Section 5. Risk Assessment

5.5 Earthquake

For the 2014 Hazard Mitigation Plan (HMP) update, the profile and vulnerability assessment were enhanced to include new relevant earthquake data. The profile was updated to include a detailed description of earthquakes and the various ways in which earthquake intensity is measured. The updated profile also includes a detailed description of the geological makeup of soils in New Jersey, as well as the fault systems present in the State. The full history of recorded earthquakes in New Jersey was added to the profile, with a detailed discussion of significant incidents. The vulnerability assessment was also enhanced and includes the results of probabilistic Hazards U.S. Multi-Hazard (HAZUS-MH) earthquake models to estimate potential losses to the updated state building and critical facility/infrastructure inventory.

5.5.1 Profile

Hazard Description

An earthquake is the sudden movement of the Earth's surface caused by the release of stress accumulated within or along the edge of the Earth's tectonic plates, a volcanic eruption, or by a manmade explosion (Federal Emergency Management Agency [FEMA] 2001; Shedlock and Pakiser 1997). Most earthquakes occur at the boundaries where the Earth's tectonic plates meet (faults); less than 10% of earthquakes occur within plate interiors. New Jersey is in an area where the rarer plate interior-related earthquakes occur. As plates continue to move and plate boundaries change geologically over time, weakened boundary regions become part of the interiors of the plates. These zones of weakness within the continents can cause earthquakes in response to stresses that originate at the edges of the plate or in the deeper crust (Shedlock and Pakiser 1997).

The location of an earthquake is commonly described by its focal depth and the geographic position of its epicenter. The focal depth of an earthquake is the depth from the Earth's surface to the region where an earthquake's energy originates, also called the focus or hypocenter. The epicenter of an earthquake is the point on the Earth's surface directly above the hypocenter (Shedlock and Pakiser 1997). Earthquakes usually occur without warning and their effects can impact areas of great distance from the epicenter (FEMA 2001).

According to the United States Geological Society (USGS) Earthquake Hazards Program, an earthquake hazard is any disruption associated with an earthquake that may affect residents' normal activities. This includes surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, tsunamis, and seiches; each of these terms is defined below:

- *Surface faulting*: Displacement that reaches the earth's surface during a slip along a fault. Commonly occurs with shallow earthquakes—those with an epicenter less than 20 kilometers.
- *Ground motion (shaking):* The movement of the earth's surface from earthquakes or explosions. Ground motion or shaking is produced by waves that are generated by a sudden slip on a fault or sudden pressure at the explosive source and travel through the Earth and along its surface.
- *Landslide*: A movement of surface material down a slope.
- *Liquefaction*: A process by which water-saturated sediment temporarily loses strength and acts as a fluid, like the wet sand near the water at the beach. Earthquake shaking can cause this effect.
- *Tectonic Deformation*: A change in the original shape of a material caused by stress and strain.

- *Tsunami*: A sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major sub-marine slides, or exploding volcanic islands.
- *Seiche*: The sloshing of a closed body of water, such as a lake or bay, from earthquake shaking (USGS 2012a).

Ground shaking is the primary cause of earthquake damage to man-made structures. Damage can be increased when soft soils amplify ground shaking. Soils influence damage in different ways. One way is that soft soils amplify the motion of earthquake waves, producing greater ground shaking and increasing the stresses on structures. Another way is that loose, wet, sandy soils may lose strength and flow as a fluid when shaken, causing foundations and underground structures to shift and break (Stanford 2003).

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, as noted in Table 5.5-1, 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.

