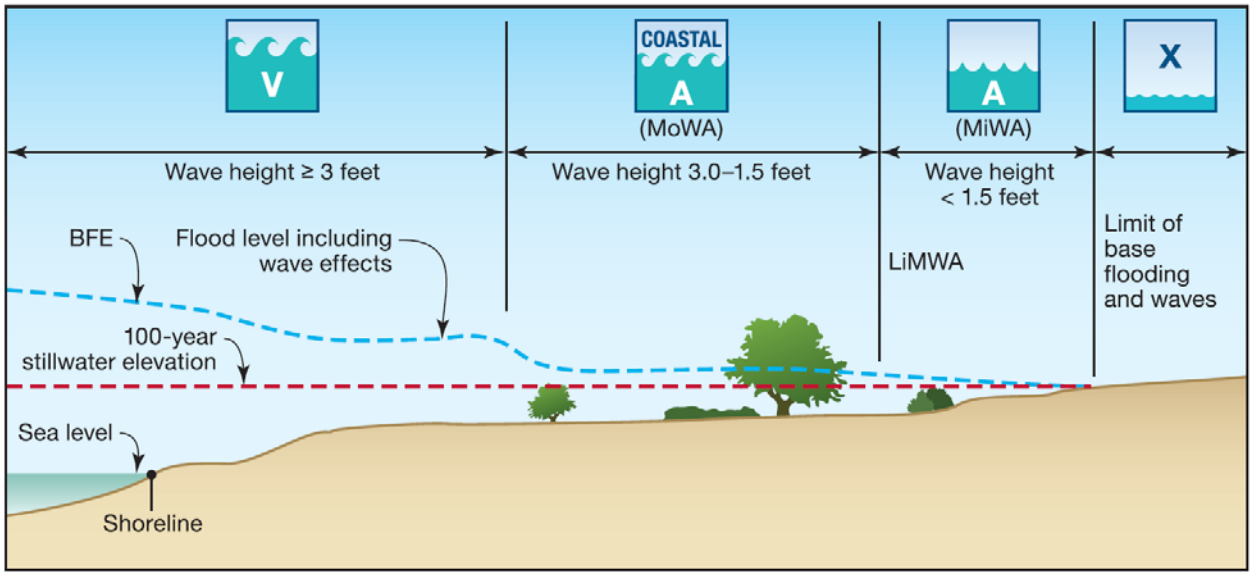

Figure 10-1. Typical Transect Schematic.

Ground Failures

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

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

Ice Jam

An ice jam is an accumulation of ice that acts as a natural dam and restricts flow of a body of water. There are two types of ice jams: a freeze up and a breakup jam. A freeze up jam usually occurs early to mid-winter during extremely cold weather when super-cooled water and ice formations extend to nearly

the entire depth of the river channel. This type of jam can act as a dam and begin to back up the flowing water behind it. The second type, a break up jam forms as a result of the breakup of ice cover at ice-out, causing large pieces of ice to move downstream potentially piling up at culverts, around bridge abutments, and at curves in river channels. Breakup ice jams occur when warm temperatures and heavy rains cause rapid snowmelt. The melting snow, combined with the heavy rain, causes frozen rivers to swell. The rising water breaks the ice layers into large chunks, which float downstream and often pile up near narrow passages and obstructions (bridges and dams). Ice jams may build up to a thickness great enough to raise the water level and cause flooding upstream of the obstruction The Ice Jam Database, maintained by the Ice Engineering Group at the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL), currently consists of over 18,000 records from across the U.S.

10.1.2 Measuring Floods

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

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

The 100-Year Flood

The term “100-year flood” is misleading. It is not the flood that will occur once every 100 years. Rather, it is the flood that has a one percent chance of being equaled or exceeded each year. Thus, the 100-year flood could occur more than once in a relatively short period of time. The 100-year flood, which is the standard used by most federal and state agencies, is used by the NFIP as the standard for floodplain management and to determine the need for flood insurance. A structure located within an SFHA shown on an NFIP map on average has a 26 percent chance of suffering flood damage during the term of a 30-year mortgage.

The extent of flooding associated with a 1-percent annual probability of occurrence (the base flood or 100-year flood) is used as the regulatory boundary by many agencies. Also referred to as the SFHA, this boundary is a convenient tool for assessing vulnerability and risk in flood-prone communities. Many communities have maps that show the extent and likely depth of flooding for the base flood. Corresponding water-surface elevations describe the elevation of water that will result from a given discharge level, which is one of the most important factors used in estimating flood damage.

The 500-Year Flood

The term “500-year flood” is the flood that has a 0.2-percent chance of being equaled or exceeded each year. The 500-year flood could occur more than once in a relatively short period of time. Statistically, the 0.2-percent (500-year) flood has a 6-percent chance of occurring during a 30-year period of time, the length of many mortgages.

For insurance purposes on FIRMS, areas outside the SFHA are identified as Zones X, B, or C. Zone B and shaded Zone X are areas within the 500-year floodplain. Zone C and unshaded Zone X are areas outside the 500-year floodplain. Areas protected by accredited levee systems are mapped as shaded Zone

X (FEMA P-55, 2011). Flood elevations or depths are not shown within this zone and insurance purchase is not required in this zone.

10.1.3 Floodplains

A floodplain is the area adjacent to a river, creek, or lake that becomes inundated during a flood. Floodplains may be broad, as when a river crosses an extensive flat landscape, or narrow, as when a river is confined in a canyon. In general, flooding can be defined as a rising and overflowing of a body of water onto normally dry land.

By their very nature, floodplains are the low, flat, periodically flooded lands adjacent to rivers, lakes, and oceans and subject to geomorphic (land-shaping) and hydrologic (water flow) processes. It is only during and after major flood events that the connections between a river and its floodplain become more apparent. These areas form a complex physical and biological system that not only supports a variety of natural resources, but also provides natural flood storage and erosion control. When a river is separated from its floodplain with levees and other flood control facilities, then natural, built-in benefits are lost, altered, or significantly reduced. Figure 10-2 depicts the flood hazard area, the flood fringe, and the floodway areas of a floodplain.

Source: North Carolina Department of Crime and Public Safety Floodplain Management Branch, 2008

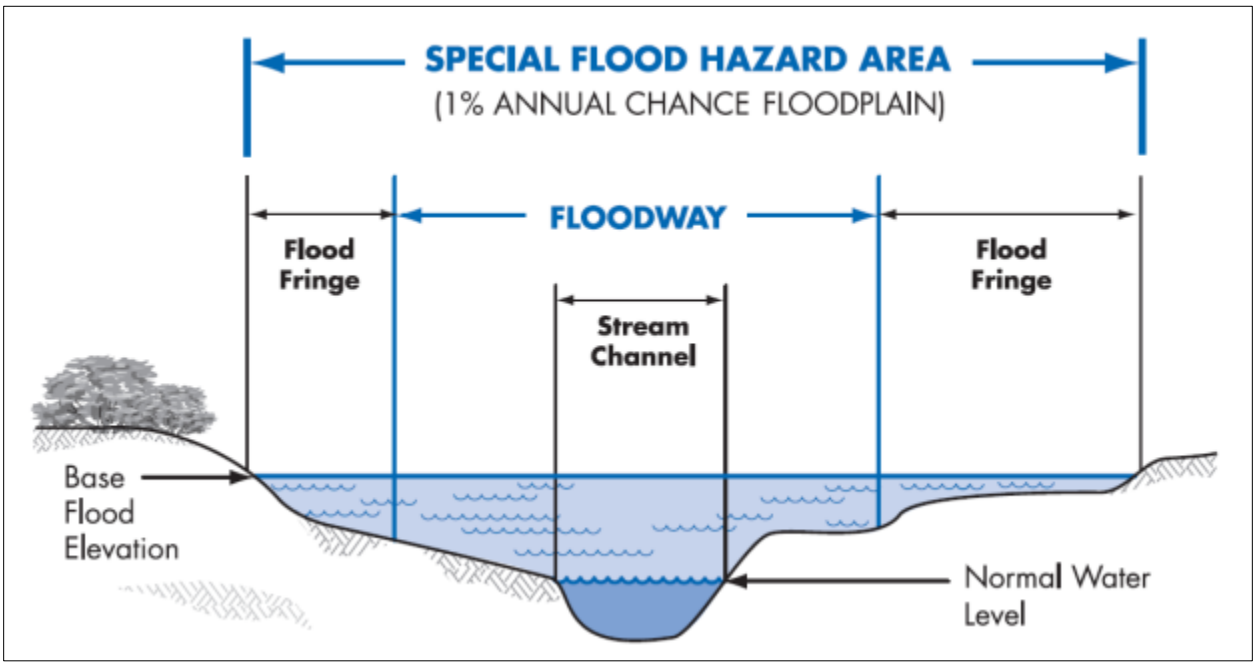

Figure 10-2. Special Flood Hazard Area

When floodwaters recede after a flood event, they leave behind layers of rock and mud. These gradually build up to create a new floor of the floodplain. Floodplains generally contain unconsolidated sediments known as alluvium (accumulations of sand, gravel, loam, silt, and/or clay), often extending below the bed of the stream. These sediments provide a natural filtering system, with water percolating back into the ground and replenishing groundwater. These are often important aquifers, the water drawn from them being filtered compared to the water in the stream.

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

- Zones A1-30 and AE: SFHAs that are subject to inundation by the base flood, determined using detailed hydraulic analysis. Base Flood Elevations are shown within these zones.
- Zone A (Also known as Unnumbered A Zones): SFHAs where, because detailed hydraulic analyses have not been performed, no Base Flood Elevations or depths are shown.
- Limit of Moderate Wave Action: Zone AE in coastal areas is divided by the LiMWA. The LiMWA represents the landward limit of the 1.5-foot wave. The area between the LiMWA and the Zone V limit is known as the Coastal A Zone for building code and standard purposes and as the Moderate Wave Action area by FEMA flood mappers. This area is subject to wave heights between 1.5 and 3 feet during the base flood. The area between the LiMWA and the landward limit of Zone A due to coastal flooding is known as the Minimal Wave Action area, and is subject to wave heights less than 1.5 feet during the base flood.
- Zone AO: SFHAs that are subject to inundation by types of shallow flooding where average depths are between 1 and 3 feet. These are normally areas prone to shallow sheet flow flooding on sloping terrain.
- Zone VE, V1-30: also referred to as Coastal High Hazard Areas, are identified as the entire extent of the primary frontal dunes (dunes closest to the beach) and the areas with projected 3-foot or greater wave heights, and/or projected 3-foot or greater wave run-up depths (the rush of the breaking waves) during a 1% chance storm, and/or the wave overtopping splash zone (area extending 30 feet landward of a seawall overtopped by waves).
- Zone B and X (shaded): Zones where the land elevation as been determined to be above the Base Flood Elevation, but below the 500 year flood elevation. These zones are not SFHAs.
- Zones C and X (unshaded): Zones where the land elevation has been determined to be above both the Base Flood Elevation and the 500-year flood elevation. These zones are not SFHAs.

Floodplain Ecosystems

Floodplains can support ecosystems that are rich in plant and animal species. A floodplain can contain 100 or even 1,000 times as many species as a river. Wetting of the floodplain soil releases an immediate surge of nutrients: those left over from the last flood, and those that result from the rapid decomposition of organic matter that has accumulated since then. Microscopic organisms thrive and larger species enter a rapid breeding cycle. Opportunistic feeders (particularly birds) move in to take advantage. The production of nutrients peaks and falls away quickly, but the surge of new growth endures for some time. This makes floodplains valuable for agriculture. Species growing in floodplains are markedly different from those that grow outside floodplains. For instance, riparian trees (trees that grow in floodplains) tend to be very tolerant of root disturbance and very quick-growing compared to non-riparian trees.

Effects of Human Activities

Because they border water bodies, floodplains have historically been popular sites to establish settlements due to the sustenance they provide. Human activities tend to concentrate in floodplains for a number of reasons: water is readily available, land is fertile and suitable for farming, transportation by water is easily accessible, and land is flatter and easier to develop. In addition, during the Industrial Revolution, factories and cities were constructed along river corridors to take advantage of power that was generated by flowing water. This development pattern is particularly evident in Massachusetts, and many dams and canals constructed for industrial purposes remain in the landscape. As a result, Massachusetts' flood plains tend to be relatively heavily developed and highly populated. Human activity in floodplains frequently interferes with the natural function of floodplains. It can affect the distribution and timing of drainage, thereby increasing flood problems. Human development can create local flooding problems by altering or confining drainage channels. This increases flood potential in two ways: it reduces the stream's capacity to contain flows and it increases flow rates or velocities downstream during all stages of a flood

event. Human activities can interface effectively with a floodplain as long as steps are taken to mitigate the activities' adverse impacts on floodplain functions.

10.2 HAZARD PROFILE

10.2.1 Location

Flooding in Massachusetts is often the direct result of frequent weather events such as coastal storms, nor'easters, heavy rains, tropical storms, and hurricanes.

Riverine Flooding

Riverine, or inland flooding, affects the majority of communities in the Commonwealth. Massachusetts encompasses 28 watershed areas; (including the Atlantic Ocean); the largest watershed completely contained within the state is the Chicopee River Watershed, which covers more than 720 square miles. The Chicopee river basin contains the Massachusetts Water Resources Authority's Quabbin Reservoir, which is the largest public water supply reservoir in the Commonwealth, and serves approximately one-third of the state's entire population within the metropolitan Boston area. Also of note are two watersheds that contain regionally significant rivers: the Connecticut River, which flows south from the New Hampshire/Vermont state line, and flows through the state of Connecticut from Massachusetts. In Massachusetts, the Deerfield, Millers, Chicopee, and Westfield watersheds are all tributaries to the Connecticut River. These high-relief areas encompass much of central Massachusetts and have experienced less development as a result of steeper slopes. The Merrimack River flows south from the White Mountains of New Hampshire and into northeast Massachusetts before discharging to the Atlantic Ocean. Tributaries to the Merrimack River in Massachusetts include the Nashua and Shawsheen watersheds. In addition to the Merrimack, the Blackstone River in south central Massachusetts was highly industrialized and has a large number of dams. The Blackstone River flows into Rhode Island and ultimately discharges to Narragansett Bay. The watersheds of eastern Massachusetts tend to have lower elevations and relief, less winter snowpack development, and are less prone to riverine flooding. In particular, the south coastal, Cape Cod and Islands basins have very little vertical relief, are composed of thick sand deposits with high infiltration rates, and have less flashy and flood-prone rivers. Coastal flooding is generally more of a problem in these areas. Figure 10-3 displays the watersheds of the Commonwealth.

