TABLES

FIGURES

SECTION 11. HURRICANES AND TROPICAL STORMS

11.1 GENERAL BACKGROUND

11.1.1 Tropical Storms

A tropical storm system is characterized by a low-pressure center and numerous thunderstorms that produce strong winds and heavy rain (winds are at a lower speed than hurricane-force winds, thus gaining its status as tropical storm versus hurricane). Tropical storms strengthen when water evaporated from the ocean is released as the saturated air rises, resulting in condensation of water vapor contained in the moist air. They are fueled by a different heat mechanism than other cyclonic windstorms such as Nor'easters and polar lows. The characteristic that separates tropical cyclones from other cyclonic systems is that at any height in the atmosphere, the center of a tropical cyclone will be warmer than its surroundings; a phenomenon called "warm core" storm systems.

The term "tropical" refers both to the geographical origin of these systems, which usually form in tropical regions of the globe, and to their formation in maritime tropical air masses. The term "cyclone" refers to such storms' cyclonic nature, with counterclockwise wind flow in the Northern Hemisphere, and clockwise wind flow in the Southern Hemisphere. The opposite direction of the wind flow is a result of the Coriolis force.

Tropical storms and tropical depressions, while generally less dangerous than hurricanes, can be deadly. The winds of tropical depressions/storms are usually not the greatest threat; rather, the rains, flooding, and severe weather associated with the tropical storms are what customarily cause more significant problems. Serious power outages can also be associated with these types of events. After the passing of Hurricane Irene through the region as a tropical storm in late August 2011, many areas of the Commonwealth were without power for in excess of 5 days.

While tropical storms can produce extremely powerful winds and torrential rain, they are also able to produce high waves, damaging storm surge, and tornadoes. They develop over large bodies of warm water, and lose their strength if they move over land due to increased surface friction and loss of the warm ocean as an energy source. This is why coastal regions can receive significant damage from a tropical cyclone. Similar impacts can be sustained from winds associated with a storm of this nature progressing far inland. Heavy rains, however, can produce significant flooding inland, and storm surges can produce extensive coastal flooding up to 25 miles from the coastline.

One measure of the size of a tropical cyclone is determined by measuring the distance from its center of circulation to its outermost closed isobar. If the radius is less than 2 degrees of latitude, or 138 miles, then the cyclone is "very small" or a "midget." A radius between 3 and 6 latitude degrees, or 207 to 420 miles, is considered "average-sized." "Very large" tropical cyclones have a radius of greater than 8 degrees or 552 miles.

11.1.2 Hurricanes

Hurricanes begin as tropical storms over the warm moist waters of the Atlantic, off the coast of West Africa, and Pacific Oceans near the equator. As the moisture evaporates, it rises until enormous amounts of heated, moist air are twisted high in the atmosphere. The winds begin to circle counterclockwise north of the equator or clockwise south of the equator. The center of the hurricane is called the eye. Figure 11-1 shows the progressive development of hurricanes.

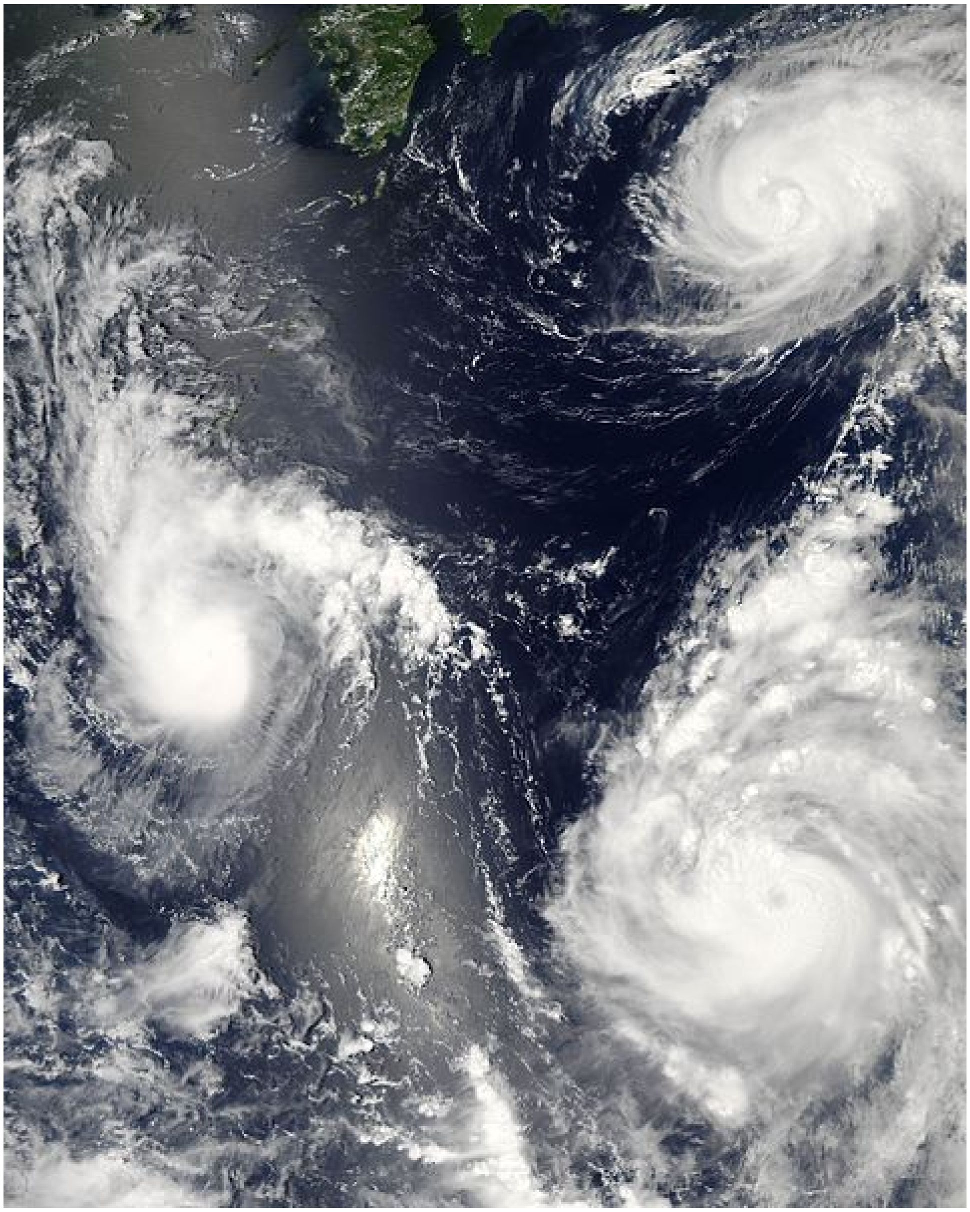

Figure 11-1. Tropical Storm Stages of Development: Weakest (left), with Only Basic Circular Shape; Stronger (top right) with Spiral Banding and Increased Centralization; Strongest (lower right) with an Eye

Tropical cyclones (tropical depressions, tropical storms, and hurricanes) form over the warm, moist waters of the Atlantic, Caribbean, and Gulf of Mexico.

- A tropical depression is declared when there is a low-pressure center in the tropics with sustained winds of 25 to 33 mph.
- A tropical storm is a named event, defined as having sustained winds from 34 to 73 mph.
- If sustained winds reach 74 mph or greater, it becomes a hurricane. The Saffir-Simpson scale ranks hurricanes based on sustained wind speeds—from Category 1 (74 to 95 mph) to Category 5 (156 mph or more). Category 3, 4, and 5 hurricanes are considered "Major" hurricanes. Hurricanes are categorized based on sustained winds; wind gusts associated with hurricanes may exceed the sustained winds and cause more severe localized damage.

When water temperatures are at least 80° F, hurricanes can grow and thrive, generating enormous amounts of energy, which is released in the form of numerous thunderstorms, flooding rainfall, and, very damaging winds. The damaging winds help create a dangerous storm surge (rise in the water above the normal astronomical tide). While in the lower latitudes, hurricanes tend to move from east to west. However, when a storm drifts further north, the westerly flow at the mid-latitudes tends to cause the storm to curve toward the north and east. When this occurs, the storm may accelerate its forward speed. This is one of the reasons why some of the strongest hurricanes of record have reached New England.

Hurricanes can range from as small as 50 miles across to as much as 500 miles wide; Hurricane Allen in 1980 took up the entire Gulf of Mexico. There generally are two source regions for the storms that have the potential to strike New England: 1) off the Cape Verde Islands near the west coast of Africa, and 2) in the Bahamas. The Cape Verde storms tend to be very large in diameter, since they have a week or more to traverse the Atlantic Ocean and grow. Bahamas storms tend to be smaller, but they can also be just as powerful, and their effects can reach New England in only a day or two.

The eye of a hurricane is a relatively calm center, where extremely low barometric pressure exists. The location of the eye is not that important for New Englanders because the average forward speed of the entire storm averages 33 mph at the latitude of the Commonwealth. Customarily, an eye that is 15 miles wide will last for 30 minutes or less at any one location.

As our tropical systems customarily come from a southerly direction and accelerate up the east coast of the U.S., most take on a distinct appearance that is different from the classic hurricanes. Instead of having a perfectly concentric storm with heavy rain blowing from one direction, then the calm eye, then the heavy rain blowing from the opposite direction, our storms (as viewed from satellite and radar) take on an almost winter storm-like appearance. To the south and east of the track of the storm, there often are only a few showers and in fact, the sky may be sunny. But, this is normally where the worst winds and storm surge are located. To the north and west of the track of the storm is customarily where dangerous flooding rains most often occur. An additional threat associated with a tropical system from a landfall perspective is the isolated Tornados which may occur. These generally would occur in the outer bands to the north and east of the storm, a few hours to as much as 15 hours prior to landfall or near land events.

The official hurricane season runs from June 1 to November 30. However, from 1950-2012, there are no records of a land-falling hurricane in New England during June or July. August, September, and the first half of October are when the storms most frequently occur for New England. This is due, in large part, to the fact that it takes a considerable amount of time for the waters south of Long Island to warm to the temperature necessary to sustain the storms this far north. Also, as the Region progresses into the fall months, the upper level jet stream has more dips, meaning that the steering winds might flow from the Great Lakes southward to the Gulf States and then back northward up the eastern seaboard. This pattern would be conducive for capturing a tropical system over the Bahamas and accelerating it northward.

11.1.3 Saffir/Simpson Hurricane Scale

The Saffir/Simpson scale categorizes or rates hurricanes from 1 (Minimal) to 5 (Catastrophic) based on their intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline, in the landfall region. All winds are using the U.S. 1-minute average, meaning the highest wind that is sustained for 1-minute. The Saffir/Simpson Scale described in Table 11-1 gives an overview of the wind speeds and range of damage caused by different hurricane categories.

TABLE 11-1.
SAFFIR/SIMPSON SCALE (NOAA)

Scale No. (Category)	Winds (mph)	Potential Damage
1	74 – 95	Minimal: Damage is primarily to shrubbery and trees, mobile homes, and some signs. No real damage is done to structures.
2	96 – 110	Moderate: Some trees topple, some roof coverings are damaged, and major damage is done to mobile homes.
3	111 – 130	Extensive: Large trees topple, some structural damage is done to roofs, mobile homes are destroyed, and structural damage is done to small homes and utility buildings.
4	131 – 155	Extreme: Extensive damage is done to roofs, windows, and doors; roof systems on small buildings completely fail; and some curtain walls fail.
5	> 155	Catastrophic: Roof damage is considerable and widespread, window and door damage is severe, there are extensive glass failures, and entire buildings could fail.
Additional Classifications		
Tropical Storm	39-73	NA
Tropical Depression	< 38	NA

mph = Miles per hour; NA = not applicable

11.1.4 SLOSH Mapping

The U.S. Army Corps of Engineers New England Division, in cooperation with FEMA, prepared Sea, Lake and Overland Surge from Hurricanes (SLOSH) inundation maps. SLOSH mapping represents potential flooding from worst-case combinations of hurricane direction, forward speed, landfall point, and high astronomical tide. It does not include riverine flooding caused by hurricane surge or inland freshwater flooding. The model, developed by the National Weather Service to forecast surges that occur from wind and pressure forces of hurricanes, considers only storm surge height and does not consider the effects of waves. The mapping was developed for New England coastal communities using the computer model, Long Island Sound bathymetry, and New England coastline topography.

In Massachusetts, hurricane category is the predominant factor in “worst case” hurricane surges. The resulting inundation areas are grouped into Category 1 and 2, Category 3, and Category 4. The hurricane category refers to the Saffir/Simpson Hurricane Intensity Scale. The Corps of Engineers considered the highest wind speed for each category, the highest surge level, combined with worst-case forward motion and developed a model to depict areas that would be inundated under those combined conditions. For New England, only Categories 1-3 were used.

For the 2013 SHMP, updated SLOSH maps split eastern Massachusetts into several sections and overlay the SLOSH inundation zones on base layers provided by FEMA Region IV Coastal Flood Loss Atlas team. These maps were developed for all Massachusetts’ coastal counties. Refer Figure 11-2 through Figure 11-8. The SLOSH maps do not account for future sea-level rise scenarios.