Table 5.5-1. NEHRP Soil Classifications

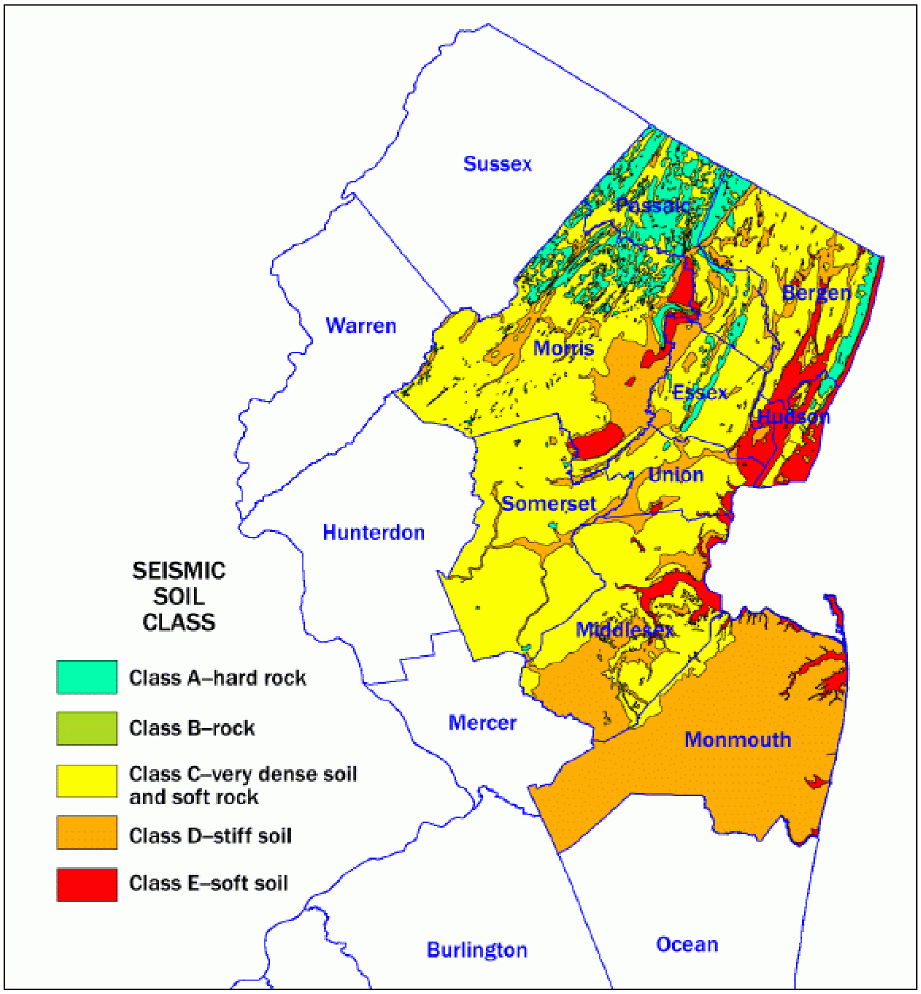
Soil Classification	Description
A	Hard Rock
B	Rock
C	Very dense soil and soft rock
D	Stiff soils
E	Soft soils

Source: FEMA 2013

Location

Earthquakes are most likely to occur in the northern parts of New Jersey, where significant faults are concentrated; however, low-magnitude events can and do occur in many other areas of the State. Figure 5.5-1 illustrates the NEHRP soils located in the northeast quadrant the State. The data was available from the New Jersey Geologic and Water Survey. The available NEHRP soils information is incorporated into the HAZUS-MH earthquake model for the risk assessment (discussed in further detail later in this section).

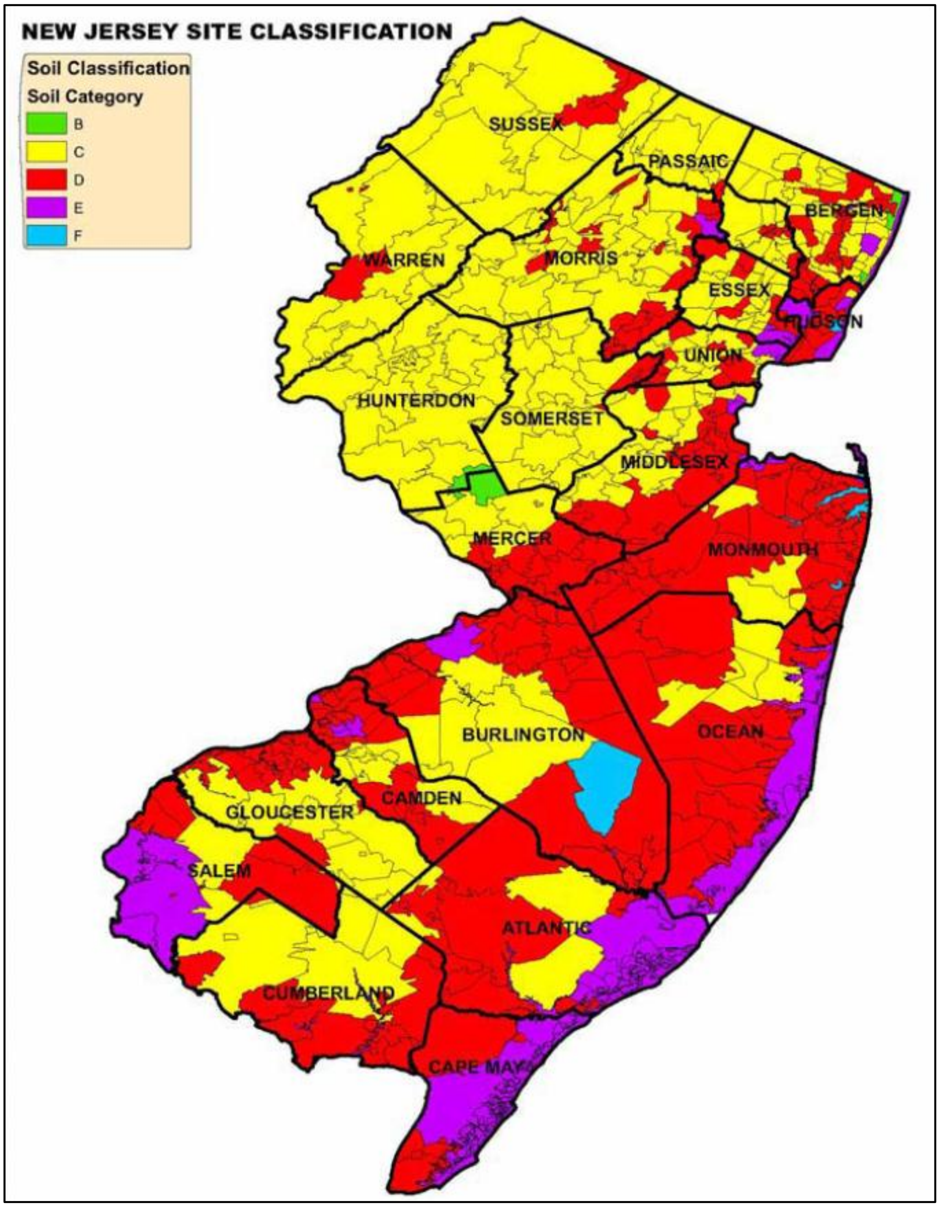
Figure 5.5-1. Seismic Soils in Northeastern New Jersey