(http://www.mass.gov/eea/air-water-climate-change/preserving-water-resources/mass-watersheds/view-watersheds-by-region.html)

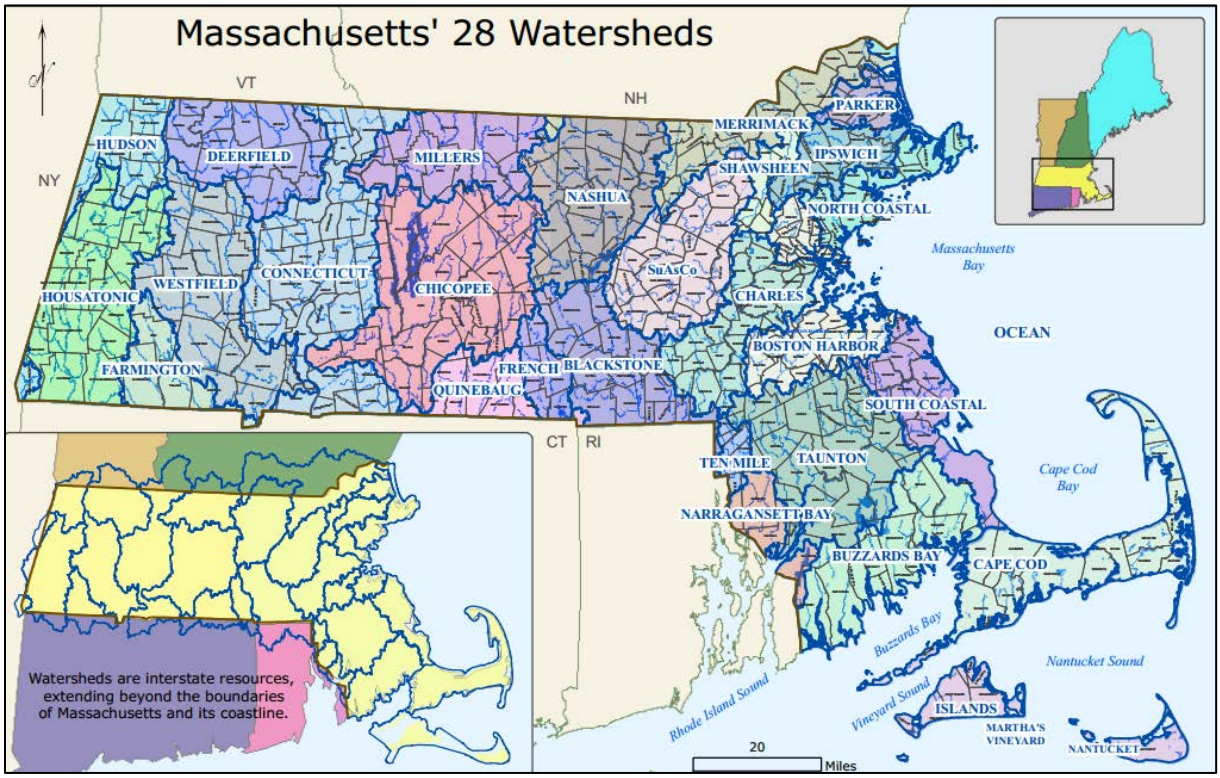

Figure 10-3. Watersheds of Massachusetts

Urban Flooding

Urban flooding resulting from stormwater runoff can occur in every community, and unfortunately, since many of the urban areas have aging infrastructure, poor or insufficient storm water drainage is a common occurrence subsequent to rain events. This problem is exacerbated by increasing development, which results in a loss of pervious surfaces (www.noaa.gov, 2006).

Ice Jams

Ice jams can occur across the entire northern United States on rivers and lakes of all sizes. Historically, Farmington River-West Branch, Marsh Brook, Millers River, Quaboag River, and Westfield River-Middle Branch have had the greatest risk of ice jamming. Very little information was available for the older jams. Most of the rivers where the jams occurred are in the western half of the state. Figure 10-4 shows ice jams in Massachusetts between 1934 and 2009.

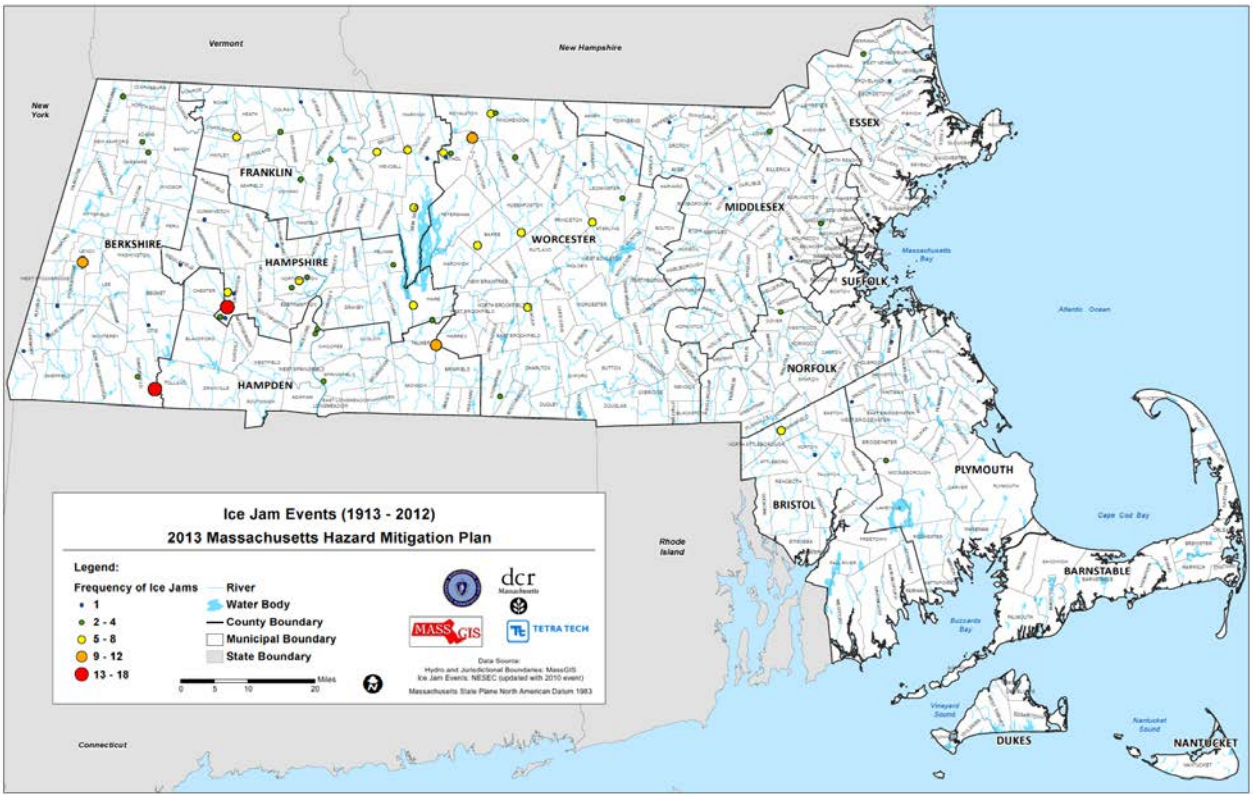

Figure 10-4. Ice Jam Events in Massachusetts (1934—2012)

10.2.2 Previous Occurrences

Flooding in Massachusetts is often the direct result of frequent weather events such as coastal storms, nor'easters, heavy rains, tropical storms, and hurricanes. Flooding in Massachusetts can be caused by one or a combination of factors. Heavy rainfall, snowmelt, and coastal flooding associated with high wind and wave action can all contribute to flooding. The state receives approximately 48 inches of rain per year on average, distributed nearly evenly over the 12 months. Average monthly rainfall is between 3 and 4 inches for all regions of the state. Heavy rainfall events have brought more than 10 inches of rain in a single storm. In almost any antecedent condition, this will result in river flooding.

Over the course of the last 50 years, there have been 20 major flood (or flood-related) events in Massachusetts, including Hurricane Sandy. Coastal counties have experienced the highest numbers of declared flood events. Essex County has had the highest number of declared flood events (16), with Norfolk and Plymouth each sustaining 14, Suffolk sustaining 13, and Middlesex sustaining 12 disaster declarations for flood events.

Riverine, or inland flooding, affects the majority of communities in the Commonwealth. Inland flooding is exacerbated by the effects of orographic lift enhancing precipitation amounts in the higher elevation areas of central and western Massachusetts. In addition, heavy precipitation associated with tropical storms is highest on the left (usually west) side of the tropical storm track, which tends to result in highest rainfall amounts associated with these coastal storms in central and western Massachusetts.

Based on all sources researched, known flooding events that have affected Massachusetts and were declared a FEMA disaster are identified in Table 10-1, which provides detailed information concerning the FEMA declarations for the Commonwealth. Figure 10-5 illustrates the number of FEMA declared disasters by County.

TABLE 10-1.
FEMA FLOOD-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-4097	Hurricane Sandy	12/19/12	10/27/12 - 11/8/12	X		X	X						X		X	X		6
DR-4028	Tropical Storm Irene	09/03/11	8/27/11 - 8/29/11	X	X	X	X		X	X	X			X	X			9
DR-1895	Severe Storm and Flooding	03/29/10	3/12/10 - 4/26/10			X		X				X		X	X	X	X	7
DR-1813	Severe Winter Storm and Flooding	01/05/09	12/11/08 - 12/18/08		X			X	X	X	X	X					X	7
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-1642	Severe Storms and Flooding	05/25/06	5/12/06 - 5/23/06					X				X				X		3
DR-1614	Severe Storms and Flooding	11/10/05	10/7/05 - 10/16/05		X	X		X	X	X	X	X		X	X		X	10
DR-1512	Flooding	04/21/04	4/1/04 - 4/30/04					X				X		X		X	X	5
DR-1364	Severe Storms & Flooding	04/10/01	3/5/01 - 4/16/01			X		X				X		X	X	X	X	7
DR-1224	Heavy Rain and Flooding	06/23/98	6/13/98 - 7/6/98			X		X				X		X	X	X	X	7
DR-1142	Severe Storms/Flooding	10/25/96	10/20/96 - 10/25/96					X				X		X	X	X		5
DR-975	Winter Coastal Storm	12/21/92	12/11/92 - 12/13/92	X			X	X				X	X	X	X	X	X	9
DR-920	Severe Coastal Storm	11/04/91	10/30/91 - 11/2/91	X			X	X					X	X	X	X		7
DR-914	Hurricane Bob	08/26/91	08/19/91	X		X	X	X		X		X	X	X	X	X	X	11
DR-790	Severe Storms, Flooding	04/18/87	3/30/87 - 4/13/87		X			X	X	X	X	X		X			X	8
DR-751	Hurricane Gloria	10/28/85	09/27/85	X	X	X	X	X	X	X	X	X		X	X	X	X	13
DR-546	Coastal Storms, Flood, Ice, Snow	02/10/78	2/6/78 - 2/8/78	X		X	X	X					X	X	X	X		8
DR-325	Severe Storms, Flooding	03/06/72	03/06/72					X						X	X	X		4
DR-43*	Hurricane, Flood	08/20/55	08/20/55															
DR-22*	Hurricanes	09/02/54	09/02/54															
Total				**8**	**6**	**9**	**8**	**16**	**6**	**7**	**6**	**12**	**5**	**14**	**14**	**13**	**10**	

Note: X indicates that particular county was declared.
* County-specific data not available for declarations prior to 1963

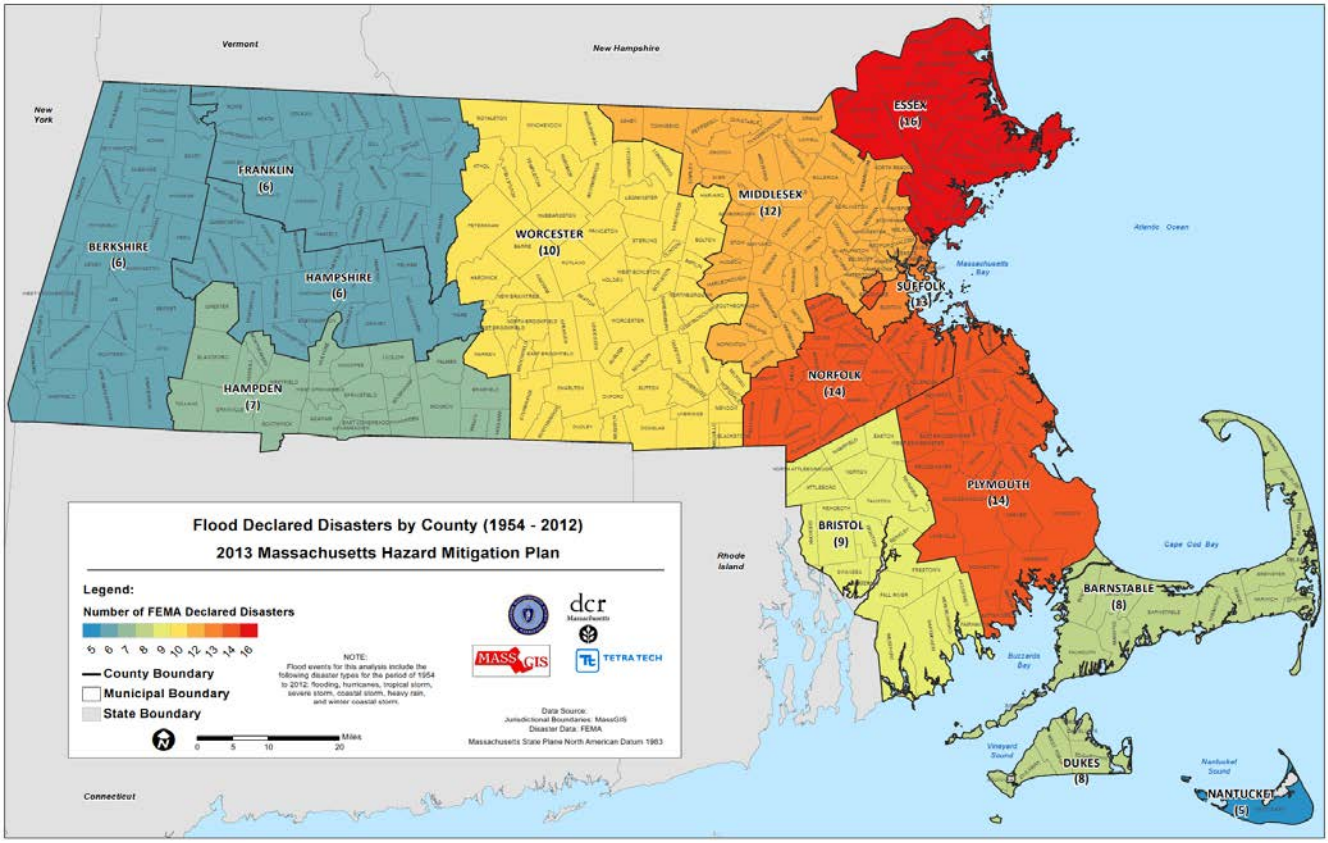

Figure 10-5. Number of FEMA Flood Declared Disasters by County

Hurricanes (FEMA-DR-22)—September 1954

During the summer of 1954, two hurricanes 12-days apart, resulted in widespread coastal damage in southern New England.

Hurricane Carol

On the morning of August 31, 1954 Hurricane Carol, the most destructive hurricane to strike Southern New England since the Great New England Hurricane of 1938, came crashing ashore near Old Saybrook, Connecticut, leaving 65 people dead in her wake. Sustained winds of 80 to 100 mph roared through the eastern half of Connecticut, all of Rhode Island, and most of eastern Massachusetts. Scores of trees and miles of power lines were blown down. Strong winds also devastated crops in the region. Nearly 40 percent of apple, corn, peach, and tomato crops were ruined from eastern Connecticut to Cape Cod. Hurricane Carol arrived shortly after high tide, causing widespread tidal flooding. Narragansett Bay and New Bedford Harbor received the largest surge values of over 14 feet in the upper reaches of both water ways. On Narragansett Bay, just north of the South Street Station site, the surge was recorded at 14.4 feet, surpassing that of the 1938 Hurricane. However, since Hurricane Carol arrived after high tide, the resulting storm tide was lower. The heaviest amounts of rainfall, up to 6 inches, occurred in the New London, Connecticut area in the vicinity of landfall, and across extreme north central Massachusetts. Hurricane Carol destroyed nearly 4,000 homes, along with 3,500 automobiles and over 3,000 boats. All of Rhode Island, much of eastern Connecticut, and much of eastern Massachusetts lost electrical power. In addition, as much as 95 percent of all phone power was interrupted in these locations. Carol is estimated to have been a Category 3 Hurricane [NOAA, 2013 (a)].