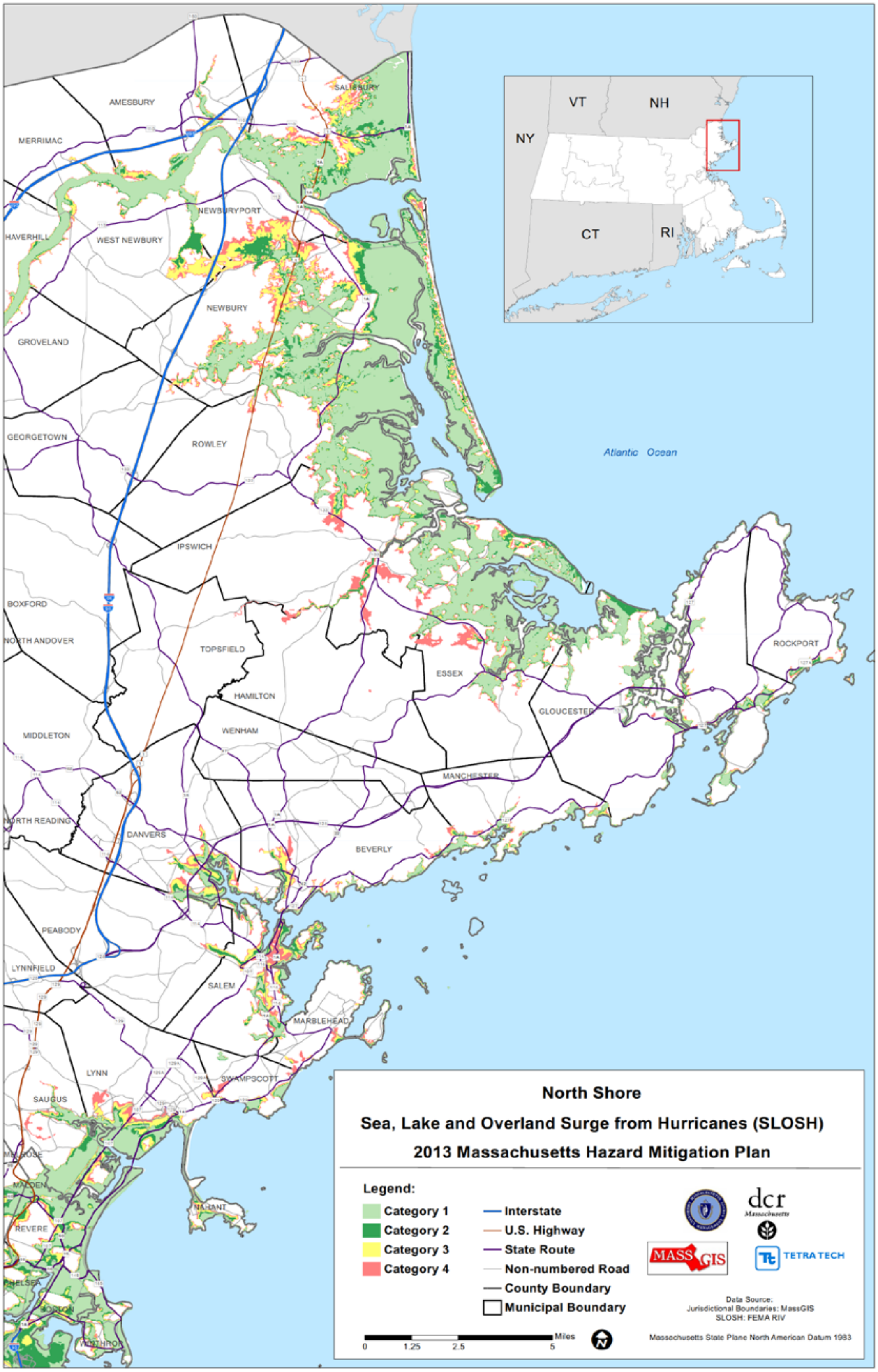

Figure 11-2. North Shore SLOSH Inundation Areas

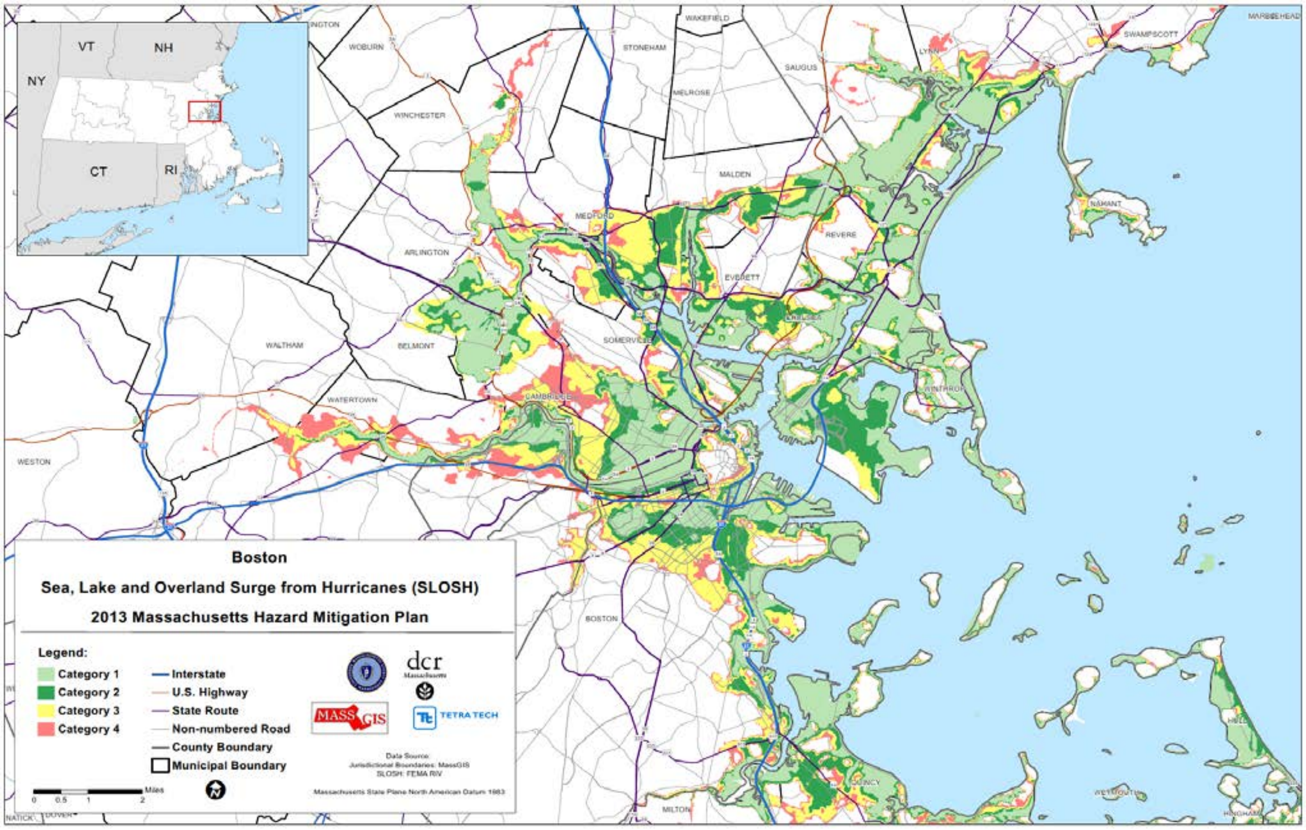

Figure 11-3. Boston SLOSH Inundation Areas

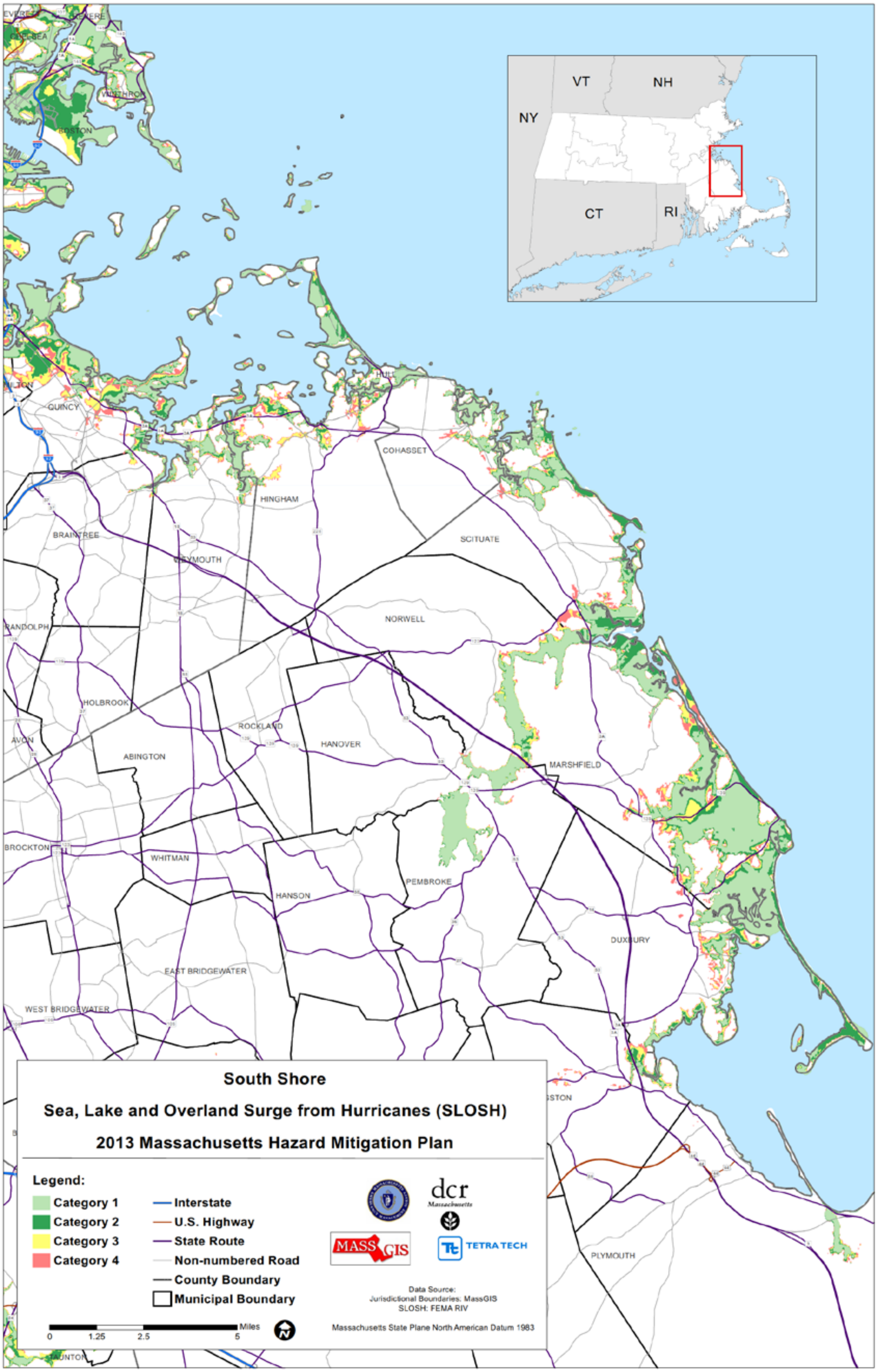

Figure 11-4. South Shore SLOSH Inundation Areas

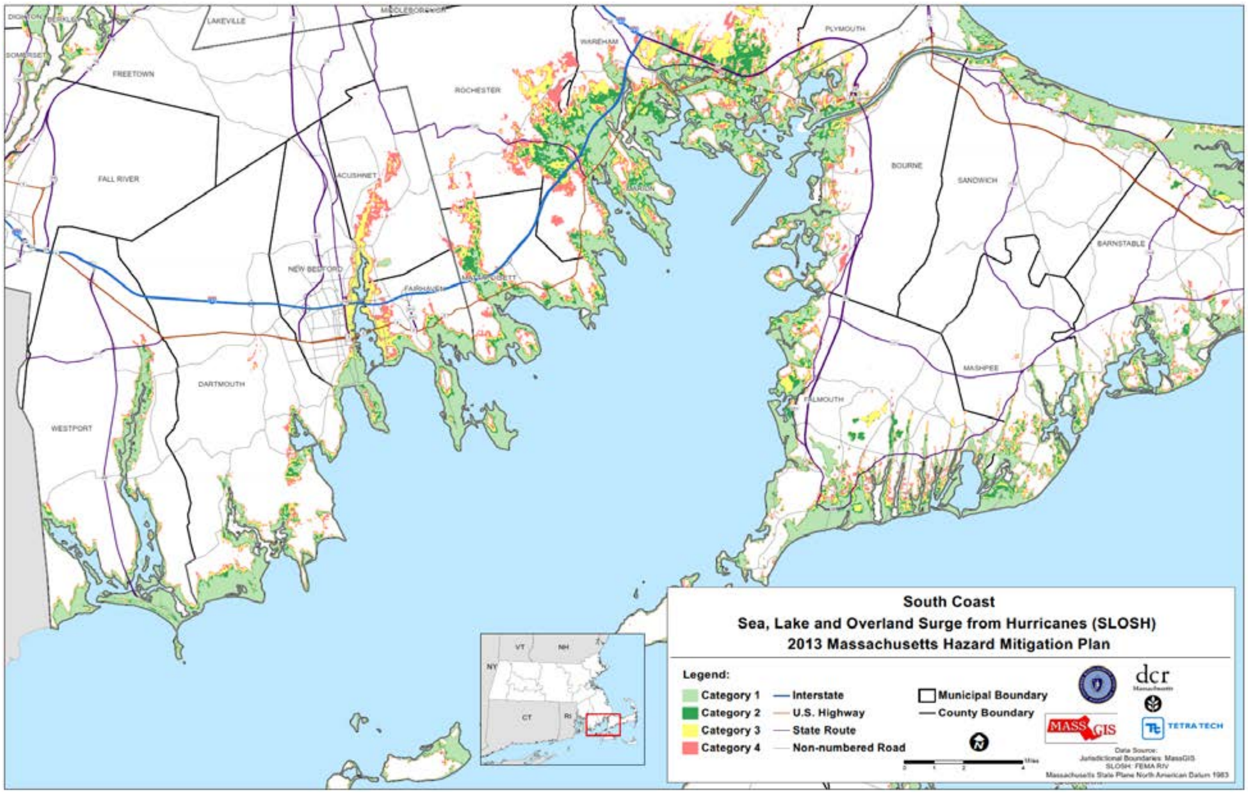

Figure 11-5. South Coastal SLOSH Inundation Areas

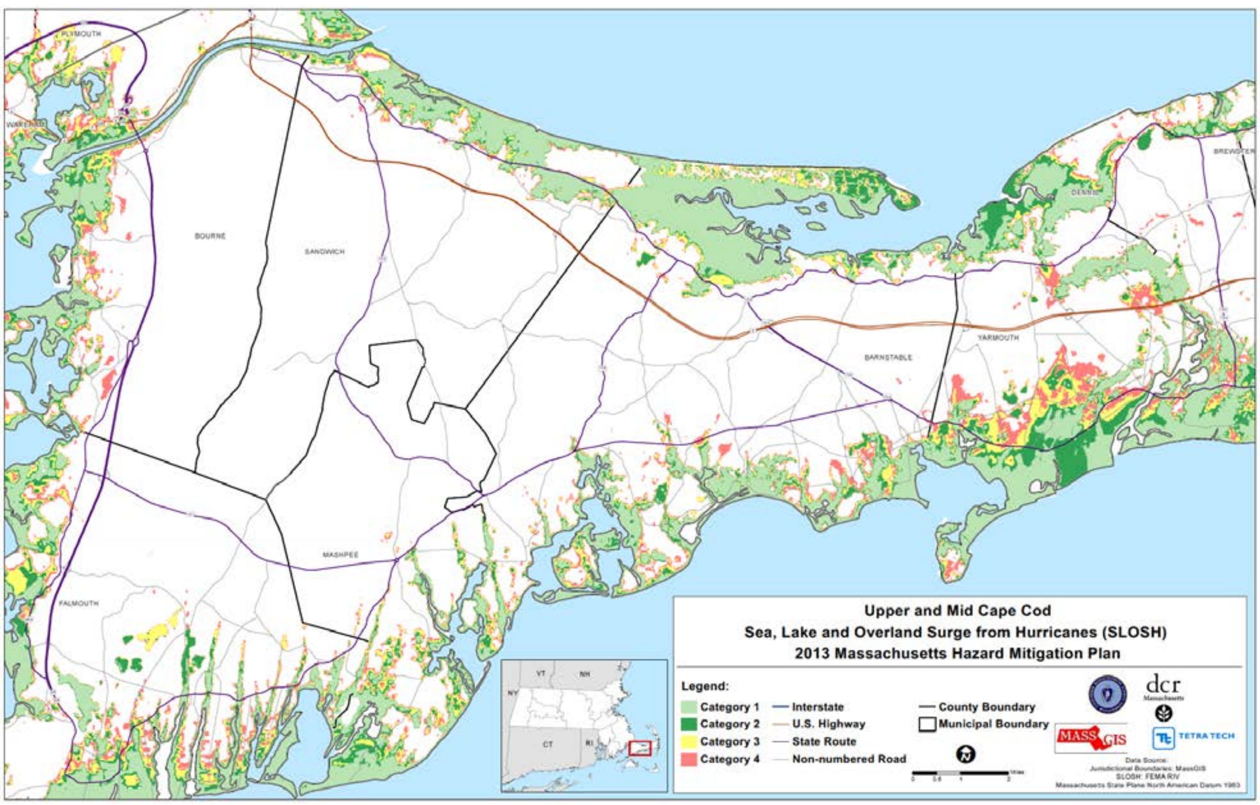

Figure 11-6. Upper and Mid Cape Cod SLOSH Inundation Areas

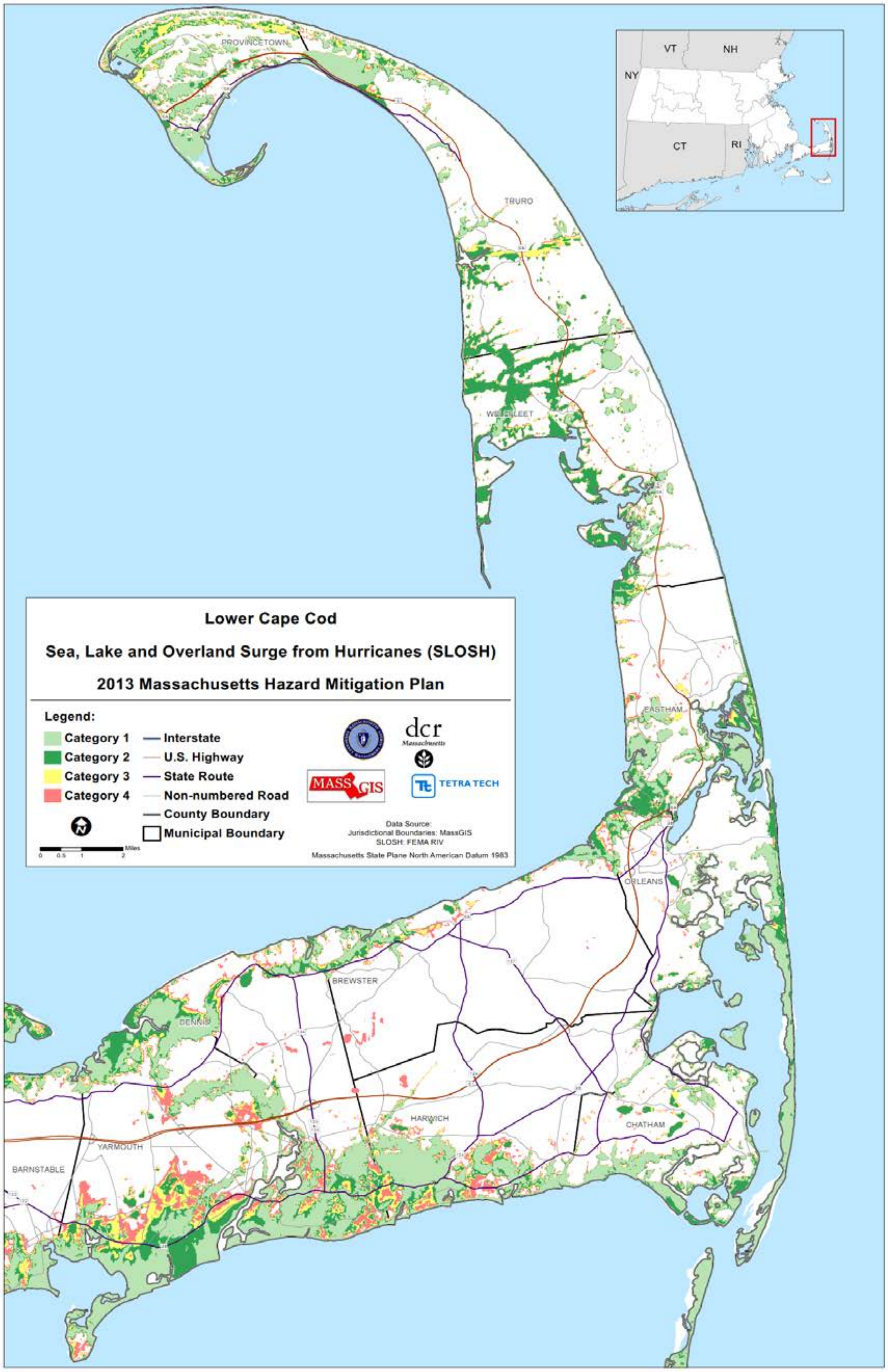

Figure 11-7. Lower Cape Cod SLOSH Inundation Areas

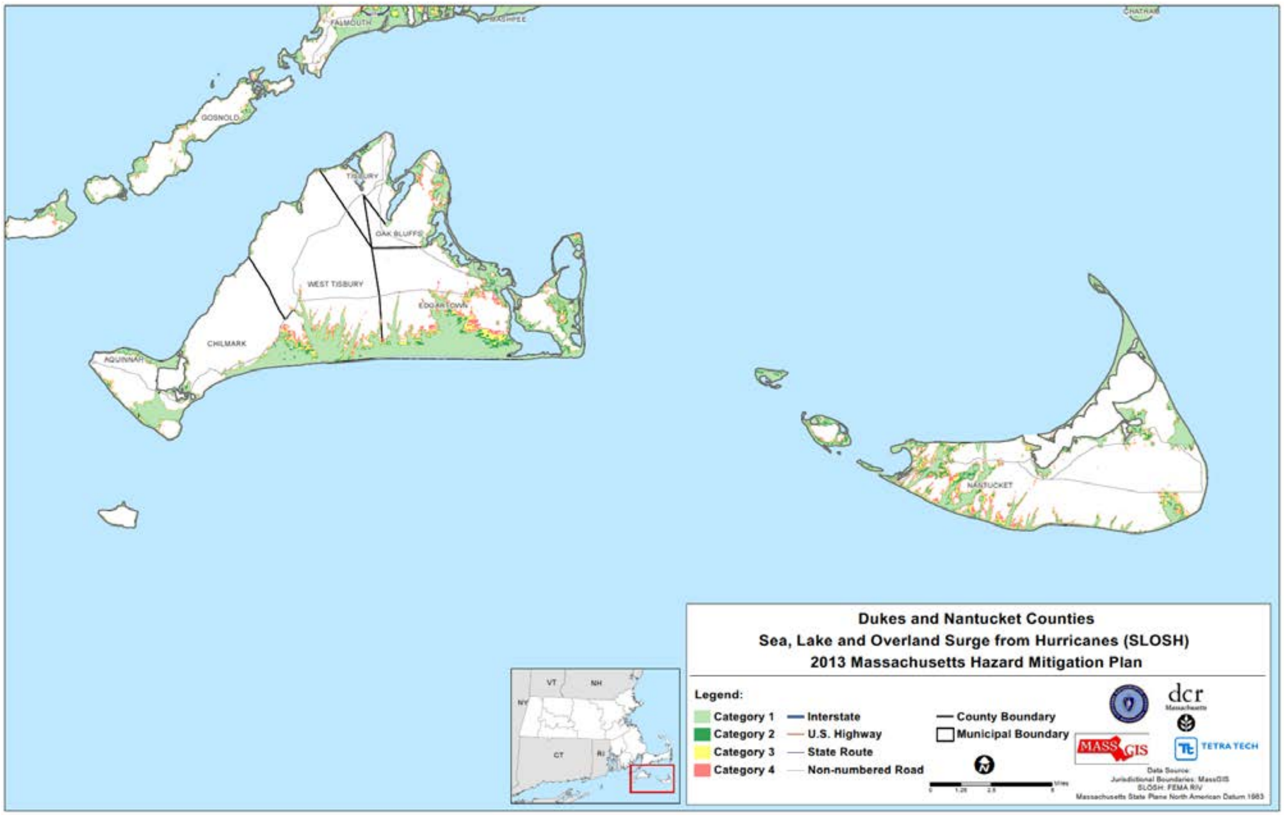

Figure 11-8. Dukes and Nantucket Counties SLOSH Inundation Areas

11.2 HAZARD PROFILE

11.2.1 Location

The Commonwealth of Massachusetts and its 78 coastal communities are vulnerable to the damaging impacts of major storms along its more than 1,500 miles of varied coastline. As development and re-development increases, less-intense storms that occur more regularly and sea-level rise will also lead to costly storm damage. The entire Commonwealth is vulnerable to hurricanes and tropical storms, dependent on the storm's track. The coastal areas are more susceptible to damage due to the combination of both high winds and tidal surge, as depicted on the SLOSH maps. Inland areas, especially those in floodplains, are also at risk for flooding, due to heavy rain, and wind damage. The majority of damage following hurricanes and tropical storms often results from residual wind damage and inland flooding, as was demonstrated during recent tropical storms.

NOAA's Historical Hurricane Tracks tool is a public interactive mapping application that displays Atlantic Basin and East-Central Pacific Basin tropical cyclone data. This interactive tool tracks tropical cyclones from 1842 to 2011 (latest date available from data source). Figure 11-9 and Figure 11-10 display tropical cyclone tracks for the Commonwealth; however, the associated names for some of these events are unknown. Between 1851 and 2011, Massachusetts has experienced in excess of 70 tropical cyclone events. These events occurred within 65 nautical miles of the Commonwealth. Abbreviations used on these figures denote tropical storms/subtropical storms as TS/SS, tropical depressions/subtropical depressions as TD/SD, and extra-tropical storms as ET.

Source: http://csc.noaa.gov/hurricanes/#

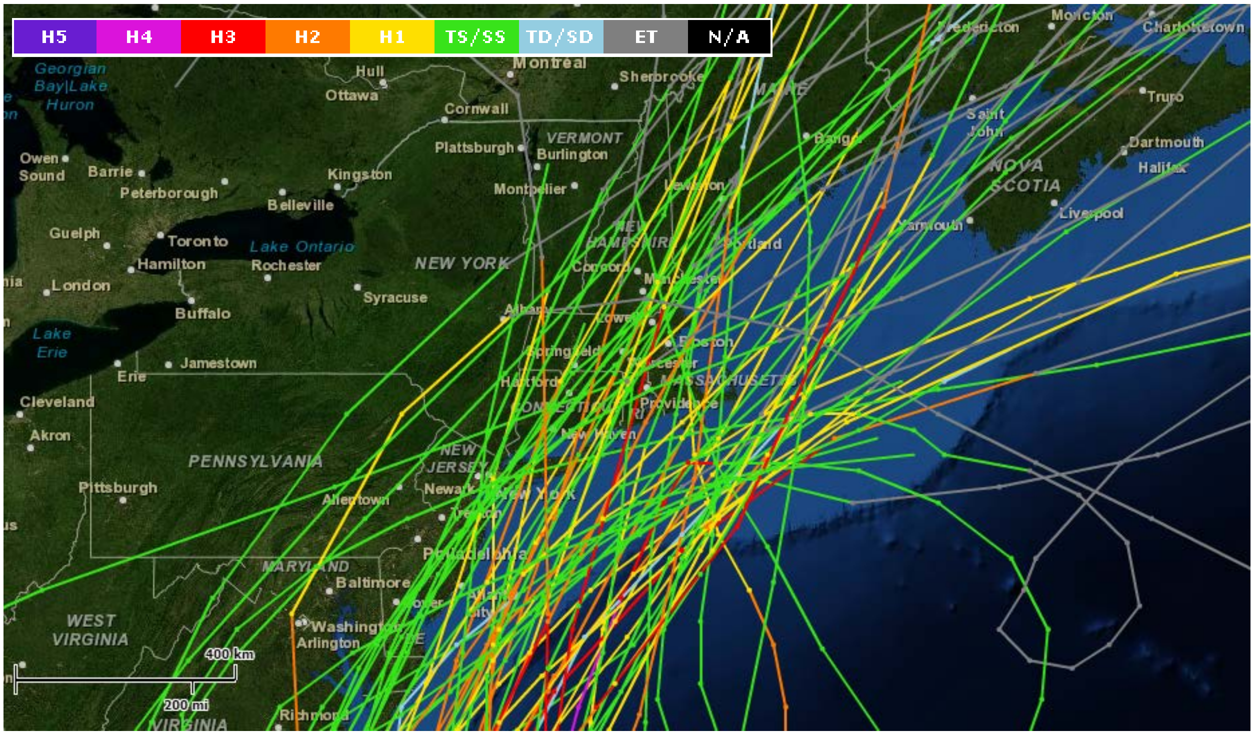

Figure 11-9 Historical North Atlantic Tropical Cyclone Tracks (1851-2011), Northeastern U.S.