Source: New Jersey Geological and Water Survey (NJGWS) and New Jersey Department of Environmental Protection (NJDEP) 2011

New Jersey Department of Transportation (NJDOT) compiled a report on seismic design consideration for bridges in New Jersey, dated March 2012. In the report, NJDOT classifies the seismic nature of soils according to the American Association of State Highway and Transportation Officials (AASHTO) Guide Specifications for Bridge Seismic Design (SGS). For the purpose of seismic analysis and design, sites can be classified into Soil Classes A, B, C, D, E and F, ranging from hard rock to soft soil and special soils. NJDOT developed a Geotechnical Database Management System (GDMS) which contains a large number of soil boring data across New Jersey. The boring logs provide information on Standard Penetration Test (SPT) blow count and soil description, and these boring logs were used to classify soil sites. Using this site classification analysis, NJDOT generated a map of soil site classes according to ZIP codes in New Jersey. Each ZIP code was assigned a site class based on its predominant soil condition. Soil site class maps were generated for all 21 counties in New Jersey; the ZIP code-based soil site class map for New Jersey is included as Figure 5.5-2.

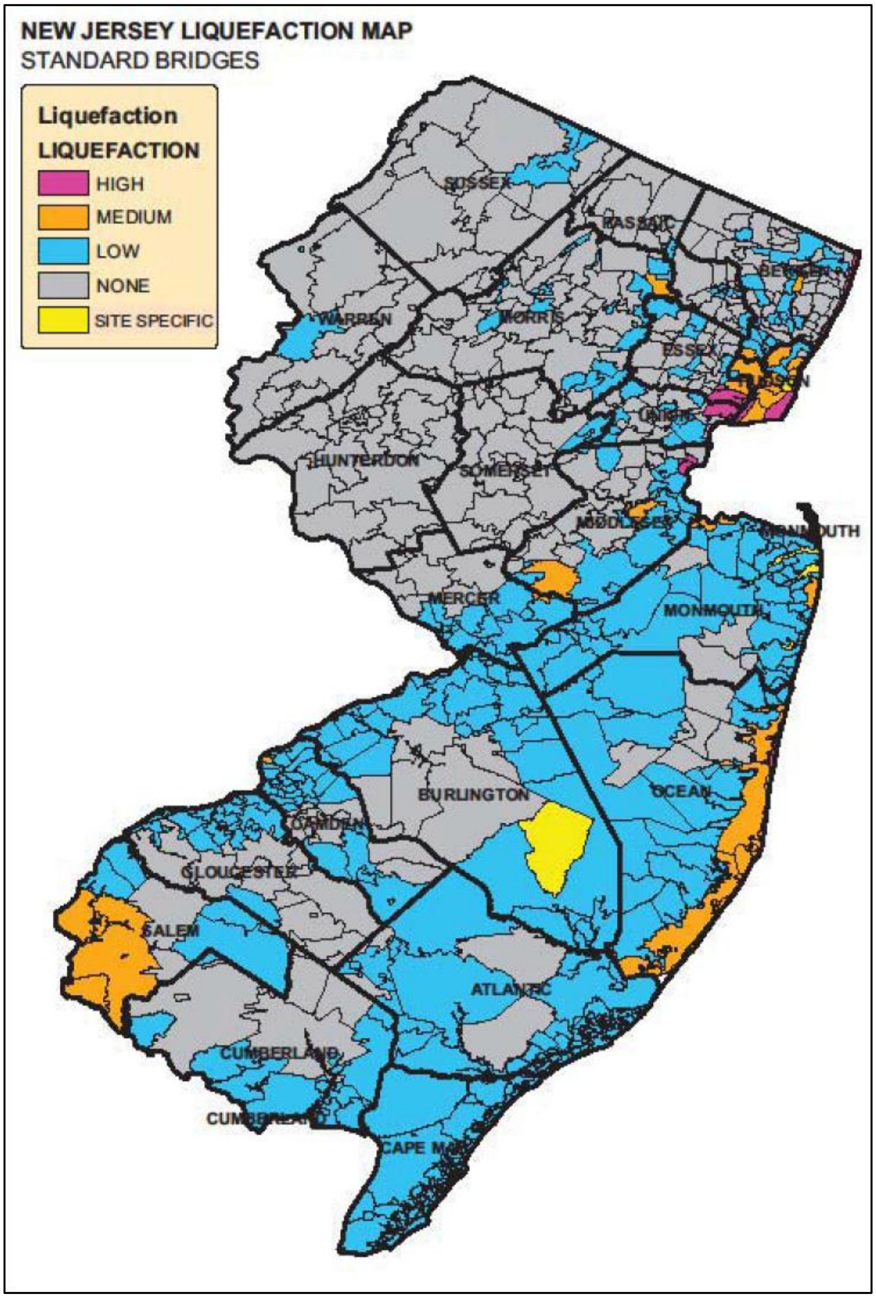
Figure 5.5-2. ZIP Code-Based Soil Site Class Map