Hurricane Edna

Following closely on the heels of Hurricane Carol was Hurricane Edna. Edna made landfall during the morning of September 11, passing over Martha's Vineyard and Nantucket, then across the eastern tip of Cape Cod, Massachusetts. Hurricane force winds of 75 to 95 mph buffeted all of eastern Massachusetts and coastal Rhode Island. Inland, sustained winds of 50 to 70 mph were common west of the Connecticut River Valley. Peak wind gusts included 120 mph on Martha's Vineyard, 110 mph on Block Island, and 100 mph at Hyannis, Massachusetts. The strong winds knocked out electrical power across sections of Rhode Island, eastern Massachusetts, and nearly all of Cape Cod and the Islands. The lowest recorded pressure was 28.02 inches at Edgartown on Martha's Vineyard. Edna arrived during a rising tide and resulted in severe flooding across Martha's Vineyard, Nantucket, and Cape Cod, where storm surges of over 6 feet were common. Farther west, storm surge values were 4 feet or less, resulting in storm tides that remained below flood stage. Damage to the boating community was severe across Cape Cod, but was much less across the remainder of Massachusetts and Rhode Island. Edna's track across the extreme eastern part of the region did result in heavy rainfall and inland flooding.

Rainfall amounts of 3 to 6 inches were common, with over seven inches across northeastern Massachusetts. This rainfall aggravated the already saturated conditions caused by Hurricane Carol ten days earlier. The total combined rainfall for Carol and Edna ranged from 5 to 7 inches along and west of the Connecticut River and over Cape Cod, to as much as 11 inches from southeast Connecticut, across most of Rhode Island, to northeast Massachusetts. Considerable urban and small stream flooding occurred. Numerous street washouts were common, along with some major river flooding in Rhode Island and northeast Massachusetts, where rivers rose several feet above flood stage. Edna was responsible for 21 deaths across the region (Vallee and Dion, Date Unknown).

Hurricane Diane and Flooding (FEMA-DR-43)—August 1955

Hurricane Diane, a Category 3 event, was one of the costliest hurricanes in U.S. history, with estimated total damage exceeding $831 million. The storm brought strong winds (sustained winds of 120 mph) and approximately 16 inches of rain in many areas, which lead to extensive flooding in much of the New England region. Throughout the impacted areas, the hurricane caused between 184 and 200 deaths. In Massachusetts, this event resulted in a FEMA disaster declaration (FEMA-DR-43).

Severe Storms and Flooding (FEMA-DR-325)—March 1972

Detailed information regarding this event was not available. No reference and/or no damage reported. This event did result in a federal disaster declaration (FEMA-DR-325).

Coastal Storms, Flood, Ice, Snow (FEMA-DR-546)—February 1978

The February 1978 Blizzard remains as the benchmark storm for comparison by all subsequent nor'easters. This life-threatening nor'easter crippled most of the state with blizzard conditions, extraordinarily heavy snow, high winds, and devastating coastal flooding. The storm claimed 73 lives in Massachusetts and 26 in neighboring Rhode Island. Over 10,000 people had to be sheltered. An unprecedented ban on non-emergency vehicle traffic lasted for a week in much of eastern Massachusetts.

The timing of the storm exacerbated its impact. This blizzard grew to its full fury during the Monday evening rush hour and caused over 3500 vehicles to be stranded on route 128 alone in eastern Massachusetts with snowfall rates of at least 3 inches per hour and visibility near zero. Boston recorded a wind gust of 79 mph, and the wind peaked out at 93 mph in Chatham. Snowfall generally ranged from 1 to 3 feet with a large swath of 30+ inch amounts in the southwest suburbs of Boston. Snowfall reports included 32.5 inches in Rockport, 27.1 inches in Boston, 20.2 inches in Worcester, and 38.0 inches in Woonsocket, RI.

Major coastal flooding occurred over multiple high tide cycles and destroyed or severely damaged over 2000 homes. This storm set the all-time high water mark (to date) of 15.25 feet above Mean Lower Low

Water at the Boston Harbor National Ocean Service tide gage. Mariner accounts refer to waves in excess of 30 feet just offshore. The storm triggered many harrowing evacuations and rescues along both the North and South Shores. This event did result in a federal disaster declaration (FEMA-DR-546) (Strauss, date unknown).

Hurricane Gloria (FEMA-DR-751)—September 1985

Hurricane Gloria was a powerful Category 4 Cape Verde-type storm that prowled the Atlantic for 13 days, with highest winds of 145 mph. Hugging the coastline, as it made its way north, Gloria crossed Long Island, making landfall at Milford, Connecticut. As it continued northeastward through New England, it became extra tropical over Maine on the 28th. In spite of arriving during low tide, it did cause severe beach erosion along the New England coast, as well as the loss of many piers and coastal roads. There was a moderate storm surge of 6.8 feet in New Bedford, Mass. The storm left over 2,000,000 people without power. It dropped up to 6” of rain in Massachusetts, causing many flooding issues in the region. Overall, casualties were relatively low with 8 deaths, but damage reached $900 million. This event resulted in a federal disaster declaration (FEMA-DR-751).

Severe Storms and Flooding (FEMA-DR-790)—March-April 1987

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).

Hurricane Bob (FEMA-DR-914)—August 1991

Formed in the Bahamas, Hurricane Bob made landfall in New England near New Bedford, Mass. with 115 mph winds, cutting a path across Southeastern Massachusetts towards the Gulf of Maine. Peak winds of in excess of 100 mph were recorded in the Towns of Brewster and Truro on Cape Cod. Over 60% of the residents of Southeastern Massachusetts and Southeastern Rhode Island lost power. There were 4 different reports of tornados as Bob came ashore. Buzzards Bay saw a 10- to 15-foot storm surge. A number of south-facing beaches on the islands of Nantucket and Martha’s Vineyard lost 50 feet of beach to erosion. Up to 7” of rain was reported to have fallen throughout New England. Bob was blamed for 18 storm-related deaths. The damage total for Southern New England was set at $1 billion, with $2.5 billion overall damage from the storm. This event resulted in a federal disaster declaration (FEMA-DR-914).

Severe Coastal Storm (FEMA-DR-920)—October-November 1991

This storm was an unusual event, as the large Nor’easter moved south and gained strength when it joined what remained of Hurricane Grace, becoming what some refer to as the Perfect Storm. Along the Massachusetts coastline, the storm produced 25 foot wave heights on top of a 4 foot high tide. In Boston, the highest tide was 14.3 feet, which was only 1 foot lower than the record from the blizzard of 1978. High waves on top of the storm tide reached about 30 feet. The storm produced heavy rainfall in southeastern Massachusetts, peaking at 5.5 inches. Coastal floods closed several roads, forcing hundreds of people to evacuate. In addition to the high tides, the storm produced strong winds; Chatham recorded a gust of 78 mph. Damage was worst from Cape Ann in northeastern Massachusetts to Nantucket, with over 100 homes destroyed or severely damaged at Marshfield, North Beach, and Brant Point. There were two injuries in the state, although there were no fatalities. Across Massachusetts, damage totaled in the hundreds of millions of dollars. This event resulted in a federal disaster declaration (FEMA-DR-920).

Winter Coastal Storm (FEMA-DR-975)—December 1992

During the 11th to 13th of December 1992, a strong nor'easter affected the Bay State. Impacts included deep and intense snowfall, freezing rain, heavy rainfall near the coast, coastal flooding, and damaging winds.

Storm total snowfall in MA was as high as 4 feet over the higher elevations of the Berkshires, with 48" reported in Beckett, Savoy, and Peru. Snow drifts as high as 12 feet were created in the Berkshires. Snowfall of 18" to 32" was common over central MA, with 6 to 20" over interior eastern MA. Some locations also experienced a coating of ice. Strong winds combined with wet, heavy snow and ice caused considerable tree damage and widespread power outages. The weight of the snow taxed snow removal equipment in many communities and also caused roof damage. There were 135,000 customers without power in the Commonwealth during the storm. The central part of the Commonwealth suffered the brunt of the outages where 30,000 households were without power, just in Worcester County.

Precipitation totals for this storm were extraordinary. Much of southern New England received up to 5 inches of liquid equivalent precipitation during a 2 to 3 day period, with locally close to 8 inches recorded in parts of southeast Massachusetts. Along coastal sections and in some interior valleys, much of the precipitation fell as rain or rain mixed with snow. This caused considerable ponding and localized flooding in poorly drained areas.

The greatest damage from this storm was due to coastal flooding. Serious coastal flooding occurred along the Massachusetts coastline during the 11th to 13th, the most damaging storm tide occurring early afternoon on the 12th. The Boston tide gage recorded a peak elevation of 14.21 feet above Mean Lower Low Water, 1 foot below the highest elevation on record at that location, from the Blizzard of 1978. A 350 foot breach of Hull's Nantasket Beach seawall occurred. Most east-facing shoreline communities from Chatham to Provincetown and Plymouth to the North Shore, as well as Nantucket Island, experienced some level of coastal flood damage. Dunes were washed away in Hull and Duxbury. As much as 20 feet of dune was lost in Sandwich and up to 25 feet in Ipswich. Many coastal road closings occurred. Dock damage occurred, and some cottages were destroyed by the sea. This event resulted in a federal disaster declaration (FEMA-DR-975).

Severe Storms and Flooding (FEMA-DR-1142)—October 1996

On October 19 through October 20, 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. In Lowell, the Merrimack River gage recorded the height of river at 53.10 feet with a discharge of 48,600 cubic feet per second. Major roadways were flooded. Many basements of homes were flooded and homes were severely damaged. This flooding event resulted in a federal disaster declaration (FEMA-DR-1142). Damage was estimated at over $60 million.

Heavy Rain and Flooding (FEMA-DR-1224)—June-July 1998

On June 12 through the 14, a slow moving storm system moved through southeast New England, producing between six and 12 inches of rain over much of eastern Massachusetts. This led to widespread urban, small stream, and river flooding. Between June 15 and June 20, another storm brought thunderstorms to the area, causing several flash floods. Flooding was reported along many brooks, streams, and rivers. Another storm on June 30 brought heavy rain and continued the flooding from the previous events. This series of storms resulted in a federal disaster declaration (FEMA-DR-1224).

Severe Storms and Flooding (FEMA-DR-1364)—March-April 2001

A series of storm events occurred in Massachusetts between March 5 and April 16. These events included a major winter storm, heavy rainfall, and melting snow. On March 5, a major winter storm affected

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).

Flooding (FEMA-DR-1512)—April 2004

Between March 31 and April 2, as much as four inches of rain fell in parts of Massachusetts, with the Merrimack Valley receiving seven inches of rain. The heavy rain, combined with snowmelt produced an excessive runoff of water, causing many streams and rivers to flood. Many roadways were closed due to flooding and some residents were forced to evacuate their homes. A second event occurred on April 15. Two inches of rain fell on already saturated ground from the floods earlier in the month. Assabet River flooded; however, it was minor and there no reports of damage. This series of flooding events resulted in a federal disaster declaration (FEMA-DR-1512) and Massachusetts received over $2.7 million in individual assistance.

Severe Storms and Flooding (FEMA-DR-1614)—October 2005

On October 9, 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.

Severe Storms and Flooding "Mother's Day Flood" (FEMA-DR-1642)—May 2006

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. There was also paralyzing urban/poor drainage flooding in portions of the northeast, especially in the Peabody area. 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 state received over $56 million in individual and public assistance.

Severe Storms and Inland and Coastal Flooding (Nor'easter) (FEMA-DR-1701)—April 2007

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 main stem 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.

Severe Winter Storm and Flooding "Patriot's Day Storm" (FEMA-DR-1813)—December 2008

A major ice storm and significant precipitation affected much of New England (December 11 through 12). The ice storm struck across interior Massachusetts, southern New Hampshire, and much of northern New England. The hardest hit areas were the Worcester Hills in central Massachusetts and the east slopes of the Berkshires in western Massachusetts. At least half an ice of ice accreted on many exposed surfaces. The ice downed many trees, branches, and power lines, which resulted in widespread power outages. More than 300,000 people were without power in the Commonwealth. Heavy rain fell in parts of Massachusetts (Berkshire, Worcester, Bristol, and Middlesex Counties), leading to minor to moderate flooding and ponding of water in low-lying, poor drainage areas, streams, creeks, and brooks. Several roadways were closed due to flooding. Rainfall totals ranged between one and four inches. There was one death in Massachusetts associated with this storm. This event resulted in a federal disaster declaration (FEMA-DR-1813). Those counties included in the disaster received over $51 million in public assistance from FEMA.

Severe Storm and Flooding Event (FEMA-DR-1895) - March-April 2010

A series of severe storms brought widespread rainfall to Massachusetts in March 2010, causing small streams to rise above their flood stages. Flooding continued into April, with prolonged river, reservoir, and lake flooding. This prolonged 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 $85 million was received in individual and public assistance.

Tropical Storm Irene (FEMA-DR-4028)—August 2011

Tropical Storm Irene (August 27-29, 2011) produced significant amounts of rain, storm surge, inland and coastal flooding, and wind damage across southern New England and much of the east coast of the U.S. In Massachusetts, rainfall totals ranged between 0.03 inches (Nantucket Memorial Airport) to 9.92 inches (Conway, MA). These heavy rains caused flooding throughout the Commonwealth and a presidential disaster was declared (FEMA-DR-4028). Tropical Storm Irene was closely followed by the remnants of Tropical Storm Lee, which brought additional heavy rain to Massachusetts and extended flooding. Severe river erosion occurred in northwestern Massachusetts, closing state Route 2 for (how long?). Landslides were also triggered by the heavy rain and wet soil in this area of steep slopes containing layers of glacial lake clay. The Commonwealth received over $31 million in individual and public assistance from FEMA.

Hurricane Sandy (FEMA-DR-4097)—October-November 2012

Hurricane Sandy was the largest Atlantic hurricane on record, with winds spanning 1,100 miles in diameter, reaching sustained forces of 110 mph. Estimated losses due to damage and business interruption are still being calculated, but are estimated to exceed $65 billion. At present count (December 2012), at least 253 people were killed along the path of the storm, with 131 of those deaths occurring within the U.S. although no deaths occurred in Massachusetts.

Ice Jams

According to the CRREL database, ice jams have formed at points along the following water bodies.