Source: http://csc.noaa.gov/hurricanes/#

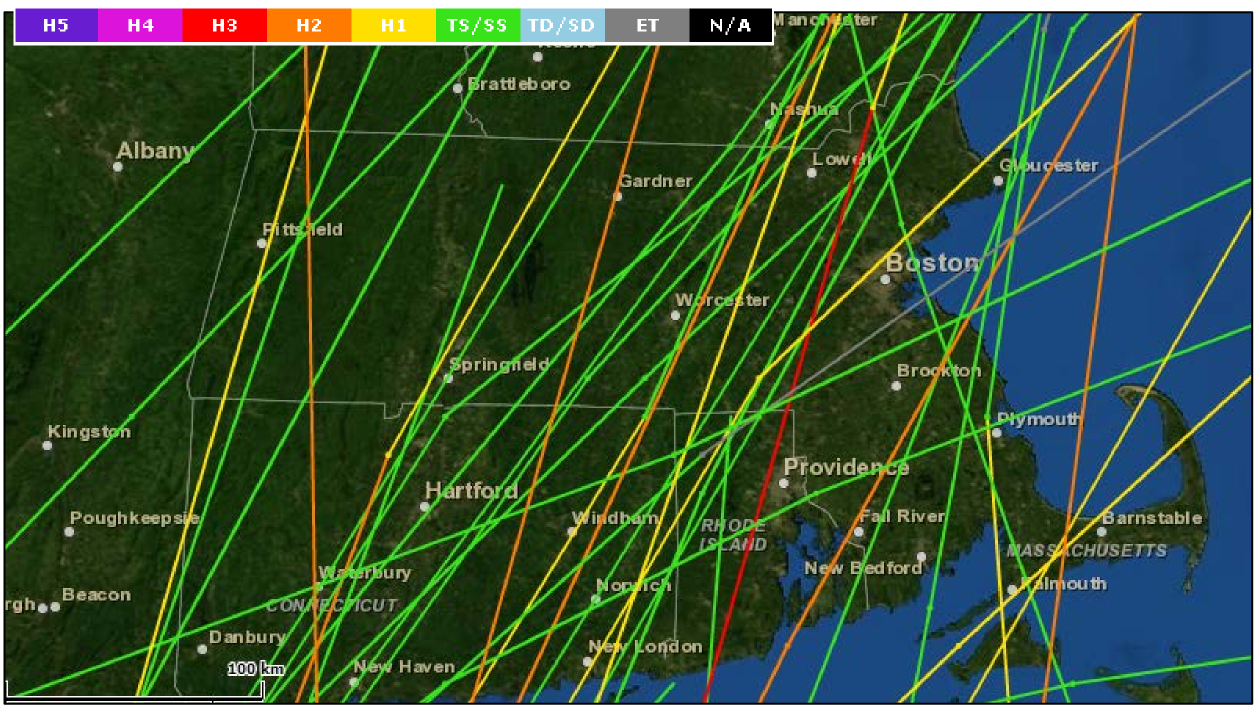

Figure 11-10. Historical North Atlantic Tropical Cyclone Tracks (1851-2011), Massachusetts Vicinity

11.2.2 Previous Occurrences

Since the destructive hurricane of 1938, several hurricanes have struck the Massachusetts coast as listed in Table 11-2. The last 10 years' worth of hurricanes to impact in Massachusetts was Hurricane Sandy (2012), the impact data for which are still being gathered as of the writing of this update. Prior hurricanes include Irene (2011), Earl (2010), Tropical Storm Bill (2009), Tropical Storm Hanna (2008), and Tropical Storm Beryl (2006). As demonstrated in the above NOAA graphics, many more tropical storms occur that do not make landfall. A hurricane or tropical storm need not make landfall to cause major damage, as the outer bands of the storm event can carry significant moisture and winds.

Based on past hurricane and tropical storms, the number of tropical systems impacting the Massachusetts coastline has increased over the course of the last six years, with six events occurring since 2006, including Hurricane Sandy. Prior to 2006, seven years had passed since the last tropical event. Utilizing simple averaging calculations, the Commonwealth averages a tropical storm event approximately every 1.75 years. It should be noted that this is not the recurrence interval, which requires a much more detailed analysis based on event type, category, and time.

The Commonwealth historically has not been impacted by a large number of Category 4 or 5 hurricanes, while Category 3 storms have caused widespread flooding. Winds have caused damage to power lines, impairing the ability of individuals to remain in their homes.

TABLE 11-2.
HISTORY OF HURRICANES AND TROPICAL STORMS

Date	Name	Category	Landfall
August 1635	Great Colonial Hurricane of 1635	3	
September 1815	Great September Gale of 1815	3	
September 1869	September Gale of 1869	3	
September 1938	New England Hurricane of 1938	3	Yes
September 1944	Great Atlantic Hurricane	4	Yes
1945	Unnamed		
1949	Unnamed		
September 1954	Edna	3	Yes
October 1954	Hazel	3	
August 1954	Carol	2-3	
August 1955	Diane	3	
September 1959	Gracie	3	
September 1960	Donna	5	Yes
September 1985	Gloria	4	
August 1991	Bob	3	Yes
July 1996	Bertha	3	
September 1999	Floyd	4	Yes
July 2006	Beryl	Tropical Storm	
September 2008	Hanna	1	
August 2009	Bill	Tropical Storm	

TABLE 11-2.
HISTORY OF HURRICANES AND TROPICAL STORMS

Date	Name	Category	Landfall
September 2010	Earl	4	
August 2011	Irene	2	
October 2012	Sandy	Tropical Storm	Yes

Table 11-2 summarizes historical hurricanes, also indicating those making landfall. Based on all sources researched, known hurricane and tropical storm events that have affected Massachusetts, and were declared a FEMA disaster, are identified in Table 11-3. This table provides detailed information concerning the FEMA declarations for the Commonwealth.

The entire Commonwealth is susceptible to hurricanes and tropical storms, in all sizes. It should be noted that it is not necessarily the strongest category storm that causes the most damage, as smaller events which stall and bring more precipitation and wind can bring greater damage than a faster moving event. Some of the hurricane events to have occurred within the region include the following:

TABLE 11-3.
FEMA HURRICANE-RELATED DISASTER DECLARATIONS (1954 TO 2012)

	DR-4097	DR-4028	EM-3315	DR-914	DR-751	DR-43	DR-22	**Total Events**
Disaster Name or Type	T Storm Sandy	Tropical Storm Irene	Hurricane Earl	Hurricane Bob	Hurricane Gloria	Hurricane/ Floods	Hurricane	
Declaration Date	12/19/2012	9/3/2011	9/2/2010	8/26/1991	10/28/1985	8/20/1955	9/2/1954	
Incident Period	10/27/12 - 11/8/12	8/27/11 - 8/29/11	9/1/10 - 9/4/10	8/19/1991	9/27/1985	8/20/1955	9/2/1954	
Affected Counties								
Barnstable	X	X	X	X	X			**5**
Berkshire		X			X			**2**
Bristol	X	X	X	X	X			**5**
Dukes	X	X	X	X	X			**5**
Essex			X	X	X			**3**
Franklin		X			X			**2**
Hampden		X		X	X			**3**
Hampshire		X			X			**2**
Middlesex			X	X	X			**3**
Nantucket	X		X	X				**3**
Norfolk		X	X	X	X			**4**
Plymouth	X	X	X	X	X			**5**
Suffolk	X		X	X	X			**4**
Worcester			X	X	X			**3**
Total	**6**	**9**	**10**	**11**	**13**	**N/A**	**N/A**	**49**

TABLE 11-3.
FEMA HURRICANE-RELATED DISASTER DECLARATIONS (1954 TO 2012)

	DR-4097	DR-4028	EM-3315	DR-914	DR-751	DR-43	DR-22	**Total Events**

Source: Sterner & Babin, Johns Hopkins University Applied Physics Laboratory, 2006

Great New England Hurricane—1938

The New England Hurricane of 1938 (or Great New England Hurricane or Long Island Express or simply The Great Hurricane of 1938) was the first major hurricane to strike New England since 1869. The storm formed near the coast of Africa in September of the 1938 Atlantic hurricane season, becoming a Category 5 hurricane on the Saffir-Simpson Hurricane Scale before making landfall as a Category 3 hurricane on Long Island on September 21. To date it remains the most powerful, costliest, and deadliest hurricane in New England history. Figure 11-11 depicts the track of this storm event. When it reached Massachusetts, it was tropical storm status. Initially, the hurricane was forecast by the U.S. National Weather Service to curve out into the Atlantic Ocean. Because the official forecasts expected mere overcast conditions, residents were unaware of the impending storm. The cyclone made landfall on Long Island, New York on September 21, 1938 as a strong Category 3 hurricane on the present-day Saffir-Simpson Hurricane Scale with a central pressure of 946 millibars. It then traveled across Long Island Sound into Connecticut, Rhode Island, Massachusetts, New Hampshire, Vermont, and finally into Canada while moving at an unusually high speed.

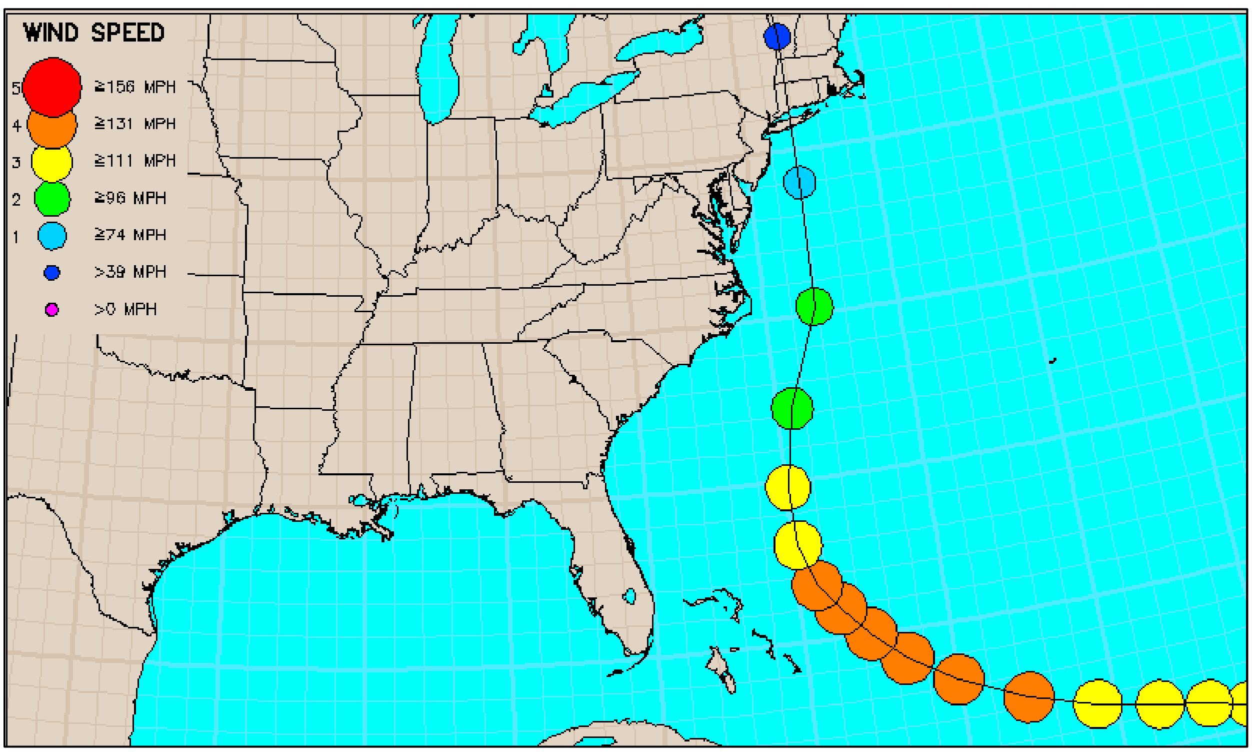

Figure 11-11. 1938 Hurricane Track, September 10 – September 22

The majority of the storm damage was from storm surge and wind. Damage is estimated at $6 billion (2004 USD), making it among the most costly hurricanes to strike the U.S. mainland. It is estimated that if an identical hurricane struck today it would cause $39.2 billion (2005 USD) in damage. Approximately

600 people died in the storm in New England, most in Rhode Island, and up to 100 people elsewhere in the path of the storm. An additional 708 people were reported injured. The hurricane also devastated the forests of the Northeast, knocking down an estimated 2 billion trees in New York and New England. The hurricane produced 18- to 25-foot tides from New London, CT east to Cape Cod in Massachusetts.

The eye of the storm followed the Connecticut River north into Massachusetts, where the winds and flooding killed 99 people. In Springfield, the river rose to 6 to 10 feet above flood stage, causing significant damage. Up to six inches of rain fell across western Massachusetts, which combined with over four inches that had fallen a few days earlier produced widespread flooding. Residents of Ware were stranded for days and relied on air-dropped food and medicine. After the flood receded, the town's Main Street was a chasm in which sewer pipes could be seen.

To the east, the surge left Falmouth and New Bedford under eight feet of water. Two-thirds of all the boats in New Bedford harbor sank. The Blue Hills Observatory registered sustained winds of 121 mph and a peak gust of 186 mph.

Hurricane Carol—August 1954

Hurricane Carol was a Category 3 hurricane with wind gusts of Category 4 strength along southern coastal Massachusetts in the Buzzards Bay area west of Cape Cod. Hurricane Carol, the most destructive hurricane to strike Southern New England since the Great New England Hurricane of 1938, made landfall on the morning of August 31, 1954 near Old Saybrook, Connecticut. During this event, 65 individuals were killed; nearly 4,000 homes, 3.500 automobiles, and over 3,000 boats were destroyed; and scores of trees and miles of power lines were blown down leaving all of Rhode Island, much of eastern Connecticut, and eastern Massachusetts without electrical power.

Hurricane Carol made landfall shortly after high-tide, causing widespread tidal flooding. Narragansett Bay and New Bedford Harbor received the largest surge value of over 14 feet in the upper reaches of both waterways. 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. The heaviest amounts of rainfall, up to 6 inches, occurred in the New London, Connecticut area and across extreme north central Massachusetts (NWS, 2005).

Hurricane Edna (FEMA DR-22)—September 1954

Hurricane Edna, a Category 3 Hurricane, made landfall on September 11, 1954, passing over Martha's Vineyard and Nantucket before crossing the eastern tip of Cape Cod. Hurricane force winds of 75 to 95 mph buffeted all of eastern Massachusetts and coastal Rhode Island. Peak winds 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.

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. Rainfall amounts of 3 to 6 inches were common, with over seven inches across northeastern Massachusetts. The 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. Edna was responsible for 21 deaths across the region (NWS, 2005).

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).

Hurricane Gloria (FEMA DR-751)—September 1985

Hurricane Gloria caused extensive damage along the east coast of the U.S. This event was responsible for eight fatalities and approximately $1.94 billion in damage. Wind gusts were sustained at 145 mph, causing Gloria to reach a Category 4 status. Historical tide data included 3.20 feet at Woods Hole, 4.42 feet at Plymouth, 2.92 feet at Chatham, and 5.04 feet at Boston. This event resulted in a federal disaster declaration (FEMA DR-751). Figure 11-12 depicts the track of Hurricane Gloria. When it reached Massachusetts, it was considered a Category 1 storm, with wind speeds of up to 74 mph.

Source: Sterner & Babin, Johns Hopkins University Applied Physics Laboratory, 2008

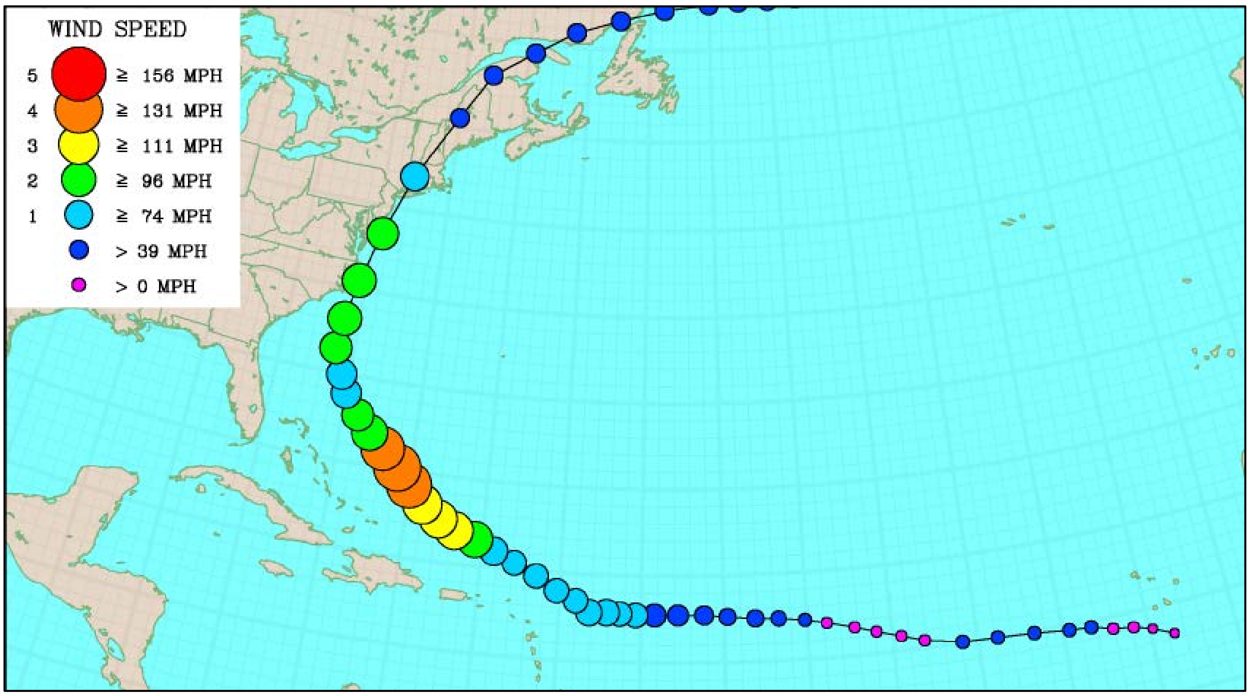

Figure 11-12. Hurricane Gloria Track, September 16 – October 2, 1985

Hurricane Bob (FEMA DR-914)—August 1991

Hurricane Bob was the second named storm and the first hurricane of the 1991 hurricane season, reaching a Category 3 status. Winds were sustained at 115 mph, impacting North Carolina, Mid-Atlantic States, New England, and Atlantic Canada, causing 15 fatalities. In Massachusetts, this storm struck the southern coast, causing $900 million in property damage from Westport east to New Bedford, Buzzards Bay, Cape Cod, and the Islands. Damage to crops was approximately $10 million, including 20 to 50% of the apple crop. Corn and vegetable crops were also seriously damaged or destroyed. The eye of the storm tracked north-northeast between Fall River and Providence through Bristol and Plymouth Counties, traveling at a speed of 40 mph. Over 500 boats broke away from their moorings, sank, or were driven ashore. Many boats were either heavily damaged or destroyed. The tidal surge reached 5.8 feet in New Bedford, inundating barrier beaches from Westport to Marion and flooding beaches around Buzzards Bay. Across Cape Cod and the Islands, thousands of trees were blown down causing power outages. Winds exceeded 80 mph, with gusts of up to 143 mph. Rainfall totals ranged between two and seven inches in the Commonwealth. This event resulted in a federal disaster declaration (FEMA DR-914).

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

On October 9th, 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 15th, 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.

Tropical Storm Beryl—July 2006

One of the strongest off-season Atlantic storms to make landfall in the U.S., Beryl moved up the eastern seaboard from its initial landfall in Florida, ultimately combining with another cold-weather system as it approached Massachusetts, producing winds and heavy rain.

Hurricane Earl (FEMA EM-3315)—September 2010

Earl was the fifth named storm of the 2010 Hurricane Season, reaching peak intensity on September 2nd, with maximum sustained winds of 145 mph. Hurricane Earl was considered a Category 4 hurricane. Damage was estimated to be low, but one fatality was suffered in Massachusetts, three in Florida, and two in New Jersey.

Tropical Storm/Hurricane 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). Wind speeds in Massachusetts ranged between 46 and 67 mph. Tide data included: 6.43 feet at Boston, 4.04 feet at Chatham, 5.57 feet at Fort Point, 5.39 feet at Plymouth, and 3.11 feet at Woods Hole. These heavy rains caused flooding throughout the Commonwealth and a presidential disaster was declared (FEMA DR-4028). The Commonwealth received over $31 million in individual and public assistance from FEMA. Figure 11-13 depicts the storm track of Hurricane Irene.

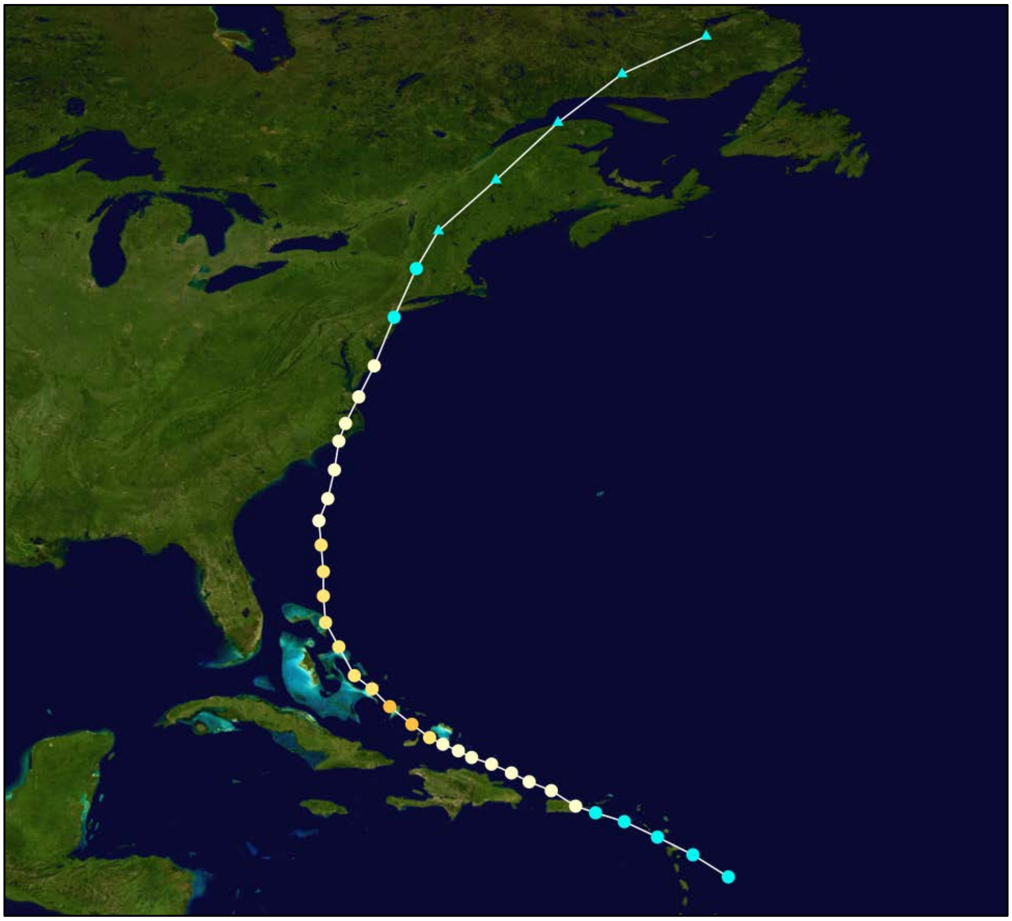

Figure 11-13. Hurricane Irene Storm Track

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 in the U.S.

