TABLES

FIGURES

SECTION 8. EARTHQUAKE

8.1 GENERAL BACKGROUND

An earthquake is the vibration, sometimes violent, of the earth's surface that follows a release of energy in the earth's crust due to fault fracture and movement. A fault is a fracture in the earth's crust along which two blocks of the crust have slipped with respect to each other. Faults are divided into three main groups, depending on how they move. Normal faults occur in response to pulling or tension: the overlying block moves down the inclined dip of the fault plane. Thrust (reverse) faults occur in response to squeezing or compression: the overlying block moves up the inclined dip of the fault plane. Strike-slip (lateral) faults occur in response to either type of stress; the blocks move horizontally along a vertical fault past one another. Most faulting along spreading zones is the normal type, along subduction zones is thrust type, and along transform faults is strike-slip.

The focal depth of an earthquake is the depth from the surface to the region where the earthquake's energy originates (the focus). Earthquakes with focal depths up to about 43.5 miles are classified as shallow. Earthquakes with focal depths of 43.5 to 186 miles are classified as intermediate. The focus of deep earthquakes may reach depths of more than 435 miles. The focuses of most earthquakes are concentrated in the upper 20 miles of the earth's crust. The depth to the Earth's core is about 3,960 miles, so even the deepest earthquakes originate in relatively shallow parts of the Earth's interior.

The epicenter of an earthquake is the point on the Earth's surface directly above the focus, and the focus is the area of the fault where a sudden rupture initiates. The location of an earthquake is commonly described by the geographic position of its epicenter and by its focal depth. Earthquakes beneath the ocean floor sometimes generate immense sea waves or tsunamis if the earthquake causes upward or downward movement of the sea floor. The tsunami originates where this movement takes place.

The cause of earthquakes in eastern North America is the forces moving the tectonic plates over the surface of the Earth. New England is located in the middle of the North American Plate. One edge of the North American plate is along the west coast where the plate is pushing against the Pacific Ocean plate. The eastern edge of the North American plate is at the middle of the Atlantic Ocean, where the plate is spreading away from the European and African plates. New England's earthquakes appear to be the result of the cracking of the crustal rocks due to compression as the North American plate is being very slowly squeezed by the global plate movements.

Seismic waves are the vibrations from earthquakes that travel through the Earth and are recorded on instruments called seismographs. The magnitude or extent of an earthquake is a seismograph-measured value of the amplitude of the seismic waves. The Richter magnitude scale (Richter scale) was developed in 1932 as a mathematical device to compare the sizes of earthquakes. The Richter scale is the most widely known scale that measures earthquake magnitude. It has no upper limit and is not used to express damage. An earthquake in a densely populated area, which results in many deaths and considerable damage, can have the same magnitude as an earthquake in a remote area that causes no damage. Table 8-1 summarizes Richter scale magnitudes and corresponding earthquake effects. Effects listed are more applicable at lower levels to California than to Massachusetts. For example, earthquakes in the 2 to 2.5 range are typically felt in Massachusetts and throughout the eastern United States. Generally, earthquakes in the eastern U.S. are felt over a larger area than those in the western U.S., as depicted in Figure 8-1. The difference between seismic shaking in the East versus the West is due in part to the geologic structure and rock properties that allow seismic waves to travel farther without weakening (USGS, 2012).

TABLE 8-1.
RICHTER SCALE

Richter Magnitude	Earthquake Effects
2.5 or less	Not felt or felt mildly near the epicenter, but can be recorded by seismographs
2.5 to 5.4	Often felt, but only causes minor damage
5.5 to 6.0	Slight damage to buildings and other structures
6.1 to 6.9	May cause a lot of damage in very populated areas
7.0 to 7.9	Major earthquake; serious damage
8.0 or greater	Great earthquake; can totally destroy communities near the epicenter

Source: (USGS, 2012)

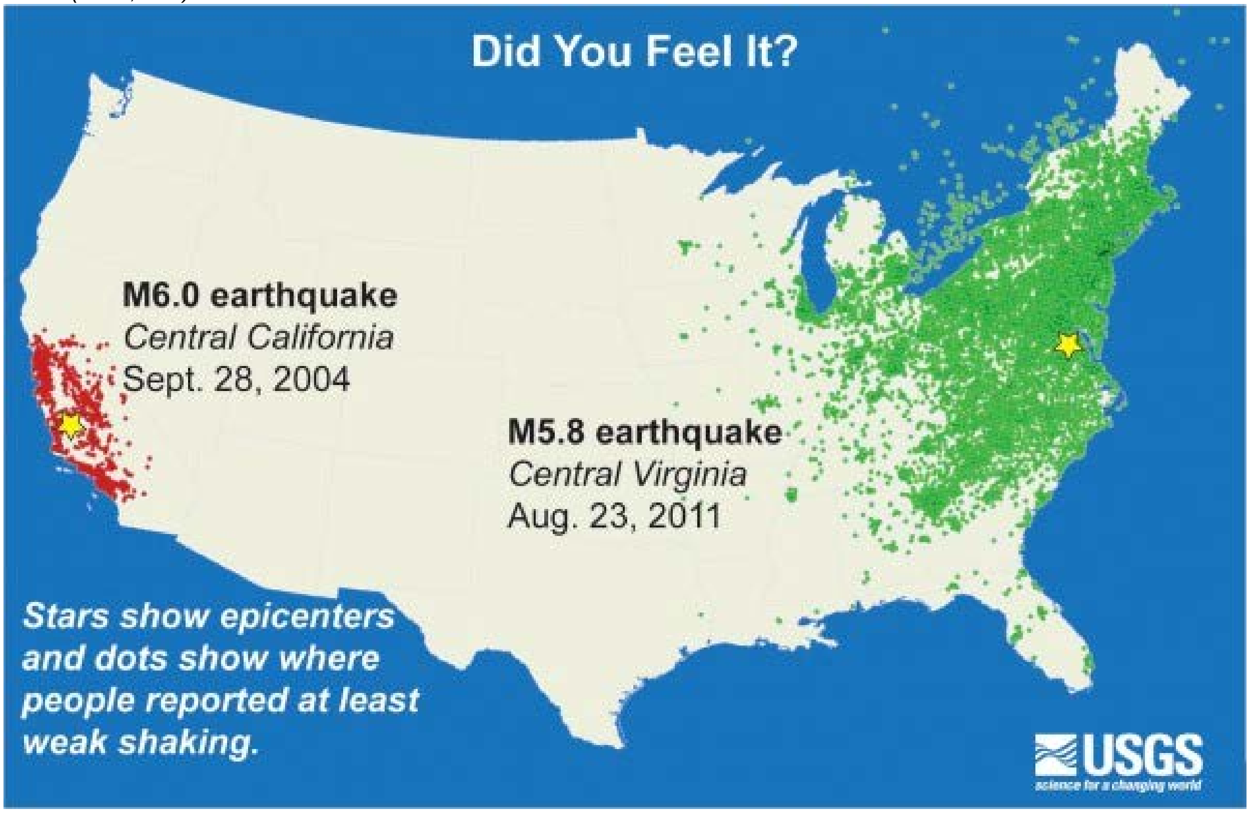


Figure 8-1. USGS "Did you Feel It?" Data from Magnitude 5.8 Earthquake in Central Virginia (green) and from an Earthquake of Similar Magnitude and Depth in California (red)

The intensity of an earthquake is based on the observed effects of ground shaking on people, buildings, and natural features, and varies with location. Intensity is expressed by the Modified Mercalli Scale; a subjective measure that describes how strongly an earthquake was felt at a particular location. The Modified Mercalli Scale expresses the intensity of an earthquake's effects in a given locality in values ranging from I to XII. Table 8-2 summarizes earthquake intensity as expressed by the Modified Mercalli Scale. Table 8-3 displays the Modified Mercalli Scale and peak ground acceleration equivalent.

TABLE 8-2.
MODIFIED MERCALLI INTENSITY SCALE

Mercalli Intensity	Description
I	Felt by very few people; barely noticeable.
II	Felt by few people, especially on upper floors.
III	Noticeable indoors, especially on upper floors, but may not be recognized as an earthquake.
IV	Felt by many indoors, few outdoors. May feel like passing truck.
V	Felt by almost everyone, some people awakened. Small objects move, trees and poles may shake.
VI	Felt by everyone; people have trouble standing. Heavy furniture can move; plaster can fall off walls. Chimneys may be slightly damaged.
VII	People have difficulty standing. Drivers feel cars shaking. Some furniture breaks. Loose bricks fall from buildings. Damage is slight to moderate in well-built buildings; considerable in poorly built buildings.
VIII	Buildings suffer slight damage if well-built, severe damage if poorly built. Some walls collapse.
IX	Considerable damage to specially built structures; buildings shift off their foundations. The ground cracks. Landslides may occur.
X	Most buildings and their foundations are destroyed. Some bridges are destroyed. Dams are seriously damaged. Large landslides occur. Water is thrown on the banks of canals, rivers, lakes. The ground cracks in large areas.
XI	Most buildings collapse. Some bridges are destroyed. Large cracks appear in the ground. Underground pipelines are destroyed.
XII	Almost everything is destroyed. Objects are thrown into the air. The ground moves in waves or ripples. Large amounts of rock may move.

TABLE 8-3.
MODIFIED MERCALLI INTENSITY (MMI) AND PGA EQUIVALENTS

MMI	Acceleration (%g) (PGA)	Perceived Shaking	Potential Damage
I	< .17	Not Felt	None
II	.17 – 1.4	Weak	None
III	.17 – 1.4	Weak	None
IV	1.4 – 3.9	Light	None
V	3.9 – 9.2	Moderate	Very Light
VI	9.2 – 18	Strong	Light
VII	18 – 34	Very Strong	Moderate
VIII	34 – 65	Severe	Moderate to Heavy
IX	65-124	Violent	Heavy
X	>124	Extreme	Very Heavy
XI	>124	Extreme	Very Heavy
XII	>124	Extreme	Very Heavy

Source: Commonwealth of Virginia, 2010

Seismic hazards are often expressed in terms of Peak Ground Acceleration (PGA) and Spectral Acceleration (SA). USGS defines PGA and SA as the following: 'PGA is what is experienced by a particle on the ground. Spectral Acceleration (SA) is approximately what is experienced by a building, as modeled by a particle mass on a massless vertical rod having the same natural period of vibration as the building'. Both PGA and SA can be measured in *g* (the acceleration due to gravity) or expressed as a percent acceleration force of gravity (%g). PGA and SA hazard maps provide insight into location specific vulnerabilities.

More specifically, a PGA earthquake measurement shows three things: the geographic area affected, the probability of an earthquake of each given level of severity, and the strength of ground movement (severity) expressed in terms of percent of acceleration force of gravity (%g). In other words, PGA expresses the severity of an earthquake and is a measure of how hard the earth shakes (or accelerates) in a given geographic area.

For the 2013 plan update, a probabilistic assessment was conducted for the 100-, 500-, 1,000-, and 2,500-year mean return periods (MRP) through a Level 2 analysis in Hazus-MH 2.1 to analyze the earthquake hazard for the Commonwealth. The Hazus analysis evaluates the statistical likelihood that a specific event will occur and what consequences will occur. For example, 100-year MRP event is an earthquake with a 1% chance that the mapped ground motion levels (PGA) will be exceeded in any given year. Figure 8-2 through Figure 8-5 show the geographic distribution of PGA (%*g*) across Massachusetts for 100-, 500-, 1,000-, and 2,500-year MRP events at the U.S. 2000 Census-tract level.

Ground shaking is the primary cause of earthquake damage to man-made structures. This damage can be increased due to the fact that soft soils amplify ground shaking. A contributor to site amplification is the velocity at which the rock or soil transmits shear waves (S-waves). The National Earthquake Hazard Reduction Program (NEHRP) developed five soil classifications defined by their shear-wave velocity that impact the severity of an earthquake. The soil classification system ranges from A to E, where A represents hard rock that reduces ground motions from an earthquake and E represents soft soils that amplify and magnify ground shaking and increase building damage and losses. NEHRP soil classifications are available for only a portion of the Commonwealth at the time of this analysis: portions of Franklin, Hampden, and Hampshire Counties as provided by the state geologist. Figure 8-6 illustrates the NEHRP soils available in Massachusetts. The available NEHRP soils were incorporated into the Hazus-MH earthquake model for the risk assessment (discussed in further detail later in this section). Where NEHRP soils were not available, the Hazus default soil type 'D' was used.