- Aberjona River
- Bassett Brook
- Buck River
- Caldwell Creek
- Charles River
- Maple Meadow Brook
- Marsh Brook
- Merrimack River
- Middle Branch Westfield River
- Mill River
- Priest Brook
- Quaboag River
- Quinebaug River
- Rocky Brook
- Saugus River

- Connecticut River
- Deerfield River
- Dorcester Brook
- Dry Brook
- East Meadow River
- Farmington River
- Green River
- Hoosic River
- Hop Brook
- Housatonic River
- Ipswich River
- Kearny Brook
- Millers River
- Moose Brook
- Moss Brook
- Nashoba Brook
- Nashua River
- North Nashua River
- North River
- Old Swamp River
- Otter River
- Parker River
- Schenob Brook
- Sevenmile River
- Swift River
- Sykes Brook
- Taunton River
- Wading River
- Ware River
- West Branch Farmington River
- West Branch Westfield River
- Westfield River

Locations of historical ice jam events are indicated in Figure 10-4. According to the U.S. Army CRREL database, North Central Massachusetts averages at least one ice jam per year for almost the last decade. Only Buck River, Millers River, Nashua River, Westfield River, Nashoba Brook, Otter River, Farmington River, and Westfield River-Middle Branch have seen jams since 1990. The two most recent occurrences were on the Miller's River in February 2008 and the Farmington River in March 2010.

The February 2008 event was reported as chunks of ice 1-2 feet thick, which was released due to runoff from snowmelt, rain, and spring-like conditions in the region. While no flooding was observed, the jam was approximately 1,500 feet long. The March 2010 jam was as a result of high precipitation levels across the Berkshires from March 12 - 13 ranging from 1 1/2 to 3 1/2 inches combining with snowmelt, which caused minor flooding in urban areas and small streams. Route 8 in North Otis was reported closed due to ice chunks in the road left over from an ice jam that broke on the West Branch of the Farmington River. The road was reopened after the ice chunks were cleared.

The CRREL database was queried for all ice jam events that occurred in Massachusetts from 1913 through 2012. Based on review of the CRREL database, 226 ice jam events have occurred in the Commonwealth and took place between 1913 and 2010. These events are listed in Appendix J and summarized by county in Table 10-2. Information regarding losses associated with these reported ice jams was limited.

TABLE 10-2.
NUMBER OF ICE EVENTS BY COUNTY

County	Number of Ice Events, 1913-2012
Worcester	55
Hampshire	55
Franklin	32
Berkshire	24
Barnstable	18
Hampden	14
Middlesex	11
Bristol	6

TABLE 10-2.
NUMBER OF ICE EVENTS BY COUNTY

County	Number of Ice Events, 1913-2012
Essex	5
Norfolk	3
Plymouth	3
Suffolk	0
Dukes	0
Nantucket	0

Source: CRREL

10.2.3 Probability of Future Occurrences

For the purposes of this plan, the frequency of hazard events of disaster declaration proportions is defined by the number of declared disaster events for the Commonwealth over a specified period of time. The historical record indicates the Commonwealth has experienced 20 flood-related disaster declaration occurrences from 1954 to 2012. Table 10-1 summarizes these disasters. Therefore, based on these statistics, the Commonwealth may experience a flood event of disaster declaration proportions once every 3 (2.95) years. It is noted, however, that some areas of the Commonwealth are more flood-prone than others therefore the frequency of flood events, of all sizes, varies based on watershed, riverine reach, and location along each reach.

10.2.4 Severity

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

10.2.5 Warning Time

Due to the sequential pattern of meteorological conditions needed to cause serious flooding, it is unusual for a flood to occur without warning. Warning times for floods can be between 24 and 48 hours. Flash flooding can be less predictable, but potential hazard areas can be warned in advanced of potential flash flooding danger. Flooding is more likely to occur due to a rain storm when the soil is already wet and/or streams are already running high from recent previous rains (conditions already in place when a storm begins are called “antecedent conditions”). NOAA’s Northeast River Forecast Center provides flood warning for Massachusetts, relying on monitoring data from the USGS stream gage network. Notice of potential flood conditions is generally available five days in advance. State agency staff monitor river, weather, and forecast conditions throughout the year. Notification of potential flooding is shared among state agency staff, including the Massachusetts Emergency Management Agency and the Office of Dam Safety. The National Weather Service provides briefings to state and local emergency managers, as well as notifications to the public via the media and social networking. MEMA also distributes information regarding potential flooding to local Emergency Managers, the press, and the public.

10.3 SECONDARY HAZARDS

The most problematic secondary hazards for flooding are fluvial erosion hazards, river bank erosion, and landslides, which can be more harmful than actual flooding. For instance, fluvial erosion attributed to

Hurricane Irene caused an excess of $23 Million in damage along Route 2. The impacts from these secondary hazards are especially prevalent in the upper courses of rivers with steep gradients, where floodwaters may pass quickly and without much damage, but scour the banks, edging properties closer to the floodplain or causing them to fall in. Flooding is also responsible for hazards such as landslides when high flows over-saturate soils on steep slopes, causing them to fail. The secondary hazards of flooding also affect roadways and bridges by undermining and completely washing out supporting structures. Secondary impacts also include urban flooding with respect to culverts and the associated increased water volume. Dam failures during flood events are of concern in Massachusetts, given the high density of dams constructed in the 19th century. Failure of wastewater treatment plants can occur during floods as well, releasing untreated wastewater directly into rivers and the ocean. Coastal erosion has been a significant hazard on Massachusetts' highly developed shores. In recent years, accelerated erosion has caused the collapse of buildings into the ocean or demolition of buildings at risk of collapse. Hazardous materials spills are also a secondary hazard of flooding if storage tanks rupture and spill into streams, rivers, or storm sewers.

10.4 CLIMATE CHANGE IMPACTS

"Climate change" refers to changes over a long period of time in patterns of temperature, precipitation, humidity, wind, and seasons. Climate change is forecast by some to have significant impacts on the Eastern Seaboard of the United States by mid-21st century. While it is not known if the number of storms will increase in the future as the result of climate changes, it is anticipated that the intensity of tropical and extra-tropical storms may increase as the storm intensity is a function of sea surface temperature, which continue to rise. Thus, we may experience more intense storms with greater rainfall in the future. In addition, recent work by Rawlins et al. (2012) shows that our winter weather will become warmer and wetter with 6% to 14% more precipitation than we receive currently.

Climate plays a fundamental role in shaping ecosystems and the human economies and cultures that depend on them. It is generally perceived that climate change will have a measurable impact on the occurrence and severity of flooding. As hydrology changes, what has historically been considered a 100-year flood may strike more often, leaving many communities at greater risk. Planners and engineers will need to factor a new level of safety into the design, operation, and regulation of flood protection facilities such as dams, floodways, bypass channels, and levees, as well as the design of local roads, sewers, and storm drains.

The amount of snow is critical for water supply and environmental needs, but so is the timing of snowmelt runoff into rivers and streams. Rising snowlines caused by climate change will allow more mountain area to contribute to peak storm runoff during winter months, although spring snowmelt floods may diminish under these conditions. High frequency flood events in particular (e.g. 10-year floods) may increase with a changing climate. Along with reductions in the amount of the snowpack and accelerated snowmelt, scientists project greater storm intensity, resulting in more direct runoff and flooding.

Changes in watershed vegetation and soil moisture conditions will likewise change runoff and recharge patterns. As stream flows and velocities change, erosion patterns will also change, altering channel shapes and depths, possibly increasing sedimentation behind dams, and affecting habitat and water quality. With potential increases in the frequency and intensity of wildfires due to climate change, there is potential for more floods following fire, which increase sediment loads and water quality impacts.

For the State of Massachusetts planning area, climate change is anticipated to impact flood conditions on three fronts—hydrology, sea level rise, and change in coastal landforms—as described in the following hydrology section and in the separate coastal erosion and sea level rise profiles. While many models are currently being developed to assess the potential impacts of climate change, there are currently none available to support flood hazard mitigation planning. As these models are developed in the future, this risk assessment may be enhanced to better measure these impacts.

1.4.1 Hydrology

Temperature changes are an obvious and easily measured change in climate, but atmospheric moisture, precipitation, and atmospheric circulation also change, as the whole system is affected. Radiative forcing alters heating, and at the Earth's surface this directly affects evaporation as well as sensible heating. Further, increases in temperature lead to increases in the moisture-holding capacity of the atmosphere at a rate of about 7% per °C. Together these effects alter the hydrological cycle, especially characteristics of precipitation (amount, frequency, intensity, duration, type) and extremes. In weather systems, convergence of increased water vapor leads to more intense precipitation, but reductions in duration and/or frequency, given that total amounts do not change much. This increase in precipitation has been experienced 5-10% over a 105-year period (1901-2005) studied by the IPCC in the Northeast United States. (IPCC, 2007).

In the last 20 years, the power of tropical storms has doubled (Emanuel, 2013). The increasing intensity of tropical storms is likely to continue in the coming century as ocean waters continue to warm. Additionally, it is thought that rainfall intensity of storms is likely to increase thus causing more inland flooding at both the large watershed level (riverine flooding) and smaller creek level (flash flooding).Overall, the amount of precipitation throughout the Northeast is projected to increase, with winter precipitation increasing 6 to 14% (Rawlins, 2012).

Use of historical hydrologic data has long been the standard of practice for designing and operating water supply and flood protection projects. For example, historical data are used for flood forecasting models and to forecast snowmelt runoff for water supply. This method of forecasting assumes that the climate of the future will be similar to that of the period of historical record. However, the hydrologic record cannot be used to predict changes in frequency and severity of extreme climate events such as floods. Going forward, model calibration or statistical relation development must happen more frequently, new forecast-based tools must be developed, and a standard of practice that explicitly considers climate change must be adopted. Climate change is already affecting water resources, and resource managers have observed the following:

- Historical hydrologic patterns can no longer be solely relied upon to forecast the water future.
- Precipitation and runoff patterns are changing, increasing the uncertainty for water supply and quality, flood management and ecosystem functions.
- Extreme climatic events will become more frequent, necessitating improvement in flood protection and emergency response.

10.5 EXPOSURE

To understand risk, the assets exposed to the hazard areas are identified. For the flood hazard, areas identified as hazard areas include the 1-percent and 0.2-percent (100- and 500-year) floodplains. The following discusses the Commonwealth of Massachusetts exposure to the flood hazard including:

- Population
- State facilities
- Critical facilities and infrastructure
- Economy

To assess the Commonwealth's exposure to the flood hazard, an analysis was conducted with the most current floodplain boundaries. These data include the locations of the FEMA flood zones: the 100-year flood zones or 1-percent annual chance event (including both A zones and V zones) and the 500-year flood zones or 0.2-percent annual chance event. Using ArcMap GIS software, these data were overlaid with the population, general building stock, state facility data (owned and leased), and critical facilities; and the appropriate flood zone determination was assigned.

The newest FEMA FIRM or DFIRMs were used in this analysis, including preliminary DFIRMs provided by the Department of Conservation and Recreation (DCR). Where DFIRMs were not available, Quality 3 (Q3) data were used. Franklin County does not have DFIRMs or Q3 data; however, a digital floodplain layer that had been developed by the Franklin Regional Council of Governments, which only includes the floodplain in those communities along the Connecticut River, was used for this analysis. Table 10-3 and Figure 10-6 summarize the data used for this risk assessment. Figure 10-7 displays the 1- and 0.2-percent flood hazard areas across the Commonwealth.

TABLE 10-3.
DATA USED FOR RISK ASSESSMENT

County	Data Used for 2013 Plan Update	Source
Barnstable	Q3	MassGIS—August 2012
Berkshire	Q3	MassGIS—August 2012
Bristol	DFIRM (July 7, 2009)	DCR - September 2012
Dukes	DFIRM (July 6, 2010)	DCR - September 2012
Essex	DFIRM (July 3, 2012)	DCR - September 2012
Franklin	Digital floodplain layer (1-percent flood event only) for Connecticut River (and some of the tributaries) only (there are no Q3 data for the rest of Franklin County)	DCR - September 2012
Hampden	Revised Preliminary July 13, 2012 DFIRM	DCR - September 2012
Hampshire	Q3	MassGIS—August 2012
Middlesex	DFIRM (June 4, 2010) *Shawsheen Watershed is located partially within Middlesex County The preliminary Risk MAP deliverable for Shawsheen Watershed (2011) was used in place of the data in the 2010 DFIRM database for this area.	DCR - September 2012
Nantucket	Preliminary DFIRM (July 26, 2012)	DCR - September 2012
Norfolk	DFIRM (July 17, 2012) The Town of Canton was not included in the July 17, 2012 Norfolk Countywide Flood Insurance Study or DFIRMs. The Q3 for the Town of Canton was used.	DCR - January 2013
Plymouth	Physical Map Revision to Preliminary DFIRM DB on August 16, 2012 for Marion, Mattapoisett, and Wareham. Remainder of the county has DFIRMs from July 17, 2012.	DCR - September 2012
Suffolk	DFIRM (September 25, 2009)	DCR - September 2012
Worcester	DFIRM (July 4, 2011) The DFIRM is only available for a portion of the County (Auburn, Berlin, Blackstone, Bolton, Boylston, Charlton, Clinton, Douglas, Dudley, Grafton, Harvard, Hopedale, Lancaster, Leicester, Mendon, Milford, Millbury, Millville, Northborough, Northbridge, Oxford, Paxton, Shrewsbury, Southborough, Southbridge, Spencer, Sturbridge, Sutton, Upton, Uxbridge, Webster, West Boylston, Westborough, and Worcester); the Q3 used for the remainder of the County	DCR - September 2012