Source: NJDOT 2012
Note: Soil Classes A and B are rock sites
Soil Class C is very dense soil
Soil Class D is dense soil
Soil Class E is soft soil
Soil Class F is special soil requiring site-specific analysis

Also in this report, if a ZIP code belonged to site class D or E has few or no soil boring logs, its liquefaction hazard was determined using an approach similar to that used for determining its site class. Using the 1,000-year earthquake spectra in AASHTO-SGS, liquefaction hazard maps for all New Jersey counties were generated. Liquefaction hazard maps are for preliminary design and reference only for bridge construction. Figure 5.5-3 illustrates the liquefaction map for New Jersey.

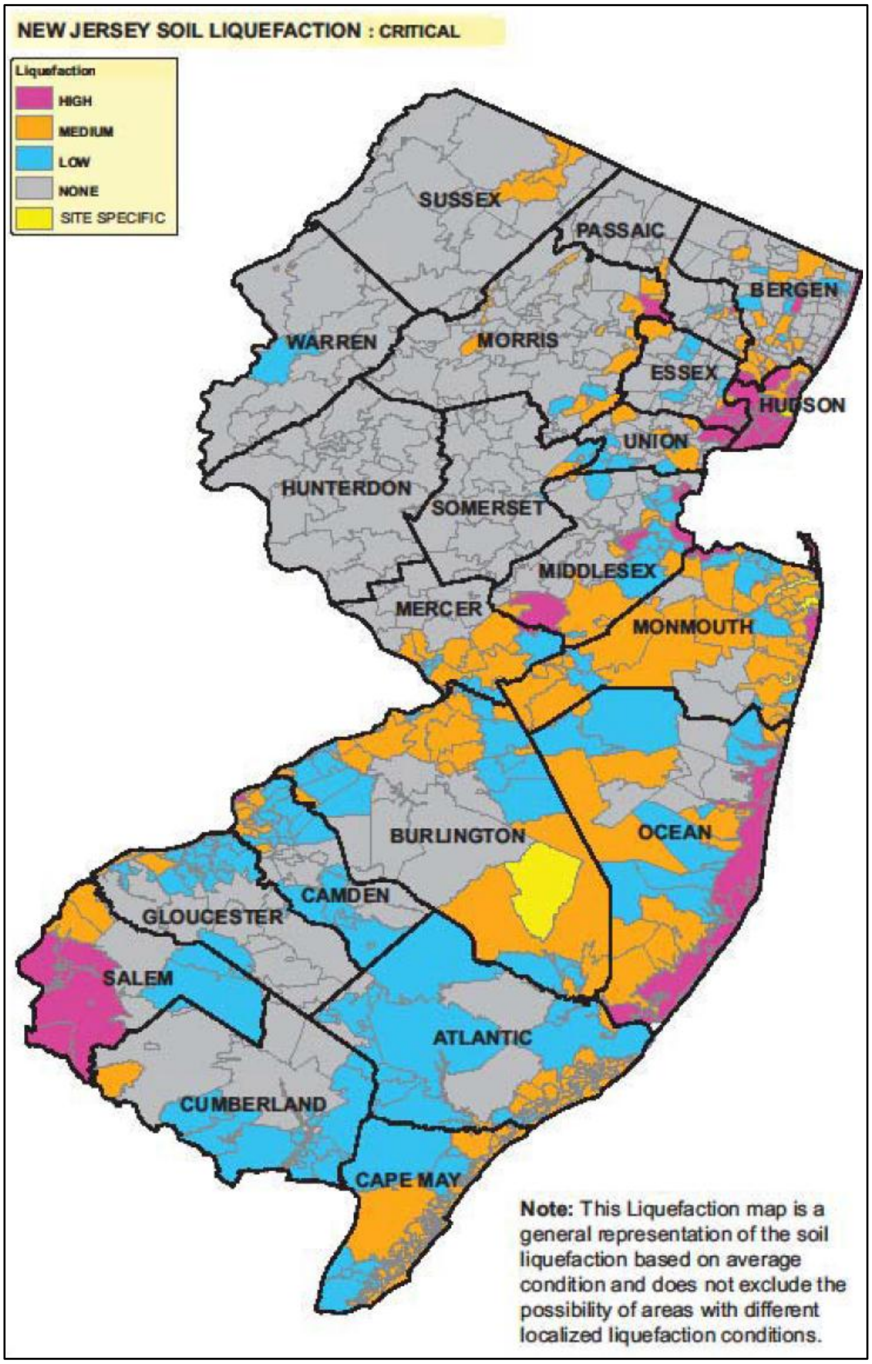
Figure 5.5-3. Liquefaction Map of New Jersey for Standard Bridges