11.2.3 Frequency

Storms are often categorized by return frequencies (e.g. this was a 100 year storm, etc.). There are several shortcomings related to trying to categorize storms by return frequencies. First, the historical record of storms is relatively short to accurately assess the true long-term frequency of long period events. Most records only go back about 100 years. It is a little like sampling 20 ocean waves and making a conclusion of the full range of wave amplitudes in that part of the ocean. Second, when it comes to coastal flood impacts, it is not a level playing field. Sea level rise changes the vulnerability such that storms of an average 100-year frequency will occur considerably more often. Determining how well that can be quantified is dependent on the accuracy of sea level rise predictions. Third, coastal flood impacts can vary significantly from one locality to another depending upon such factors as onshore wind component and incidence of wave activity to the coastline. Fourth, a storm may have been a once in a hundred year storm for coastal flooding but a once in 10-year storm for wind or snowfall or rainfall, etc. Also, the impact of a storm can be compounded if it has multiple severe dimensions (e.g. major coastal flooding in addition to very heavy snow and extreme winds) or if it impacts such a large area that mutual aid cannot be exercised. Fifth, development along the coastline or in other vulnerable areas can significantly increase the impact of a storm. Thus, the same storm in 1950 might not have garnered as much attention then as it would now with the increased coastal development.

In addition, there is a great deal of misunderstanding surrounding the reference to a "100 year storm" or a return frequency of 100 years. Similar to the flood events, a 100 year storm event does not mean that one should expect such a storm (or a storm of greater intensity) once every 100 years. Rather, a 100-year storm, to use that frequency as an example, is best described as a 1% chance of occurring in any given year. There might be two or three such storms in one hundred year period and then no more for the next 200 or 300 years. Figure 11-14 shows the number of hurricanes expected to occur during a 100-year period. According to this map, all of Massachusetts can expect between 20 and 40 hurricanes during a 100-year return period.

11.2.4 Probability of Future Occurrences

The National Oceanic and Atmospheric Administration Hurricane Research Division published a map (refer to Figure 11-15) showing the chance that a tropical storm or hurricane (of any intensity) will affect a given area during the hurricane season (June to November). This analysis was based on historical data from 1944 to 1999. Based on this analysis, the Commonwealth has a six- to 30-percent chance of a tropical storm or hurricane affecting the area each year. The probability increases as you move from the northwest portion of the Commonwealth to the southeast, with the highest probability along the coast, more specifically the Islands and Cape Cod.

Source: http://pubs.usgs.gov/fs/2005/3121/2005-3121.pdf

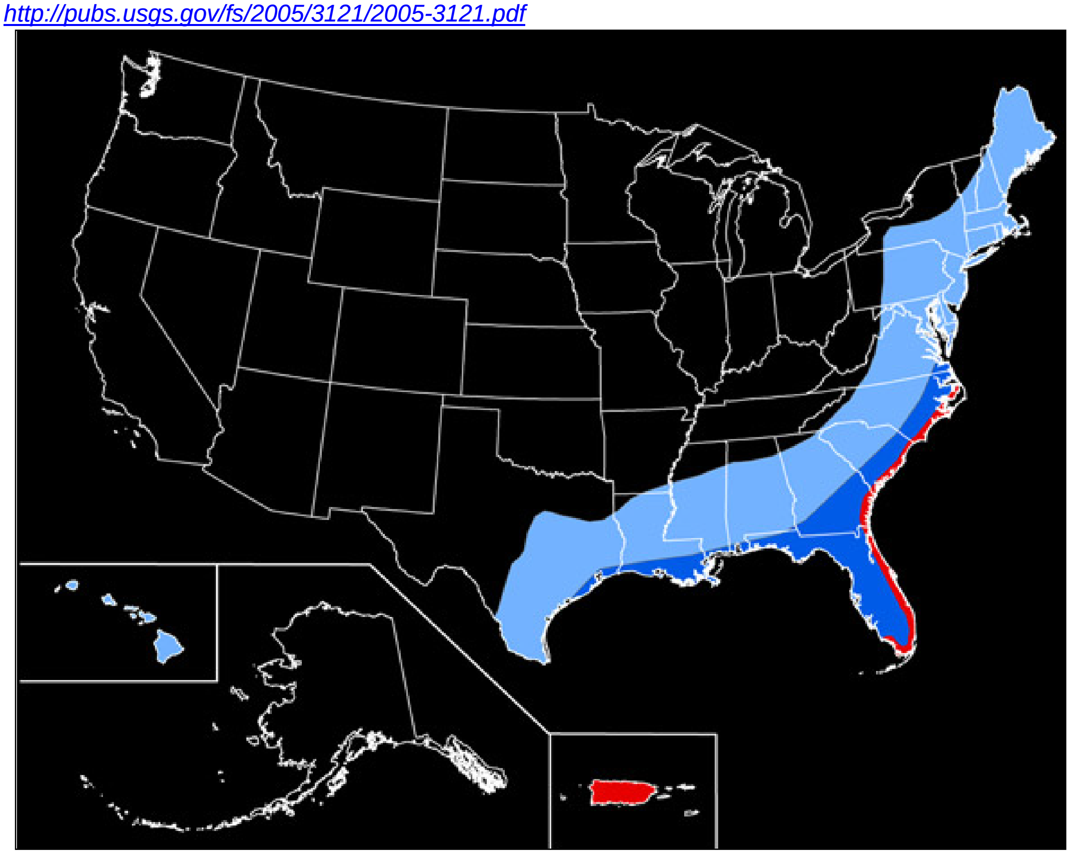

Figure 11-14. Number of Hurricanes for a 100-year Return Period: Light Blue Area, 20 to 40; Dark Blue Area, 40 to 60; Red Area, More Than 60

Source: *http://www.aoml.noaa.gov/hrd/tcfaq/G11.html*

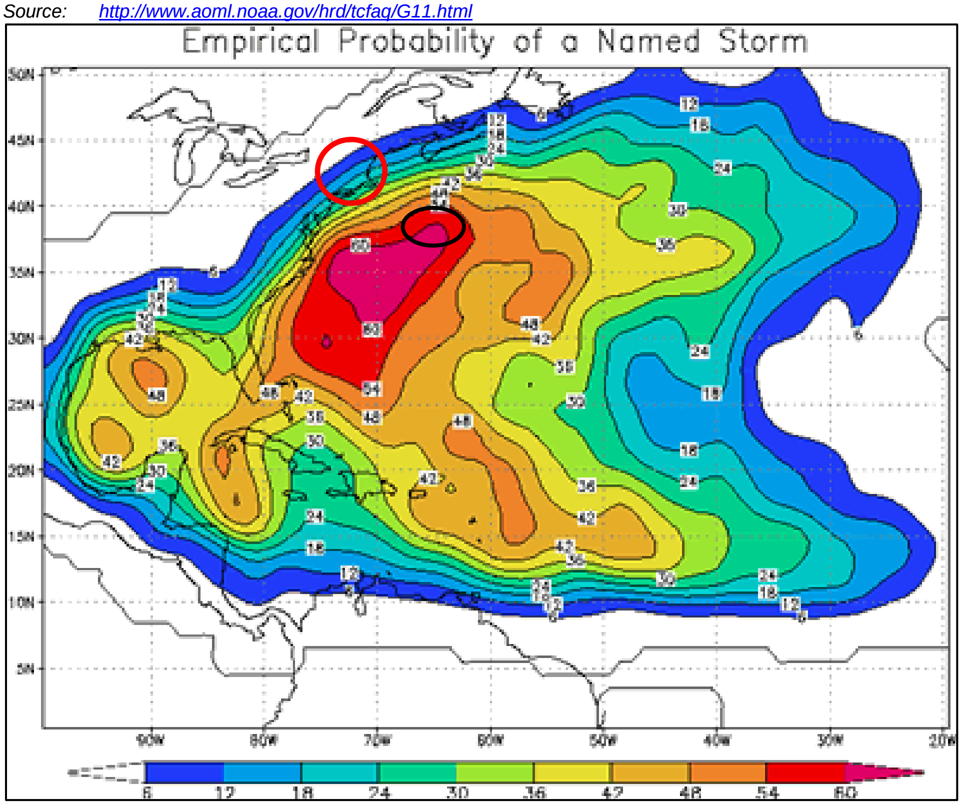

Figure 11-15. Probability of a Hurricane or Tropical Storm across Massachusetts (Circled)

A similar analysis was conducted to determine the probability that a major hurricane (Category 3, 4, or 5) will directly affect the area during hurricane season (June through November). The analysis was based on historical data from 1944 to 1999 for hurricanes within approximately 30 miles. Refer to

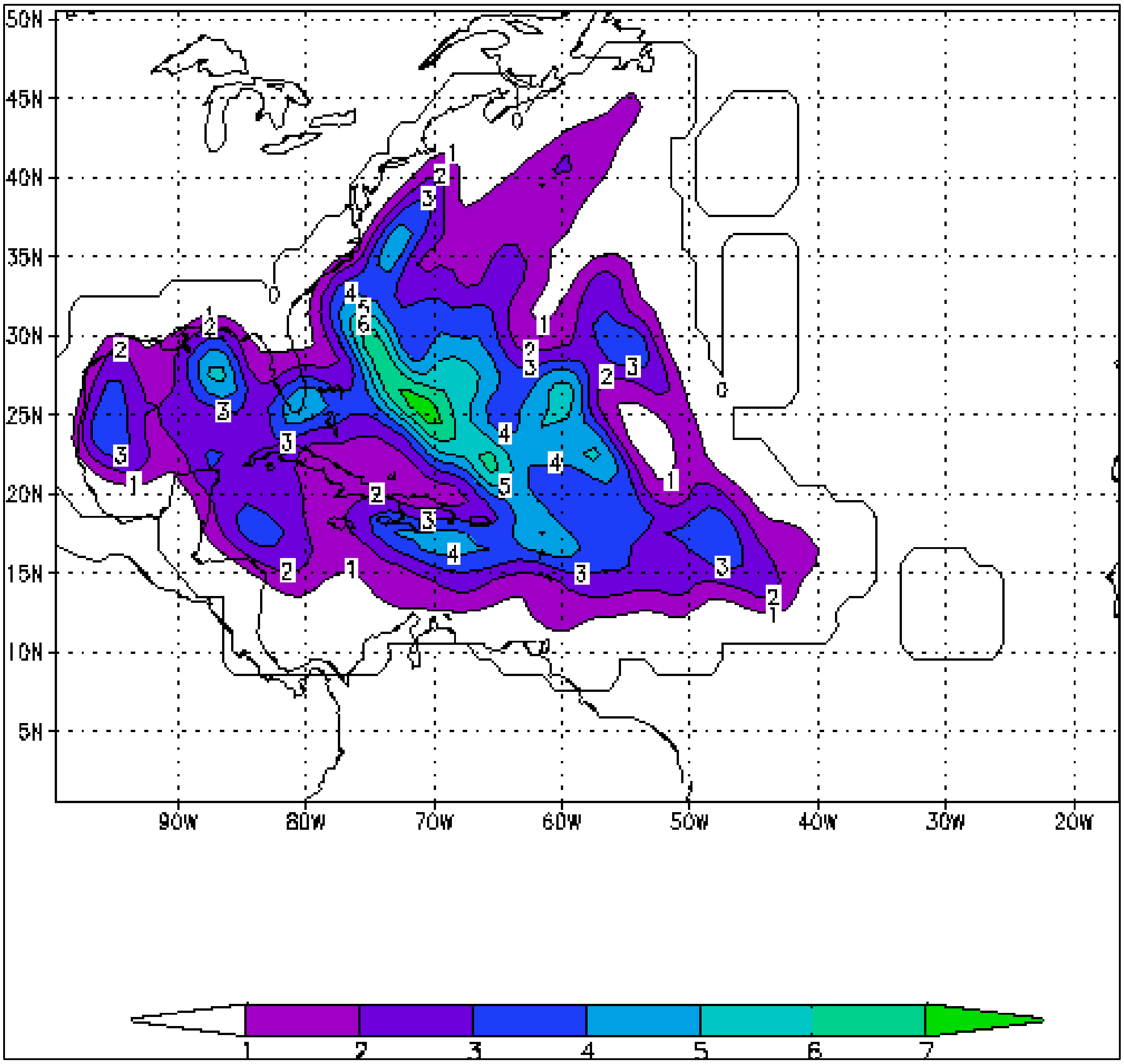

Figure 11-16. This analysis indicates that the Commonwealth has a one- to two-percent chance per year of a Category 3, 4 or 5 hurricane approaching the southern portion of the Commonwealth, but remaining off-shore to the east/southeast. This is not to say that a Category 3 through 5 hurricane could not come on-shore or that the Commonwealth could not be impacted by an event of this magnitude; but this does indicate the Commonwealth has a low probability of future occurrence for these category hurricanes.

Source: http://www.aoml.noaa.gov/hrd/tcfaq/ih_prob.gif

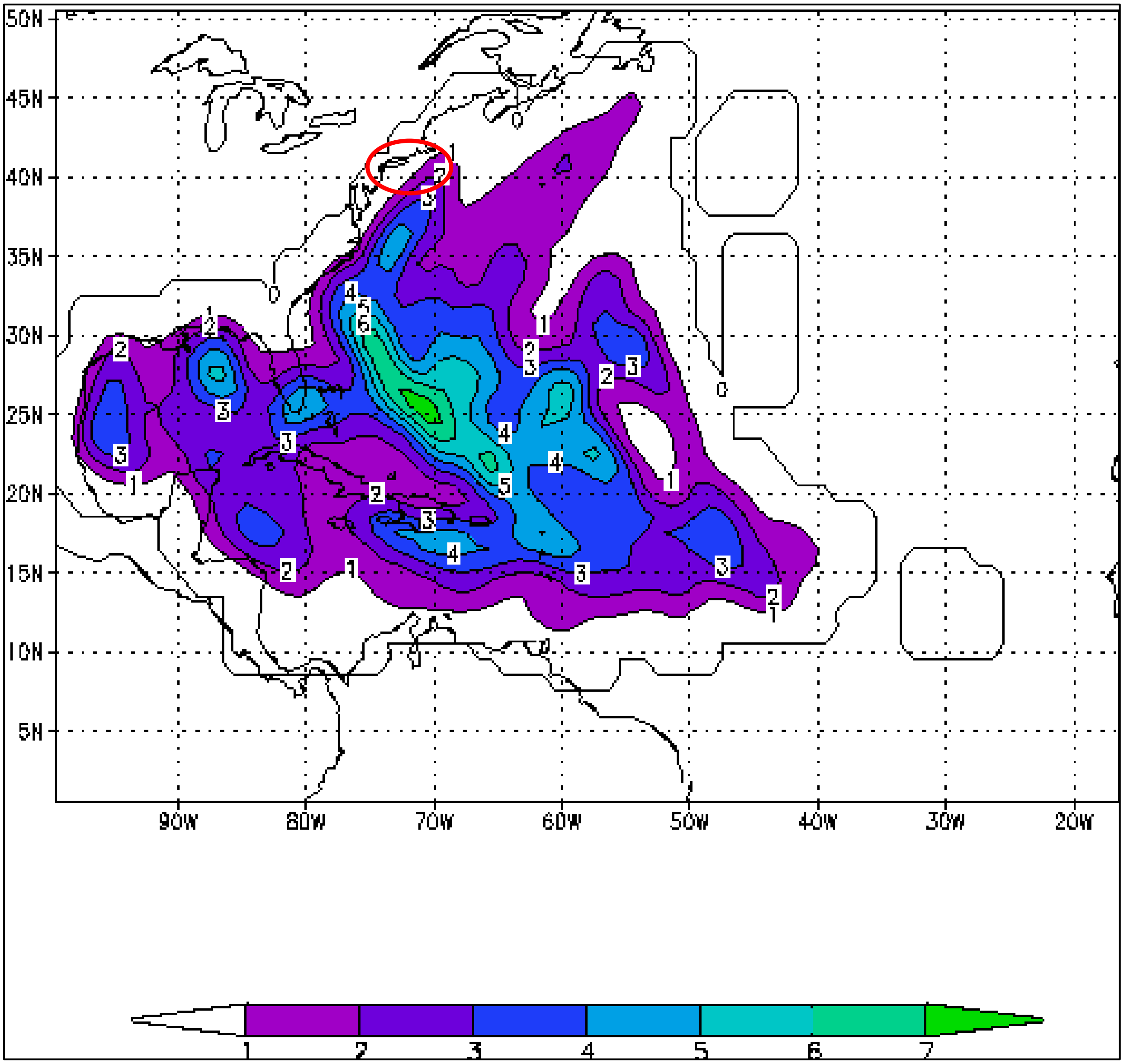

Figure 11-16. Probability of a Category 3, 4, or 5 Hurricane (Massachusetts Circled)

11.2.5 Severity

The extent of a hurricane is categorized by the Saffir-Simpson Hurricane Scale (Table 11-1). This scale categorizes or rates hurricanes from 1 (Minimal) to 5 (Catastrophic) based on their intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale.

Location and track of a system can also be a major factor to indicate severity of storm impacts, especially when it comes to storm surge. Most storm surge happens when the force of the wind (called wind stress) pushes water toward the shore. For hurricanes in the northern hemisphere, this effect creates the largest storm surge in the right-front quadrant of the storm. The winds are strongest there due to the combination of a storm's counter-clockwise rotation and forward motion (NOAA, date unknown). For Massachusetts, a serious scenario would be for the eye of a major hurricane to track west of Buzzards Bay. This would direct the strongest winds to push large quantities of water towards the shore, producing potential storm surge of 25 feet or more at the upper part of Buzzards Bay. According to a SHMIC subject-matter expert and National Weather Service Meteorologist, this was most likely the scenario when the Colonial Hurricane of 1635 produced storm surge of 20 feet at the upper part of Buzzards Bay; this surge was 5 feet higher than what was recorded during the 1938 hurricane.

11.2.6 Warning Time

The National Weather Service issues a hurricane warning when sustained winds of 74 mph or higher are *expected* in a specified area in association with a tropical, subtropical, or post-tropical cyclone. A warning is issued 36 hours in advance of the anticipated onset of tropical-storm-force winds. A hurricane watch is announced when sustained winds of 74 mph or higher are *possible* within the specified area in association with a tropical, subtropical, or post-tropical cyclone. A watch is issued 48 hours in advance of the anticipated onset of tropical storm force winds (NWS, 2013). One should always prepare for a storm that is one category higher than expected because the fast forward speed of the storm means that wind gusts will be much higher, especially to the east of the track. Preparations should be complete by the time the storm is at the latitude of North Carolina. Outer bands containing squalls with heavy showers and wind gusts to tropical storm force can occur as much as 12-14 hours in advance of the eye, which can cause coastal flooding and may cut off exposed coastal roadways. The 1938 hurricane raced from Cape Hatteras to the Connecticut coast in 8 hours.

11.3 SECONDARY HAZARDS

Precursor events or hazards that may exacerbate hurricane damage include heavy rains, winds, tornadoes, storm surge, insufficient flood preparedness, sub-sea level infrastructure, and levee or dam breach or failure. Potential cascading events include health issues (mold, mildew); increased risk of fire hazards; hazardous materials, including waste byproducts; coastal erosion; compromise of levee or dam; isolated islands of humanity; increased risk of landslides or other types of land movement; disruption to transportation; disruption of power transmission and infrastructure; structural and property damage; debris distribution; and environmental impact.

11.4 CLIMATE CHANGE IMPACTS

Climate is defined not simply as average temperature and precipitation, but also by the type, frequency, and intensity of weather events. Both globally and at the local scale, climate change has the potential to alter the prevalence and severity of extremes such as storms, including those which may bring precipitation, high winds, and tornado events. While predicting changes of storm events under a changing climate is difficult, understanding vulnerabilities to potential changes is a critical part of estimating future climate change impacts on human health, society, and the environment (U.S. Environmental Protection Agency (EPA), 2006).

The Northeast has been experiencing more frequent days with temperatures above 90°F, increasing sea surface temperatures and sea levels, changes in precipitation patterns and amounts, and alterations in hydrological patterns. According to the Massachusetts Climate Change Adaptation Report, large storm events are becoming more frequent. Although there is still some level of uncertainty, research indicates the warming climate may double the frequency of Category 4 and 5 hurricanes by the end of the century, and decrease the frequency of less severe hurricane events. More frequent and intense storm events will cause an increase in damage to the built environment and have devastating effects on the economy and environment (EOEEA, 2011).

Massachusetts is committed to adapting to climate change as it continues to occur. More detailed information on climate change and its potential impact on the Commonwealth can be found in the 2011 *Massachusetts Climate Change Adaptation Report*.

11.5 EXPOSURE

To understand risk, the assets exposed to the hazard areas are identified. For the hurricane and tropical storm hazard the entire Commonwealth of Massachusetts is exposed; more specifically the wind and rains associated with these events. However, certain areas, types of building, and infrastructure are at greater risk than others, due to proximity to the coast and/or their manner of construction. Storm surge from a hurricane/tropical storm poses one of the greatest risks to residents and property.

The following discusses the Commonwealth of Massachusetts' exposure to the hurricane/tropical storm hazard including:

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

FEMA Region IV Risk Analysis Team developed storm surge inundation grids for the Commonwealth in GIS format from the "maximum of maximums" outputs from the SLOSH model. These represent the worst-case storm surge scenarios for each hurricane category (1 through 4). To assess the Commonwealth's exposure to the hurricane/tropical surge, a spatial analysis was conducted using the SLOSH model. The SLOSH boundaries do not account for any inland flash flooding.

Using ArcMap, GIS software, the SLOSH zones were overlaid with the population, general building stock, state facility data (owned and leased) and critical facilities, and the appropriate SLOSH zone determination (categories one through four) was assigned.