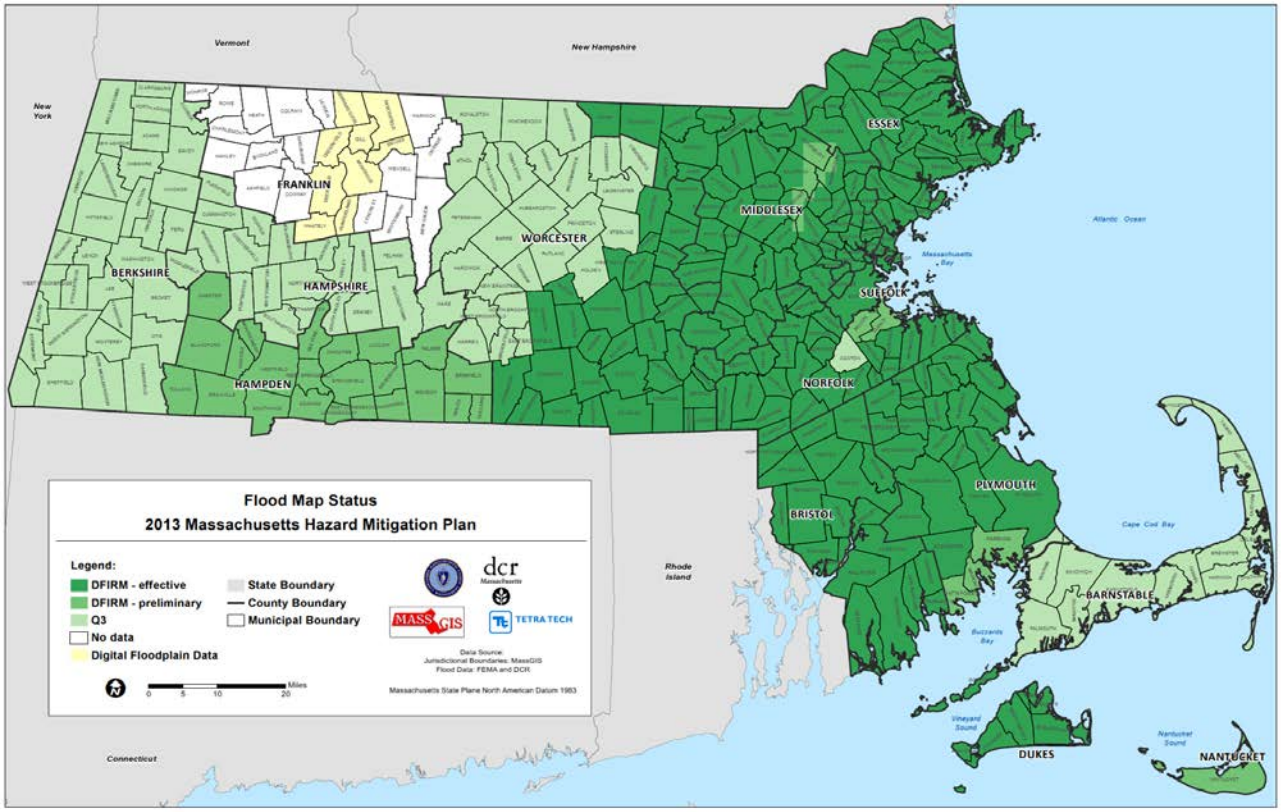

Figure 10-6. FEMA Flood Map Status for the Commonwealth of Massachusetts

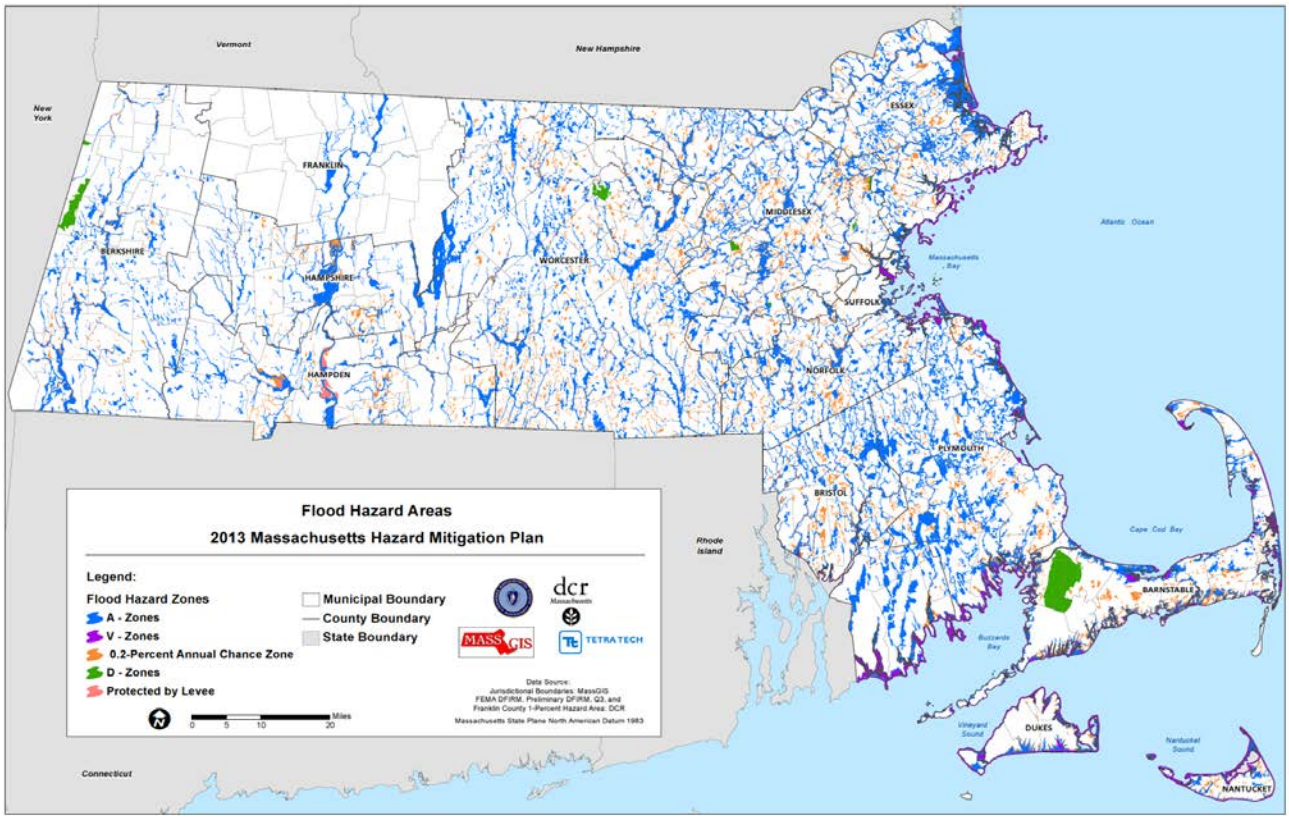

Figure 10-7. FEMA Flood Hazard Areas in the Commonwealth of Massachusetts

10.5.1 Population

The impact of flooding on life, health, and safety is dependent upon several factors including the severity of the event and whether or not adequate warning time is provided to residents. Exposure represents the population living in or near floodplain areas that could be impacted should a flood event occur. Additionally, exposure should not be limited to only those who reside in a defined hazard zone, but everyone who may be affected by the effects of a hazard event (e.g., people are at risk while traveling in flooded areas, or their access to emergency services is compromised during an event). The degree of that impact will vary and is not strictly measurable.

To estimate the population exposed to the 1-percent and 0.2-percent annual chance flood events, the flood hazard boundaries were overlaid upon the 2010 Census block population data in GIS (U.S. Census 2010). Census blocks do not follow the boundaries of the floodplain. The Census blocks with their centroid in the flood boundaries were used to calculate the estimated population exposed to this hazard. Table 10-4 lists the estimated population located within the 1-percent and 0.2-percent flood zones by County. The limitations of this analysis are recognized, and this methodology may over- or underestimate the population exposed.

TABLE 10-4.
ESTIMATED POPULATION EXPOSED TO THE 1-PERCENT AND 0.2-PERCENT ANNUAL CHANCE FLOOD EVENTS

		1-Percent Chance Flood Event						0.2-Percent Chance Flood Event	
		A-Zone		V-Zone		SFHA		X500-Zone	
County	Total 2010 Population	Population	% of Total	Population	% of Total	Population	% of Total	Population	% of Total
Barnstable	215,888	16,335	7.6	1,695	0.8	18,030	8.4	13,283	6.2
Berkshire	131,219	11,064	8.4	0	0.0	11,064	8.4	1,742	1.3
Bristol	548,285	31,059	5.7	2,316	0.4	33,375	6.1	20,178	3.7
Dukes	16,535	511	3.1	68	0.4	579	3.5	377	2.3
Essex	743,159	48,482	6.5	2,799	0.4	51,281	6.9	20,894	2.8
Franklin	71,372	1,270	1.8	0	0.0	1,270	1.8	NA	NA
Hampden	463,490	13,025	2.8	0	0.0	13,025	2.8	13,689	3.0
Hampshire	158,080	6,360	4.0	0	0.0	6,360	4.0	2,436	1.5
Middlesex	1,503,085	56,190	3.7	0	0.0	56,190	3.7	46,520	3.1
Nantucket	10,172	200	2.0	86	0.8	286	2.8	481	4.7
Norfolk	670,850	45,185	6.7	1,236	0.2	46,421	6.9	19,807	3.0
Plymouth	494,919	59,278	12.0	3,914	0.8	63,192	12.8	12,955	2.6
Suffolk	722,023	19,201	2.7	205	0.0	19,406	2.7	7,586	1.1
Worcester	798,552	31,504	3.9	1,695	0.2	33,199	4.2	17,455	2.2
Total	**6,547,629**	**339,664**	**5.2**	**14,014**	**0.2**	**353,678**	**5.4**	**177,403**	**2.7**

10.5.2 State Facilities

To assess the exposure of the state owned and leased facilities provided by DCAMM and the Office of Leasing, an analysis was conducted with the most current floodplain boundaries. Using ArcMap, GIS

software, the flood hazard area data were overlaid with the state facility data and the appropriate flood zone determination was assigned to each facility.

This analysis is much more refined since the 2010 plan due to improved DFIRMs in a number of counties and the more complete state-owned/leased building dataset used—the DCAMM data. Table 10-5 and Table 10-6 summarize the number of state buildings located in the 1-percent and 0.2-percent annual chance flood zones by County. Table 10-7 and Table 10-8 summarize the number of state buildings located in the respective zones by agency. The DCR operates numerous flood control and water recreation areas, which accounts for a large number of the structures in the flood zone.

TABLE 10-5.
2012 STATE BUILDING EXPOSURE TO FLOOD HAZARD BY COUNTY (BUILDING COUNT)

	Number of Buildings							
	Total		In A-Zone		In V-Zone		In 500-Year Zone	
County	Owned	Leased	Owned	Leased	Owned	Leased	Owned	Leased
Barnstable	297	12	31	0	23	0	3	0
Berkshire	338	20	9	0	0	0	0	0
Bristol	431	51	22	1	37	0	5	2
Dukes	10	3	0	0	1	0	1	0
Essex	499	39	44	4	5	0	9	7
Franklin	204	7	12	0	0	0	0	0
Hampden	430	36	8	0	0	0	3	3
Hampshire	546	16	23	1	0	0	1	0
Middlesex	1,043	64	13	1	0	0	18	6
Nantucket	3	2	0	2	0	0	0	0
Norfolk	654	26	23	2	0	0	3	2
Plymouth	508	34	17	0	1	0	12	1
Suffolk	326	73	36	0	0	0	4	0
Worcester	1,044	49	18	5	0	0	7	0
Total	**6,333**	**432**	**256**	**16**	**67**	**0**	**66**	**21**

Building data are updated as agencies change or modify. State-owned building information current as of October 3, 2012. State-leased building information current as of October 10, 2010. Total of 6,765 buildings for which data are available and reported in the best available DFIRM databases.

TABLE 10-6.
2012 STATE BUILDING EXPOSURE TO FLOOD HAZARD BY COUNTY (REPLACEMENT COST VALUE)

	Replacement Cost Value							
	Total		In A-Zone		In V-Zone		In 500-Year Zone	
County	Owned	Leased	Owned	Leased	Owned	Leased	Owned	Leased
Barnstable	$1,129,133,087	$17,181,274	$117,148,240	$0	$232,605,111	$0	$1,345,758	$0
Berkshire	$1,810,562,200	$41,438,632	$2,029,700	$0	$0	$0	$0	$0
Bristol	$2,862,545,772	$149,664,578	$35,722,252	$1,779,954	$40,692,248	$0	$7,385,920	$11,816,302
Dukes	$9,965,088	$6,258,960	$0	$0	$205,534	$0	$1,171,214	$0
Essex	$4,336,334,705	$136,866,724	$168,964,271	$14,182,864	$23,577,507	$0	$156,141,552	$22,369,000
Franklin	$789,074,575	$24,162,354	$14,595,793	$0	$0	$0	$0	$0
Hampden	$4,896,066,804	$155,583,444	$46,229,452	$0	$0	$0	$9,600,319	$21,533,472
Hampshire	$4,654,345,657	$33,042,196	$40,165,436	$3,767,238	$0	$0	$1,886,302	$0
Middlesex	$9,556,026,897	$325,969,758	$88,369,664	$5,154,170	$0	$0	$74,354,460	$31,334,120
Nantucket	$30,440,058	$941,186	$0	$941,186	$0	$0	$0	$0
Norfolk	$4,994,008,904	$147,822,352	$230,333,614	$26,855,864	$0	$0	$1,015,972	$21,216,764
Plymouth	$3,089,420,567	$92,983,586	$43,224,320	$0	$179,646	$0	$12,223,798	$391,418
Suffolk	$7,795,245,796	$487,827,934	$224,491,144	$0	$0	$0	$8,254,654	$0
Worcester	$9,226,864,179	$217,834,816	$138,834,085	$11,561,146	$0	$0	$24,202,417	$0
Total	**$55,180,034,288**	**$1,837,577,794**	**$1,150,107,970**	**$64,242,422**	**$297,260,047**	**$0**	**$297,582,366**	**$108,661,076**

Replacement cost value is the sum of the replacement cost value for the building and contents.

Building data are updated as agencies change or modify. State-owned building information current as of October 3, 2012. State-leased building information current as of October 10, 2010. Total of 6,765 buildings for which data are available and reported in the best available DFIRM databases.

TABLE 10-7.
2012 STATE BUILDING EXPOSURE TO FLOOD HAZARDS BY AGENCY (BUILDING COUNT)

	Number of Buildings									
	Total		A-Zone		V-Zone		SFHA Total (A & V)		500-Year Zone	
Agency	Owned	Leased	Owned	Leased	Owned	Leased	Owned	Leased	Owned	Leased
Bridgewater State University	34	4	2	0	0	0	2	0	0	0
Department of Children and Families		34	0	1	0	0	0	1	0	2
Department of Conservation and Recreation	1,963	1	148	0	43	0	191	0	21	0
Department of Corrections	593	1	1	0	0	0	1	0	0	0
Department of Developmental Services	490	31	2	3	0	0	2	3	0	1
Department of Early Education and Care		5	0	0	0	0	0	0	0	1
Department of Environmental Protection	7	5	0	0	0	0	0	0	0	0
Department of Fish and Game	177	1	28	0	1	0	29	0	3	0
Department of Food and Agriculture	1		0	0	0	0	0	0	0	0
Department of Industrial Accidents		4	0	0	0	0	0	0	0	1
Department of Mental Health	187	11	0	2	0	0	0	2	0	0
Department of Public Health	125	11	0	1	0	0	0	1	0	0
Department of State Police	129	7	1	0	0	0	1	0	2	0
Department of Transitional Assistance		27	0	2	0	0	0	2	0	1
Department of Transportation	892	23	51	1	0	0	51	1	6	3
Department of Veterans Services	9	1	3	0	0	0	3	0	0	0
Department of Youth Services	25	1	4	0	0	0	4	0	0	0
Department of Workforce Development		7	0	0	0	0	0	0	0	1
Division of Capital Asset Management	261	1	1	0	0	0	1	0	0	0
Exec. Office of Energy & Environmental. Affairs		3	0	0	0	0	0	0	0	1
Exec. Office of Health & Human Services		7	0	1	0	0	0	1	0	0
Framingham State University	25		1	0	0	0	1	0	0	0
Greenfield Community College	9	1	1	0	0	0	1	0	0	0
Massachusetts Maritime Academy	24		0	0	23	0	23	0	0	0
Massachusetts Parole Board		6	0	1	0	0	0	1	0	0
Massachusetts Rehabilitation Commission		28	0	0	0	0	0	0	0	2
Military Division	152		3	0	0	0	3	0	11	0
North Shore Community College	10	2	0	1	0	0	0	1	0	0
Northern Essex Community College	17	1	0	0	0	0	0	0	1	1
Office of Labor and Workforce Development	5		0	0	0	0	0	0	1	0
Public Employee Retirement Admin. Comm.		1	0	0	0	0	0	0	0	1
Quinsigamond Community College	14	1	0	0	0	0	0	0	0	0
Salem State University	68	1	0	0	0	0	0	0	8	0
Secretary of State	1	5	1	1	0	0	1	1	0	1
Sheriff's Department Essex	17	4	0	0	0	0	0	0	0	1
Sheriff's Department Middlesex	16	4	0	0	0	0	0	0	0	1
Sheriff's Department Nantucket		1	0	1	0	0	0	1	0	0
Trial Court	69	35	4	1	0	0	4	1	1	2
University of Massachusetts at Amherst	372	1	1	0	0	0	1	0	12	0
University of Massachusetts at Dartmouth	37	1	2	0	0	0	2	0	0	0
University of Massachusetts at Lowell	77		2	0	0	0	2	0	0	0
Westfield State University	27	2	0	0	0	0	0	0	0	1
Total	**5,833**	**279**	**256**	**16**	**67**	**0**	**323**	**16**	**66**	**21**

Building data are updated as agencies change or modify. State-owned building information current as of October 3, 2012. State-leased building information current as of October 10, 2010. Total of 6,765 buildings for which data are available and reported in the best available DFIRM databases.
Per the data provided, state agencies listed in this table do not have any buildings located in the defined flood zones.