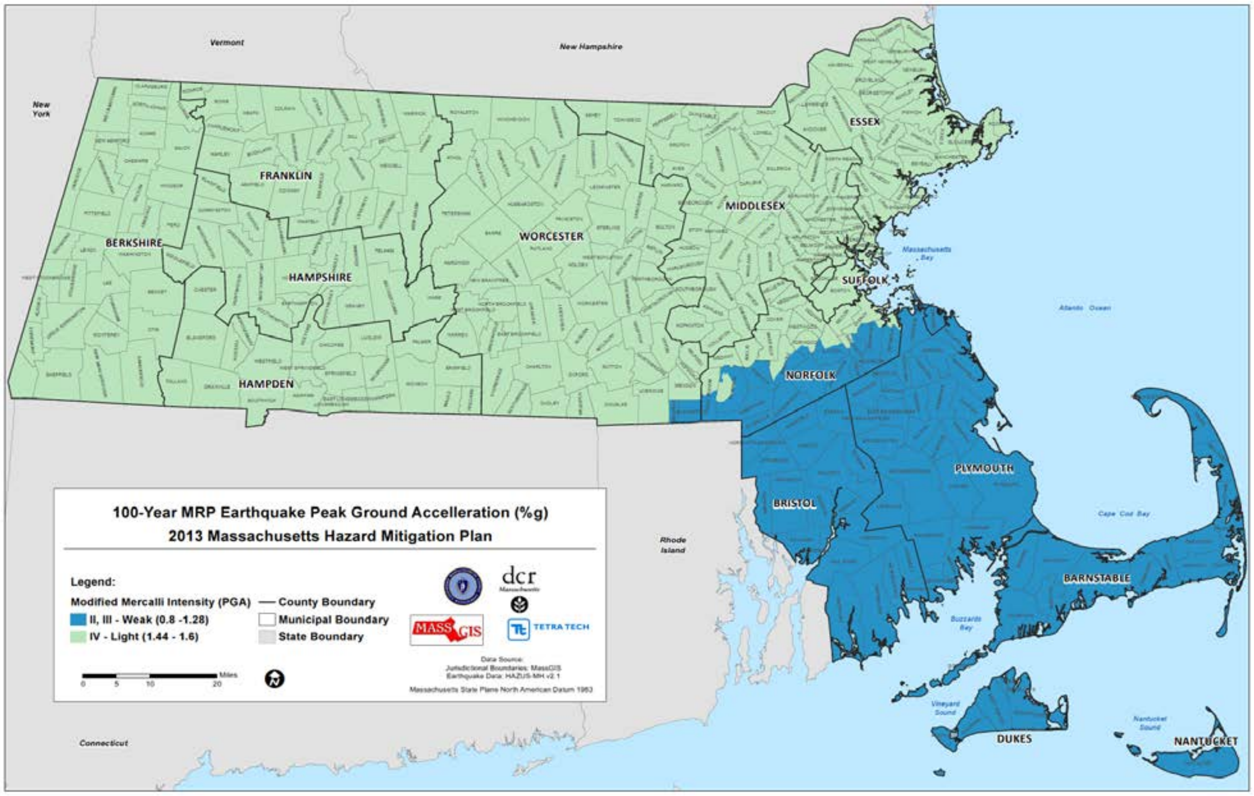


Figure 8-2. Peak Ground Acceleration Modified Mercalli Scale for a 100-Year MRP Earthquake Event

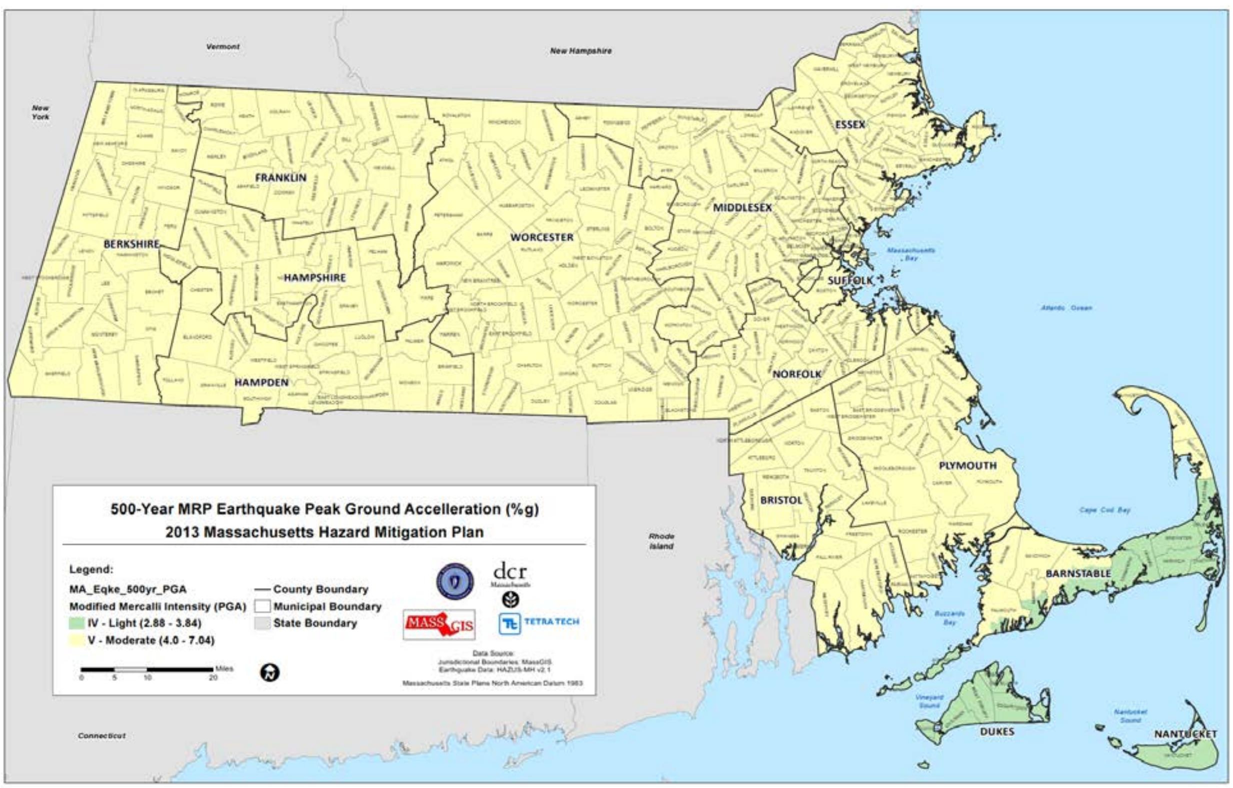


Figure 8-3. Peak Ground Acceleration Modified Mercalli Scale for a 500-Year MRP Earthquake Event

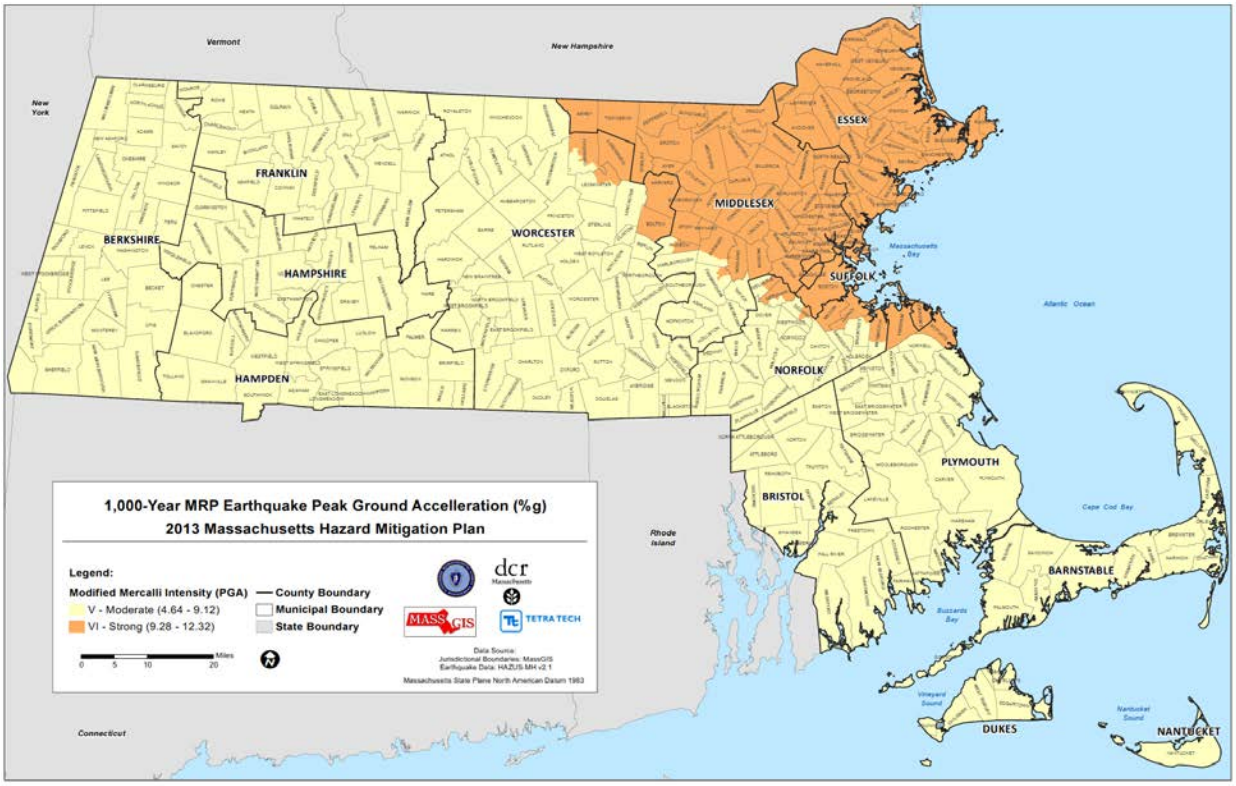


Figure 8-4. Peak Ground Acceleration Modified Mercalli Scale for a 1,000-Year MRP Earthquake Event

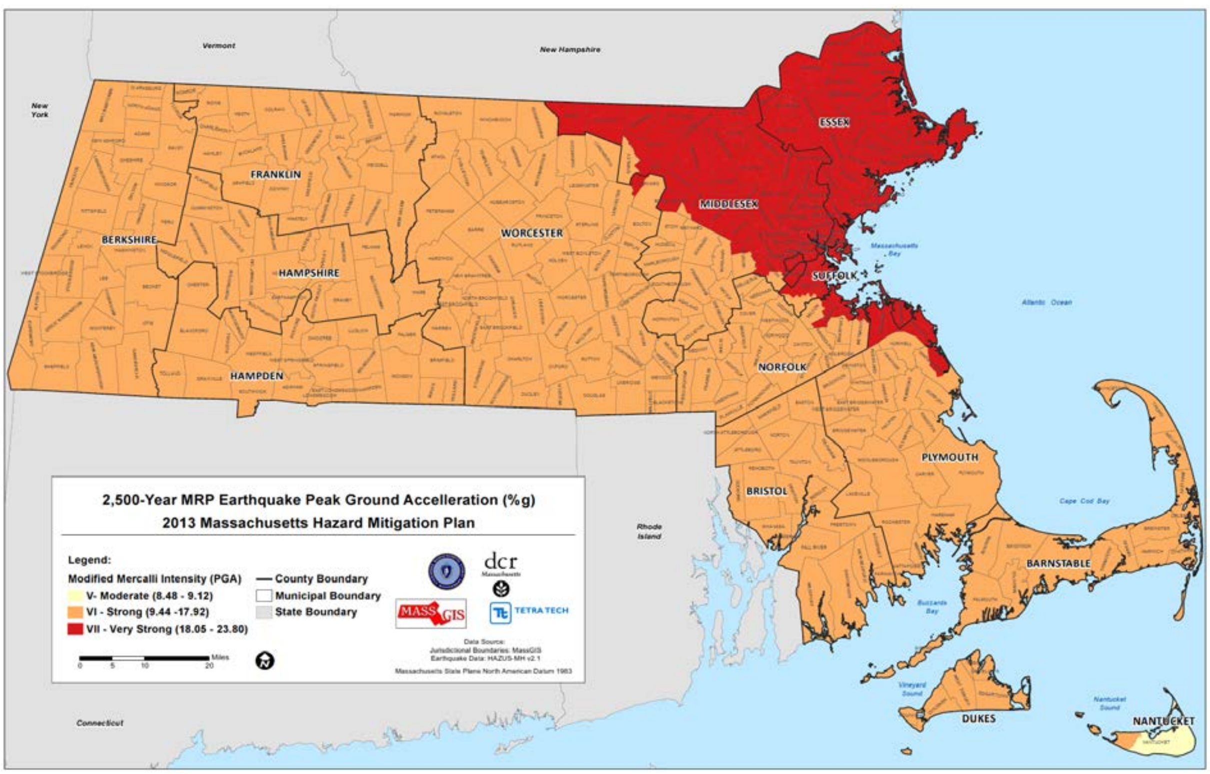


Figure 8-5. Peak Ground Acceleration Modified Mercalli Scale for a 2,500-Year MRP Earthquake Event