11.5.1 Population

The impact of a hurricane or tropical storm on life, health, and safety is dependent upon several factors including the severity of the event and whether or not adequate warning time was provided to residents. It is assumed that the entire Commonwealth's population is exposed to this hazard.

To estimate the population exposed to the surge inundation areas, the SLOSH category one through four zones were overlaid on 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 SLOSH boundaries were used to calculate the estimated population exposed to the hurricane surge hazard. Table 11-4 summarizes the 2010 Census population in the Category 1 through 4 SLOSH zones by county.

TABLE 11-4.
ESTIMATED POPULATION EXPOSURE TO THE HURRICANE HAZARD

		Category 1		Category 2		Category 3		Category 4	
County	Total Population	Population	% of Total	Population	% of Total	Population	% of Total	Population	% of Total
Barnstable	215,888	21,546	10.0	31,949	14.8	43,048	19.9	53,893	25.0
Berkshire	131,219	—	—	—	—	—	—	—	—
Bristol	548,285	18,618	3.4	25,101	4.6	41,747	7.6	53,284	9.7
Dukes	16,535	1,029	6.2	1,706	10.3	2,185	13.2	2,847	17.2
Essex	743,159	21,409	2.9	30,029	4.0	48,321	6.5	68,055	9.2
Franklin	71,372	—	—	—	—	—	—	—	—

TABLE 11-4.
ESTIMATED POPULATION EXPOSURE TO THE HURRICANE HAZARD

County	Total Population	Category 1 Population	Category 1 % of Total	Category 2 Population	Category 2 % of Total	Category 3 Population	Category 3 % of Total	Category 4 Population	Category 4 % of Total
Hampden	463,490	—	—	—	—	—	—	—	—
Hampshire	158,080	—	—	—	—	—	—	—	—
Middlesex	1,503,085	35,539	2.4	75,501	5.0	152,071	10.1	186,568	12.4
Nantucket	10,172	71	0.7	181	1.8	474	4.7	723	7.1
Norfolk	670,850	12,503	1.9	25,095	3.7	40,360	6.0	53,743	8.0
Plymouth	494,919	19,694	4.0	30,931	6.2	38,313	7.7	46,308	9.4
Suffolk	722,023	84,728	11.7	161,104	22.3	243,901	33.8	269,737	37.4
Worcester	798,552	—	—	—	—	—	—	—	—
Total	**6,547,629**	**215,137**	**3.3**	**381,597**	**5.8**	**610,420**	**9.3**	**735,158**	**11.2**

Economically disadvantaged populations are more vulnerable because they are likely to evaluate their risk and make decisions based on the major economic impact to their family and may not have funds to evacuate. The population over the age of 65 is also more vulnerable and, physically, they may have more difficulty evacuating. The elderly are considered most vulnerable because they require extra time or outside assistance during evacuations and are more likely to seek or need medical attention which may not be available due to isolation during a storm event.

11.5.2 State Facilities

All Commonwealth state-owned and leased buildings are exposed to the wind and/or rain from the hurricane/tropical storm hazard. Refer to Table 11-5, which summarizes the total replacement cost value of all 6,765 state-owned and leased buildings in the Commonwealth.

To assess the exposure of the state-owned and leased facilities to the surge inundation from a hurricane event, the SLOSH boundaries provided by the FEMA Region IV Coastal Flood Loss Atlas team were used. The digital SLOSH zones were overlaid upon the state facility data and the appropriate SLOSH zone was determined. Table 11-6 and Table 11-7 summarize the results of the analysis by county and state agency, respectively.

TABLE 11-5.
TOTAL STATE BUILDING REPLACEMENT COST VALUE EXPOSED TO THE HURRICANE/TROPICAL STORM HAZARD

County	Exposed Replacement Cost Value (Structure and Contents)		
	Owned Facilities	Leased Facilities	Total
Barnstable	$1,129,133,087	$17,181,274	$1,146,314,361
Berkshire	$1,810,562,200	$41,438,632	$1,852,000,832
Bristol	$2,862,545,772	$149,664,578	$3,012,210,350
Dukes	$9,965,088	$6,258,960	$16,224,048
Essex	$4,336,334,705	$136,866,724	$4,473,201,429

TABLE 11-5. TOTAL STATE BUILDING REPLACEMENT COST VALUE EXPOSED TO THE HURRICANE/TROPICAL STORM HAZARD

	Exposed Replacement Cost Value (Structure and Contents)		
County	Owned Facilities	Leased Facilities	Total
Franklin	$789,074,575	$24,162,354	$813,236,929
Hampden	$4,896,066,804	$155,583,444	$5,051,650,248
Hampshire	$4,654,345,657	$33,042,196	$4,687,387,853
Middlesex	$9,556,026,897	$325,969,758	$9,881,996,655
Nantucket	$30,440,058	$941,186	$31,381,244
Norfolk	$4,994,008,904	$147,822,352	$5,141,831,256
Plymouth	$3,089,420,567	$92,983,586	$3,182,404,153
Suffolk	$7,795,245,796	$487,827,934	$8,283,073,730
Worcester	$9,226,864,179	$217,834,816	$9,444,698,995
Total	**$55,180,034,288**	**$1,837,577,794**	**$57,017,612,082**

Note: Building data are always being updated as agencies change or modify. The 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.

TABLE 11-6. STATE BUILDING EXPOSURE IN THE SLOSH ZONES (CUMULATIVE), BY COUNTY

	Number of State-Owned or Leased Buildings, by SLOSH Zone									
	Category 1		Category 2		Category 3		Category 4		Total All	Replacement
County	Owned	Leased	Owned	Leased	Owned	Leased	Owned	Leased	Categories	Cost Value
Barnstable	—		—	—	—	—	—	—	—	—
Berkshire	—	—	—	—	—	—	—	—	—	—
Bristol	54	1	56	2	59	5	62	7	69	$110,771,656
Dukes	2	—	4	—	4	1	4	1	5	$7,187,848
Essex	47	2	64	2	78	5	100	16	116	$807,906,384
Franklin	—	—	—	—	—	—	—	—	—	—
Hampden	—	—	—	—	—	—	—	—	—	—
Hampshire	—	—	—	—	—	—	—	—	—	—
Middlesex	8	2	18	5	27	8	31	14	45	$444,582,213
Nantucket	—	—	—	—	—	—	—	—	—	—
Norfolk	4	—	18	3	81	3	87	4	91	$443,072,666
Plymouth	14	—	31	1	32	1	46	1	47	$53,556,970
Suffolk	76	10	124	16	180	31	184	32	216	$4,019,078,238
Worcester	—	—	—	—	—	—	—	—	—	—
Total	**234**	**15**	**364**	**30**	**527**	**57**	**582**	**78**	**660**	**$6,188,087,060**

Note: SLOSH zones provided by FEMA Coastal Flood Loss Atlas Team.

**TABLE 11-7.
STATE FACILITIES IN THE SLOSH ZONES (CUMULATIVE), BY STATE AGENCY**

Agency	Category 1 #	Category 1 Replacement Cost Value	Category 2 #	Category 2 Replacement Cost Value	Category 3 #	Category 3 Replacement Cost Value	Category 4 #	Category 4 Replacement Cost Value
Alcoholic Beverages Control Commission	1	$1,619,110	1	$1,619,110	1	$1,619,110	1	$1,619,110
Board of Higher Education	1	$1,402,696	1	$1,402,696	1	$1,402,696	1	$1,402,696
Board of Library Commissioners	1	$1,846,748	1	$1,846,748	1	$1,846,748	1	$1,846,748
Bunker Hill Community College		—	—	—	6	$261,138,948	6	$261,138,948
Bureau of State Buildings		—	1	$166,987,500	1	$166,987,500	1	$166,987,500
Committee For Public Counsel Services		—	1	$1,867,322	4	$5,352,684	6	$9,578,134
Council of Government	1	$17,497,010	1	$17,497,010	1	$17,497,010	1	$17,497,010
Department of Business & Technology		—	—	—	1	$141,072	1	$141,072
Department of Children and Families	2	$10,495,898	3	$15,786,062	5	$27,676,908	9	$46,879,134
Department of Conservation and Recreation	146	$365,085,448	218	$500,827,231	322	$966,810,976	346	$1,013,824,763
Department of Corrections		—	—	—	1	$2,162,554	1	$2,162,554
Department of Developmental Services	2	$9,822,690	2	$9,822,690	5	$14,842,202	5	$14,842,202
Department of Early Education and Care	1	$4,153,848	1	$4,153,848	1	$4,153,848	1	$4,153,848
Department of Fish and Game	3	$1,537,838	19	$16,850,590	19	$16,850,590	19	$16,850,590
Department of Mental Health	1	$1,408,572	2	$132,920,922	10	$180,971,440	13	$185,037,262
Department of Public Health	2	$6,043,612	3	$9,650,542	4	$15,709,116	4	$15,709,116
Department of Public Utilities		—	1	$8,941,446	1	$8,941,446	1	$8,941,446
Department of State Police		—	7	$19,195,552	7	$19,195,552	7	$19,195,552
Department of Transitional Assistance	2	$10,638,306	3	$15,203,344	5	$25,997,950	7	$36,423,580
Department of Transportation	25	$31,343,123	37	$72,328,813	54	$113,001,267	64	$116,921,821
Department of Transportation		—	—	—	—	—	1	$1,068,720
Division of Capital Asset Management	2	$61,122,501	4	$152,585,151	4	$152,585,151	4	$152,585,151
Exec. Office of Energy & Environmental Affairs	1	$23,551,116	2	$23,942,534	2	$23,942,534	2	$23,942,534
Exec. Office of Health & Human Services	1	$4,353,698	3	$33,803,346	3	$33,803,346	3	$33,803,346
Massachusetts Department of Revenue		—	—	—	1	$8,762,970	3	$22,828,930
Massachusetts College of Art and Design		—	—	—	10	$527,402,394	10	$527,402,394
Massachusetts Cultural Council		—	—	—	1	$1,965,376	1	$1,965,376
Massachusetts Gaming Commission		—	—	—	1	$1,499,146	1	$1,499,146
Massachusetts Maritime Academy	23	$232,605,111	23	$232,605,111	23	$232,605,111	23	$232,605,111

TABLE 11-7.
STATE FACILITIES IN THE SLOSH ZONES (CUMULATIVE), BY STATE AGENCY

	Category 1		Category 2		Category 3		Category 4	
Agency	#	Replacement Cost Value	#	Replacement Cost Value	#	Replacement Cost Value	#	Replacement Cost Value
Massachusetts Rehabilitation Commission		—	1	$1,461,208	3	$16,835,012	4	$18,183,202
Massachusetts Teachers' Retirement System	1	$4,755,804	1	$4,755,804	1	$4,755,804	1	$4,755,804
Military Division	1	$19,341,560	3	$41,755,222	4	$61,096,782	8	$69,870,700
North Shore Community College		—	—	—	6	$14,810,266	6	$14,810,266
Office of Labor and Workforce Development		—	—	—	1	$6,237,764	1	$6,237,764
Office of the Chief Medical Examiner		—	—	—	1	$19,345,938	1	$19,345,938
Office of the D.A. Cape & Island		—	—	—	1	$1,595,866	1	$1,595,866
Office of the D.A. Eastern		—	—	—	—	—	2	$9,641,990
Office of the D.A. Northern		—	—	—	—	—	2	$1,961,102
Office of the State Treasurer		—	—	—	1	$2,381,108	1	$2,381,108
Public Employee Retirement Admin. Comm.		—	—	—	1	$3,874,110	1	$3,874,110
Salem State University	8	$164,933,284	15	$175,103,763	16	$183,912,917	29	$344,537,884
Secretary of State	1	$62,377,670	1	$62,377,670	1	$62,377,670	2	$72,822,538
Sex Offenders' Registry		—	—	—	—	—	1	$4,048,044
Sheriff's Department Middlesex		—	1	$3,990,652	2	$93,358,596	2	$93,358,596
Sheriff's Department Suffolk		—	—	—	8	$512,677,154	9	$874,251,452
Trial Court	1	$62,649,746	3	$79,396,854	8	$247,489,074	11	$312,342,990
University of Massachusetts at Amherst		—	13	$15,069,570	13	$15,069,570	13	$15,069,570
University of Massachusetts at Boston	20	$1,380,001,842	20	$1,380,001,842	20	$1,380,001,842	20	$1,380,001,842
University of Massachusetts at Dartmouth	2	$142,500	2	$142,500	2	$142,500	2	$142,500
Total	**249**	**$2,478,729,732**	**394**	**$3,203,892,653**	**584**	**$5,460,827,619**	**660**	**$6,188,087,060**

Note: SLOSH zones provided by FEMA Coastal Flood Loss Atlas Team.

A total of 660 structures, or nearly 10-percent of state-owned and leased facilities, are located within the SLOSH inundation zones. The Category 1 zone has 249 state structures located within and thus exposed to a Category 1 hurricane's storm surge. Category 1 storms occur more frequently than higher category storms, and structures located in this zone are the most vulnerable because they tend to be in the low lying areas very close to the coastline. Category 2 zone has 150 structures, Category 3 zone has 185 structures, and Category 4 has 76 structures. The total number of buildings exposed to each category noted in Table 11-6 and Table 11-7 are cumulative. For example, the total number of state buildings exposed to a Category 3 zone includes the buildings in Categories 1 and 2 zones as well. All other state structures that are not presented in the tables are not located in a defined SLOSH zone.

A comparison analysis was conducted to understand the changes in hurricane surge exposure to state-owned and leased buildings from the 2010 plan to the 2013 plan. Table 11-8 and Table 11-9 summarize these findings. The analysis shows an increase in the number of state buildings exposed to the Category 1 surge inundation. As noted earlier, the best available data were used for this analysis including the FEMA Region IV Coastal Flood Loss Atlas team SLOSH data. The differences between the SLOSH data and the state building database used for both plan updates may help explain the changes in the number of buildings exposed.

TABLE 11-8.
CHANGE IN NUMBER OF STATE BUILDINGS IN SLOSH ZONES BY COUNTY, 2009 TO 2012

County	Category 1			Category 2			Category 3			Category 4		
	2009	2012	Change	2009	2012	Change	2009	2012	Change	2009	2012	Change
Barnstable	10	29	19	7	21	14	9	19	10	2	2	0
Berkshire	0	0	0	0	0	0	0	0	0	0	0	0
Bristol	3	55	52	8	3	-5	13	6	-7	9	5	-4
Dukes	0	2	2	2	2	0	0	1	1	0	0	0
Essex	4	49	45	22	21	-1	10	13	3	12	33	21
Franklin	0	0	0	0	0	0	0	0	0	0	0	0
Hampden	0	0	0	0	0	0	0	0	0	0	0	0
Hampshire	0	0	0	0	0	0	0	0	0	0	0	0
Middlesex	7	10	3	12	13	1	0	12	12	5	10	5
Nantucket	0	0	0	0	0	0	0	0	0	1	0	-1
Norfolk	2	4	2	5	18	13	0	62	62	2	7	5
Plymouth	2	14	12	18	18	0	10	1	-9	6	14	8
Suffolk	29	86	57	54	54	0	7	71	64	6	5	-1
Worcester	0	0	0	0	0	0	0	0	0	0	0	0
Total	**57**	**249**	**192**	**128**	**150**	**22**	**49**	**185**	**136**	**43**	**76**	**33**

Note: To be consistent with the 2010 SHMP methodology and compare the data, the number of buildings is not cumulative in this table per zone as presented in other tables in this section.

TABLE 11-9.
CHANGE IN VALUE OF STATE BUILDINGS IN ALL SLOSH ZONES BY COUNTY, 2009 TO 2012

	Replacement Cost Value of State Buildings in All SLOSH Zones		
County	2009 (using April 2007 values)	2012	Change, 2009 - 2012
Barnstable	$93,758,283.00	$301,931,085	$208,172,802
Berkshire	0	$0	$0
Bristol	$21,709,222.00	$110,771,656	$89,062,434
Dukes	$1,528,329.00	$7,187,848	$5,659,519
Essex	$162,042,865.00	$807,906,384	$645,863,519
Franklin	0	$0	$0
Hampden	0	$0	$0
Hampshire	0	$0	$0
Middlesex	$43,190,889.00	$444,582,213	$401,391,324
Nantucket	$492,212.00	$0	-$492,212
Norfolk	$13,840,070.00	$443,072,666	$429,232,596
Plymouth	$20,833,937.00	$53,556,970	$32,723,033
Suffolk	$1,807,055,620.00	$4,019,078,238	$2,212,022,618
Worcester	0	$0	$0
Total	**$2,164,451,427.00**	**$6,188,087,060**	**$4,023,635,633**

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 data set was obtained from DCAMM and the Office of Leasing for the 2013 plan update. The following are key differences between the two building data sets:

- 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 data set is unknown; however, the 2010 plan indicates the Commonwealth of Massachusetts owns and operates more than 6,000 properties across the Commonwealth. 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.

11.5.3 Critical Facilities

An exposure analysis was completed using the police stations, fire stations, medical facilities, and schools (pre-K through grade 12 and colleges), emergency operation centers (state only) provided by MassGIS. Table 11-10 and Table 11-11 summarize critical facility exposure to the SLOSH Category 1 through 4 storm surge inundation summarized by facility type and county, respectively.

**TABLE 11-10.
CRITICAL FACILITY EXPOSURE TO SURGE INUNDATION SLOSH ZONES**

County	Total	Category 1	Category 2	Category 3	Category 4
Police Stations	437	13	29	45	53
Fire Stations	789	18	32	57	79
Hospitals	82	1	3	8	11
Schools (pre-K-12)	2,767	42	96	166	208
Colleges	205	12	24	46	57
Emergency Operation Centers	2	0	0	0	0

Source: Facilities provided by MassGIS (provided September 2012)

**TABLE 11-11.
CRITICAL FACILITY EXPOSURE TO SURGE INUNDATION SLOSH ZONES, BY COUNTY**

County	Police Stations	Fire Stations	Hospitals	Schools (pre-K-12)	Colleges	Emergency Operation Centers
Barnstable	6	14	1	10	1	—
Berkshire	—	—	—	—	—	—
Bristol	5	8	—	13	—	—
Dukes	5	2	1	2	—	—
Essex	4	5	—	22	3	—
Franklin	—	—	—	—	—	—
Hampden	—	—	—	—	—	—
Hampshire	—	—	—	—	—	—
Middlesex	11	17	2	49	15	—
Nantucket	—	—	—	—	1	—
Norfolk	1	3	—	18	2	—
Plymouth	2	8	1	14	—	—
Suffolk	19	22	6	80	35	—
Worcester	—	—	—	—	—	—
Total	**53**	**79**	**11**	**208**	**57**	**0**

Source: Facilities provided by MassGIS (provided September 2012)

Some roads and bridges are also considered critical infrastructure, particularly those providing ingress and egress and allow emergency vehicles access to those in need. Refer to Figure 11-2 through Figure 11-8, which illustrate the major Massachusetts Department of Transportation roads layer to determine which segments are located in the SLOSH inundation areas and vulnerable to surge.

The default Hazus-MH highway bridge inventory developed from the 2001 National Bridge Inventory database was used to conduct an exposure analysis for the bridges in the Commonwealth. Table 11-12 identifies the number of highway bridges in the Hazus-MH default highway bridge inventory exposed to the SLOSH Category 1 through 4 zones summarized by county. The exposure analysis indicates 558 highway bridges are located within the Category 1 through 4 SLOSH zones of the total inventory in Hazus-MH (4,832 bridges).

TABLE 11-12.
NUMBER OF BRIDGES IN THE SLOSH HAZARD ZONES BY COUNTY

	Category 1			Category 2			Category 3			Category 4		
County	Federal	State	Local	Federal	State	Local	Federal	State	Local	Federal	State	Local
Barnstable	1	8	19	1	9	21	1	12	20	1	14	21
Berkshire	—	—	—	—	—	—	—	—	—	—	—	—
Bristol	—	13	17	—	15	23	—	24	27	—	26	29
Dukes	—	—	—	—	—	—	—	—	—	—	—	—
Essex	—	23	14	—	28	18	—	31	20	—	40	25
Franklin	—	—	—	—	—	—	—	—	—	—	—	—
Hampden	—	—	—	—	—	—	—	—	—	—	—	—
Hampshire	—	—	—	—	—	—	—	—	—	—	—	—
Middlesex	—	29	1	—	44	2	—	59	6	—	68	9
Nantucket	—	—	2	—	—	2	—	—	2	—	—	2
Norfolk	—	1	2	—	—	3	—	12	4	—	16	5
Plymouth	—	19	12	—	26	13	—	31	14	—	36	15
Suffolk	—	100	11	—	142	13	—	209	20	—	230	21
Worcester	—	—	—	—	—	—	—	—	—	—	—	—
Total	**1**	**193**	**78**	**1**	**264**	**95**	**1**	**378**	**113**	**1**	**430**	**127**

Source: Hazus-MH v 2.1; FEMA Region IV Coastal Flood Loss Atlas SLOSH Boundaries

11.5.4 Economy

Damage to buildings can impact a community's economy and tax base. In determining this level of impact, the area of each county (square miles) exposed to the Category 1 through 4 SLOSH inundation was determined. Of the nine counties with area in the SLOSH inundation zones, four counties have greater than 10-percent of their area within the Category 1 boundary. Suffolk County has the greatest percent of their area in the inundation zones from 21.5-percent (Category 1) to greater than 42-percent (Category 4). The Islands (Dukes and Nantucket Counties) and Barnstable County also have a large percentage of their total area exposed to storm surge inundation. Table 11-13 summarizes these findings.