TABLE 10-8.
2012 STATE BUILDING EXPOSURE TO FLOOD HAZARDS BY AGENCY (REPLACEMENT COST VALUE)

	Replacement Cost Value					
	Total		In SFHA (A & V Zones)		In 500-Year Zone	
Agency	Owned	Leased	Owned	Leased	Owned	Leased
Bridgewater State University	$621,405,638	$8,144,326	$9,983,126	$0	$0	$0
Department of Children and Families	$0	$168,416,910	$0	$5,782,042	$0	$11,475,380
Department of Conservation and Recreation	$3,925,871,934	$593,140	$655,301,906	$0	$49,067,950	$0
Department of Corrections	$5,511,376,140	$2,162,554	$1,019,286	$0	$0	$0
Department of Developmental Services	$2,273,503,983	$61,275,328	$621,164	$5,214,554	$0	$1,322,542
Department of Early Education and Care	$0	$11,035,338	$0	$0	$0	$2,144,120
Department of Environmental Protection	$30,835,588	$64,020,068	$0	$0	$0	$0
Department of Fish and Game	$126,701,367	$2,409,696	$30,276,612	$0	$1,203,368	$0
Department of Food and Agriculture	$4,528,850	$0	$0	$0	$0	$0
Department of Industrial Accidents	$0	$21,884,716	$0	$0	$0	$2,127,288
Department of Mental Health	$2,505,491,673	$15,495,368	$0	$2,668,592	$0	$0
Department of Public Health	$1,716,192,441	$65,004,896	$0	$2,054,348	$0	$0
Department of State Police	$567,970,734	$61,081,512	$1,704,452	$0	$1,250,732	$0
Department of Transitional Assistance	$0	$119,954,202	$0	$8,749,076	$0	$5,387,952
Department of Transportation	$1,479,411,960	$56,547,308	$64,856,197	$126,376	$3,044,436	$21,529,364
Department of Veterans Services	$12,463,486	$1,522,124	$7,192,502	$0	$0	$0
Department of Youth Services	$466,504,706	$4,123,924	$95,984,262	$0	$0	$0
Department of Workforce Development	$0	$16,480,732	$0	$0	$0	$3,041,578
Division of Capital Asset Management	$3,071,661,624	$76,495,772	$7,686,501	$0	$0	$0
Exec. Office of Energy & Environmental. Affairs	$0	$24,156,812	$0	$0	$0	$391,418
Exec. Office of Health & Human Services	$0	$58,210,506	$0	$25,706,456	$0	$0
Framingham State University	$525,548,586	$0	$17,943,000	$0	$0	$0
Greenfield Community College	$196,362,192	$5,955,640	$187,325	$0	$0	$0
Massachusetts Maritime Academy	$232,687,325	$0	$232,605,111	$0	$0	$0
Massachusetts Parole Board	$0	$9,475,002	$0	$1,149,408	$0	$0
Massachusetts Rehabilitation Commission	$0	$61,647,774	$0	$0	$0	$2,905,048
Military Division	$1,476,931,058	$0	$34,326,892	$0	$41,271,262	$0
North Shore Community College	$236,057,960	$10,662,448	$0	$4,741,258	$0	$0
Northern Essex Community College	$320,744,766	$9,272,584	$0	$0	$48,264,364	$9,272,584
Office of Labor and Workforce Development	$38,062,268	$0	$0	$0	$6,237,764	$0
Public Employee Retirement Admin. Comm.	$0	$3,874,110	$0	$0	$0	$3,874,110
Quinsigamond Community College	$298,979,215	$2,986,432	$0	$0	$0	$0
Salem State University	$1,018,650,440	$4,126,890	$0	$0	$107,877,188	$0
Secretary of State	$62,377,670	$26,693,420	$62,377,670	$3,468,264	$0	$3,119,326
Sheriff's Department Essex	$303,181,072	$9,988,614	$0	$0	$0	$1,404,350
Sheriff's Department Middlesex	$375,809,742	$7,995,202	$0	$0	$0	$3,990,652
Sheriff's Department Nantucket	$0	$814,810	$0	$814,810	$0	$0
Trial Court	$4,924,453,586	$196,022,756	$172,207,994	$3,767,238	$27,141,504	$21,486,614
University of Massachusetts at Amherst	$4,028,521,689	$3,050,668	$2,845,772	$0	$12,223,798	$0
University of Massachusetts at Dartmouth	$735,541,470	$30,960,288	$142,500	$0	$0	$0
University of Massachusetts at Lowell	$2,527,775,117	$0	$50,105,744	$0	$0	$0
Westfield State University	$566,499,830	$15,409,090	$0	$0	$0	$15,188,750
Total	**$40,182,104,110**	**$1,237,950,960**	**$1,447,368,016**	**$64,242,422**	**$297,582,366**	**$108,661,076**

1 - 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.
2 - Where data are available and reported in the best available Digital Flood Insurance Rate Map databases.
3 - Per the data provided, State agencies listed in this table do not have any buildings located in the defined flood zones.

In summary, all mainland counties have state owned or leased property in an A zone. There are five counties with at least one or more state facilities in a V-zone. Structures located within the coastal high hazard area, or V-zone, were assigned a level of high risk to reflect the high levels of damage that can be sustained due to the forces of associated waves. Structures located outside of the V-zone but within the 100-year or 1-percent annual chance flood zone (A-zone), were assigned a moderate risk. Structures located in the 500-year or 0.2-percent annual chance of occurrence zone were assigned a low risk due to the infrequent occurrence of this event. In summary, there are 67 high risk structures, 272 moderate risk structures, and 87 low risk structures. The risk level of the structures is displayed in Figure 10-8.

An assessment was made of the change in flood exposure of state-owned and leased buildings from the 2010 plan to the 2013 plan. Table 10-9 and Table 10-10 summarize the findings.

As noted earlier, the best available data were used for this analysis including effective and preliminary DFIRMs, Q3 data and the digital floodplain layer that had been developed by the Franklin Regional Council of Governments, which only includes the 1-percent floodplain in nine communities along the Connecticut River in Franklin County (see Table 10-3). Since the 2010 update, numerous Counties had updated DFIRM data released: Dukes (2010), Essex (2012), Hampden (preliminary 2012), Middlesex (2010 with Shawsheen Watershed preliminary 2011), Nantucket (preliminary 2012), Plymouth (preliminary 2012), and Worcester (2011 for portion of the County). Further, 2012 preliminary updates have been made for three communities along Buzzards Bay in Plymouth County (Marion, Mattapoisett, and Wareham). The increase/decrease in buildings exposed is due in part to the updated and more accurate flood hazard boundary data available and used for this analysis.

The comparison study shows an increase in the number of buildings exposed to the 1-percent annual chance flood event (both in A and V zones), while a decrease in the number of buildings located in the 0.2-percent flood zone. As mentioned, the new flood hazard boundary data released since 2009 could account for these changes. In general, the hydrograph is changing and the 1-percent annual chance flood hazard areas have increased which are reflected in the new DFIRM databases. This may in part account for the increased number of buildings exposed to the 1-percent annual chance flood event (i.e., located in the A and V zones). Because of the changing hydrograph, the 0.2-percent annual chance flood zones have become 1-percent annual chance flood zones and thus may in part be the reason for the decrease in the number of buildings in the 0.2-percent annual chance flood zones.

The comparison study shows a large increase in the number of state buildings exposed to the flood hazard in Barnstable County. Barnstable County had preliminary DFIRMs at the time of the 2010 plan; however, they were pulled in April 2011 due to inaccuracies and their mapping is being revised as part of the FEMA Risk MAP program. Therefore, only the Q3 data were available for Barnstable County's analysis for this plan update. The differences between the former preliminary DFIRM and Q3 may help explain the increase in number of buildings exposed.

It is important to note that even for counties that did not have new flood hazard boundary data released since 2009, there are changes in the number of buildings exposed. This is due to differences between the December 2009 and the October 2012 building datasets. According to DCAMM, the building data are always being updated, changed and corrected as agencies change or modify. The 2010 plan's building dataset was not available, and an entirely new and updated dataset was obtained from DCAMM and the Office of Leasing for the 2013 plan update.

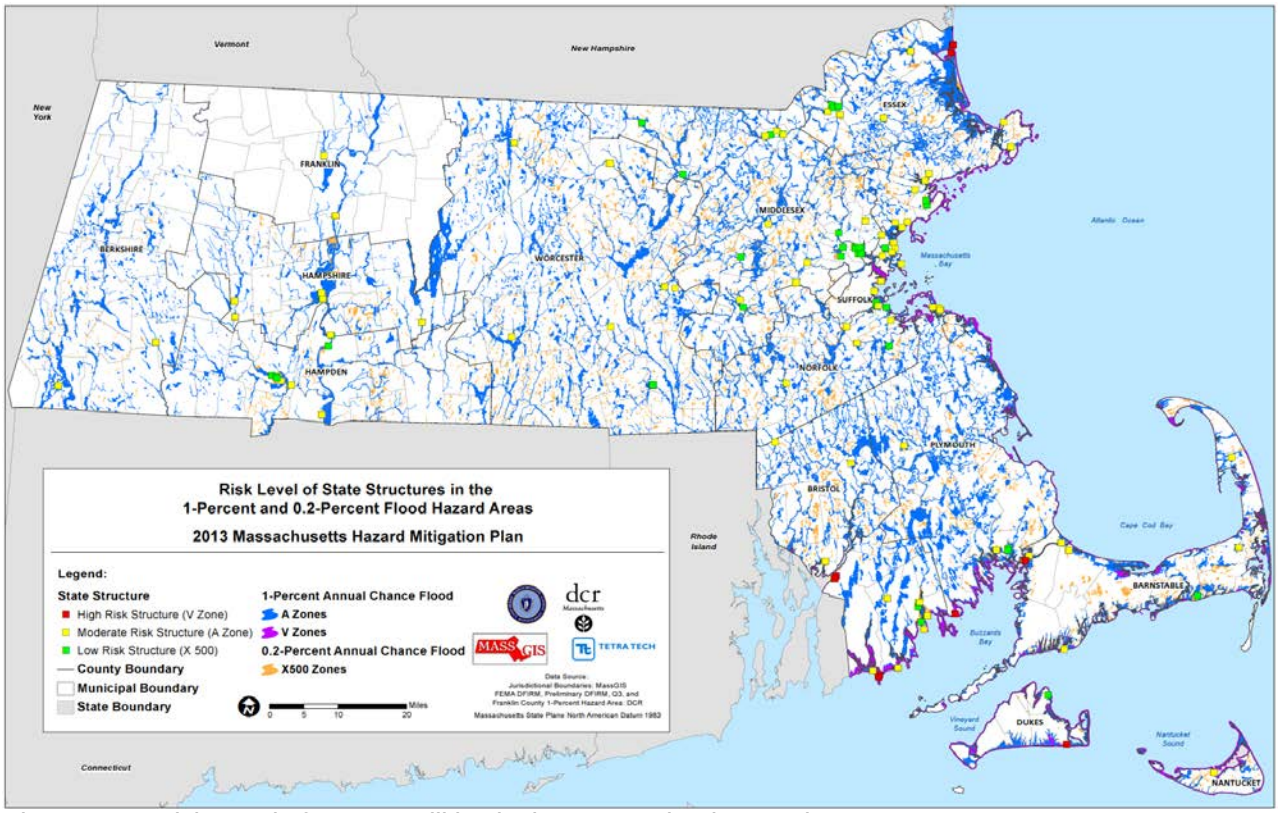

Figure 10-8. Risk Level of State Facilities in the FEMA Flood Hazard Areas

TABLE 10-9.
STATE BUILDING EXPOSURE TO FLOOD HAZARD, 2009 TO 2012 (BUILDING COUNT)

	Number of Buildings in A-Zone			Number of Buildings in V-Zone			Number of Buildings in 500-year Zone		
County	2009	2012	Change	2009	2012	Change	2009	2012	Change
Barnstable*	16	31	+15	4	23	+19	0	3	+3
Berkshire	18	9	-9	0	0	0	3	0	-3
Bristol	22	23	+1	15	37	+22	4	7	+3
Dukes*	0	0	0	1	1	0	1	1	0
Essex*	22	48	+26	1	5	+4	19	16	-3
Franklin	1	12	+11	0	0	0	-	-	-
Hampden*	12	8	-4	0	0	0	13	6	-7
Hampshire	14	24	+10	0	0	0	7	1	-6
Middlesex*	40	14	-26	0	0	0	17	24	+7
Nantucket*	0	2	2	0	0	0	3	0	-3
Norfolk*	25	25	0	0	0	0	13	5	-8
Plymouth*	12	17	+5	11	1	-10	11	13	+2
Suffolk*	28	36	+8	0	0	0	7	4	-3
Worcester*	23	23	0	0	0	0	6	7	+1
Total	**233**	**272**	**+39**	**32**	**67**	**+35**	**104**	**87**	**-17**

*New flood hazard boundary data available since 2009.

TABLE 10-10.
STATE BUILDING EXPOSURE TO FLOOD HAZARD, 2009 TO 2012 (REPLACEMENT COST VALUE)

	Building Replacement Cost Value Exposed to Flood Hazard		
County	2009 (April 2007 values)	2012	Change
Barnstable*	$64,915,500	$351,099,109	+$286,183,609
Berkshire	$7,365,485	$2,029,700	-$5,335,785
Bristol	$107,538,324	$97,396,676	-$10,141,648
Dukes*	0	$1,376,748	+$1,376,748
Essex*	$38,534,447	$385,235,194	+$346,700,747
Franklin	$10,907,370	$14,595,793	+3,688,423
Hampden*	$1,373,630	$77,363,243	+$75,989,613
Hampshire	$72,890,168	$45,818,976	-$27,071,192
Middlesex*	$166,678,526	$199,212,414	+$32,533,888
Nantucket*	0	$941,186	+$941,186
Norfolk*	$17,583,618	$279,422,214	+$261,838,596
Plymouth*	$89,963,517	$56,019,182	-$33,944,335
Suffolk*	$127,815,569	$232,745,798	+104,930,229
Worcester*	$58,515,403	$174,597,647	+$116,082,244
Total	**$764,081,557**	**$1,917,853,880**	**+$1,153,772,323**

*New flood hazard boundary data available since 2009.