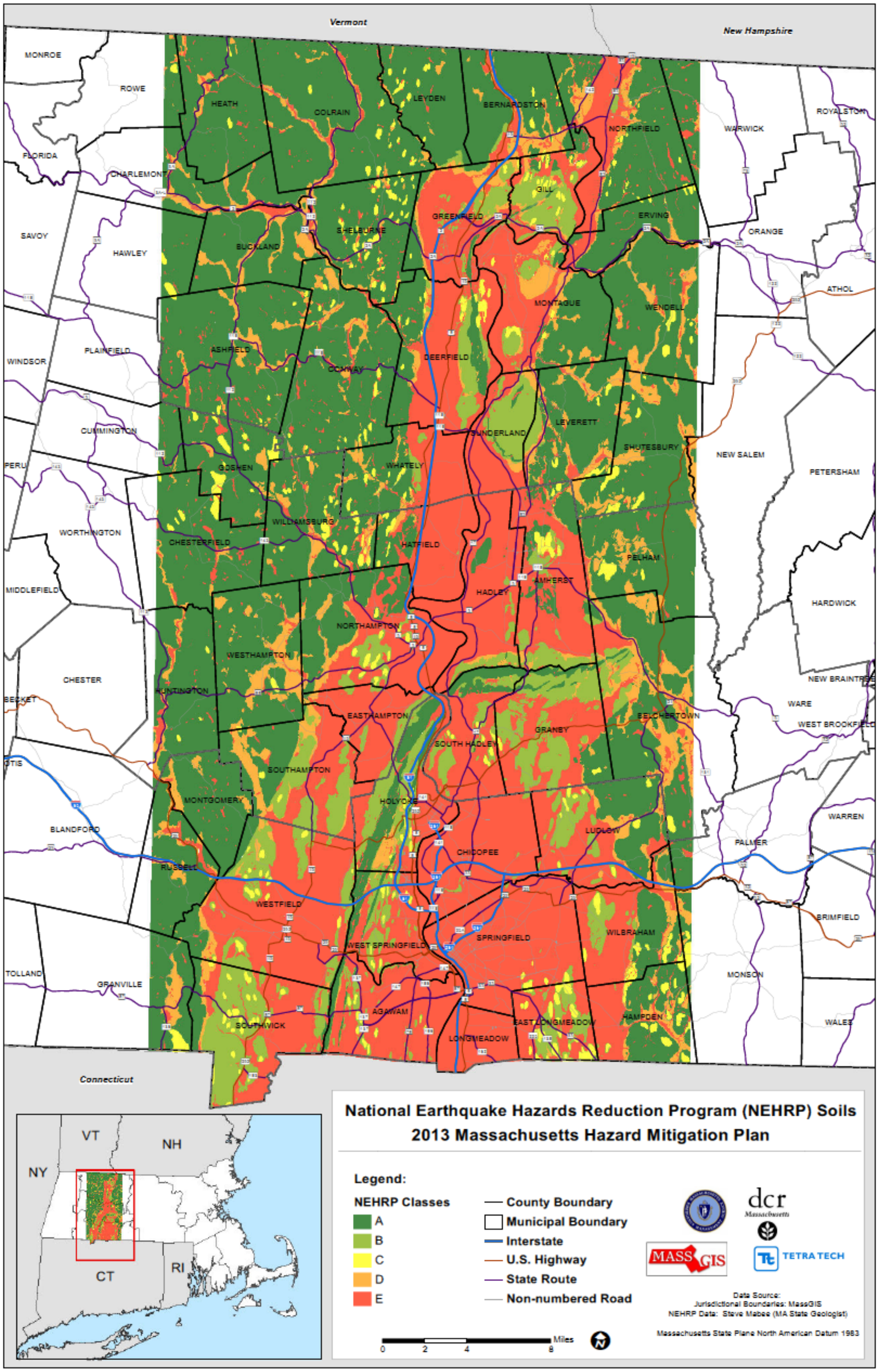


Figure 8-6. National Earthquake Hazards Reduction Program Soils in Massachusetts

8.2 HAZARD PROFILE

8.2.1 Location

Review of available data reveals that the New England epicenters do not follow the major mapped faults of the region, nor are they confined to particular geologic structures or terrains. As opposed to plate boundary regions similar to the West Coast in California, Washington or Oregon where many of the earthquakes align along known geologic faults, New England's earthquakes to date have not aligned along mapped faults. Because earthquakes have been detected all over New England, seismologists suspect that a strong earthquake could be centered anywhere in the region. Furthermore, the mapped geologic faults of New England currently do not provide any indications detailing specific locations where strong earthquakes are most likely to be centered. The GIS analysis included in this analysis represent the locations of earthquake epicenters occurring between 1638-2008 with the magnitude of each event depicted by a graduated symbol, fault locations, and Peak Ground Acceleration (PGA) zones, expressed as percentages of gravity with a two percent probability of the depicted PGA being exceeded in a 50-year period.

In an attempt to quantify the risk of damage due to an earthquake throughout the United States, the USGS through the Earthquake Hazard Program, has developed national maps displaying likely levels of ground motion due to future earthquakes. When developing these maps, the USGS considered the potential magnitude and locations of future earthquakes based on historical data and geological information on the recurrence intervals of fault ruptures. Using these data, the extent of potential ground shaking with a 10 percent, 5 percent, and 2 percent chance of being exceeded in a 50-year period has been calculated, and color maps displaying these ground-motion values on a national scale have been prepared. Information about the nation's seismic hazard maps is available from the USGS Earthquake Hazards Program website: http://eqhazmaps.usgs.gov/. The highest percentages of PGA areas in the Commonwealth are located in Northern Middlesex and Essex Counties; however, the PGA percentages are very low compared to the national averages.

The most commonly used method to quantify potential ground motion is in terms of peak ground acceleration (PGA), which measures the strength of a potential earthquake in terms of the greatest acceleration value of ground movement. The potential damage due to earthquake ground shaking increases as the acceleration of ground movement increases. Peak ground acceleration is expressed as a percentage of a known acceleration, the acceleration of gravity, and is commonly referred to as "%g" in the national seismic hazard maps.

Major damage can occur in earthquakes due to secondary effects triggered by strong earthquake ground shaking. The Richter magnitude scale is a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. The Richter scale does not reflect damage caused by an earthquake.

A secondary effect that is often observed in low-lying areas near water bodies is ground liquefaction. Liquefaction is the conversion of water-saturated soil into a fluid-like mass. This can occur when loosely packed, waterlogged sediments lose their strength in response to strong shaking. Liquefaction may occur along the shorelines of the ocean, rivers, and lakes, and they can also happen in low-lying areas away from water bodies but where the ground water is near the Earth's surface. Landslides and land slumps are other secondary effects that can be induced by earthquake shaking and that can be very damaging.

A U.S. Geological Survey National Earthquake Hazard Reduction Program study was funded to conduct a detailed study to characterize the surface and subsurface distribution of potentially liquefiable sediments and artificial fill in the City of Boston. Several areas in the study region, including a majority of downtown Boston are 'underlain by extensive regions of non-engineered artificial fill that, when saturated, are susceptible to liquefaction during seismic loading' (Baise and Brankman, 2004). 'Holocene alluvial and marsh deposits in the region are also moderately to highly susceptible to liquefaction. Much of the outlying area is underlain by Pleistocene and Quaternary glacial and glacio-fluvial deposits, which have low to moderate susceptibility to liquefaction' (Brankman and Baise, 2008). Figure 8-7 illustrates the liquefaction susceptibility of the Boston, Massachusetts metropolitan area (Baise and Brankman,

Although it is well documented that the zone of greatest seismic activity in the United States is along the Pacific Coast in Alaska and California, it may be surprising to most people that an average of six earthquakes are felt each year somewhere in New England, and that damaging earthquakes have taken place in historical time in New England.

New England has had a long history of earthquakes, starting with that recorded by the Plymouth Pilgrims and other early settlers in 1638. Of the over 5,000 earthquakes recorded in the Northeast Earthquake Catalog through 2008, 1,530 occurred within the boundaries of the six New England States, with 366 earthquakes recorded for Massachusetts between 1627 and 2008. Between 1924 and 2008, there have been 101 earthquakes in the Northeast with a magnitude of 4.5 or greater on the Richter scale. Out of these 101 earthquakes, 8 were within the six New England States and the other 93 within New York State or the Province of Quebec. Many of these earthquakes were so strong that they were felt throughout all of New England.

Based on the data provided by Weston Observatory and on the national earthquake hazards map, it appears that northeastern Massachusetts, especially along the Massachusetts coastline from the northern portion of Plymouth County through the Boston Metropolitan area to the New Hampshire border, has greater vulnerability to potential earthquake activity than the rest of the Commonwealth. There are very few earthquakes in western Massachusetts. However, the shaking from earthquakes in eastern New York State can affect western Massachusetts, so all of the Commonwealth has some measure of earthquake hazard.

Earthquakes above about magnitude 5.0 have the potential for causing damage near their epicenters, and larger magnitude earthquakes have the potential for causing damage over larger wider areas. A 1994 report by the USGS, based on a meeting of experts at the Massachusetts Institute of Technology, found that the probability of a magnitude 5.0 or greater earthquake centered somewhere in New England in a 10-year period is about 10%-15%. This probability rises to about 41% to 56% for a 50-year period. The last earthquake with a magnitude above 5.0 that was centered in New England took place in the Ossipee Mountains of New Hampshire in 1940.

In some places in New England, including Massachusetts, small earthquakes seem to occur with some regularity. For example, since 1985 there has been a small earthquake experienced approximately every 2.5 years within a few miles of Littleton, Massachusetts. It is not clear why some localities experience such clustering of earthquakes, but a possibility suggested by John Ebel of Boston College's Weston Observatory is that these clusters occur where strong earthquakes were centered in the prehistoric past. The clusters may indicate locations where there is an increased likelihood of future earthquake activity. Figure 8-8 illustrates the major fault lines and historical earthquake epicenters across the Commonwealth from 1638 to 2009.

According to the Northeast States Emergency Consortium, the USGS is increasing the number of seismic stations in New England. Their goal is to reduce uncertainties and to improve procedures for locating smaller earthquakes (Fratto, email, 2012). Figure 8-9 illustrates the seismic stations located throughout New England.