TABLE 11-13.
AREA LOCATED IN THE SLOSH ZONES (SQUARE MILES)

		Category 1		Category 2		Category 3		Category 4	
County	Total Area	Area	% of Total	Area	% of Total	Area	% of Total	Area	% of Total
Barnstable	412.48	59.3	14.4	82.9	20.1	98.0	23.8	111.8	27.1
Berkshire	946.39	—	—	—	—	—	—	—	—
Bristol	571.86	24.4	4.3	30.9	5.4	40.7	7.1	49.7	8.7
Dukes	109.90	22.4	20.4	26.1	23.7	29.5	26.8	33.1	30.1
Essex	514.90	47.3	9.2	55.6	10.8	64.3	12.5	74.0	14.4
Franklin	724.58	—	—	—	—	—	—	—	—
Hampden	634.06	—	—	—	—	—	—	—	—
Hampshire	545.27	—	—	—	—	—	—	—	—
Middlesex	846.59	6.5	0.8	10.4	1.2	16.1	1.9	19.0	2.2
Nantucket	49.03	8.3	16.9	10.6	21.7	12.6	25.8	14.9	30.5
Norfolk	408.54	5.1	1.2	7.0	1.7	8.6	2.1	10.2	2.5
Plymouth	689.77	34.6	5.0	48.4	7.0	60.4	8.8	71.7	10.4
Suffolk	59.74	12.9	21.5	18.4	30.8	23.4	39.1	25.4	42.5
Worcester	1,579.21	—	—	—	—	—	—	—	—
Total	**8,092.30**	**220.8**	**2.7**	**290.3**	**3.6**	**353.6**	**4.4**	**409.8**	**5.1**

Source: FEMA Region IV Coastal Flood Loss Atlas SLOSH boundaries

11.6 VULNERABILITY

To assess the Commonwealth's vulnerability to the hurricane and tropical storm hazard, potential losses were determined for historical events selected by the SHMT and the THIRA Workgroup: Tropical Storm Irene (2011), Category 1 Hurricane Gloria (1985), Category 2 Hurricane Bob (1991), and Category 3 Unnamed Hurricane (1938). The Hazus-MH model and the SLOSH data were used to estimate potential losses to these events.

11.6.1 Population

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

The historical events were run in Hazus-MH to estimate the sheltering needs (U.S. Census 2000) should this event occur today. It should be noted that Hazus-MH utilizes 2000 Census data, and therefore, the totals will vary slightly. The estimated shelter needs are summarized in Table 11-14. All counties, with the exception of Barnstable and Berkshire Counties, have experienced an increase in population growth since the 2000 Census (see Section 5); therefore, the numbers in Table 11-14 are conservative.

**TABLE 11-14.
ESTIMATED SHELTER NEEDS - WIND ONLY ANALYSIS**

County	Tropical Storm		Category 1 - Hurricane		Category 2 - Hurricane		Category 3 - Hurricane	
	Displaced Households	Short Term Shelter Needs	Displaced Households	Short Term Shelter Needs	Displaced Households	Short Term Shelter Needs	Displaced Households	Short Term Shelter Needs
Barnstable	0	0	0	0	486	112	4	1
Berkshire	0	0	0	0	0	0	69	15
Bristol	0	0	0	0	1,203	344	732	201
Dukes	0	0	0	0	57	13	1	0
Essex	0	0	0	0	15	1	143	35
Franklin	0	0	0	0	0	0	180	44
Hampden	0	0	9	2	0	0	2,211	611
Hampshire	0	0	3	1	0	0	524	129
Middlesex	0	0	25	4	23	1	971	216
Nantucket	0	0	0	0	2	0	0	0
Norfolk	0	0	0	0	94	15	349	72
Plymouth	0	0	0	0	408	90	104	27
Suffolk	0	0	2	0	160	43	860	248
Worcester	0	0	263	68	0	0	2,230	591
Total	**0**	**0**	**302**	**75**	**2,448**	**619**	**8,378**	**2,190**

Source: Hazus-MH v. 2.1 (U.S. Census 2000)

11.6.2 State Facilities

To estimate the potential losses to state-owned and leased structures, the SLOSH data were used. There are 6,765 state-owned/leased structures in the Commonwealth; all of which are exposed to the hurricane/tropical storm hazard. Table 11-5 summarizes the total replacement cost value of these structures.

Structures located in the storm surge inundation areas are at greatest risk to surge-related damage. The SLOSH inundation area for a Category 4 event and the estimated depth of flooding per FEMA Region IV are shown in Figure 11-17 through Figure 11-23 for the coastal regions. A total risk exposure of nearly $6.2 billion is estimated for state-owned and leased buildings located in the Category 1 through 4 SLOSH zones. The Hurricane Category 4 SLOSH depth grids provided by FEMA Region IV were imported into the Hazus-MH flood model, and the potential losses were estimated for the state-owned and leased facilities. Table 11-15 and Table 11-16 summarize the potential losses by county and agency, respectively.