Source: NJDOT 2012

Using a factor of 1.5 to the Peak Ground Acceleration (PGA) of 1,000-year earthquake, the liquefaction hazard maps for New Jersey's counties were generated. Compared to the hazard for 1,000-year earthquake, the areas with "medium" liquefaction hazard are classified as "high," and some areas with "low" hazard have "medium" liquefaction hazard. Figure 5.5-4 presents the liquefaction hazard map for critical bridges in New Jersey.

Figure 5.5-4. Liquefaction Hazard Map of New Jersey for Critical Bridges

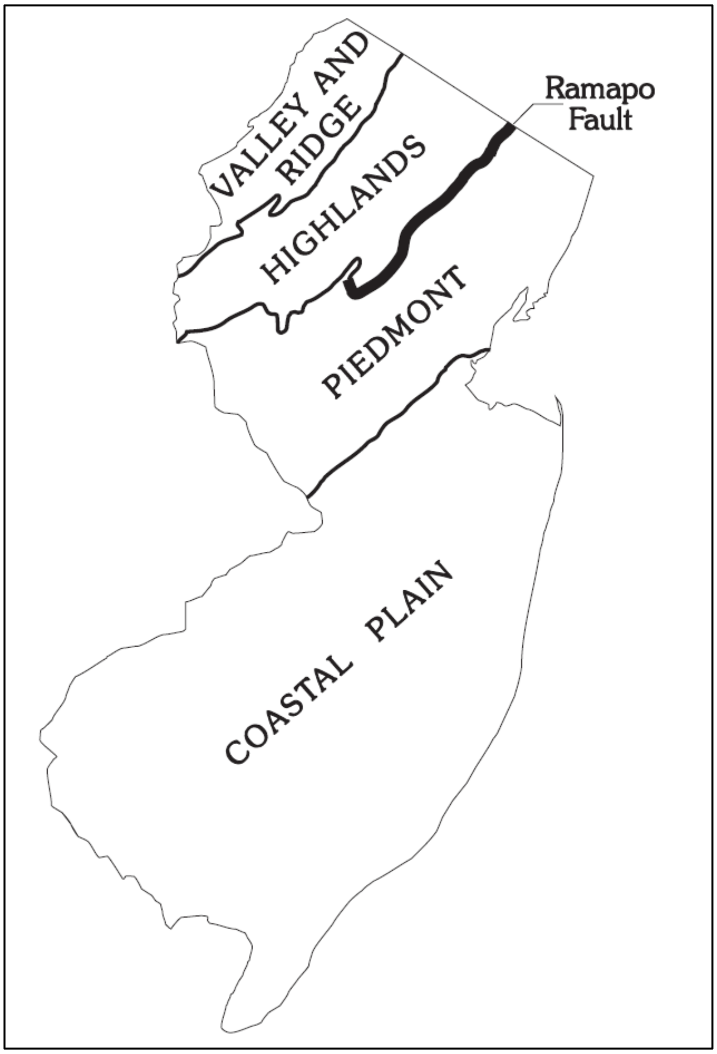


Source: NJDOT 2012

Faults are observed and mapped at the surface. There is no known surface ground displacement along faults in the eastern United States from historic earthquakes. Earthquake epicenters in eastern North America and the New Jersey area, in general, do not now occur on known faults. The faults in these parts are from tectonic activity more than 200 million years ago (Muessig 2013).