The following are the key differences between the two building datasets:

- The 2010 plan used November 2009 DCAMM data with 2007 financial figures as the replacement cost values. For this analysis, replacement cost values not provided by DCAMM or the Office of Leasing were calculated based on square footage and 2011 R.S. Means values for the structure and contents.
- The exact number of buildings in the 2009 DCAMM dataset is unknown; however, the 2010 plan indicates the Commonwealth of Massachusetts owns and operates *just under 6,000 properties across the state*. However, the exact number of buildings could not be determined because the data are no longer available and could not be used or verified for this update. As discussed, for the 2013 plan update the state building data set contained both owned and leased buildings provided by both DCAMM and the Office of Leasing (a total of 6,765 buildings: 432 leased buildings and 6,333 owned buildings). The 2009 building locations were based on 'digitally enhanced and GPS corrected data.' The building data provided by DCAMM and the Office of Leasing in October 2012 were geocoded using the ArcGIS Online North America Streets 10.0 online geocoding service. This is because the data provided with the attributes needed for the risk assessment could not be joined with any existing spatial data set provided by DCAMM. A more detailed description of the methodology can be found in Appendix A.

An analysis was conducted to determine the exposure of the entire building inventory of the Commonwealth of Massachusetts to the flood hazard. To estimate the buildings exposed to the 1-percent and 0.2-percent annual chance flood events, the flood hazard boundaries were overlaid upon the Hazus-MH version 2.1 default general building stock inventory. Census blocks do not follow the boundaries of the floodplain. The Census blocks with their centroid in the flood boundaries were used to calculate the

estimated building replacement cost value exposed to this hazard by County (refer to Table 10-11 and Table 10-12.)

TABLE 10-11.
2012 ESTIMATED GENERAL BUILDING STOCK EXPOSURE TO THE 1-PERCENT ANNUAL CHANCE FLOOD EVENT

		A-Zone		V-Zone		SFHA	
County	Total Replacement Cost Value	Replacement Cost Value	% of Total	Replacement Cost Value	% of Total	Replacement Cost Value	% of Total
Barnstable	$47,450,250,000	$4,997,314,000	10.5	$885,946,000	1.9	$5,883,260,000	12.4
Berkshire	$20,566,219,000	$1,863,294,000	9.1	$0	0.0	$1,863,294,000	9.1
Bristol	$74,946,506,000	$5,043,388,000	6.7	$658,348,000	0.9	$5,701,736,000	7.6
Dukes	$4,894,499,000	$341,598,000	7.0	$69,885,000	1.4	$411,483,000	8.4
Essex	$100,099,771,000	$8,798,859,000	8.8	$675,898,000	0.7	$9,474,757,000	9.5
Franklin	$10,130,548,000	$339,747,000	3.4	$0	0.0	$339,747,000	3.4
Hampden	$67,212,508,000	$2,183,975,000	3.2	$0	0.0	$2,183,975,000	3.2
Hampshire	$20,961,384,000	$1,286,170,000	6.1	$0	0.0	$1,286,170,000	6.1
Middlesex	$244,161,008,000	$12,573,322,000	5.1	$0	0.0	$12,573,322,000	5.1
Nantucket	$3,610,072,000	$387,236,000	10.7	$108,214,000	3.0	$495,450,000	13.7
Norfolk	$111,344,832,000	$9,681,951,000	8.7	$212,539,000	0.2	$9,894,490,000	8.9
Plymouth	$70,614,087,000	$9,447,746,000	13.4	$1,162,525,000	1.6	$10,610,271,000	15.0
Suffolk	$115,439,212,000	$2,764,314,000	2.4	$76,732,000	0.1	$2,841,046,000	2.5
Worcester	$112,858,251,000	$7,134,892,000	6.3	$0	0.0	$7,134,892,000	6.3
Total	**$1,004,289,147,000**	**$66,843,806,000**	**6.7**	**$3,850,087,000**	**0.4**	**$70,693,893,000**	**7.0**

TABLE 10-12.
2012 ESTIMATED GENERAL BUILDING STOCK EXPOSURE TO THE 0.2-PERCENT ANNUAL CHANCE FLOOD EVENT

		X500-Zone	
County	Total Replacement Cost Value	Replacement Cost Value	% of Total
Barnstable	$47,450,250,000	$3,776,587,000	8.0
Berkshire	$20,566,219,000	$352,331,000	1.7
Bristol	$74,946,506,000	$3,444,025,000	4.6
Dukes	$4,894,499,000	$252,480,000	5.2
Essex	$100,099,771,000	$4,013,636,000	4.0
Franklin	$10,130,548,000	NA	NA
Hampden	$67,212,508,000	$2,438,523,000	3.6
Hampshire	$20,961,384,000	$352,804,000	1.7
Middlesex	$244,161,008,000	$9,199,293,000	3.8
Nantucket	$3,610,072,000	$210,985,000	5.8
Norfolk	$111,344,832,000	$2,657,019,000	2.4
Plymouth	$70,614,087,000	$2,088,030,000	3.0
Suffolk	$115,439,212,000	$828,568,000	0.7
Worcester	$112,858,251,000	$2,584,991,000	2.3

Total	**$1,004,289,147,000**	**$32,199,272,000**	**3.2**

10.5.3 Critical Facilities

To estimate the critical facilities exposed to the flood hazard, the flood hazard boundaries were overlaid upon the police stations, fire stations, hospitals, schools (pre-K through grade 12), colleges, and state emergency operation centers. Table 10-13 summarizes the number of facilities in each zone. Critical facilities exposed to the flood hazard are summarized by County in Table 10-14 through Table 10-19.

TABLE 10-13.
SUMMARY OF CRITICAL FACILITY EXPOSURE BY FLOOD HAZARD AREA

Facility Type	Total Number	A Zone	V Zone	X500 Zone	Total Exposed
Police Stations	437	13	0	12	25
Fire Stations	789	30	1	19	50
Hospitals	82	0	0	0	0
Schools (pre-K-12)	2,767	22	0	41	63
Colleges	205	3	0	2	5
Emergency Operations Centers	2	0	0	0	0
Total		**68**	**1**	**74**	**166**

Source: MassGIS, 2012

TABLE 10-14.
POLICE STATIONS EXPOSED TO THE FLOOD HAZARD BY COUNTY

County	Total	A Zone	V Zone	X500
Barnstable	20	2	—	1
Berkshire	33	1	—	1
Bristol	27	4	—	1
Dukes	10	—	—	—
Essex	39	1	—	1
Franklin	26	—	—	—
Hampden	28	—	—	2
Hampshire	23	1	—	2
Middlesex	64	1	—	4
Nantucket	3	—	—	—
Norfolk	32	—	—	—
Plymouth	31	—	—	—
Suffolk	34	1	—	—
Worcester	67	—	—	—
Total	**437**	**11**	**0**	**12**

Source: MassGIS, 2012

TABLE 10-15.
FIRE STATIONS EXPOSED TO THE FLOOD HAZARD BY COUNTY

County	Total	A Zone	V Zone	X500
Barnstable	37	3	—	1
Berkshire	46	3	—	1
Bristol	63	—	—	3
Dukes	8	—	—	1
Essex	82	4	—	1
Franklin	31	—	—	—
Hampden	51	3	—	4
Hampshire	28	1	—	3
Middlesex	164	7	—	4
Nantucket	1	—	—	—
Norfolk	59	—	1	—
Plymouth	67	5	—	—
Suffolk	47	1	—	—
Worcester	105	3	—	1
Total	**789**	**30**	**1**	**19**

Source: MassGIS, 2012

TABLE 10-16.
EMERGENCY OPERATION CENTERS EXPOSED TO THE FLOOD HAZARD BY COUNTY

County	Total	A Zone	V Zone	X500
Barnstable	—	—	—	—
Berkshire	—	—	—	—
Bristol	—	—	—	—
Dukes	—	—	—	—
Essex	—	—	—	—
Franklin	—	—	—	—
Hampden	1	—	—	—
Hampshire	—	—	—	—
Middlesex	1	—	—	—
Nantucket	—	—	—	—
Norfolk	—	—	—	—
Plymouth	—	—	—	—
Suffolk	—	—	—	—
Worcester	—	—	—	—
Total	2	0	0	0

Source: MassGIS, 2012

TABLE 10-17.
HOSPITALS EXPOSED TO THE FLOOD HAZARD BY COUNTY

County	Total	A Zone	V Zone	X500
Barnstable	2	—	—	—
Berkshire	4	—	—	—
Bristol	5	—	—	—
Dukes	1	—	—	—
Essex	10	—	—	—
Franklin	1	—	—	—
Hampden	6	—	—	—
Hampshire	2	—	—	—
Middlesex	16	—	—	—
Nantucket	1	—	—	—
Norfolk	5	—	—	—
Plymouth	4	—	—	—
Suffolk	15	—	—	—
Worcester	10	—	—	—
Total	**82**	**0**	**0**	**0**

Source: MassGIS, 2012

TABLE 10-18.
SCHOOLS EXPOSED TO THE FLOOD HAZARD BY COUNTY

County	Total	A Zone	V Zone	X500
Barnstable	82	2	—	—
Berkshire	76	—	—	—
Bristol	243	—	—	5
Dukes	10	—	—	—
Essex	309	2	—	8
Franklin	53	—	—	—
Hampden	217	—	—	6
Hampshire	113	1	—	4
Middlesex	576	4	—	9
Nantucket	4	—	—	—
Norfolk	286	4	—	1
Plymouth	197	4	—	2
Suffolk	244	3	—	5
Worcester	357	2	—	1
Total	**2,767**	**22**	**0**	**41**

Source: MassGIS, 2012

TABLE 10-19.
COLLEGES EXPOSED TO THE FLOOD HAZARD BY COUNTY

County	Total	A Zone	V Zone	X500
Barnstable	6	1	—	—
Berkshire	6	1	—	—
Bristol	12	—	—	—
Dukes	0	—	—	—
Essex	13	1	—	1
Franklin	3	—	—	—
Hampden	16	—	—	—
Hampshire	5	—	—	—
Middlesex	47	—	—	1
Nantucket	1	—	—	—
Norfolk	21	—	—	—
Plymouth	6	—	—	—
Suffolk	48	—	—	—
Worcester	21	—	—	—
Total	**205**	**3**	**0**	**2**

Source: MassGIS, 2012

To estimate the highway bridges exposed to the flood hazard, the flood hazard boundaries were overlaid upon the major bridge inventory (4,832 total bridges) provided in Hazus-MH 2.1. There are 1,210 bridges with their center within the A zone, 25 bridges in the V zone, and an additional 180 bridges in the X500 zone. Further, there are 9 bridges located in the 'protected by a levee' zone, all of which are located in Hampden County. This listing does not convey whether or not the bridge is designed and built above the base flood elevation. Table 10-20 summarizes these results.

TABLE 10-20.
NUMBER OF BRIDGES IN THE FLOOD HAZARD AREAS BY COUNTY

	Total	A Zone			V Zone			X500 Zone		
County	Exposed	Federal	State	Local	Federal	State	Local	Federal	State	Local
Barnstable	35	1	7	15	—	1	8	—	1	2
Berkshire	169	—	51	104	—	—	—	—	6	8
Bristol	109	—	38	52	—	4	4	—	4	7
Dukes	5	—	3	1	—	1	—	—	—	—
Essex	115	—	53	46	—	—	—	—	14	2
Franklin	27	—	11	16	—	—	—	—	—	—
Hampden	100	2	38	42	—	—	—	—	11	7
Hampshire	118	1	39	70	—	—	—	—	6	2
Middlesex	216	—	81	95	—	—	—	—	32	8

TABLE 10-20.
NUMBER OF BRIDGES IN THE FLOOD HAZARD AREAS BY COUNTY

County	Total Exposed	A Zone			V Zone			X500 Zone		
		Federal	State	Local	Federal	State	Local	Federal	State	Local
Nantucket	—	—	—	—	—	—	—	—	—	—
Norfolk	83	—	33	38	—	1	1	—	8	2
Plymouth	99	—	37	51	—	3	2	—	5	1
Suffolk	47	—	32	15	—	—	—	—	—	—
Worcester	292	5	99	134	—	—	—	—	25	29
Total	**1,415**	**9**	**522**	**679**	**—**	**10**	**15**	**—**	**112**	**68**

Source: Hazus-MH v. 2.1 default highway bridge inventory
Notes: The following owners were listed in the Hazus-MH v. 2.1 default highway bridge inventory (total of 4,832 bridges) and summarized into the federal, state, and local categories. The total number of bridges for each category is noted in parentheses:
Federal (22): National Park Service, Corps of Engineers (CIV)
State (3,344): State Highway Agency; State Park Reservation Agency; Bureau of Fish & Wildlife; Other State Agencies
Local (1,466): Town Highway Agency; City Highway Agency; Local Park Reservation Agency; Local Toll Authority

10.5.4 Economy

Damage to buildings can affect a community's economy and tax base. The area of each County (square miles including water bodies) exposed to the flood hazard was determined. Ten of the 14 Counties have greater than 10-percent of their area in the SFHA (A and V zones). Table 10-21 summarizes these findings.

TABLE 10-21.
2012 AREA LOCATED IN THE FLOOD HAZARD BOUNDARIES

		Area in SFHA (square miles)						Area in 0.2-Percent Flood (X500) Zone (square miles)	
		A-Zones		V-Zones		Total SFHA			
County	Total Area	Area	% of Total	Area	% of Total	Area	% of Total	Area	% of Total
Barnstable	412.48	60.29	14.62	15.27	3.70	75.56	18.32	21.72	5.27
Berkshire	946.39	65.84	6.96	0.00	0.00	65.84	6.96	6.76	0.71
Bristol	571.86	88.94	15.55	24.05	4.21	112.99	19.76	18.7	3.27
Dukes	109.90	11.28	10.26	6.80	6.19	18.08	16.45	3.13	2.85
Essex	514.90	90.36	17.55	4.32	0.84	94.68	18.39	18.89	3.67
Franklin	724.58	17.79	2.46	0.00	0.00	17.79	2.46	NA	NA
Hampden	634.06	46.63	7.35	0.00	0.00	46.63	7.35	13.8	2.18
Hampshire	545.27	51.62	9.47	0.00	0.00	51.62	9.47	10.49	1.92
Middlesex	846.59	99.34	11.73	0.00	0.00	99.34	11.73	34.94	4.13
Nantucket	49.03	7.23	14.75	3.69	7.53	10.92	22.27	2.02	4.12
Norfolk	408.54	56.38	13.80	0.79	0.19	57.17	13.99	15.47	3.79
Plymouth	689.77	129.62	18.79	10.40	1.51	140.02	20.30	18.68	2.71
Suffolk	59.74	10.11	16.92	0.30	0.50	10.41	17.43	1.62	2.71
Worcester	1,579.21	165.01	10.45	0.00	0.00	165.01	10.45	39.51	2.50
Total	**8,092.30**	**900.44**	**11.13**	**65.62**	**0.81**	**966.06**	**11.94**	**205.73**	**2.54**

Note: Franklin County does not have DFIRMs or Q3 data; however, a digital floodplain layer that had been developed by the Franklin Regional Council of Governments, which only includes the floodplain in the nine communities along the Connecticut River, was used for this analysis.

10.6 VULNERABILITY

To assess the Commonwealth's vulnerability to the flood hazard, potential losses were determined for the 1-percent and 0.2-percent annual chance flood events. The methodology used to assess vulnerability and the results are summarized within each subsection below.