Source: Baise and Brankman, 2004

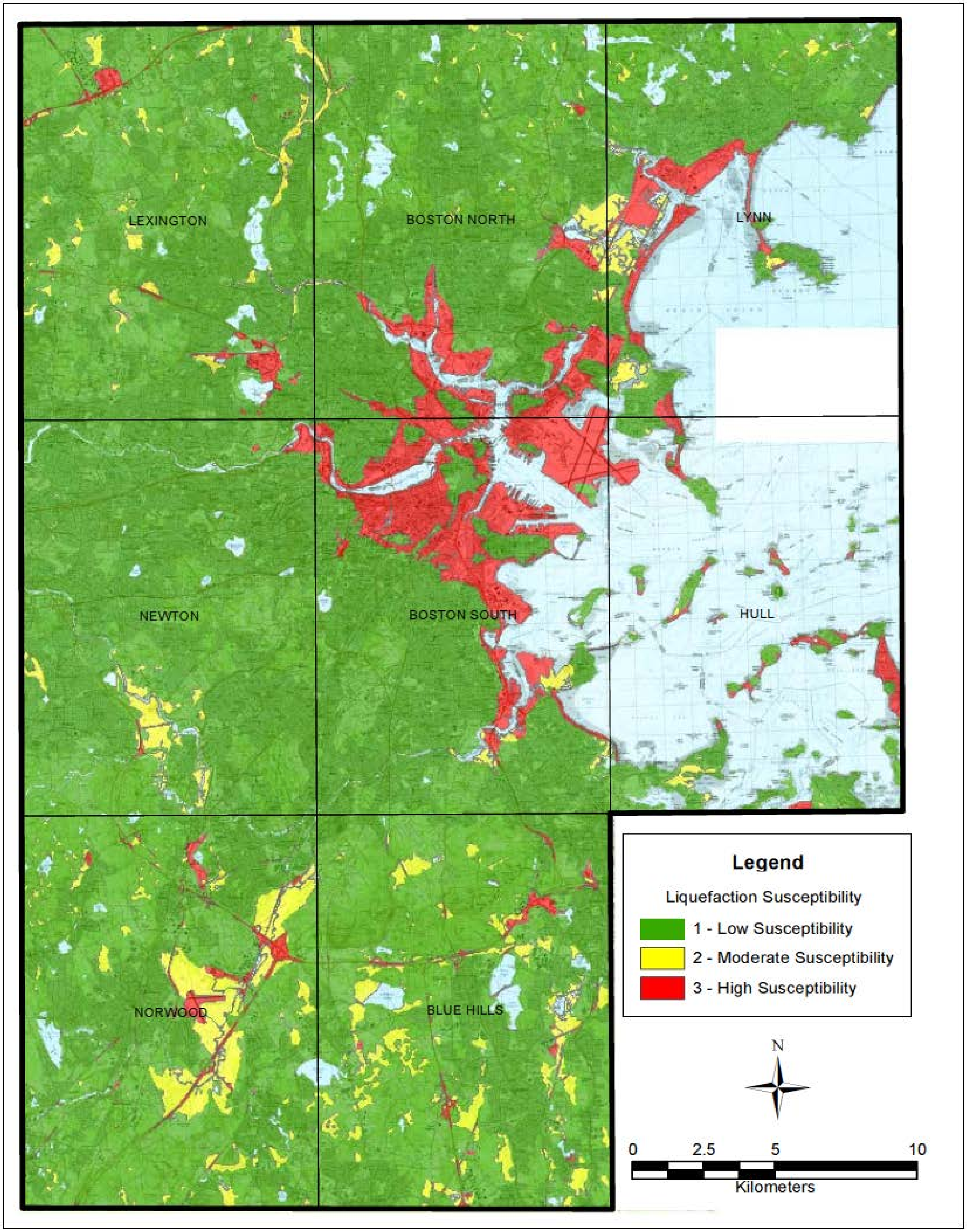


Figure 8-7. Liquefaction Susceptibility of the Boston Metropolitan Area

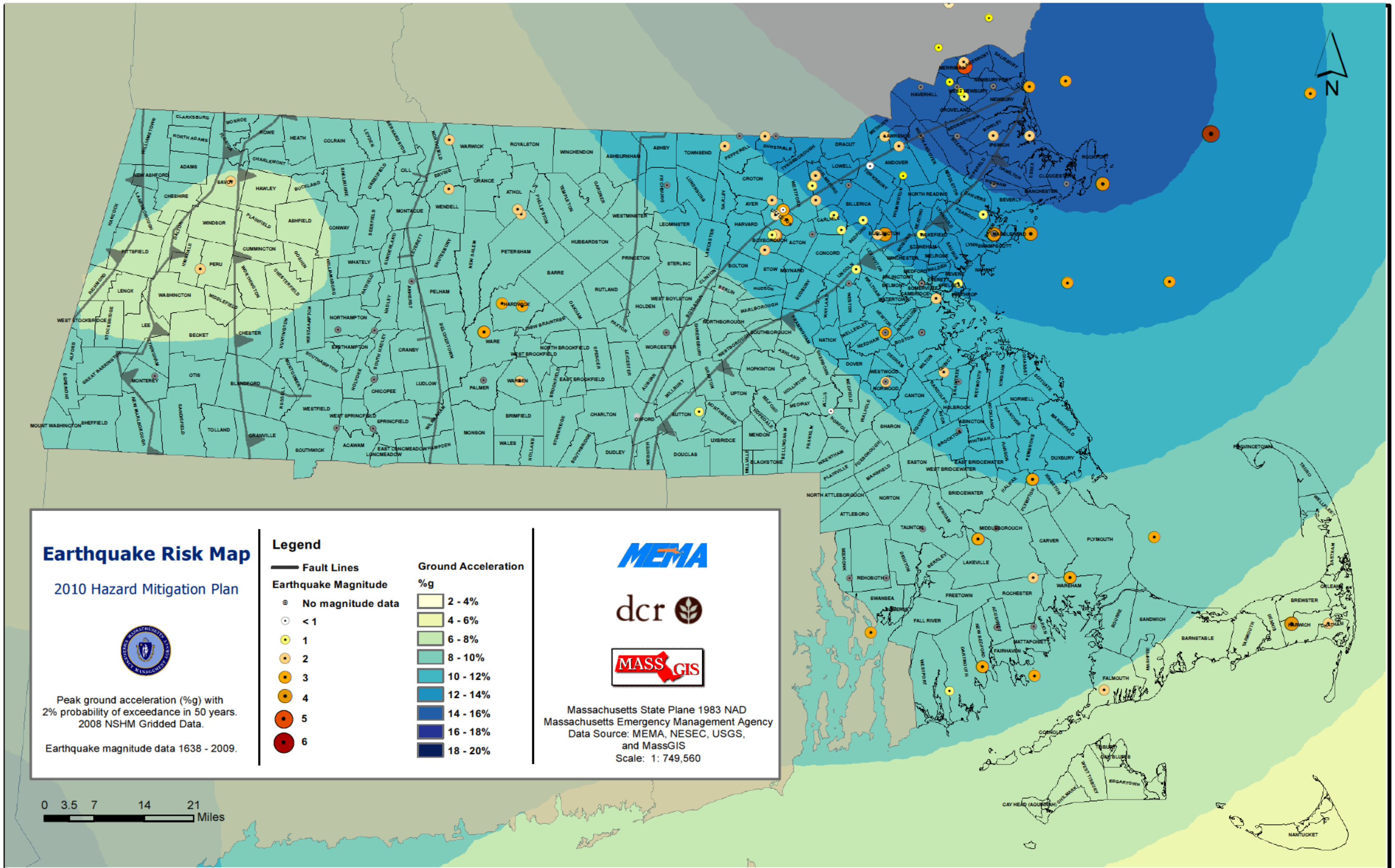


Figure 8-8. Earthquake Risk Map of the Commonwealth of Massachusetts

Source: http://www.bc.edu/content/bc/research/westonobservatory/northeast/eqmaps.html

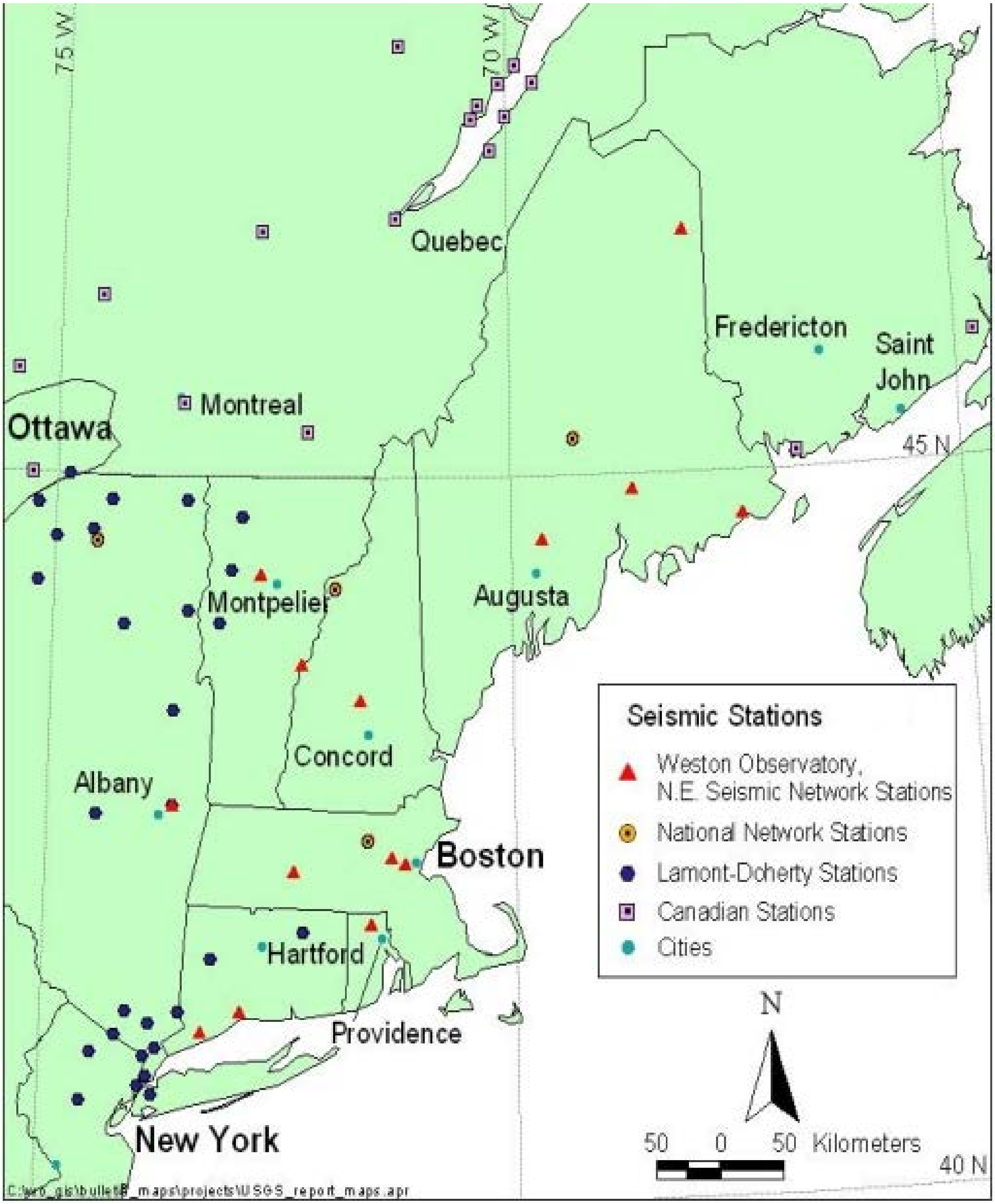


Figure 8-9. New England Seismic Map Station

8.2.2 Previous Occurrences

Since the Plymouth Pilgrims and other early settlers recorded an earthquake in 1638, New England has been a common location for earthquake activity. Since then, over 5,000 earthquakes have been recorded in the Weston Observatory Northeast Earthquake Catalog, which accounts for New England and adjacent regions. Over 1,530 earthquakes occurred within the boundaries of the six New England States and 366 were recorded to have epicenters in Massachusetts. Generally, most earthquakes that occur in the Northeast U.S. tend to be small in magnitude and cause little damage, however; 104 earthquakes between 1924 and 2012 have measured a magnitude 4.5 or greater on the Richter scale. Out of these 104 earthquakes, 10 were centered within New England and the other 94 occurred within New York State and the Province of Quebec. Due to the geologic composition and rock structure of the Northeast U.S. seismic shaking for many of these earthquakes were felt throughout all of New England.

Historically, moderately damaging earthquakes strike somewhere in the region every few decades, and smaller earthquakes are felt approximately twice per year. The Boston area was damaged three times within 28 years in the middle 1700s, and New York City was damaged in 1737 and 1884. The largest known New England earthquakes occurred in 1638 (magnitude 6.5) in Vermont or New Hampshire, and in 1755 (magnitude 5.8) offshore from Cape Ann northeast of Boston. The Cape Ann earthquake caused severe damage to the Boston waterfront. The most recent New England earthquake to cause moderate damage occurred in 1940 (magnitude 5.6) in central New Hampshire.

Moderate earthquakes in 1847 (August 8), 1852 (November 27), 1854 (December 10), 1876 (September 21), 1880 (May 12), 1903 (January 21 and April 24), 1907 (October 15), 1925 (January 7 and April 24), 1940 (January 28), and 1963 (October 16 and 30), were felt over limited areas of eastern Massachusetts. The epicenter of the January 7, 1925, earthquake was off Cape Ann; the reported felt area extended from Providence, Rhode Island, to Kennebunk, Maine. The October 16, 1963, earthquake caused some plaster to fall in Somerville, and a wall was reported cracked and stones fell from a building foundation (intensity VI). Dishes were broken and many persons were alarmed in Amesbury, and a window was cracked in Winthrop. The other earthquakes did not exceed intensity V. The residents of Nantucket Island were jolted by a moderate earthquake on October 24, 1965. Very slight damage, mostly to ornaments, was reported. Doors, windows, and dishes rattled, and house timbers creaked.

The most recent earthquake in the region (through 2012) occurred on December 30, 2012, when a Magnitude-1.2 earthquake occurred about 7 miles south of Gardner (Weston Observatory of Boston College, 2013). In April 2012, a swarm of 12 or more earthquakes occurred off the New England coast on the continental shelf about 250 miles east of Boston. The largest earthquake measured Magnitude 4.4 on the Richter scale. This swarm was of particular concern because of the major earthquake on the continental shelf further north in 1929 that produced a deadly and damaging tsunami in Nova Scotia.

8.2.3 Probability of Future Occurrences

Earthquakes cannot be predicted and may occur any time of the day, any time of the year. PGA maps are used as tools to determine the likelihood an earthquake of a given intensity may be exceeded over a period of time. Figure 8-10 shows the PGA values (6 percent to 16 percent of g) for the Commonwealth that have a 2-percent chance of being exceeded in 50 years. If it were to occur, this earthquake would likely have moderate to strong perceived shaking and very light to light potential damage (refer to Table 8-3 earlier in this profile – Modified Mercalli Intensity and PGA Equivalents).

The Weston Observatory at Boston College conducted an analysis on spatial earthquake probabilities in the New England region. According to that analysis, there is a 66-percent chance that the next earthquake with a magnitude of 2.7 or greater in New England will occur in one of the green areas on Figure 8-11.

Source: http://earthquake.usgs.gov/earthquakes/states/massachusetts/hazards.php

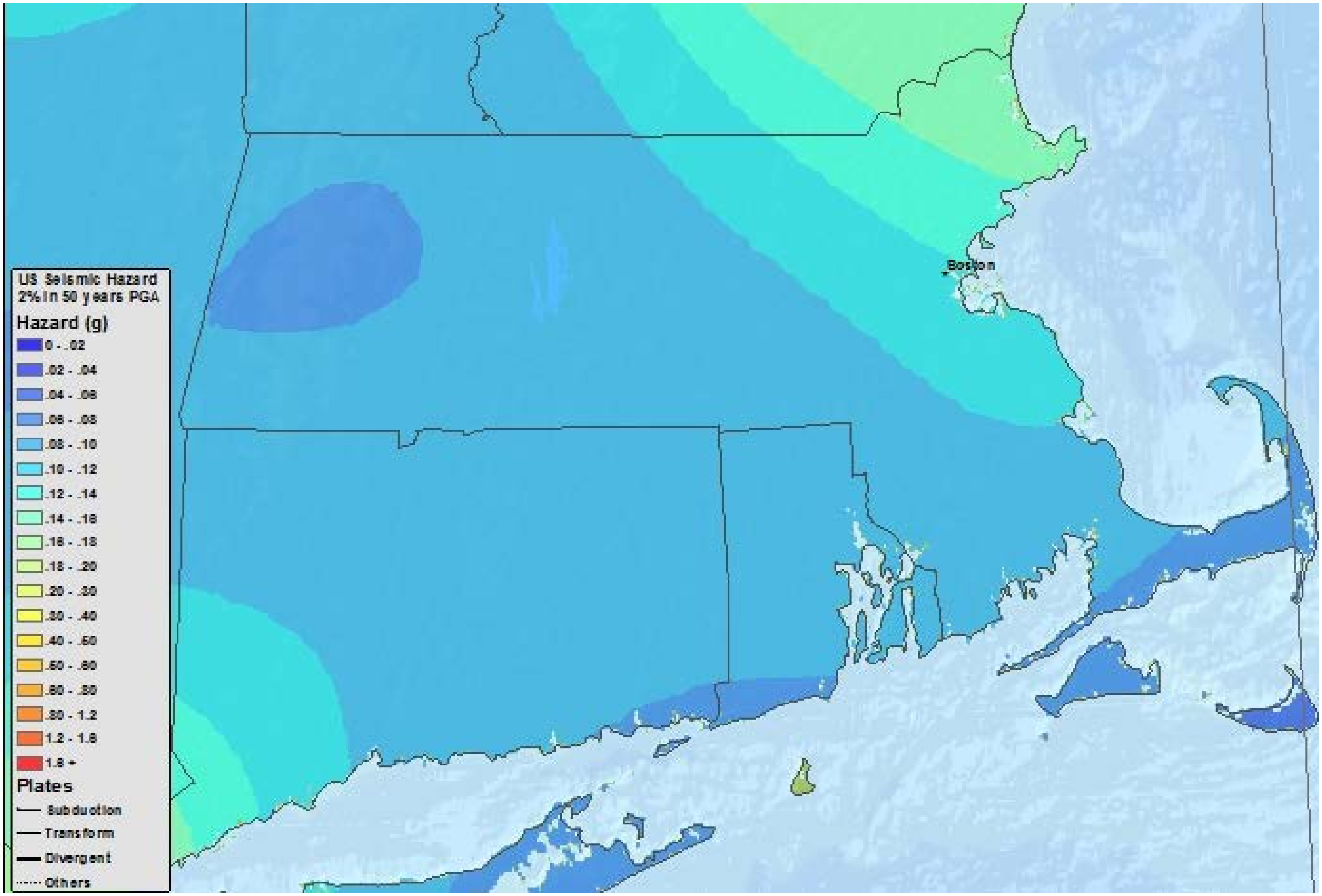


Figure 8-10. Seismic Hazard Map for Massachusetts

Source: Weston Observatory at Boston College
http://www.bc.edu/content/bc/research/westonobservatory/northeast/eqprobability.html