There are many faults in New Jersey; however, the Ramapo Fault, which separates the Piedmont and Highlands Physiographic Provinces, is best known. Numerous minor earthquakes have been recorded in the Ramapo Fault zone, a 10- to 20-mile-wide area lying adjacent to, and west, of the actual fault (Dombroski 1973 [revised 2005]). Figure 5.5-5 illustrates the relationship of the Ramapo fault line with the physiologic provinces of New Jersey.

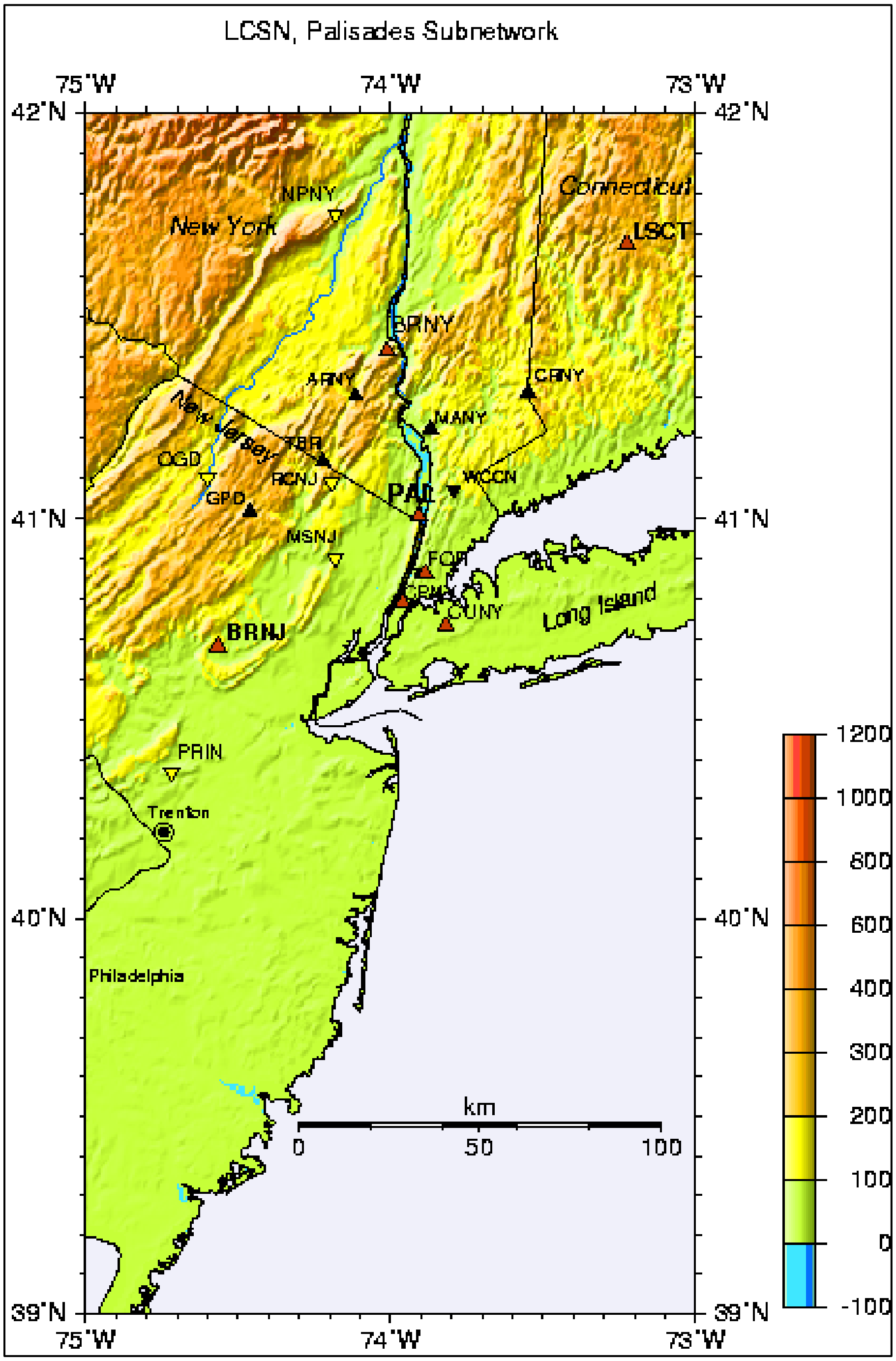
Figure 5.5-5. Physiographic Provinces of New Jersey and the Ramapo Fault Line