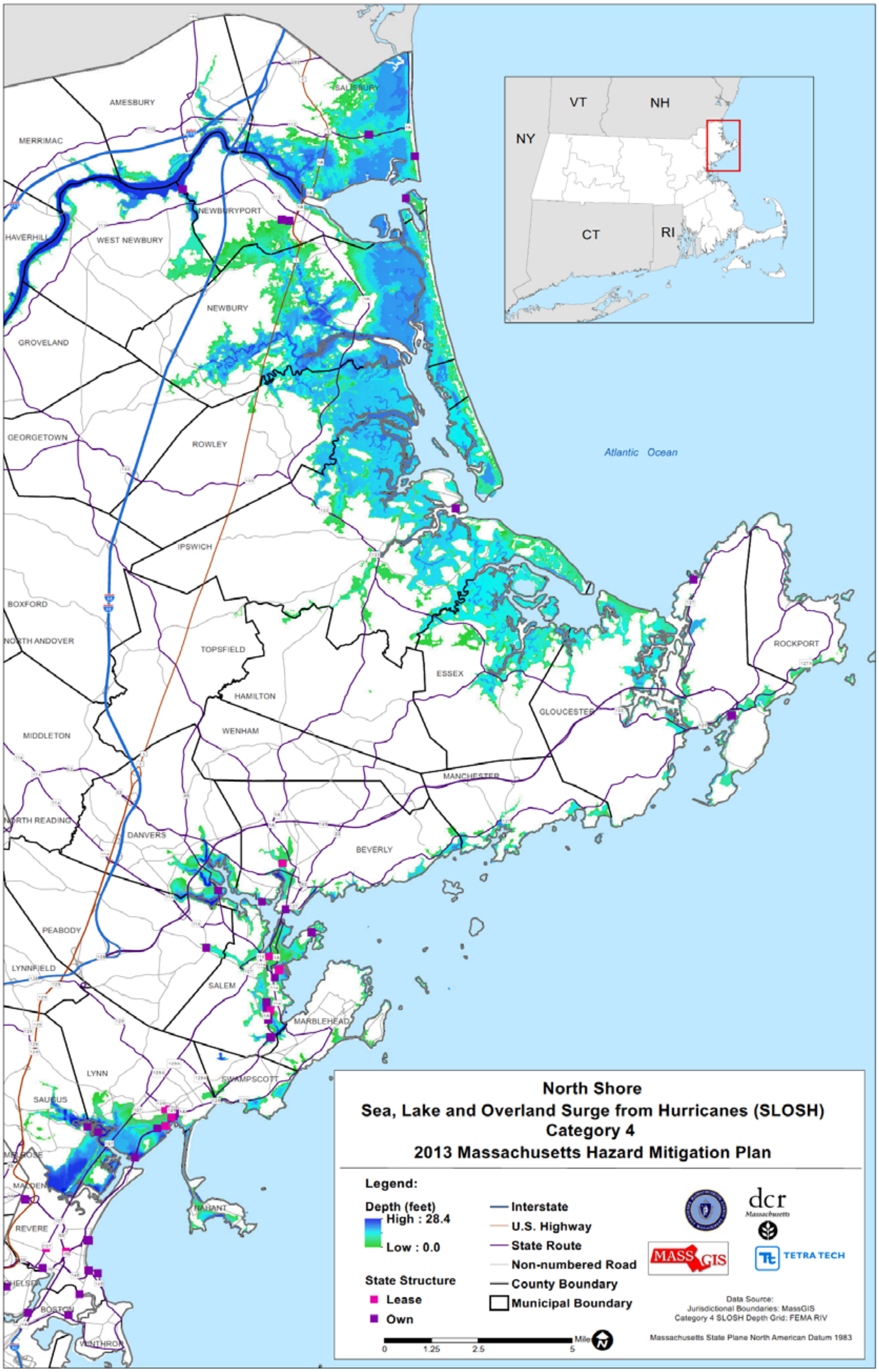

Figure 11-17. North Shore SLOSH Inundation for a Category 4 Event

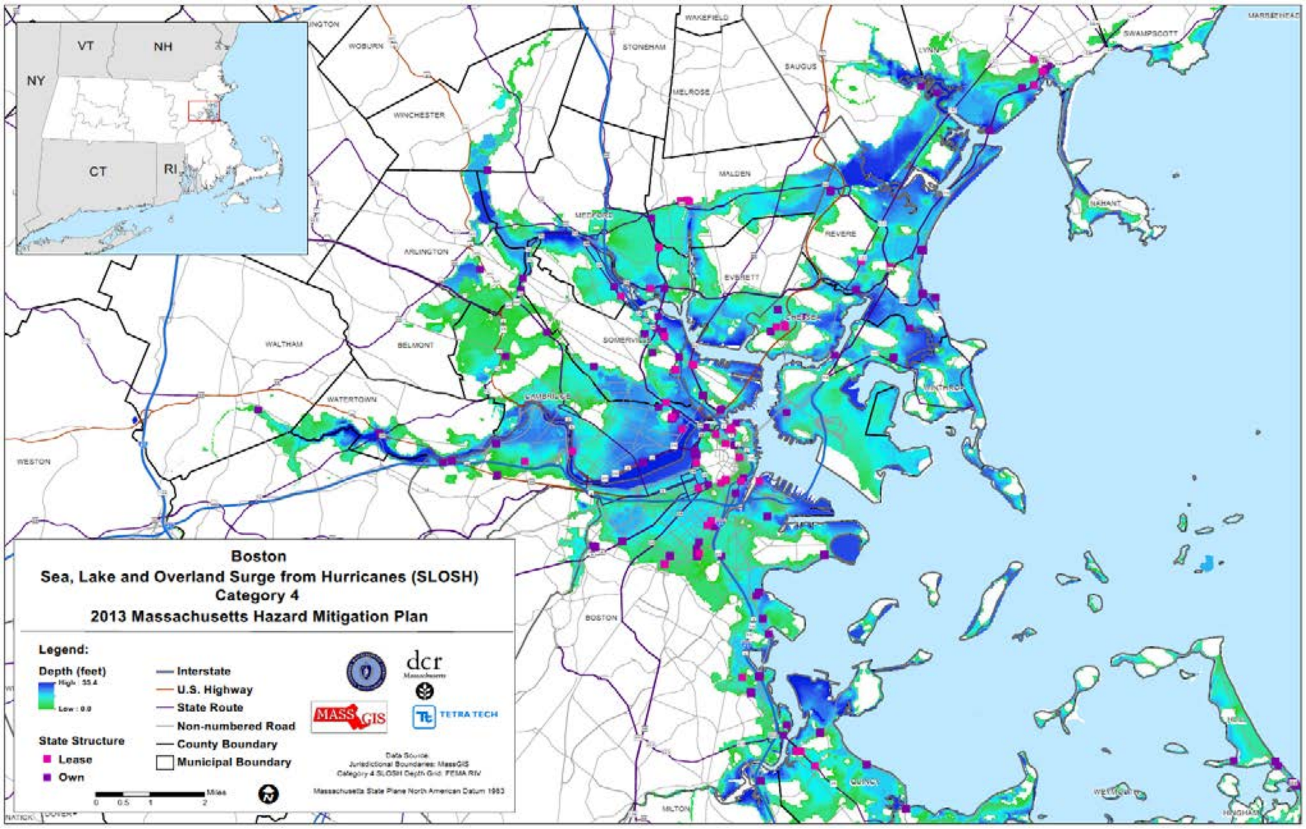

Figure 11-18. Boston SLOSH Inundation for a Category 4 Event

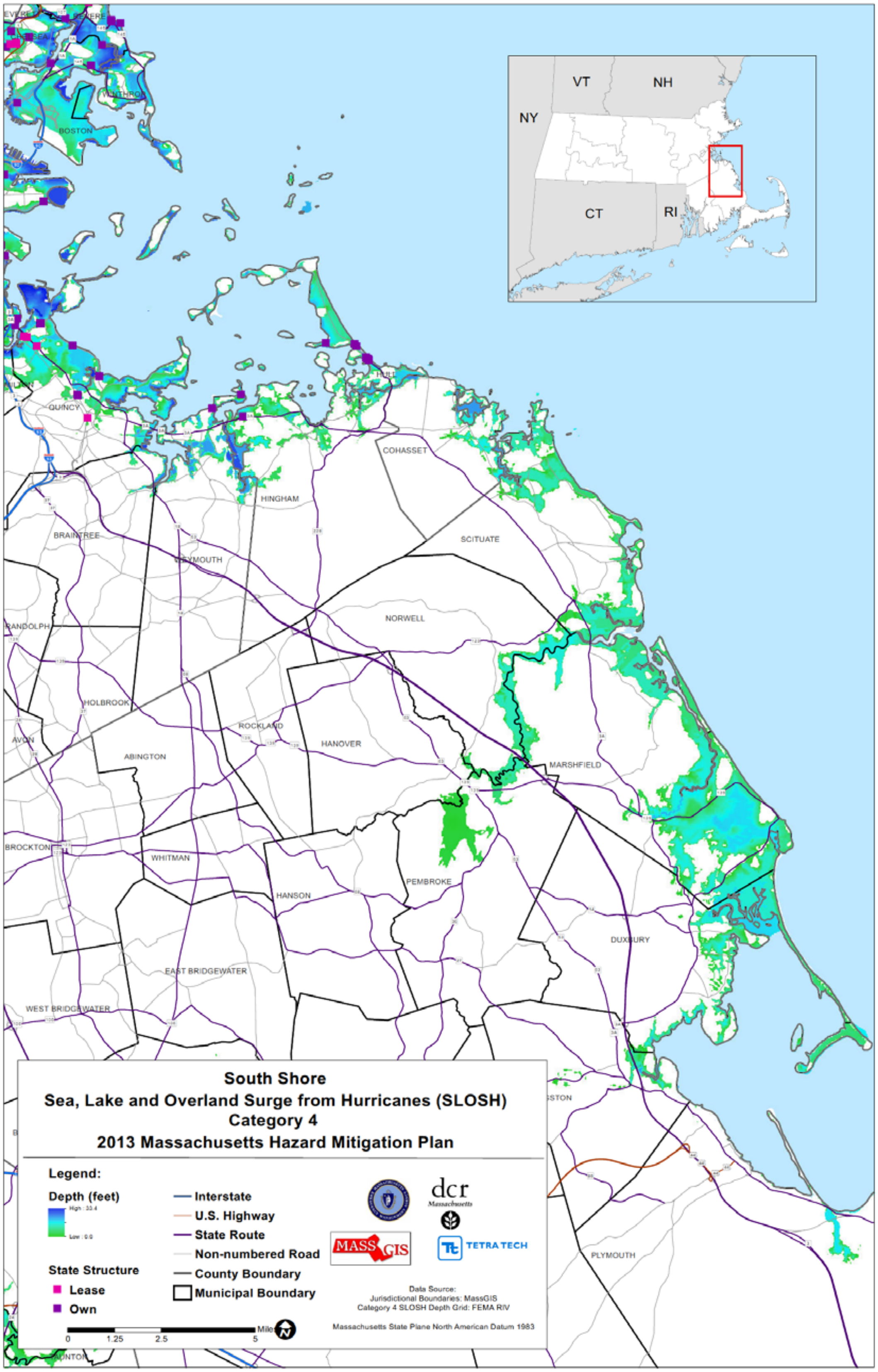

Figure 11-19. South Shore SLOSH Inundation for a Category 4 Event

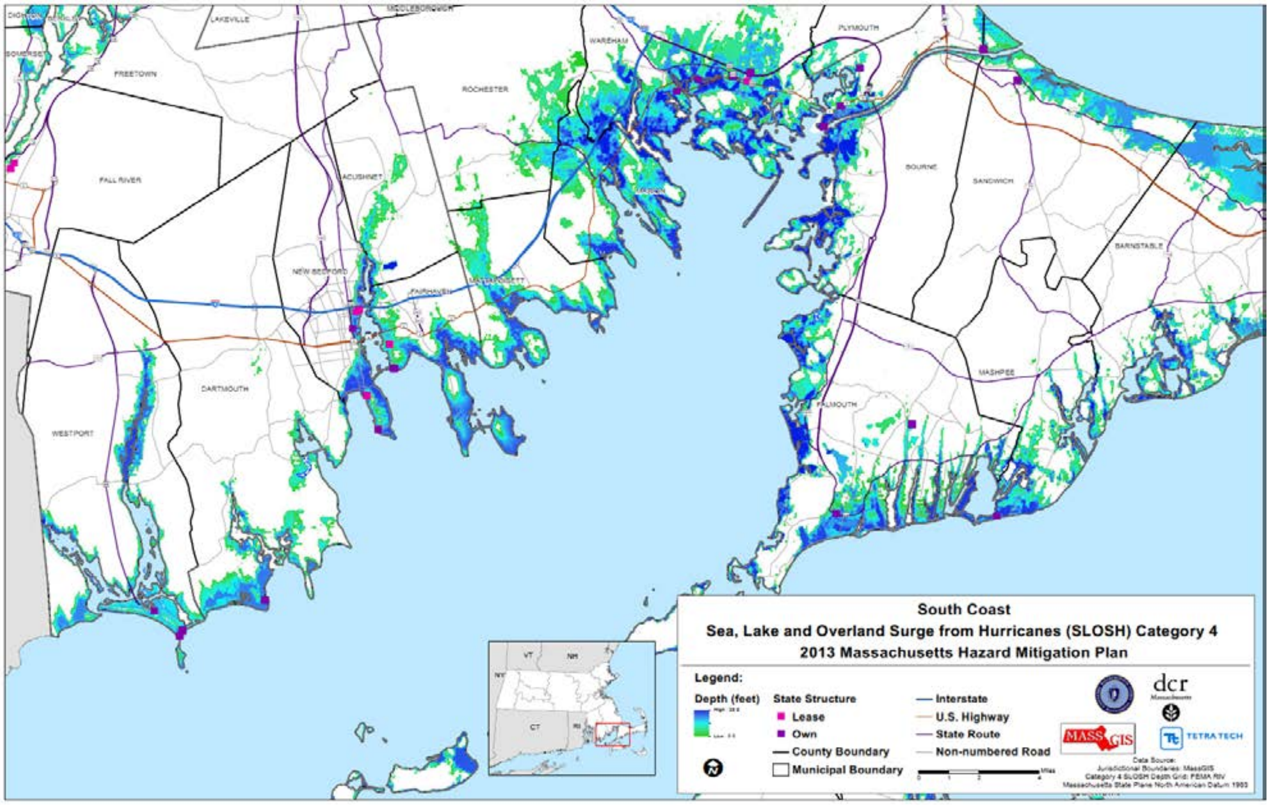

Figure 11-20. South Coastal SLOSH Inundation for a Category 4 Event

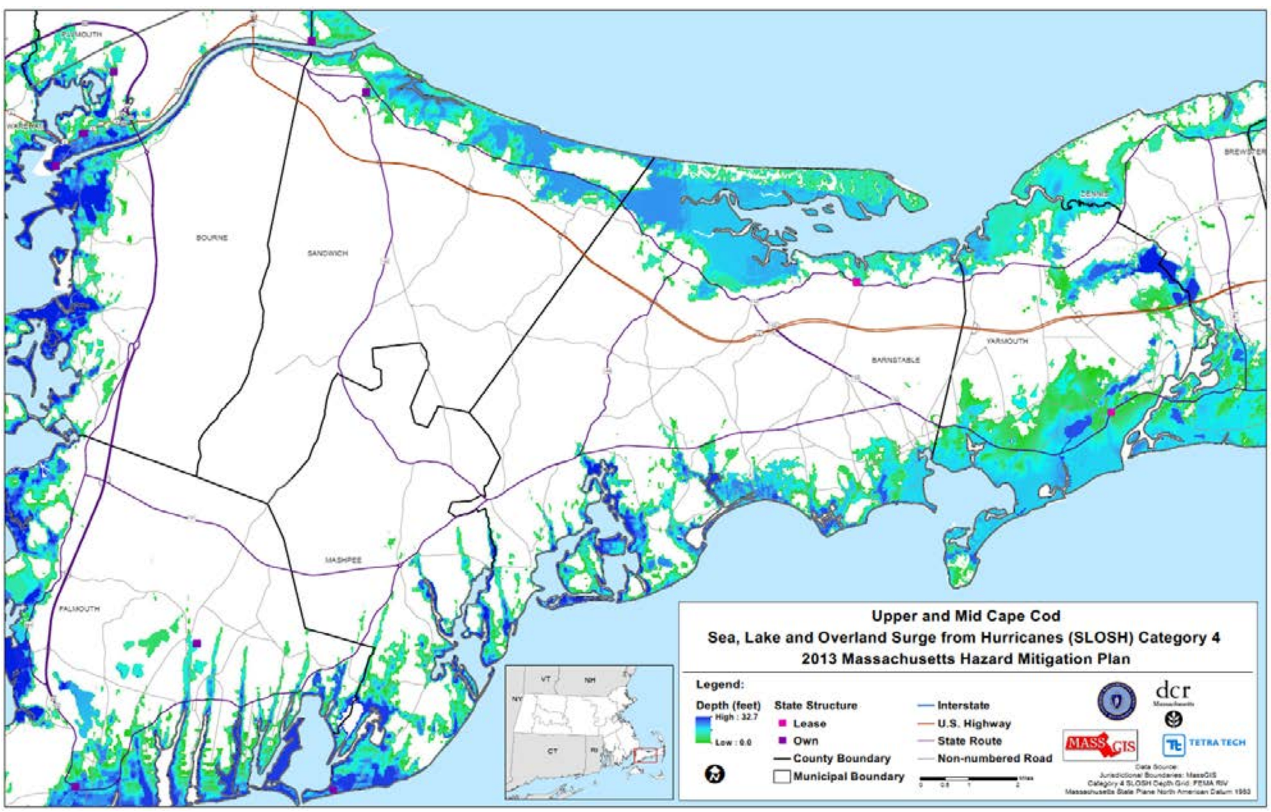

Figure 11-21. Upper and Mid Cape Cod SLOSH Inundation for a Category 4 Event

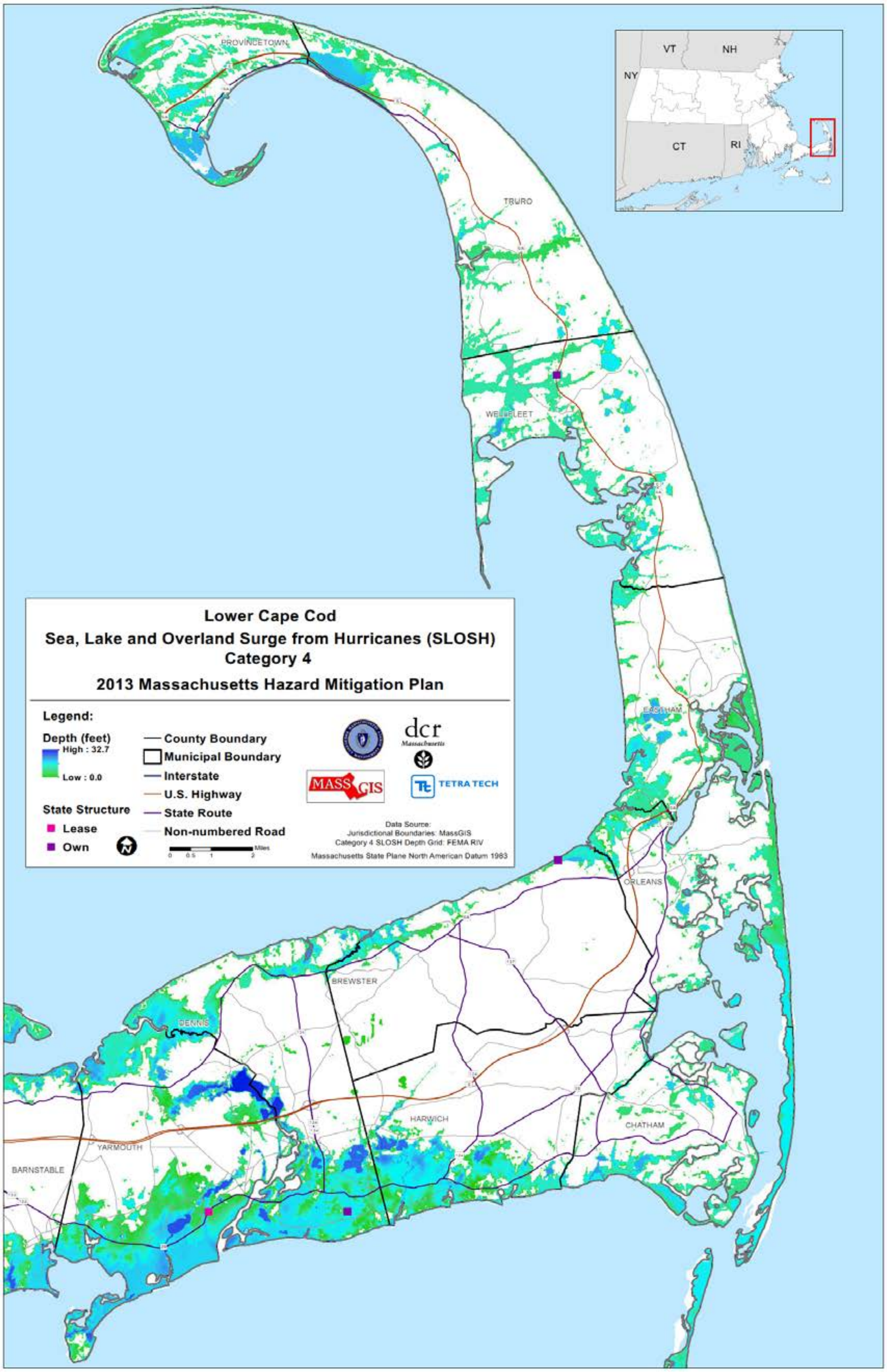

Figure 11-22. Lower Cape Cod SLOSH Inundation for a Category 4 Event

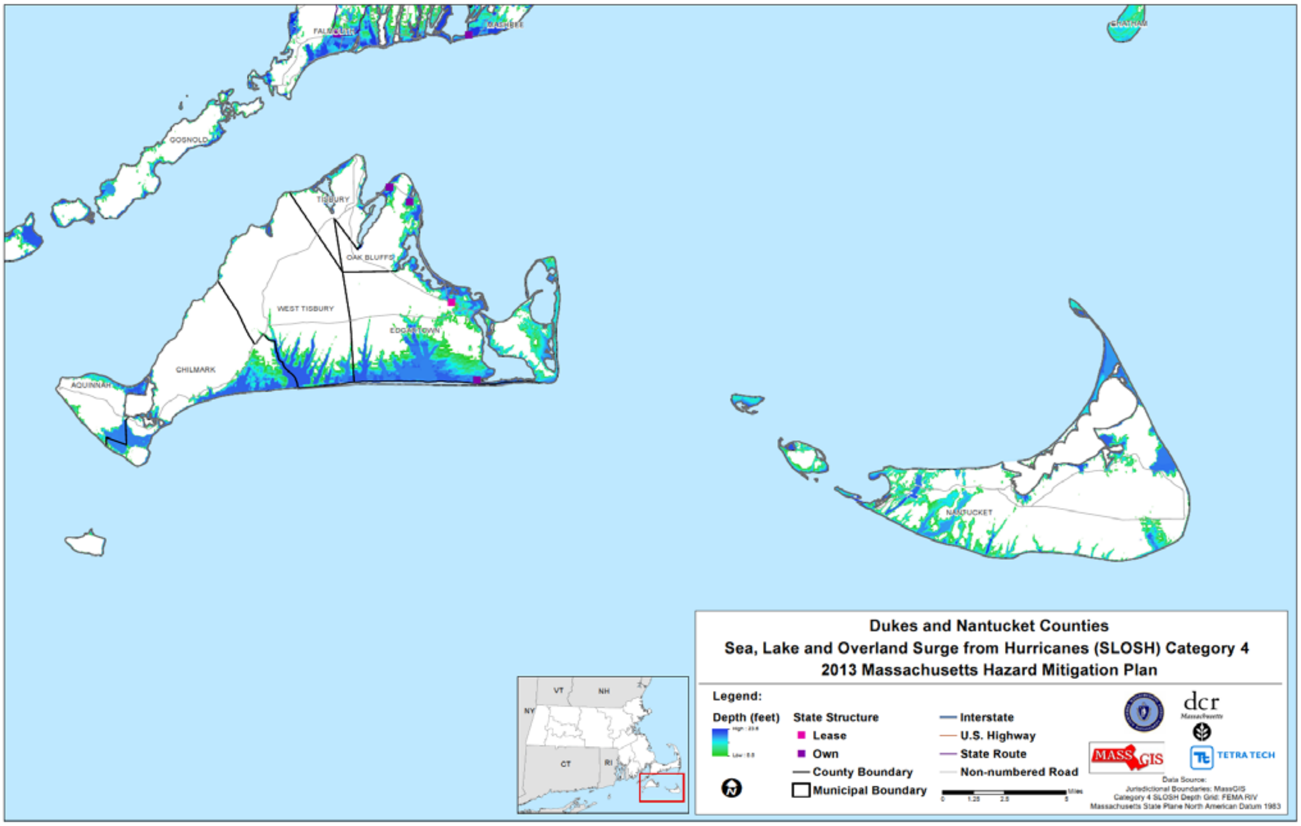

Figure 11-23. Dukes and Nantucket Counties SLOSH Inundation for a Category 4 Event

TABLE 11-15.
ESTIMATED POTENTIAL STATE-OWNED AND LEASED BUILDING LOSS FROM HURRICANE CATEGORY 4 STORM SURGE BY COUNTY

	State-Owned Structures		State-Leased Structures		Total Loss		Loss as Percent of Total Exposed[a]	
County	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Value
Barnstable	50	$249,484,117	3	$1,062,726	53	$250,546,843	75%	83.0%
Berkshire	—	—	—	—	—	—	—	—
Bristol	56	$53,412,358	6	$14,537,016	62	$67,949,374	90%	61.3%
Dukes	4	$1,271,978	1	$1,400,697	5	$2,672,675	100%	37.2%
Essex	71	$340,393,691	9	$11,552,589	80	$351,946,280	69%	43.6%
Franklin	—	—	—	—	—	—	—	—
Hampden	—	—	—	—	—	—	—	—
Hampshire	—	—	—	—	—	—	—	—
Middlesex	28	$199,025,028	11	$27,205,515	39	$226,230,543	87%	50.9%
Nantucket	—	—	—	—	—	—	—	—
Norfolk	80	$157,365,033	3	$25,365,895	83	$182,730,928	91%	41.2%
Plymouth	36	$35,535,485	1	$313,831	37	$35,849,316	79%	66.9%

TABLE 11-15.
ESTIMATED POTENTIAL STATE-OWNED AND LEASED BUILDING LOSS FROM HURRICANE CATEGORY 4 STORM SURGE BY COUNTY

	State-Owned Structures		State-Leased Structures		Total Loss		Loss as Percent of Total Exposed[a]	
County	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Value
Suffolk	181	$2,211,450,558	32	$130,170,940	213	$2,341,621,497	99%	58.3%
Worcester	—	—	—	—	—	—	—	—
Total	**506**	**3247938248**	**66**	**211609209.8**	**572**	**$3,459,547,458**	**87%**	**55.9%**

a. Percentage of number of exposed buildings based on 2012 building count from Table 11-8. Percentage of building value based on 2012 value listed in Table 11-9

Source: (SLOSH and Hazus-MH v. 2.1)

TABLE 11-16.
ESTIMATED POTENTIAL STATE-OWNED AND LEASED BUILDING LOSS FROM HURRICANE CATEGORY 4 STORM SURGE BY STATE AGENCY

	State-Owned Structures		State-Leased Structures		Total Loss		Loss as Percent of Total Exposed[a]	
Agency	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Value
Alcoholic Beverages Control Commission	—	—	1	$1,363,246	1	$1,363,246	100	84.2
Board of Higher Education	—	—	1	$1,048,449	1	$1,048,449	100	74.7
Board of Library Commissioners	—	—	1	$1,244,432	1	$1,244,432	100	67.4
Bunker Hill Community College	6	$126,040,875	—	—	6	$126,040,875	100	48.3
Bureau of State Buildings	1	$100,549,460	—	—	1	$100,549,460	100	60.2
Committee For Public Counsel Services	—	—	5	$3,107,376	5	$3,107,376	83.3	32.4
Council of Government	1	$13,624,281	—	—	1	$13,624,281	100	77.9
Department of Business & Technology	—	—	1	$83,761	1	$83,761	100	59.4
Department of Children and Families	—	—	8	$19,577,794	8	$19,577,794	88.9	41.8
Department of Conservation and Recreation	312	$543,824,436	—	—	312	$543,824,436	90.2	53.6
Department of Corrections	—	—	1	$1,279,438	1	$1,279,438	100	59.2
Department of Developmental Services	2	$571,427	3	$8,930,011	5	$9,501,438	100	64.0
Department of Early Education and Care	—	—	1	$3,828,847	1	$3,828,847	100	92.2
Department of Fish and Game	19	$9,726,114	—	—	19	$9,726,114	100	57.7

TABLE 11-16.
ESTIMATED POTENTIAL STATE-OWNED AND LEASED BUILDING LOSS FROM HURRICANE CATEGORY 4 STORM SURGE BY STATE AGENCY

	State-Owned Structures		State-Leased Structures		Total Loss		Loss as Percent of Total Exposed[a]	
Agency	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Value
Department of Mental Health	9	$106,129,240	2	$1,628,207	11	$107,757,447	84.6	58.2
Department of Public Health	—	—	4	$8,504,461	4	$8,504,461	100	54.1
Department of Public Utilities	—	—	1	$5,511,256	1	$5,511,256	100	61.6
Department of State Police	7	$11,303,854	—	—	7	$11,303,854	100	58.9
Department of Transitional Assistance	—	—	5	$15,106,162	5	$15,106,162	71.4	41.5
Department of Transportation	39	$34,897,699	4	$17,027,396	43	$51,925,095	67.2	44.4
Department of Workforce Development	—	—	1	$172,142	1	$172,142	100	16.1
Division of Capital Asset Management	3	$40,637,218	1	$46,060,984	4	$86,698,202	100	56.8
Exec. Office of Energy & Environmental Affairs	—	—	2	$18,720,345	2	$18,720,345	100	78.2
Exec. Office of Health & Human Services	—	—	3	$18,947,403	3	$18,947,403	100	56.1
Massachusetts Department of Revenue	—	—	2	$5,631,121	2	$5,631,121	66.7	24.7
Massachusetts College of Art and Design	10	$320,596,092	—	—	10	$320,596,092	100	60.8
Massachusetts Cultural Council	—	—	1	$1,089,452	1	$1,089,452	100	55.4
Massachusetts Gaming Commission	—	—	1	$134,326	1	$134,326	100	9.0
Massachusetts Maritime Academy	23	$217,485,779	—	—	23	$217,485,779	100	93.5
Massachusetts Rehabilitation Commission	—	—	3	$4,870,086	3	$4,870,086	75.0	26.8
Massachusetts Teachers' Retirement System	—	—	1	$4,195,897	1	$4,195,897	100	88.2
Military Division	3	$23,827,749	—	—	3	$23,827,749	37.5	34.1
North Shore Community College	4	$1,829,596	2	$4,640,883	6	$6,470,479	100	43.7
Office of Labor and Workforce Development	1	$4,527,536	—	—	1	$4,527,536	100	72.6
Office of the Chief Medical Examiner	1	$8,594,737	—	—	1	$8,594,737	100	44.4
Office of the D.A. Cape & Island	—	—	1	$78,651	1	$78,651	100	4.9
Office of the State Treasurer	—	—	1	$213,352	1	$213,352	100	9.0
Public Employee Retirement Admin. Comm.	—	—	1	$2,175,170	1	$2,175,170	100	56.1

**TABLE 11-16.
ESTIMATED POTENTIAL STATE-OWNED AND LEASED BUILDING LOSS FROM HURRICANE CATEGORY 4 STORM SURGE BY STATE AGENCY**

	State-Owned Structures		State-Leased Structures		Total Loss		Loss as Percent of Total Exposed[a]	
Agency	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Loss (Structure and Contents)	Number	Value
Salem State University	17	$144,094,487	—	—	17	$144,094,487	58.6	41.8
Secretary of State	1	$48,812,498	1	$534,067	2	$49,346,565	100	67.8
Sex Offenders' Registry	—	—	1	$206,985	1	$206,985	100	5.1
Sheriff's Department Middlesex	1	$45,731,190	1	$3,391,395	2	$49,122,585	100	52.6
Sheriff's Department Suffolk	9	$369,589,776	—	—	9	$369,589,776	100	42.3
Trial Court	4	$127,745,589	5	$12,306,116	9	$140,051,705	81.8	44.8
University of Massachusetts at Amherst	13	$9,318,753	—	—	13	$9,318,753	100	61.8
University of Massachusetts at Boston	20	$938,479,861	—	—	20	$938,479,861	100	68.0
Total	**506**	**$3,247,938,248**	**66**	**$211,609,210**	**572**	**$3,459,547,458**	**86.7**	**55.9**

a. Percentages based on Category 4 building count and value listed in Table 11-7.
Source: (SLOSH and Hazus-MH v. 2.1)

An analysis was conducted to determine the wind-only impacts from hurricane/tropical storm events for four categories (Tropical Storm and Categories 1 through 3) for the entire general building stock of the Commonwealth. Figure 11-24 through Figure 11-27 display the modeled wind speeds for the four events analyzed. Because of differences in building construction, residential structures are generally more susceptible to wind damage than commercial and industrial structures. Wood and masonry buildings in general, regardless of their occupancy class, tend to experience more damage than concrete or steel buildings.

Historical hurricanes selected by the SHMT and THIRA workgroup were runs in Hazus-MH version 2.1 to estimate the potential losses to the Commonwealth's general building stock inventory. Table 11-17 summarizes the estimated building loss (structure only) from the wind from these historical events. Total dollar damage reflects the overall impact to buildings at an aggregate level.

**TABLE 11-17.
ESTIMATED BUILDING LOSS—WIND ONLY**

	Estimated Building Loss (Structure Replacement Cost Value) - Wind Only			
County	Tropical Storm	Category 1 - Hurricane	Category 2 - Hurricane	Category 3 - Hurricane
Barnstable	$550,164	$8,338,069	$499,560,100	$71,830,501
Berkshire	$1,063,884	$611,203	$0	$90,154,567
Bristol	$3,783,342	$41,697,917	$475,212,659	$365,998,827

TABLE 11-17.
ESTIMATED BUILDING LOSS—WIND ONLY

County	Estimated Building Loss (Structure Replacement Cost Value) - Wind Only			
	Tropical Storm	Category 1 - Hurricane	Category 2 - Hurricane	Category 3 - Hurricane
Dukes	$29,543	$1,022,482	$86,437,805	$13,002,014
Essex	$3,814,974	$81,159,400	$76,981,069	$198,751,407
Franklin	$2,459,610	$2,838,860	$0	$107,144,442
Hampden	$18,712,164	$80,678,760	$1,033,838	$1,039,617,581
Hampshire	$5,497,184	$14,274,115	$431,019	$279,193,870
Middlesex	$16,152,101	$281,451,429	$159,437,291	$839,387,681
Nantucket	$0	$307,560	$13,942,210	$5,666,945
Norfolk	$5,168,628	$83,316,231	$199,960,533	$389,425,228
Plymouth	$3,003,919	$33,991,768	$430,676,992	$203,313,119
Suffolk	$4,150,185	$63,563,158	$138,425,859	$339,014,544
Worcester	$19,933,588	$282,271,445	$26,583,708	$986,287,259
Total	**$84,319,286**	**$975,522,397**	**$2,108,683,082**	**$4,928,787,985**

Note: Default Hazus-MH v. 2.1 general building stock inventory based on 2000 Census and 2006 R.S. Means replacement cost values. The general building stock inventory includes all occupancy classes no matter type of ownership (private, state, etc.)

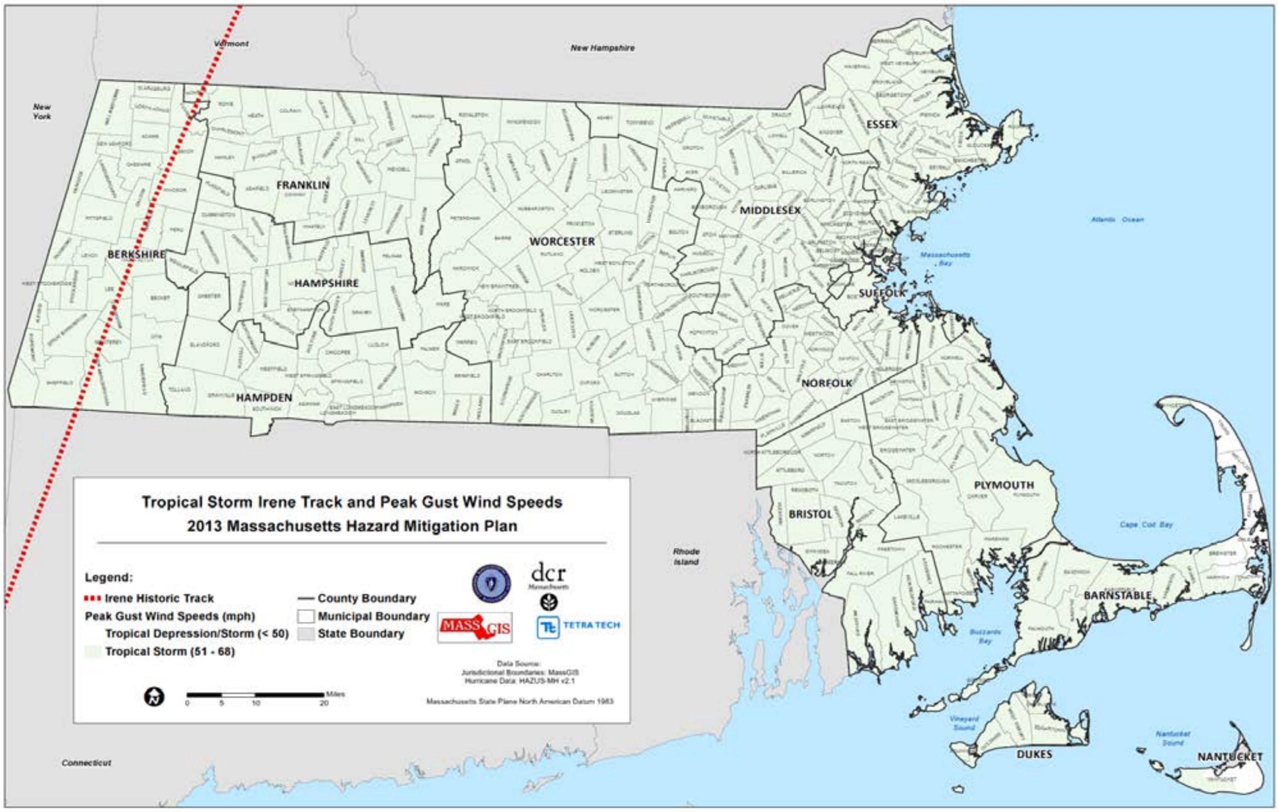

Figure 11-24. Tropical Storm Irene Track and Peak Gust Wind Speeds in Massachusetts