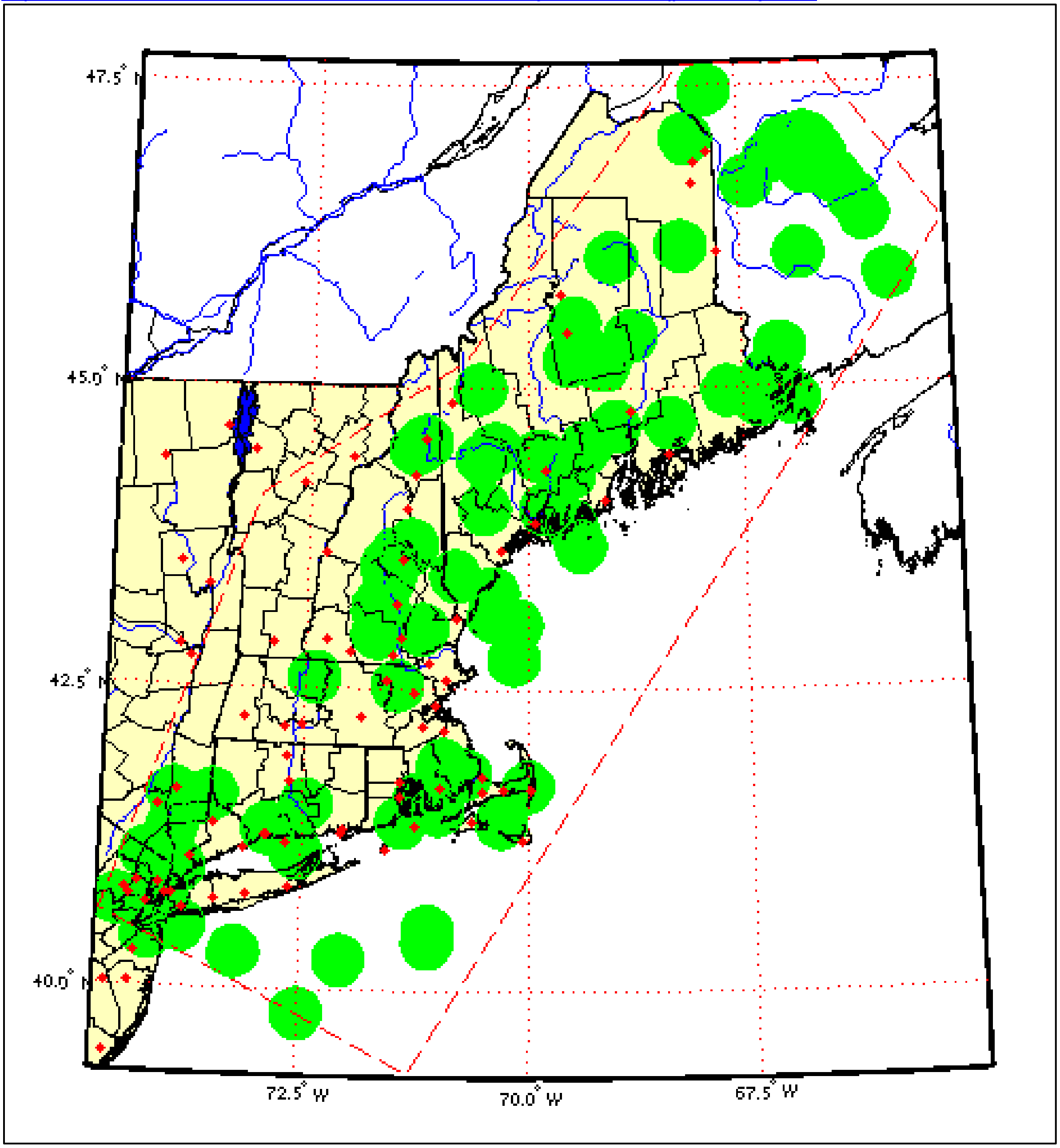


Figure 8-11. Spatial Earthquake Probabilities in New England

There have been no earthquake declared disasters for the Commonwealth; therefore the entire historical record was consulted. The historical record indicates 366 earthquakes recorded for Massachusetts from 1627 to 2012. However, according to Ed Fratto, Executive Director of the Northeast States Emergency Consortium and SHMT member, only recently have earthquakes been recorded instrumentally in New England. In the 17th, 18th, 19th, and part of the 20th centuries, earthquakes were only documented in populated developed areas, thus concluding that seismic activity was inadequately documented during those centuries. Since the emergence of proper recording instruments in the 20th century, documentation of earthquake occurrences has increased. Therefore, it is difficult to estimate the probability of future occurrence defined by the number of events that have historically occurred from 1627 to 2012.

8.2.4 Severity

According to USGS data, damage due to an earthquake will begin at a level of ground shaking of approximately 0.1 g. The MMI intensity scale associates damage with levels of earthquakes. According to this scale, the damage that can be expected from this range of ground shaking will vary from plaster cracking and disruption of building contents, to moderate damage to poorly constructed buildings. It should be noted, however, that the expected probability of such a level of ground shaking is extremely low, and according to the USGS data can be expected to occur once every 2,476 years.

Because of this low frequency of occurrence and the relatively low levels of ground shaking that would be experienced, the entire Commonwealth can be expected to have a low to moderate risk to earthquake damage as compared to other areas of the country. However, the impacts at the local level can vary based on types of construction, building density, soil type among other factors. This is demonstrated in the Hazus analysis summarized below.

8.2.5 Warning Time

There is currently no reliable way to predict the day or month that an earthquake will occur at any given location. Research is being done with early-warning systems that use the low energy waves that precede major earthquake to issue an alert that earthquake shaking is about to be felt. These potential early-warning systems can give up to approximately 40-60 seconds notice that earthquake shaking is about to be experienced, with shorter warning times for places closer to the earthquake epicenter. Although the warning time is very short, it could allow for immediate safety measures such as getting under a desk, stepping away from a hazardous material, or shutting down a computer system to prevent damage.

8.3 SECONDARY HAZARDS

Secondary hazard can occur to all forms of critical infrastructure and key resources as a result of earthquake. Earthquakes can cause large and sometimes disastrous landslides and mudslides. River valleys are vulnerable to slope failure, often as a result of loss of cohesion in clay-rich soils. Soil liquefaction occurs when water-saturated sands, silts or gravelly soils are shaken so violently that the individual grains lose contact with one another and float freely in the water, turning the ground into a pudding-like liquid. Building and road foundations lose load-bearing strength and may sink into what was previously solid ground. Unless properly secured, hazardous materials can be released, causing significant damage to the environment and people. Earthen dams and levees are highly susceptible to seismic events and the impacts of their eventual failures can be considered secondary risks for earthquakes.

8.4 CLIMATE CHANGE IMPACTS

The impacts of global climate change on earthquake probability are unknown. Some scientists feel that melting glaciers could induce tectonic activity. As ice melts and water runs off, tremendous amounts of weight are shifted on the earth’s crust. As newly freed crust returns to its original, pre-glacier shape, it could cause seismic plates to slip and stimulate volcanic activity according to research into prehistoric earthquakes and volcanic activity. NASA and USGS scientists found that retreating glaciers in southern Alaska might be opening the way for future earthquakes.

Secondary impacts of earthquakes could be magnified by climate change. Soils saturated by repetitive storms could experience liquefaction during seismic activity due to the increased saturation. Dams storing increased volumes of water due to changes in the hydrograph could fail during seismic events. There are currently no models available to estimate these impacts.

8.5 EXPOSURE

To understand risk, the assets exposed to the hazard areas are identified. For the earthquake hazard, the entire Commonwealth of Massachusetts is exposed. However, some locations, building types, and infrastructure types are at greater risk than others are, due to the surrounding soils or their manner of construction. This section discusses exposure of the following to the earthquake hazard:

- Population
- State facilities
- Critical facilities
- Economy

8.5.1 Population

The entire population of Massachusetts is potentially exposed to direct and indirect impacts from earthquakes. The degree of exposure is dependent on many factors, including the age and construction type of the structures people live in, the soil type their homes are constructed on, their proximity to fault location, etc. Further, the time of day also exposes different sectors of the community to the hazard. For example, Hazus considers the residential occupancy at its maximum at 2:00 a.m., where the educational, commercial, and industrial sectors are at their maximum at 2:00 p.m., and peak commute time is at 5:00 p.m. Whether directly impacted or indirectly impact, the entire population will have to deal with the consequences of earthquakes to some degree. Business interruption could keep people from working, road closures could isolate populations, and loss of functions of utilities could impact populations that suffered no direct damage from an event itself.

8.5.2 State Facilities

All 6,765 Commonwealth of Massachusetts-owned and leased buildings are exposed to the earthquake hazard. Table 8-4. summarizes the total replacement cost value of these facilities.

NEHRP soil classifications affect earthquake severity. The classifications range from A to E, where A is hard rock that reduces ground motions and E is soft soil that amplifies ground shaking and increases building losses. NEHRP soil classes D and E can amplify ground shaking to damaging levels even in a moderate earthquake (NYCEM, 2003). Table 8-5. summarizes the number of state-owned and state-leased buildings on soil classes A through E (where data are available). Figure 8-12 illustrates the state-owned and leased facilities located on NEHRP soil classes D and E.

8.5.3 Critical Facilities

All critical facilities in the planning area are exposed to the earthquake hazard. In addition, there is increased risk associated with hazardous materials releases, which have the potential to occur during an earthquake from fixed facilities, transportation-related incidents (vehicle transportation), and pipeline distribution. Transportation corridors and pipelines can be disrupted during an earthquake, leading to the release of materials to the surrounding environment, and disrupting services well beyond the primary area of impact. Facilities holding hazardous materials are of particular concern because of possible isolation of surrounding neighborhoods. During an earthquake, structures storing these materials could rupture and leak into the surrounding area or an adjacent waterway, having a disastrous effect on the environment.

TABLE 8-4.
STATE BUILDING EXPOSURE TO EARTHQUAKE HAZARD (STRUCTURE AND CONTENTS)

County	Value of Owned Facilities	Value of Leased Facilities	Total Replacement Cost Value
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

TABLE 8-4.
STATE BUILDING EXPOSURE TO EARTHQUAKE HAZARD (STRUCTURE AND CONTENTS)

County	Value of Owned Facilities	Value of Leased Facilities	Total Replacement Cost Value
Dukes	$9,965,088	$6,258,960	$16,224,048
Essex	$4,336,334,705	$136,866,724	$4,473,201,429
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 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 8-5.
NUMBER OF STATE-OWNED AND LEASED BUILDINGS PER NEHRP SOIL CLASS

County	Class A	Class B	Class C	Class D	Class E	No data available	Total
Barnstable	—	—	—	—	—	309	309
Berkshire	—	—	—	—	—	358	358
Bristol	—	—	—	—	—	482	482
Dukes	—	—	—	—	—	13	13
Essex	—	—	—	—	—	538	538
Franklin	21	19	0	40	68	63	211
Hampden	13	54	0	0	245	154	466
Hampshire	217	46	18	24	179	78	562
Middlesex	—	—	—	—	—	1,107	1,107
Nantucket	—	—	—	—	—	5	5
Norfolk	—	—	—	—	—	680	680
Plymouth	—	—	—	—	—	542	542
Suffolk	—	—	—	—	—	399	399
Worcester	—	—	—	—	—	1,093	1,093
Total	**251**	**119**	**18**	**64**	**492**	**5,821**	**6,765**

Note: Building data are 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.