Source: Dombroski 1973 (revised 2005)

The Lamont-Doherty Cooperative Seismographic Network (LCSN) monitors earthquakes that occur primarily in the northeastern United States. The goal of the project is to compile a complete earthquake catalog for this region, to assess the earthquake hazards, and to study the causes of the earthquakes in the region. The LCSN operates 40 seismographic stations in the following seven states: Connecticut, Delaware, Maryland, New Jersey, New York, Pennsylvania, and Vermont. In New Jersey, there are several Lamont-Doherty Seismic Stations as part of the Palisades Sub-Network, as shown in Figure 5.5-6. The network is composed of broadband and short-period seismographic stations (LCSN 2012a).

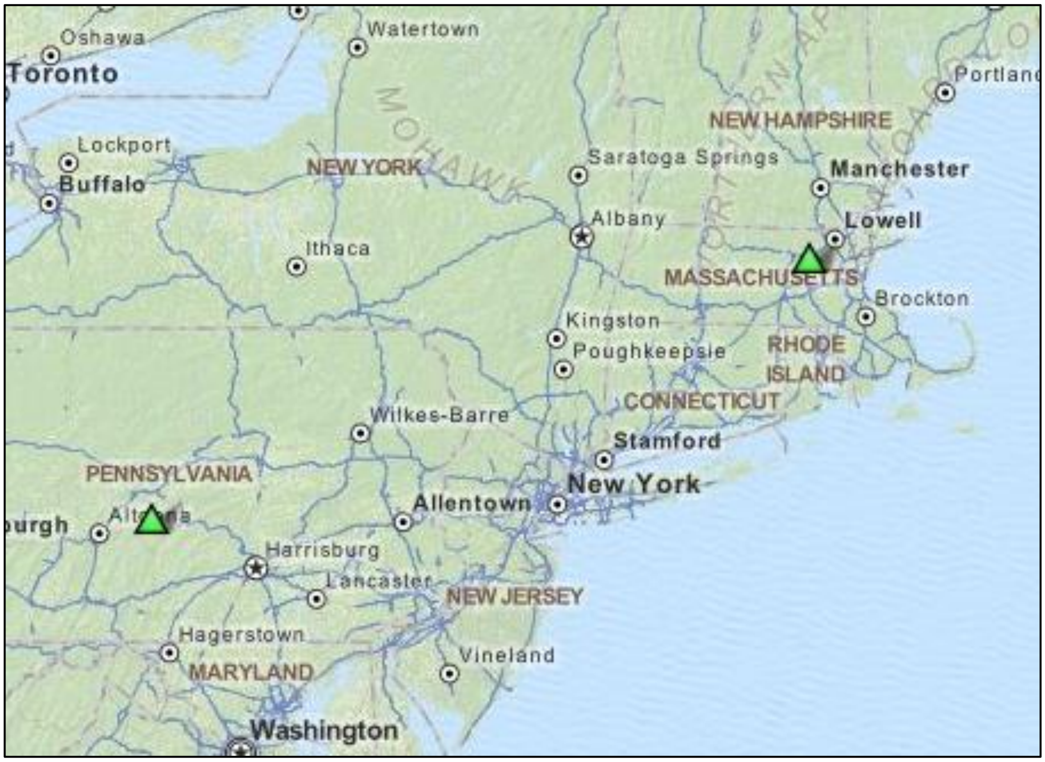
Figure 5.5-6. New Jersey Lamont-Doherty Seismic Stations Locations



Source: LCSN 2006

In addition to the Lamont-Doherty Seismic Stations, the USGS operates a global network of seismic stations to monitor seismic activity. While no seismic stations are located in New Jersey, nearby stations are positioned in State College, Pennsylvania and New Haven, Connecticut. Figure 5.5-7 shows locations of USGS seismic stations near New Jersey.