10.6.1 Population

Of the population exposed, the most vulnerable include the economically disadvantaged and the population over the age of 65. Economically disadvantaged populations are more vulnerable because they are likely to evaluate their risk and make decisions to evacuate based on the net economic impact to their family. The population over the age of 65 is also more vulnerable because they are more likely to seek or need medical attention, which may not be available due to isolation during a flood event, and they may have more difficulty evacuating (see Section 4)

The total number of injuries and casualties resulting from typical riverine flooding is generally limited based on advance weather forecasting, blockades, and warnings. This historical record from 1993 to 2011 indicates there have only been two fatalities associated with a flood event (May 2006) and five injuries associated with two flood events (events occurred within two weeks of each other in March 2010). Injuries and deaths generally are not anticipated if proper warning and precautions are in place.

Ongoing mitigation efforts should help to avoid the most likely cause of injury, which results from persons trying to cross flooded roadways or channels during a flood.

Similar to riverine flooding, of the population exposed to flash flooding, the most vulnerable include the economically disadvantaged and the population over the age of 65. There is often limited warning time for flash flooding. These events are frequently associated with other natural hazard events such as earthquakes, landslides, or severe weather, which limits their predictability and compounds the hazard. Populations without adequate warning of the event are highly vulnerable to this hazard.

10.6.2 State Facilities

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 10-8 identifies a total risk exposure of greater than $1.5 billion for state-owned and leased buildings in areas potentially subject to the 1-percent annual chance flood event (A- and V-zones). For the 0.2-percent annual chance event, an additional $406 million is exposed and potentially at risk. These figures assume 100-percent loss to each structure and its contents. This estimate is considered high because flood events are generally centered within a region or watershed and do not typically occur across the entire Commonwealth at the same time. In addition, structure and content losses generally do not occur to the entire inventory exposed.

We acknowledge this methodology's limitations and have identified activities in our mitigation strategy that will advance the accuracy of the flood potential loss estimates. This includes the state agency review and validation of the owned and leased structure data in terms of location, replacement cost value of structure and contents and all relevant attributes for analysis. In addition, performing further GIS analysis in the Hazus-MH flood model by incorporating the flood-depth grids that will be available through FEMA's Risk MAP in the future.

10.6.3 Critical Facilities

Similar to the state facilities, to estimate potential losses to critical facilities and infrastructure, the exposure analysis methodology was used. 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. As these data become available, the Commonwealth will update this section of the plan with new information.

In terms of highway bridges, the Hazus-MH v. 2.1 default replacement cost value for the bridges located in the 1-percent hazard area (A and V zones) is greater than $18 Billion (of the greater than $68 Billion total); an additional $2.6 Billion located in the 0.2-percent annual chance hazard area.

10.6.4 Severe Repetitive Loss Data

The NFIP data are a useful tool to determine the location of areas vulnerable to flood and severe storm hazards. Table 10-22 summarizes the NFIP policies, claims, repetitive loss, and severe repetitive loss properties in each county. Appendix I provides a detailed list of NFIP flood claims by county and municipality. As a method to examine the percentage of policies, repetitive loss and severe repetitive loss properties to the total number of housing units in each County, the 2011 total number of housing units was used.

TABLE 10-22.
NFIP POLICIES, CLAIMS, AND REPETITIVE LOSS STATISTICS

County	Number of Housing Units (2011)	Policies	% of Housing Units	Claims	Total Loss Payment	Repetitive Losses	% of Housing Units	Severe Repetitive Losses	% of Housing Units
Barnstable	161,001	10,567	6.6	1,523	$13,145,429	149	0.09	4	< 1
Berkshire	68,497	1,160	1.7	372	$2,811,377	31	0.05		
Bristol	231,083	4,067	1.8	3,296	$26,044,259	70	0.03		
Dukes	17,385	894	5.1	162	$1,605,265	17	0.10		
Essex	307,559	8,483	2.8	4,518	$68,578,887	500	0.16	17	< 1
Franklin	33,806	219	< 1	99	$3,713,435	3	0.01		
Hampden	192,197	1,185	< 1	237	$2,341,848	9	0.00		
Hampshire	62,766	555	< 1	184	$1,647,256	21	0.03	1	< 1
Middlesex	614,036	7,453	1.2	3,165	$30,069,052	365	0.06	13	< 1
Nantucket	11,776	896	7.6	414	$12,222,739	49	0.42		
Norfolk	271,502	6,401	2.4	2,612	$27,370,558	265	0.10	12	< 1
Plymouth	201,419	10,564	5.2	8,979	$104,700,955	1,060	0.53	107	< 1
Suffolk	317,327	4,158	1.3	3,914	$21,570,064	457	0.14	22	< 1
Worcester	328,586	2,071	< 1	648	$9,041,964	66	0.02	1	< 1
Total	**2,818,940**	**58,673**	**2.1**	**30,123**	**$324,863,088**	**3,062**	**0.11**	**177**	**< 1**

Sources:
Number of policies (as of November 30, 2012) is from http://bsa.nfipstat.fema.gov/reports/1011.htm#MAT
Number of claims, total loss payments, and number of repetitive loss and severe repetitive loss properties is from FEMA Region 1 as of November 30, 2012.

Barnstable, Nantucket, and Dukes Counties have the highest percentage of policies. The majority of the repetitive loss and severe repetitive loss properties are located in eastern Massachusetts, with the largest number along the coast in the Counties of Barnstable, Essex, Middlesex, Norfolk, Plymouth, and Suffolk.

Figure 10-9 and Figure 10-10 show the number of repetitive loss and severe repetitive loss properties in each municipality.

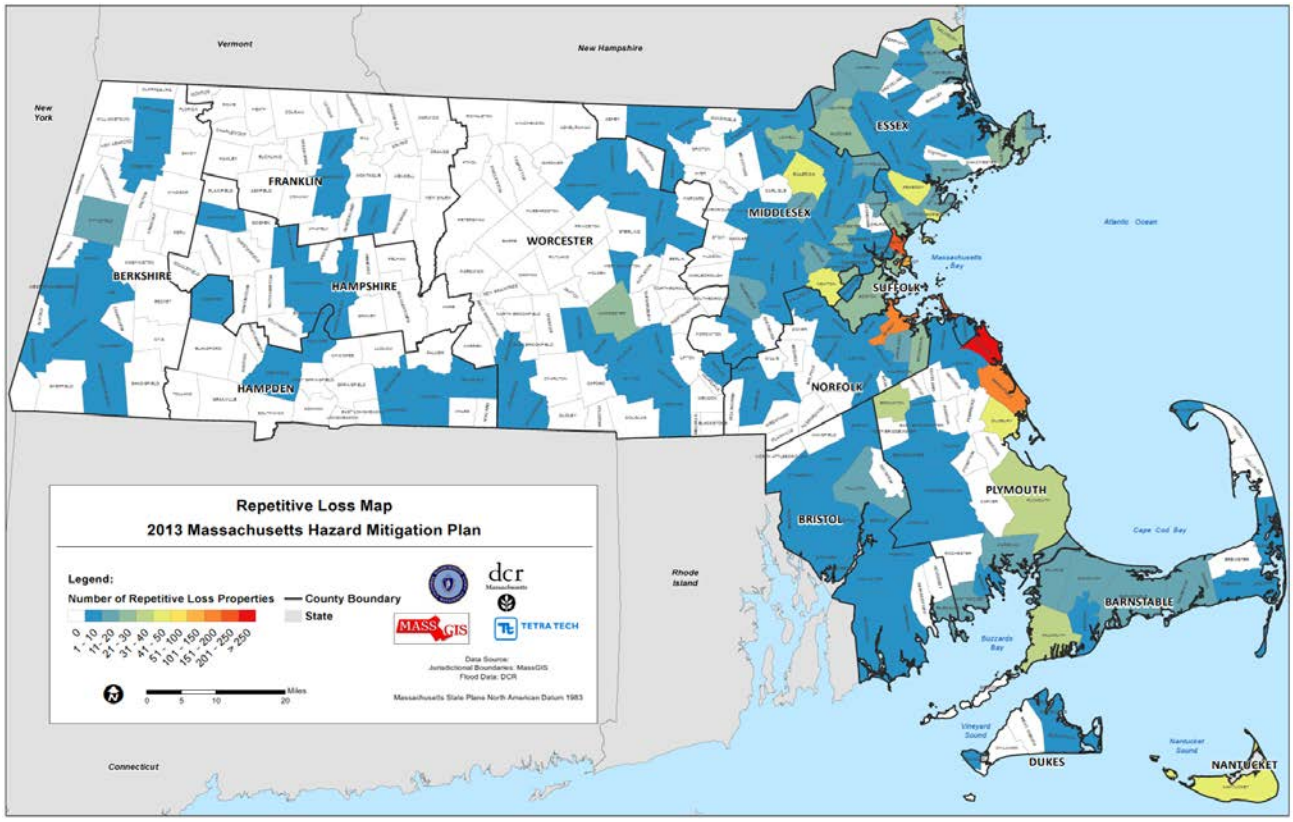

Figure 10-9. NFIP Repetitive Loss Areas

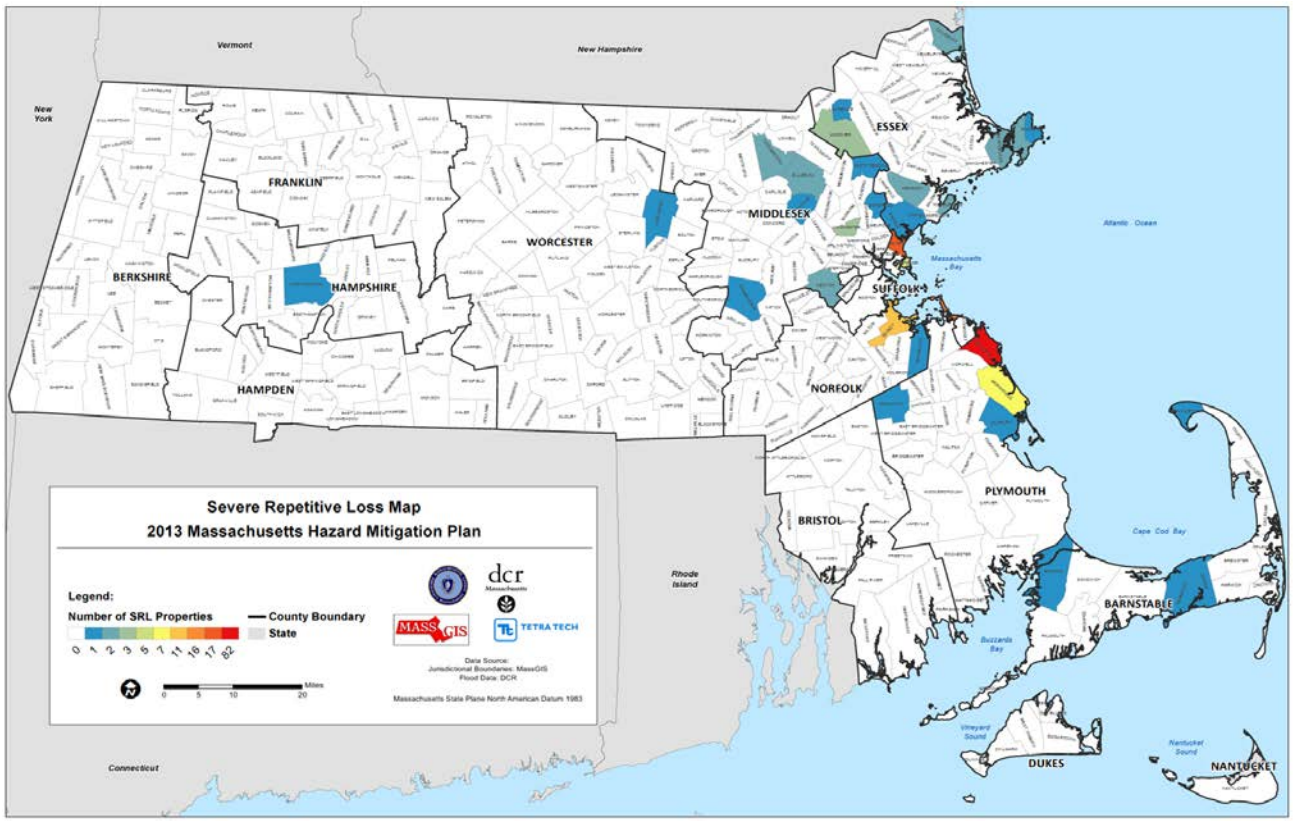

Figure 10-10. NFIP Severe Repetitive Loss Areas

Updated data for Repetitive Loss and Severe Repetitive Loss properties are identified for the years 2006-2012 in Table 10-23. In the 2010 Plan, the top 15 municipalities with the highest number of repetitive loss properties were examined. The same municipalities appear in the top 15 again, with the exception of Brockton, which is new to the list. To include all 15 municipalities previously included in the 2006 and 2010 analysis, the top 20 municipalities are reported. These municipalities are all located in eastern Massachusetts with the exception of Worcester in Worcester County.

TABLE 10-23.
NFIP REPETITIVE LOSS AND SEVERE REPETITIVE LOSS DATA

	2006			2009			2012		
Community	SRL Properties	RL Properties	RL Claims	SRL Properties	RL Properties	RL Claims	SRL Properties	RL Properties	RL Claims
Scituate	50	502	1,504	52	503	1,551	82	490	1,708
Revere	16	274	873	16	288	935	17	293	962
Hull	6	230	680	7	235	713	16	238	778
Quincy	1	131	364	1	144	408	11	169	513
Marshfield	3	155	419	3	156	442	7	158	474
Winthrop	1	139	386	5	136	396	5	140	411
Billerica	1	38	104	1	41	110	2	50	151
Nantucket	1	45	106	1	47	113	0	49	122
Nahant	1	45	123	1	46	133	2	46	136
Peabody	0	30	105	1	37	131	2	44	179
Swampscott	1	37	107	1	37	108	0	44	128
Duxbury	1	39	107	1	42	121	1	42	126
Newton	2	29	77	2	30	81	2	42	109
Brockton	*	*	*	*	*	*	1	38	100
Plymouth	2	33	86	2	34	91	0	37	100
Salisbury	*	*	*	*	*	*	2	34	100
Falmouth	0	32	72	0	34	76	0	33	74
Saugus	*	*	*	*	*	*	1	30	77
Worcester	*	*	*	*	*	*	0	29	81
Arlington	*	*	*	*	*	*	0	29	66

Source: FEMA Region 1
Notes: Top 20 repetitive loss communities for 2012, ordered by number of repetitive loss properties are provided in the table. Data listed for 2009 are through December 2009. Data listed for 2012 are through November 30, 2012. RL = Repetitive Loss; SRL = Severe Repetitive Loss. Asterisk (*) = data not available.

10.6.5 Economy

Economic losses due to a flood include, but are not limited to damage to buildings and infrastructure, agricultural losses, business interruption, impacts on tourism, and tax base. Damage to buildings can be estimated using the exposure analysis above. Other economic components such as loss of facility use, functional downtime, and social economic factors are less measurable with a high degree of certainty.

Flooding can cause extensive damage to public utilities and disruptions to the delivery of services. Loss of power and communications may occur, and drinking water and wastewater treatment facilities may be temporarily out of operation. Flooded streets and roadblocks make it difficult for emergency vehicles to respond to calls for service. Floodwaters can wash out sections of roadway and bridges, and the removal and disposal of debris can also be an enormous cost during the recovery phase of a flood event.

Direct building losses are the estimated costs to repair or replace the damage caused to the building. As discussed, the potential damage estimated to the state facilities associated with the 1-percent annual chance flood is greater than $1.5 billion.