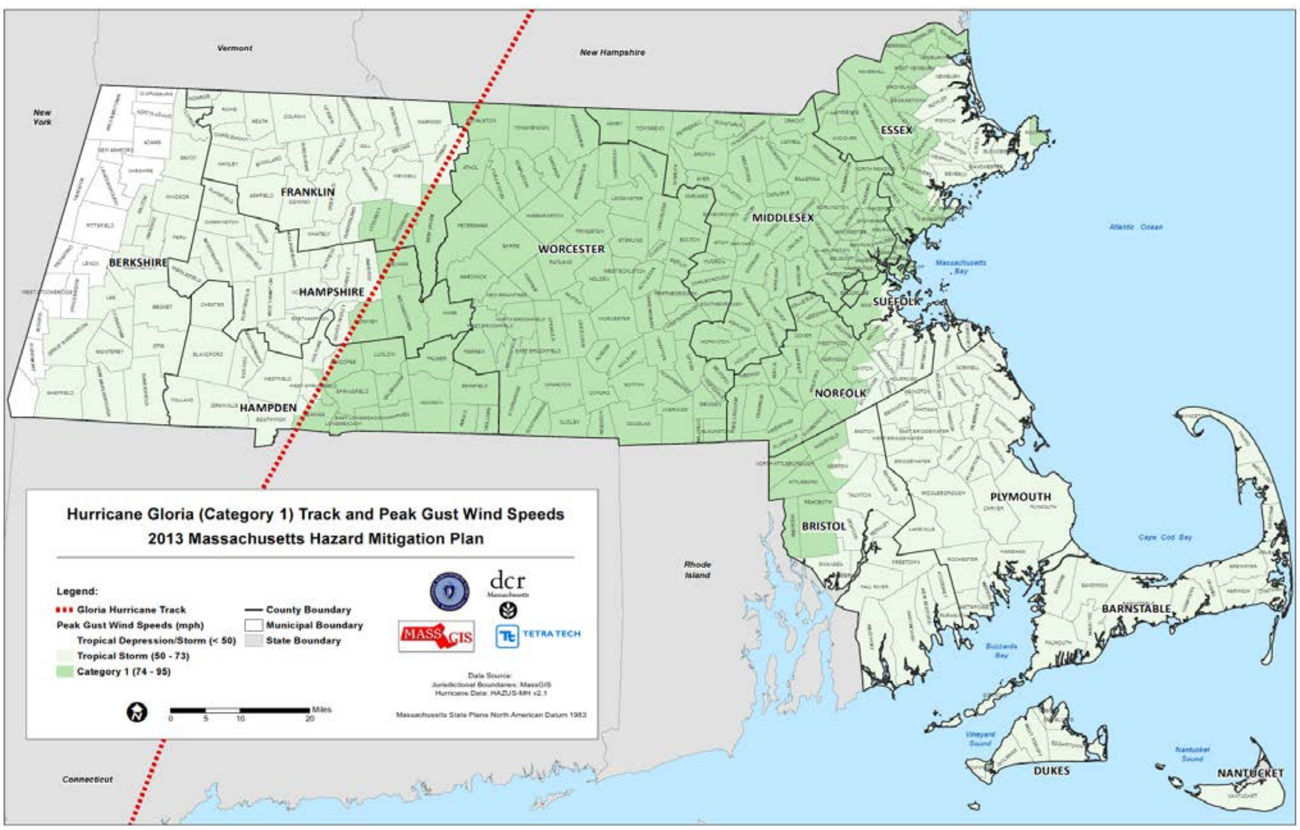

Figure 11-25. Hurricane Gloria (Category 1) Track and Peak Gust Wind Speeds in Massachusetts

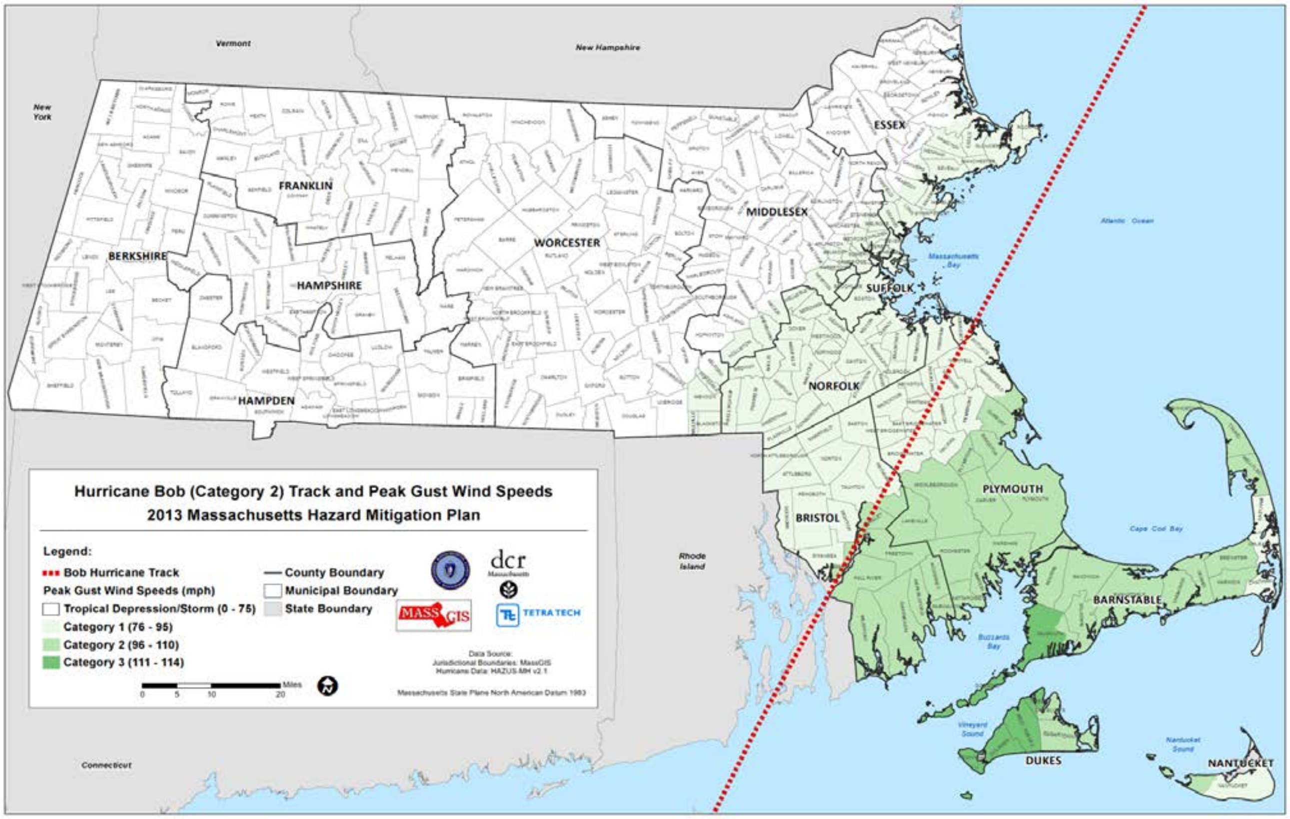

Figure 11-26. Hurricane Bob (Category 2) Track and Peak Gust Wind Speeds in Massachusetts

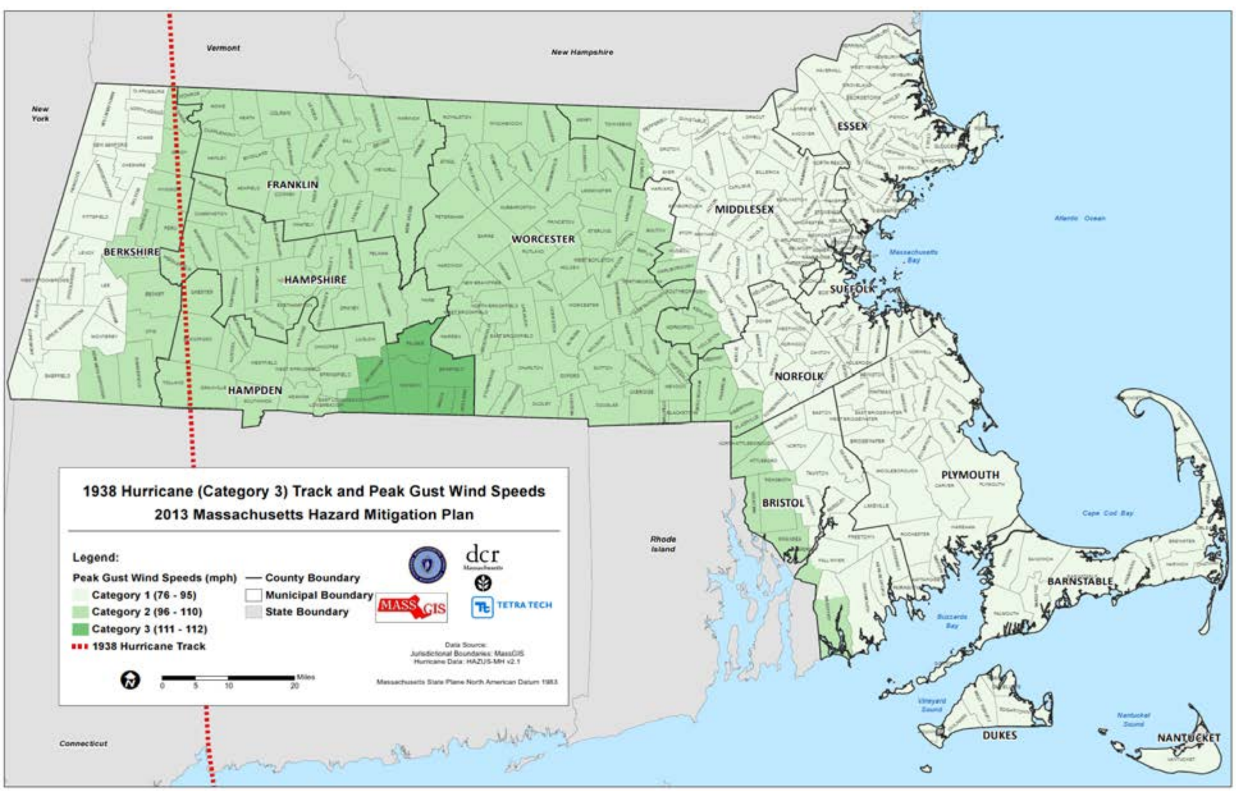

Figure 11-27. 1938 Unnamed Hurricane (Category 3) Track and Peak Gust Wind Speeds in Massachusetts

11.6.3 Critical Facilities

Hazus-MH does not estimate potential dollar losses to critical facilities at this time. When this capability is available, the Commonwealth can enhance this section of the plan. For the purposes of this plan update, to estimate potential losses to critical facilities and infrastructure, the exposure analysis methodology was used. As mentioned earlier, all critical facilities and infrastructure are exposed to hurricane and tropical storm winds and rain; however, those located within the surge inundation zones are at greater risk. 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.

At this time, Hazus-MH v. 2.1 does not estimate losses to transportation lifelines and utilities as part of the hurricane model. Transportation lifelines are not considered particularly vulnerable to the wind hazard; they are more vulnerable to cascading effects such as flooding, falling debris etc. Impacts to transportation lifelines affect both short-term (e.g., evacuation activities) and long-term (e.g., day-to-day commuting) transportation needs. In terms of highway bridges, the Hazus-MH v. 2.1 default replacement cost value for the bridges located in the SLOSH Category 1 through 4 hazard areas is $17 billion (of the greater than $68 billion total).

11.6.4 Economy

Hurricane/tropical storm events can greatly impact the economy, including loss of business function (e.g., tourism, recreation), damage to inventory, relocation costs, wage loss, and rental loss due to the repair/replacement of buildings. Hazus-MH estimates the total economic loss associated with each storm scenario (direct building losses and business interruption losses). Direct building losses are the estimated costs to repair or replace the damage caused to the building. This is discussed earlier in this section. Business interruption losses are the losses associated with the inability to operate a business because of the wind damage sustained during the storm or the temporary living expenses for those displaced from their home because of the event. The economic losses generated by Hazus-MH for each of the deterministic scenarios are summarized in Table 11-18 through Table 11-21.

Hazus-MH v 2.1 also estimates the amount of debris that may be produced a result of wind events. The debris produced is summarized in Table 11-22 through Table 11-25. Because the estimated debris production does not include flooding, this is likely a conservative estimate and may be higher if multiple impacts occur. Please note the following as documented in the Hazus-MH Hurricane User Manual:

> *'The Eligible Tree Debris columns provide estimates of the weight and volume of downed trees that would likely be collected and disposed at public expense. As discussed in Chapter 12 of the Hazus-MH Hurricane Model Technical Manual, the eligible tree debris estimates produced by the Hurricane Model tend to underestimate reported volumes of debris brought to landfills for a number of events that have occurred over the past several years. This indicates that that there may be other sources of vegetative and non-vegetative debris that are not currently being modeled in Hazus. For landfill estimation purposes, it is recommended that the Hazus debris volume estimate be treated as an approximate lower bound. Based on actual reported debris volumes, it is recommended that the Hazus results be multiplied by three to obtain an approximate upper bound estimate. It is also important to note that the Hurricane Model assumes a bulking factor of 10 cubic yards per ton of tree debris. If the debris is chipped prior to transport or disposal, a bulking factor of 4 is recommended. Thus, for chipped debris, the eligible tree debris volume should be multiplied by 0.4'.*

TABLE 11-18.
ESTIMATED ECONOMIC LOSS - WIND ONLY ANALYSIS—TROPICAL STORM

County	Inventory	Relocation	Income	Rental	Wage
Barnstable	$0	$2,027	$0	$0	$0
Berkshire	$0	$1,401	$0	$0	$0
Bristol	$0	$11,110	$0	$0	$0
Dukes	$0	$147	$0	$0	$0
Essex	$0	$14,592	$0	$0	$0
Franklin	$0	$1,151	$0	$0	$0
Hampden	$0	$39,056	$0	$32,509	$0
Hampshire	$0	$3,709	$0	$0	$0
Middlesex	$0	$29,791	$0	$0	$0
Nantucket	$0	$90	$0	$0	$0
Norfolk	$0	$9,400	$0	$0	$0
Plymouth	$0	$4,380	$0	$0	$0
Suffolk	$0	$28,381	$0	$0	$0
Worcester	$0	$34,613	$0	$20,764	$0
Total	**$0**	**$179,850**	**$0**	**$53,273**	**$0**

TABLE 11-19.
ESTIMATED ECONOMIC LOSS - WIND ONLY ANALYSIS— CATEGORY 1 HURRICANE

County	Inventory	Relocation	Income	Rental	Wage
Barnstable	$0	$24,092	$0	$34,383	$0
Berkshire	$0	$246	$0	$0	$0
Bristol	$0	$343,640	$0	$475,695	$0
Dukes	$0	$1,476	$0	$1,853	$0
Essex	$3,101	$1,198,574	$0	$1,687,150	$0
Franklin	$0	$1,428	$0	$224	$0
Hampden	$27,622	$1,922,278	$0	$1,233,825	$0
Hampshire	$9,605	$189,336	$0	$134,777	$0
Middlesex	$34,332	$3,926,543	$12,942	$3,849,975	$12,354
Nantucket	$0	$226	$0	$69	$0
Norfolk	$0	$482,274	$0	$589,650	$0
Plymouth	$0	$118,150	$0	$156,308	$0
Suffolk	$7	$1,683,517	$0	$2,440,722	$0
Worcester	$234,153	$9,729,543	$942,587	$9,161,341	$965,280
Total	**$308,820**	**$19,621,322**	**$955,528**	**$19,765,972**	**$977,635**

TABLE 11-20.
ESTIMATED ECONOMIC LOSS - WIND ONLY ANALYSIS—CATEGORY 2 HURRICANE

County	Inventory	Relocation	Income	Rental	Wage
Barnstable	$914,358	$43,621,607	$4,887,287	$20,277,628	$7,437,197
Berkshire	$0	$0	$0	$0	$0
Bristol	$1,567,800	$27,212,483	$3,951,471	$23,409,079	$5,686,125
Dukes	$261,260	$10,156,843	$685,006	$4,345,912	$1,431,531
Essex	$5,040	$1,732,128	$9,121	$1,914,259	$3,241
Franklin	$0	$0	$0	$0	$0
Hampden	$0	$2,654	$0	$0	$0
Hampshire	$0	$179	$0	$0	$0
Middlesex	$3,728	$2,013,132	$0	$2,660,773	$0
Nantucket	$8,579	$728,688	$164,458	$451,192	$230,201
Norfolk	$47,407	$5,255,841	$187,454	$4,497,384	$93,549
Plymouth	$613,285	$20,416,867	$2,722,476	$10,672,014	$4,196,047
Suffolk	$16,711	$5,200,997	$38,584	$7,022,634	$33,489
Worcester	$0	$114,170	$0	$127,700	$0
Total	**$3,438,169**	**$116,455,589**	**$12,645,857**	**$75,378,575**	**$19,111,380**

TABLE 11-21.
ESTIMATED ECONOMIC LOSS - WIND ONLY ANALYSIS— CATEGORY 3 HURRICANE

County	Inventory	Relocation	Income	Rental	Wage
Barnstable	$14,495	$2,490,381	$154,868	$1,451,431	$128,893
Berkshire	$125,457	$2,938,005	$170,025	$2,304,071	$188,577
Bristol	$729,256	$16,173,442	$2,314,907	$16,058,167	$3,111,610
Dukes	$9,271	$481,145	$77,366	$341,198	$96,707
Essex	$66,328	$7,354,357	$366,031	$6,988,385	$130,057
Franklin	$387,305	$6,543,605	$1,075,793	$3,554,837	$2,195,021
Hampden	$6,895,455	$98,936,571	$12,794,122	$49,021,751	$20,790,666
Hampshire	$948,277	$21,614,918	$3,072,611	$10,856,486	$6,476,624
Middlesex	$673,522	$29,352,528	$4,824,120	$27,993,029	$4,454,761
Nantucket	$1,115	$239,681	$28,854	$144,911	$10,251
Norfolk	$329,542	$12,632,902	$1,987,433	$10,348,853	$1,849,797
Plymouth	$91,639	$5,826,556	$474,344	$4,183,729	$320,450
Suffolk	$133,387	$17,537,733	$3,528,169	$21,561,065	$3,069,888
Worcester	$3,811,338	$57,308,453	$11,360,720	$42,243,231	$18,430,050
Total	**$14,216,387**	**$279,430,278**	**$42,229,364**	**$197,051,144**	**$61,253,352**

TABLE 11-22.
ESTIMATED DEBRIS - WIND ONLY ANALYSIS— TROPICAL STORM

County	Brick/Wood (tons)	Concrete (tons)	Trees (tons)	Tree Volume (cubic yards)
Barnstable	0	0	0	0
Berkshire	0	0	22,729	227,295
Bristol	179	0	11,008	110,083
Dukes	0	0	0	0
Essex	325	0	6,355	63,558
Franklin	58	0	33,908	339,094
Hampden	1,463	0	27,529	275,313
Hampshire	205	0	24,675	246,709
Middlesex	1,004	0	23,066	230,567
Nantucket	0	0	0	0
Norfolk	218	0	9,484	94,849
Plymouth	25	0	12,696	126,943
Suffolk	933	0	609	6,147
Worcester	1,227	0	49,510	495,117
Total	**5,637**	**0**	**221,569**	**2,215,675**

TABLE 11-23.
ESTIMATED DEBRIS - WIND ONLY ANALYSIS— CATEGORY 1 HURRICANE

County	Brick/Wood (tons)	Concrete (tons)	Trees (tons)	Tree Volume (cubic yards)
Barnstable	390	0	10,941	109,405
Berkshire	0	0	17,824	178,251
Bristol	4,801	0	39,135	391,373
Dukes	46	0	1,376	13,750
Essex	10,213	0	46,418	464,224
Franklin	103	0	43,162	431,628
Hampden	8,644	0	135,626	1,356,271
Hampshire	1,161	0	67,290	672,890
Middlesex	28,705	0	184,036	1,840,306
Nantucket	13	0	0	0
Norfolk	6,902	0	36,138	361,379
Plymouth	2,105	0	40,546	405,423
Suffolk	12,800	0	3,185	31,824
Worcester	38,571	0	634,560	6,345,566
Total	**114,454**	**0**	**1,260,237**	**12,602,289**

TABLE 11-24.
ESTIMATED DEBRIS - WIND ONLY ANALYSIS— CATEGORY 2 HURRICANE

County	Brick/Wood (tons)	Concrete (tons)	Trees (tons)	Tree Volume (cubic yards)
Barnstable	78,229	334	217,535	2,175,341
Berkshire	0	0	0	0
Bristol	82,800	94	282,486	2,824,789
Dukes	13,994	102	99,627	996,267
Essex	10,068	0	39,437	394,364
Franklin	0	0	0	0
Hampden	0	0	5,849	58,501
Hampshire	1	0	4,787	47,871
Middlesex	19,541	0	49,041	490,358
Nantucket	2,112	2	5,171	51,706
Norfolk	21,920	0	85,963	859,612
Plymouth	49,705	111	427,102	4,271,032
Suffolk	29,373	0	5,862	58,622
Worcester	2,357	0	42,115	421,146
Total	**310,100**	**643**	**1,264,975**	**12,649,608**

TABLE 11-25.
ESTIMATED DEBRIS - WIND ONLY ANALYSIS— CATEGORY 3 HURRICANE

County	Brick/Wood (tons)	Concrete (tons)	Trees (tons)	Tree Volume (cubic yards)
Barnstable	7,929	0	56,764	567,643
Berkshire	12,966	3	642,976	6,429,759
Bristol	60,938	16	261,013	2,610,177
Dukes	1,687	0	26,769	267,697
Essex	28,838	0	114,722	1,147,180
Franklin	15,503	37	735,129	7,351,280
Hampden	163,750	713	734,365	7,343,637
Hampshire	41,320	125	641,215	6,412,152
Middlesex	112,133	9	401,286	4,012,869
Nantucket	673	0	2,894	28,942
Norfolk	46,464	6	167,894	1,678,960
Plymouth	20,478	0	252,527	2,525,272
Suffolk	70,185	0	10,819	108,175
Worcester	155,732	178	1,415,750	14,157,481
Total	**738,596**	**1,087**	**5,464,123**	**54,641,226**