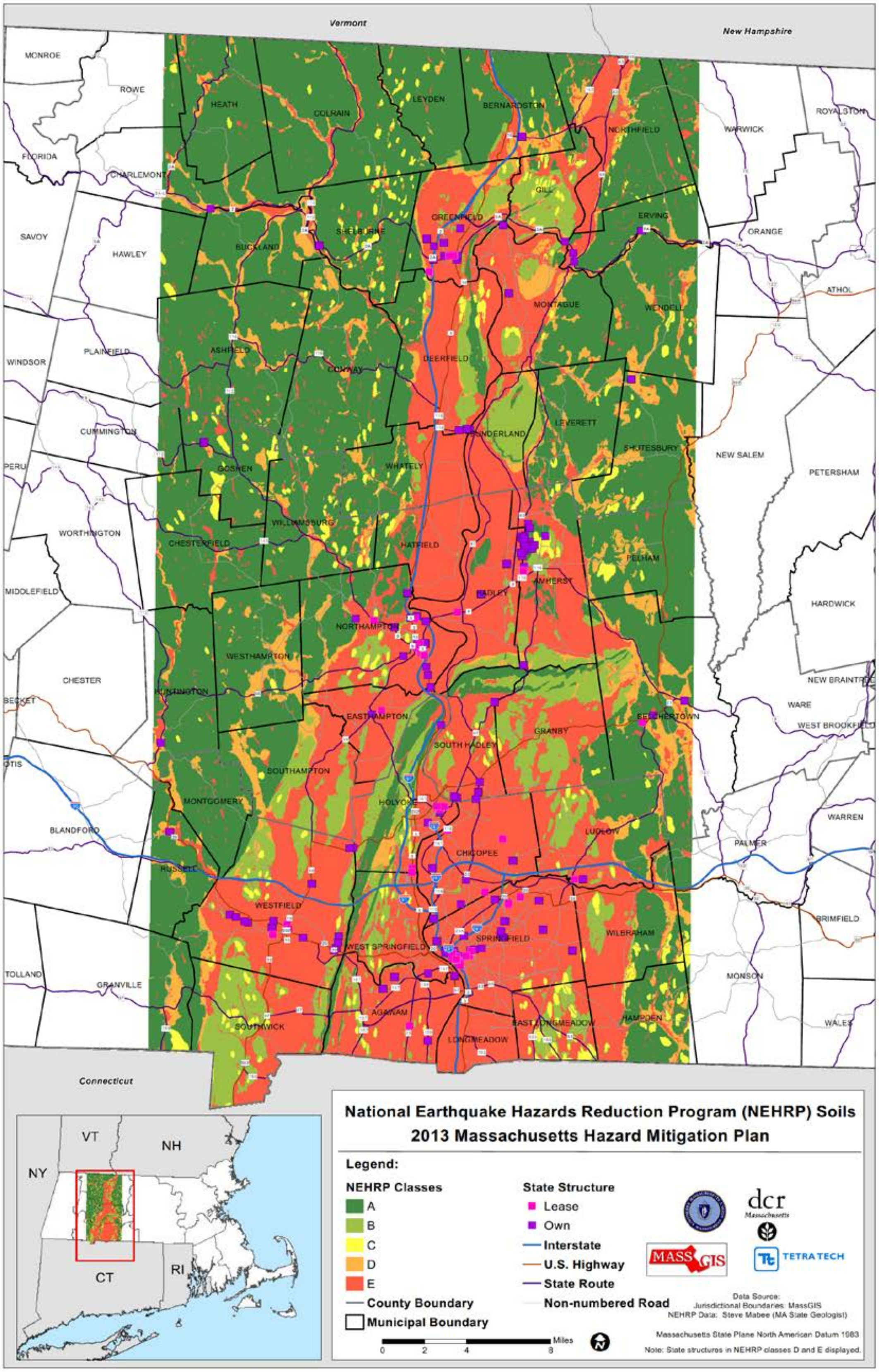


Figure 8-12. State-Owned and State-Leased Facilities on NEHRP Soils D and E

As mentioned earlier, softer soils can amplify and magnify ground shaking and increase building damage and losses. Table 8-6 summarizes the critical facilities and the NEHRP soil class upon which they are located (where data are available).

TABLE 8-6.
NUMBER OF CRITICAL FACILITIES PER NEHRP SOIL CLASS

County	Class A	Class B	Class C	Class D	Class E	**Total**
Police Stations						
Franklin	5	2	1	3	11	**26**
Hampden	0	1	0	1	17	**28**
Hampshire	3	2	0	2	9	**23**
Total	***8***	***5***	***1***	***6***	***37***	***437***
Fire Stations						
Franklin	7	1	0	4	12	**31**
Hampden	2	2	0	2	32	**51**
Hampshire	7	3	0	2	10	**28**
Total	***16***	***6***	***0***	***8***	***54***	***789***
Emergency Operation Centers						
Hampden	0	1	0	0	0	**1**
Total	***0***	***1***	***0***	***0***	***0***	***1***
Hospitals						
Franklin	0	0	0	0	1	**1**
Hampden	0	0	0	0	5	**6**
Hampshire	0	0	0	0	1	**2**
Total	***0***	***0***	***0***	***0***	***7***	***82***
Schools						
Franklin	6	2	0	10	28	**53**
Hampden	0	13	19	4	166	**217**
Hampshire	9	4	6	4	82	**113**
Total	***15***	***19***	***25***	***18***	***276***	***2,767***
Colleges						
Franklin	0	1	0	2	0	**3**
Hampden	0	0	1	15	0	**16**
Hampshire	0	1	2	2	0	**5**
Total	***181***	***2***	***3***	***19***	***0***	***205***
Grand Total	**259**	**66**	**58**	**102**	**748**	**4,885**

Earthquake events can significantly impact road bridges. A key factor in the degree of vulnerability will be the age of the bridge, which will help indicate to which standards the bridge was built. Table 8-7 summarizes the number of highway bridges located on each NEHRP soil classification. Due to limited NEHRP soils data, all bridges listed are in Franklin, Hampden, and Hampshire Counties, only where NEHRP soil data are available (see Figure 8-12).

TABLE 8-7.
NUMBER OF HIGHWAY BRIDGES LOCATED ON EACH NEHRP SOIL TYPE

Owner	A	B	C	D	E	Total Exposed
Federal	0	0	0	0	2	2
State	25	25	3	40	322	415
Local	65	7	0	49	157	278
Total	**90**	**32**	**3**	**89**	**481**	**695**

Source: Hazus-MH v. 2.1 default highway bridge inventory; Mabee, 2012

8.5.4 Economy

Earthquakes losses can include structural and non-structural damage to buildings, loss of business function, damage to inventory, relocation costs, wage loss, and rental loss due to the repair/replacement of buildings. Roads that cross earthquake-prone soils have the potential to be significantly damaged during an earthquake event, potentially impacting commodity flows. Access to major roads is crucial to life and safety after a disaster event, as well as to response and recovery operations. Further, water and sewer infrastructure would likely suffer considerable damage in the event of an earthquake. It should be assumed that these systems are exposed to potential breakage and failure.

8.6 VULNERABILITY

To assess the Commonwealth's vulnerability to the earthquake hazard, probabilistic analyses were run in Hazus for the 100-, 500-, 1,000-, and 2,500-year mean return period events. The Hazus-MH model was used to estimate potential losses to these events.

8.6.1 Population

The populations most vulnerable to an earthquake event include persons over the age of 65 and those living below the Census poverty threshold. These socially vulnerable populations are most susceptible, based on a number of factors including their physical and financial ability to react or respond during a hazard, the location and construction quality of their housing, and the ability to be self-sustaining for prolonged periods of time after an incident due to limited ability to stockpile supplies. Refer to Section 4, which summarizes the Commonwealth's demographics by County, as well as further information contained within Section 3, Local Plan Coordination.

Residents may be displaced or require temporary to long-term sheltering due to the event. The number of people requiring shelter is generally less than the number displaced as some displaced persons use hotels or stay with family or friends following a disaster event. Impacts on persons and households in the planning area were estimated for the 100-, 500-, 1,000-, and 2,500-year earthquakes through the Level 2 Hazus-MH analysis. Table 8-8. summarizes the results.

Hazus-MH estimates the number of people that may be injured or killed by an earthquake depending on the time of day the event occurs. Estimates are provided for three times of day representing periods when different sectors of the community are at their peak: peak residential occupancy at 2:00 a.m.; peak educational, commercial, and industrial occupancy at 2:00 p.m.; and peak commuter traffic at 5:00 p.m. Table 8-9 summarizes the estimates for the 100-, 500-, 1,000-, and 2,500-year MRP earthquake events. No injuries or casualties are estimated for the 100-year event.

TABLE 8-8.
ESTIMATED SHELTER REQUIREMENTS HAZUS-MH PROBABILISTIC SCENARIOS

	100-Year MRP		500-Year MRP		1,000-Year MRP		2,500-Year MRP	
County	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs
Barnstable	0	0	9	5	29	16	125	70
Berkshire	0	0	26	16	76	48	271	170
Bristol	0	0	72	48	236	158	1,094	731
Dukes	0	0	0	0	1	1	5	3
Essex	0	0	200	136	642	436	3,045	2,058
Franklin	0	0	13	8	37	23	132	81
Hampden	0	0	78	60	236	183	898	694
Hampshire	0	0	24	18	72	53	266	197
Middlesex	0	0	373	222	1,192	707	4,770	2,835
Nantucket	0	0	0	0	1	0	3	2
Norfolk	0	0	110	59	364	195	1,461	785
Plymouth	0	0	41	28	142	97	618	417
Suffolk	0	0	294	211	952	685	3,735	2,687
Worcester	0	0	138	93	426	287	1,619	1,090
Total	**0**	**0**	**1,378**	**905**	**4,406**	**2,888**	**18,041**	**11,821**

TABLE 8-9.
ESTIMATED NUMBER OF INJURIES AND CASUALTIES, HAZUS-MH

	100-Year MRP Event			500-Year MRP Event			1,000-Year MRP Event			2,500-Year MRP Event		
	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.
Barnstable												
Injuries	0	0	0	5	6	5	14	17	14	51	68	55
Hospitalization	0	0	0	0	1	1	1	2	2	6	11	9
Casualties	0	0	0	0	0	0	0	0	0	1	2	1
Berkshire												
Injuries	0	0	0	7	7	6	19	19	17	58	67	58
Hospitalization	0	0	0	1	1	1	2	3	2	9	12	11
Casualties	0	0	0	0	0	0	0	0	0	1	2	2
Bristol												
Injuries	0	0	0	19	16	15	56	50	46	210	216	195
Hospitalization	0	0	0	2	2	2	7	7	7	32	39	39
Casualties	0	0	0	0	0	0	1	1	1	5	7	6
Dukes												
Injuries	0	0	0	0	1		1	2	1	3	6	4
Hospitalization	0	0	0	0	0	0	0	0	0	0	1	1
Casualties	0	0	0	0	0	0	0	0	0	0		

TABLE 8-9.
ESTIMATED NUMBER OF INJURIES AND CASUALTIES, HAZUS-MH

	100-Year MRP Event			500-Year MRP Event			1,000-Year MRP Event			2,500-Year MRP Event		
	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.
Essex												
Injuries	0	0	0	49	47	43	141	140	127	522	616	535
Hospitalization	0	0	0	5	6	5	18	22	20	91	123	119
Casualties	0	0	0	1	1	1	3	3	3	16	24	21
Franklin												
Injuries	0	0	0	4	3	3	10	8	8	29	28	26
Hospitalization	0	0	0	0	0	0	1	1	1	4	5	5
Casualties	0	0	0	0	0	0	0	0	0	1	1	1
Hampden												
Injuries	0	0	0	21	20	18	58	57	50	186	213	182
Hospitalization	0	0	0	2	2	2	8	9	8	28	39	39
Casualties	0	0	0	0	0	0	1	1	1	4	7	6
Hampshire												
Injuries	0	0	0	8	6	7	20	17	18	65	62	62
Hospitalization	0	0	0	1	1	1	2	2	2	10	11	12
Casualties	0	0	0	0	0	0	0	0	0	2	2	2
Middlesex												
Injuries	0	0	0	90	97	87	255	285	255	830	1117	952
Hospitalization	0	0	0	11	13	13	34	44	44	137	214	204
Casualties	0	0	0	1	2	2	5	7	6	23	39	36
Nantucket												
Injuries	0	0	0	0	0	0	0	1	0	1	2	2
Hospitalization	0	0	0	0	0	0	0	0	0	0	0	0
Casualties	0	0	0	0	0	0	0	0	0	0	0	0
Norfolk												
Injuries	0	0	0	30	33	29	87	100	88	287	398	335
Hospitalization	0	0	0	3	4	3	11	15	14	45	73	71
Casualties	0	0	0	0	1	1	1	2	2	7	13	12
Plymouth												
Injuries	0	0	0	16	16	15	51	50	46	180	211	187
Hospitalization	0	0	0	2	2	2	5	8	7	26	38	41
Casualties	0	0	0	0	0	0	1	1	1	4	7	6
Suffolk												
Injuries	0	0	0	52	65	53	150	193	156	492	749	583
Hospitalization	0	0	0	6	9	8	22	29	25	88	143	126
Casualties	0	0	0	1	1	1	3	5	4	16	26	22
Worcester												
Injuries	0	0	0	37	34	32	102	97	90	322	363	321
Hospitalization	0	0	0	4	4	4	13	14	14	50	66	68
Casualties	0	0	0	1	1	1	2	2	2	8	12	11
Total	**0**	**0**	**0**	**379**	**402**	**361**	**1,105**	**1,214**	**1,082**	**3,850**	**5,033**	**4,368**

8.6.2 State Facilities

Hazus-MH does not estimate potential dollar losses to facilities at this time. When this capability is available, the Commonwealth can enhance this section of the plan. For the purposes of the 2013 plan update, to estimate potential losses to the state-owned and leased buildings, the exposure analysis methodology was used. As mentioned earlier, all buildings are exposed to an earthquake; however, those located on NEHRP soil classes D and E may have increased potential for building damage and losses. Refer to Table 8-6 for the number of critical facilities on NEHRP soil classes D and E (in areas for which data are available). A total risk exposure would equal to the full replacement value of each state facility exposed. Table 8-10 summarizes the replacement cost value of the state-owned and leased buildings located on each NEHRP soil class by County. Table 8-11 summarizes the replacement cost value of buildings located on each NEHRP soil class by state agency.

**TABLE 8-10.
STATE-OWNED AND LEASED BUILDING REPLACEMENT COST VALUE BY COUNTY AND NEHRP SOIL CLASS**

	State-Owned and Leased Building Replacement Cost Value						
County	Class A	Class B	Class C	Class D	Class E	No Soil Classification Data	**Total**
Barnstable	—	—	—	—	—	$1,146,314,361	**$1,146,314,361**
Berkshire	—	—	—	—	—	$1,852,000,832	**$1,852,000,832**
Bristol	—	—	—	—	—	$3,012,210,350	**$3,012,210,350**
Dukes	—	—	—	—	—	$16,224,048	**$16,224,048**
Essex	—	—	—	—	—	$4,473,201,429	**$4,473,201,429**
Franklin	$38,921,952	$14,020,165	$0	$83,735,368	$517,037,985	$159,521,459	**$813,236,929**
Hampden	$1,473,865	$1,223,200,695	$0	$0	$2,648,853,750	$1,178,121,938	**$5,051,650,248**
Hampshire	$2,284,863,881	$341,662,602	$257,871,490	$47,822,859	$1,689,568,762	$65,598,259	**$4,687,387,853**
Middlesex	—	—	—	—	—	$9,881,996,655	**$9,881,996,655**
Nantucket	—	—	—	—	—	$31,381,244	**$31,381,244**
Norfolk	—	—	—	—	—	$5,141,831,256	**$5,141,831,256**
Plymouth	—	—	—	—	—	$3,182,404,153	**$3,182,404,153**
Suffolk	—	—	—	—	—	$8,283,073,730	**$8,283,073,730**
Worcester	—	—	—	—	—	$9,444,698,995	**$9,444,698,995**
Total	**$2,325,259,698**	**$1,578,883,461**	**$257,871,490**	**$131,558,227**	**$4,855,460,497**	**$47,868,578,708**	**$57,017,612,082**

**TABLE 8-11.
STATE-OWNED AND LEASED BUILDING REPLACEMENT COST VALUE BY AGENCY AND NEHRP SOIL CLASS**

State Agency	Class A	Class B	Class C	Class D	Class E	**Total**
Attorney General						**$2,149,464**
Replacement Cost Value	—	—	—	—	$2,149,464	
% of Total	—	—	—	—	100	
Bureau of State Buildings						**$33,722,612**
Replacement Cost Value	—	—	—	—	$33,722,612	
% of Total	—	—	—	—	100	
Committee for Public Counsel Services						**$4,504,654**
Replacement Cost Value	—	—	—	—	$4,504,654	
% of Total	—	—	—	—	100	
Department of Agricultural Resources						**$641,232**
Replacement Cost Value	—	—	—	—	$641,232	
% of Total	—	—	—	—	100	
Department of Children and Families						**$24,500,940**
Replacement Cost Value	—	—	—	—	$24,500,940	
% of Total	—	—	—	—	100	
Department of Conservation and Recreation						**$206,419,815**
Replacement Cost Value	$32,424,201	$3,109,912	—	$22,983,110	$147,902,592	
% of Total	15.7	1.5	—	11.1	71.7	
Department of Developmental Services						**$44,957,634**
Replacement Cost Value	—	—	—	$8,903,612	$36,054,022	
% of Total	—	—	—	19.8	80.2	
Department of Environmental Protection						**$26,698,134**
Replacement Cost Value	—	—	—	—	$26,698,134	
% of Total	—	—	—	—	100	
Department of Fish and Game						**$23,268,004**
Replacement Cost Value	$145,034				$23,122,970	
% of Total	0.6				99.4	
Department of Food and Agriculture						**$4,528,850**
Replacement Cost Value	—	—	—	—	$4,528,850	
% of Total	—	—	—	—	100	
Department of Mental Health						**$377,113,387**
Replacement Cost Value	—	—	—	—	$377,113,387	
% of Total	—	—	—	—	100	
Department of Public Health						**$5,101,241**
Replacement Cost Value	—	$1,515,380	—	—	$3,585,861	
% of Total	—	29.7	—	—	70.3	
Department of State Police						**$136,643,668**
Replacement Cost Value	$1,704,452	—	—	—	$134,939,216	
% of Total	1.2	—	—	—	98.8	
Department of Transitional Assistance						**$19,675,136**
Replacement Cost Value	—	—	—	—	$19,675,136	
% of Total	—	—	—	—	100	
Department of Transportation						**$415,691,948**
Replacement Cost Value	$7,519,396	$5,809,914	—	$92,672,725	$309,689,913	
% of Total	1.8	1.4	—	22.3	74.5	
Department of Veterans Services						**$7,192,502**
Replacement Cost Value	—	—	—	—	$7,192,502	

TABLE 8-11.
STATE-OWNED AND LEASED BUILDING REPLACEMENT COST VALUE BY AGENCY AND NEHRP SOIL CLASS

State Agency	Class A	Class B	Class C	Class D	Class E	**Total**
% of Total	—	—	—	—	100	
Department of Youth Services						**$30,353,600**
Replacement Cost Value	—	—	—	—	$30,353,600	
% of Total	—	—	—	—	100	
Department of Workforce Development						**$4,685,536**
Replacement Cost Value	—	—	—	—	$4,685,536	
% of Total	—	—	—	—	100	
Division of Capital Asset Management						**$27,514,446**
Replacement Cost Value	$1,870,260	—	—	—	$25,644,186	
% of Total	6.8	—	—	—	93.2	
Emergency Management Agency						**$3,160,504**
Replacement Cost Value	—	—	—	—	$3,160,504	
% of Total	—	—	—	—	100	
Executive Office of Health & Human Services						**$3,282,306**
Replacement Cost Value	—	—	—	—	$3,282,306	
% of Total	—	—	—	—	100	
Greenfield Community College						**$202,317,832**
Replacement Cost Value	—	—	—	—	$202,317,832	
% of Total	—	—	—	—	100	
Holyoke Community College						**$408,181,944**
Replacement Cost Value	—	$403,189,126	—	—	$4,992,818	
% of Total	—	98.8	—	—	1.2	
Holyoke Soldiers' Home						**$210,550,728**
Replacement Cost Value	—	$210,550,728	—	—	—	
% of Total	—	100	—	—	—	
Information Technology Division						**$21,182,030**
Replacement Cost Value	—	—	—	—	$21,182,030	
% of Total	—	—	—	—	100	
Massachusetts Department of Revenue						**$3,900,828**
Replacement Cost Value	—	—	—	—	$3,900,828	
% of Total	—	—	—	—	100	
Massachusetts State Lottery Commission						**$1,637,012**
Replacement Cost Value	—	—	—	—	$1,637,012	
% of Total	—	—	—	—	100	
Massachusetts National Guard						**$816,248**
Replacement Cost Value	—	—	—	—	$816,248	
% of Total	—	—	—	—	100	
Massachusetts Rehabilitation Commission						**$4,447,744**
Replacement Cost Value	—	—	—	—	$4,447,744	
% of Total	—	—	—	—	100	
Massachusetts Teachers' Retirement System						**$710,966**
Replacement Cost Value	—	—	—	—	$710,966	
% of Total	—	—	—	—	100	
Military Division						**$205,031,491**
Replacement Cost Value	—	—	—	—	$205,031,491	
% of Total	—	—	—	—	100	

**TABLE 8-11.
STATE-OWNED AND LEASED BUILDING REPLACEMENT COST VALUE BY AGENCY AND NEHRP SOIL CLASS**

State Agency	Class A	Class B	Class C	Class D	Class E	**Total**
Office of the Chief Medical Examiner						**$830,130**
Replacement Cost Value	—	—	—	—	$830,130	
% of Total	—	—	—	—	100	
Office of the D.A. Hampden						**$3,168,488**
Replacement Cost Value	—	—	—	—	$3,168,488	
% of Total	—	—	—	—	100	
Office of the D.A. Northwestern						**$7,491,192**
Replacement Cost Value	—	—	—	—	$7,491,192	
% of Total	—	—	—	—	100	
Office of the State Auditor						**$648,980**
Replacement Cost Value	—	—	—	—	$648,980	
% of Total	—	—	—	—	100	
Sheriff's Department Franklin						**$102,865,098**
Replacement Cost Value	—	—	—	—	$102,865,098	
% of Total	—	—	—	—	100	
Sheriff's Department Hampden						**$700,865,566**
Replacement Cost Value	—	$607,535,874	—	—	$93,329,692	
% of Total	—	86.7	—	—	13.3	
Sheriff's Department Hampshire						**$97,011,962**
Replacement Cost Value	—	$94,653,804	—	—	$2,358,158	
% of Total	—	97.6	—	—	2.4	
Springfield Technical Community College						**$1,154,896,536**
Replacement Cost Value	—	—	—	—	$1,154,896,536	
% of Total	—	—	—	—	100	
Trial Court						**$216,744,257**
Replacement Cost Value	—	—	—	$6,998,780	$209,745,477	
% of Total	—	—	—	3.2	96.8	
University of Massachusetts at Amherst						**$3,822,019,809**
Replacement Cost Value	$2,281,596,355	$252,518,724	$257,871,490	—	$1,030,033,240	
% of Total	59.7	6.6	6.7	—	26.9	
Westfield State University						**$581,908,920**
Replacement Cost Value	—	—	—	—	$581,908,920	
% of Total	—	—	—	—	100	
Total						**$9,149,033,373**
Replacement Cost Value	**$2,325,259,698**	**$1,578,883,461**	**$257,871,490**	**$131,558,227**	**$4,855,460,497**	
% of Total	**25.4**	**17.3**	**2.8**	**1.4**	**53.1**	

8.6.3 State 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 this update, the exposure analysis methodology was used to estimate potential losses to critical facilities and infrastructure. Critical facilities and infrastructure located on NEHRP soil classes D and E may have increased building damage and losses. Table 8-6 lists critical facilities on NEHRP soil classes D and E (where data are available). The replacement cost values for critical facilities and infrastructure were not available for this planning effort. A total risk exposure would equal to the full replacement value of each critical facility exposed.

Hazus-MH estimates the extent of damage and cost to repair highway bridges as a result of each probabilistic scenario. Table 8-12 summarizes the total loss to highway bridges across the Commonwealth (4,835 bridges total) for each probabilistic scenario.

TABLE 8-12.
ESTIMATED COST TO REPAIR HIGHWAY BRIDGES FOR PROBABILISTIC EARTHQUAKE EVENTS

Scenario	100-Year	500-Year	1,000-Year	2,500-Year
Number Requiring Repair/Loss	0	1,490	4,835	4,835
Number Completely Destroyed	0	0	0	1
Loss	$130,397	$21,012,253	$117,497,068	$684,184,238

Source: Hazus-MH v. 2.1

8.6.4 Economy

Earthquakes also have impacts on the economy, including: loss of business function, 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 earthquake scenario, which includes building- and lifeline-related losses (transportation and utility losses) based on the available inventory (facility [or GIS point] data only). Direct building losses are the estimated costs to repair or replace the damage caused to the building. Refer to Table 8-13 which summarizes the estimated potential losses to all of the buildings in the Commonwealth per earthquake scenario per County.

Lifeline-related losses include the direct repair cost to transportation and utility systems and are reported in terms of the probability of reaching or exceeding a specified level of damage when subjected to a given level of ground motion. Additionally, economic loss include business interruption losses associated with the inability to operate a business due to the damage sustained during the earthquake, as well as temporary living expenses for those displaced. These losses are presented in Table 8-14.

In 2011, the New England Shake Map/Hazus Working Group estimated losses from 11 New England scenario earthquakes, three of which have epicenters in or offshore of Massachusetts:

- 1727 Newburyport, MA (Moment Magnitude 5.8);
- Littleton, MA (Moment Magnitude 5.0); and
- 1755 Cape Ann Offshore, MA (Moment Magnitude 6.5).

Hazus-MH version 2.0 was used for this analysis, and detailed loss summaries for each state in New England are included in the report. The estimated direct economic losses (structural and non-structural damage to buildings) for these three scenarios are shown in Figure 8-13 through Figure 8-15.

The report indicates that the estimates are low, particularly for the Cape Ann earthquake, because the extensive inventory of unreinforced masonry buildings in the Boston area is understated in the Hazus-MH model. In addition, the fill and alluvial areas in Boston have not been incorporated into the NEHRP site class map. 'The losses should be considered preliminary first-order estimates that can be improved with future improvements in the NEHRP incorporation of a site class map and building inventories' (FEMA, 2012). Additional loss information pertaining to these three and other earthquake scenarios for Massachusetts and all of New England can be found in the report entitled 'HAZUS Analyses of Eleven Scenario Earthquakes in New England' prepared for FEMA in 2012.

TABLE 8-13.
EARTHQUAKE ESTIMATED POTENTIAL LOSSES TO BUILDINGS (STRUCTURE AND CONTENTS) HAZUS-MH PROBABILISTIC SCENARIOS

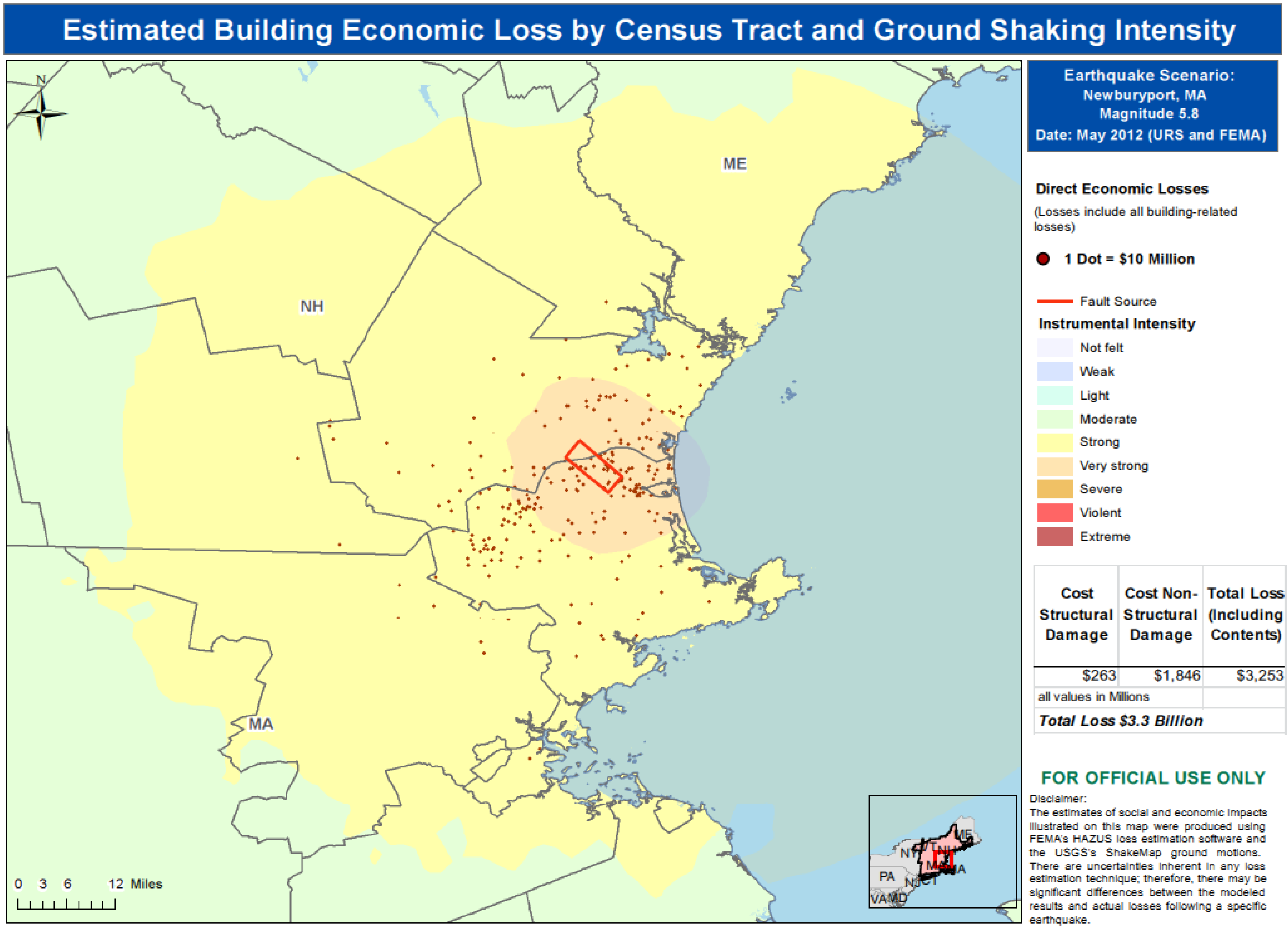
County	100-Year MRP	500-Year MRP	1,000-Year MRP	2,500-Year MRP
Barnstable	$0	$23,010,003	$85,379,039	$366,462,378
Berkshire	$0	$23,423,146	$70,788,093	$240,840,054
Bristol	$0	$54,738,967	$204,386,297	$884,379,688
Dukes	$0	$2,007,951	$7,559,777	$30,853,998
Essex	$0	$166,341,965	$563,000,060	$2,178,399,281
Franklin	$0	$12,226,591	$36,359,908	$121,288,736
Hampden	$0	$67,617,917	$218,279,715	$792,727,328
Hampshire	$0	$22,984,509	$71,173,359	$248,402,385
Middlesex	$0	$337,025,347	$1,139,891,816	$4,143,316,406
Nantucket	$0	$824,179	$3,363,189	$15,030,312
Norfolk	$0	$120,136,983	$421,461,487	$1,593,539,418
Plymouth	$0	$60,019,177	$224,156,207	$917,075,021
Suffolk	$0	$157,946,629	$551,143,237	$2,037,692,334
Worcester	$0	$127,094,194	$409,848,891	$1,466,297,635
Total	**$0**	**$1,175,397,557**	**$4,006,791,076**	**$15,036,304,973**

Notes: Building losses include structural and non-structural damage estimates.
Source: Default general building stock data in Hazus-MH v. 2.1

TABLE 8-14.
ESTIMATED POTENTIAL ECONOMIC LOSSES FOR THE COMMONWEALTH OF MASSACHUSETTS

	100-Year MRP	500-Year MRP	1,000-Year MRP	2,500-Year MRP
Income Losses				
Wage	0	$77,890,000	$234,250,000	$953,160,000
Capital-Related	0	$55,800,000	$174,600,000	$713,930,000
Rental	0	$88,620,000	$250,520,000	$880,570,000
Relocation	0	$129,190,000	$390,360,000	$1,465,390,000
Subtotal	***0***	***$351,500,000***	***$1,049,730,000***	***$4,013,050,000***
Capital Stock Losses				
Structural	0	$230,380,000	$656,250,000	$2,306,430,000
Non-Structural	0	$724,610,000	$2,454,080,000	$9,039,290,000
Content	0	$220,410,000	$896,460,000	$3,690,590,000
Inventory	0	$6,490,000	$24,690,000	$94,210,000
Subtotal	***0***	***$1,181,890,000***	***$4,031,480,000***	***$15,130,520,000***
Total	**0**	**$1,533,390,000**	**$5,081,210,000**	**$19,143,570,000**

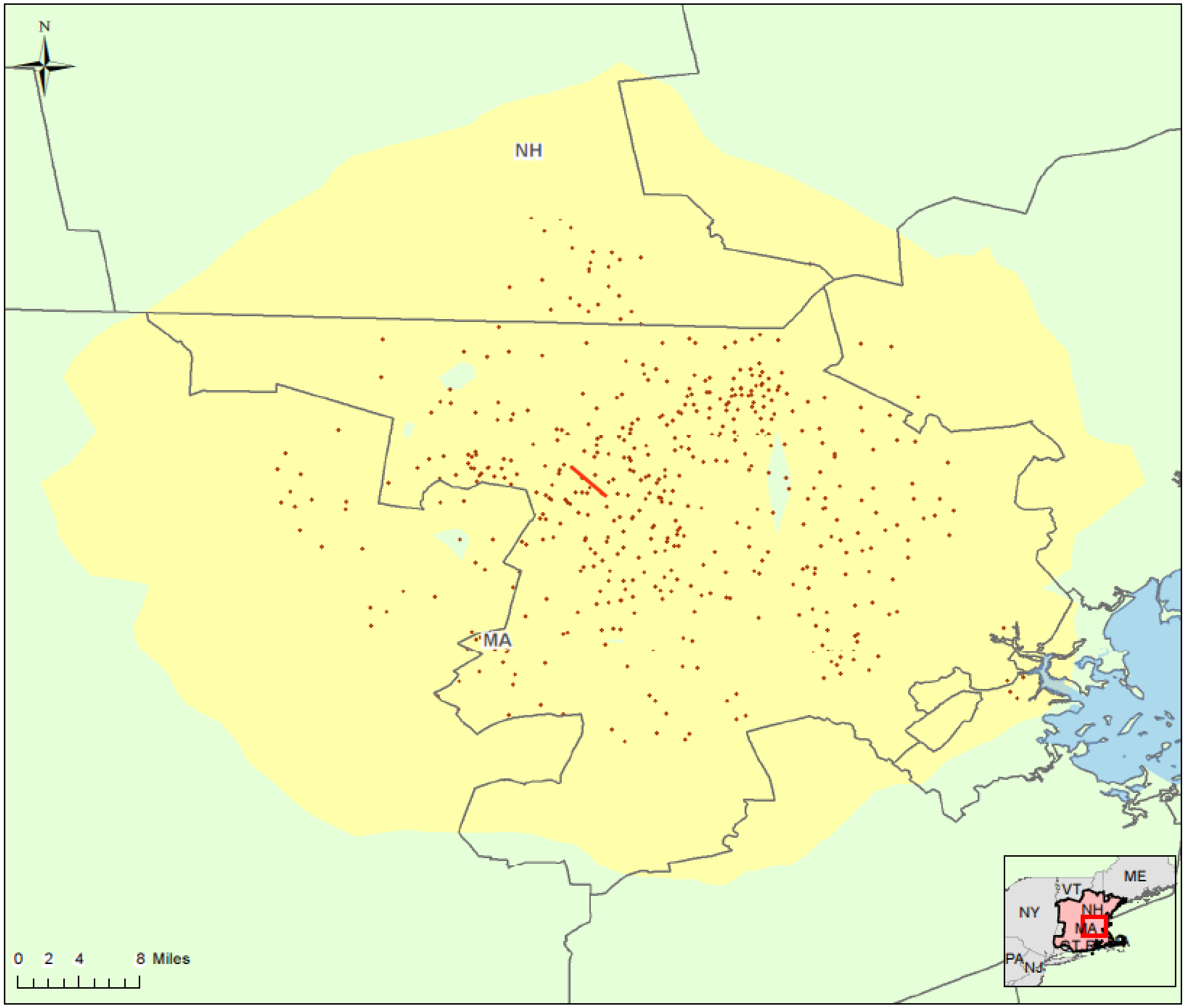
Source: Hazus-MH v. 2.1



Shakemap Description: Shakemap Version 1 - Maps of ground shaking and intensity for event Newburyport5.8_se, Newburyport M5.8 Scenario

Figure 8-13. Estimated Building Damage from the Newburyport Magnitude 5.8 Scenario

Estimated Building Economic Loss by Census Tract and Ground Shaking Intensity



Earthquake Scenario:
Littleton, MA
Magnitude 5
Date: May 2012 (URS and FEMA)

Direct Economic Losses

(Losses include all building-related losses)

1 Dot = $1 Million

Fault Source

Instrumental Intensity

- Not felt
- Weak
- Light
- Moderate
- Strong
- Very strong
- Severe
- Violent
- Extreme

Cost Structural Damage	Cost Non-Structural Damage	Total Loss (Including Contents)
$5	$311	$553
all values in Millions		
Total Loss $553 Million		

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Disclaimer:
The estimates of social and economic impacts illustrated on this map were produced using FEMA's HAZUS loss estimation software and the USGS's ShakeMap ground motions. There are uncertainties inherent in any loss estimation technique; therefore, there may be significant differences between the modeled results and actual losses following a specific earthquake.

Shakemap Description: Shakemap Version 1 - Maps of ground shaking and intensity for event Littleton5.0_se, Littleton M5.0 Scenario

Figure 8-14. Estimated Building Damage from the Littleton, MA Scenario

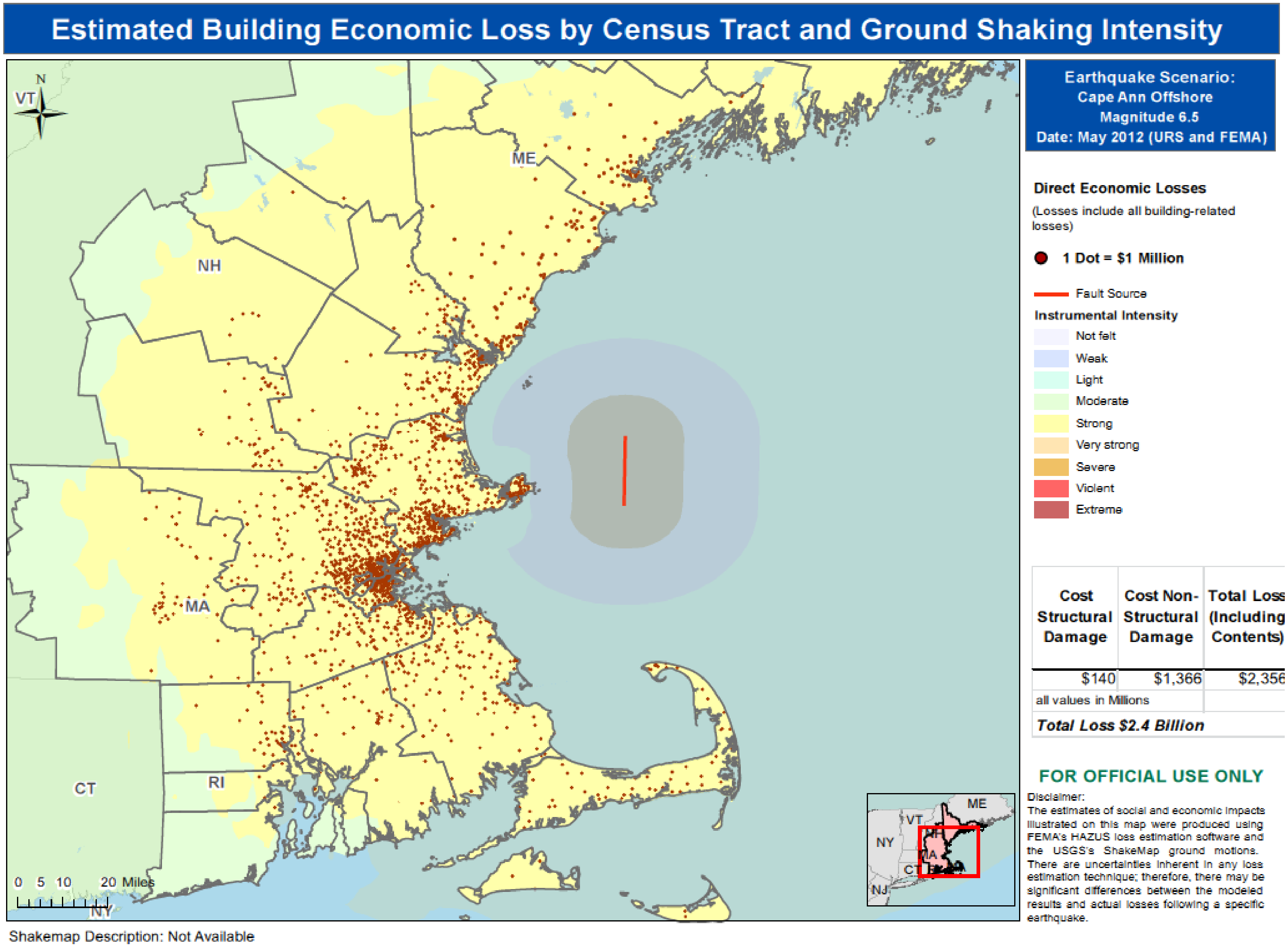

Figure 8-15. Estimated Building Damage from the 1755 Cape Ann Offshore Magnitude 5.9 Scenario