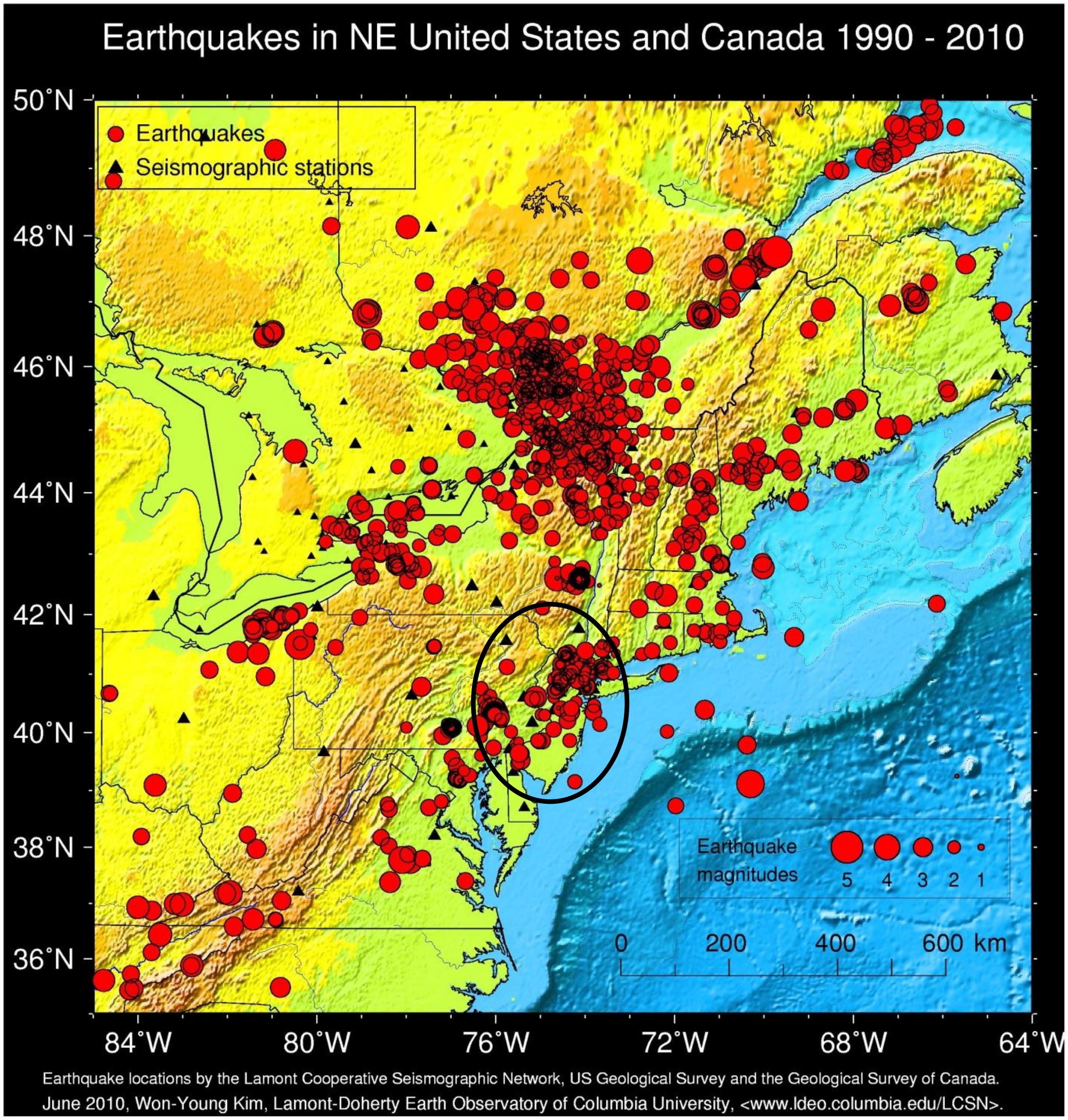
Figure 5.5-7. USGS Seismic Stations near New Jersey



Source: USGS 2012c

Earthquakes above a 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. In New Jersey history, the earthquake with the highest magnitude occurred in 1783 with an epicenter west of New York City. This earthquake had a magnitude of 5.3. Earthquakes seem to occur with regularity across New Jersey. As mentioned earlier, earthquakes are concentrated along the Ramapo Fault System; however, earthquakes have occurred as far south as Salem County. A full discussion of past occurrences of earthquakes in New Jersey is presented in the following section. Figure 5.5-8 illustrates earthquake activity in the northeastern United States from 1990 – 2010, with New Jersey circled in black.

Figure 5.5-8. Earthquake Epicenters in the Northeast 1990 – 2010



Source: LCSN 2010

Extent

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 measured value of the earthquake size, or amplitude of the seismic waves, using a seismograph. 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 the magnitude of earthquakes. 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, may have the same magnitude and shock in a remote area that did not experience any damage. Table 5.5-2 presents the Richter scale magnitudes and corresponding earthquake effects.

Table 5.5-2. Richter Magnitude Scale

Richter Magnitude	Earthquake Effects
2.5 or less	Usually not felt, but can be recorded by seismograph
2.5 to 5.4	Often felt, but causes only 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: Michigan Tech University 2007

The intensity of an earthquake is based on the observed effects of ground shaking on people, buildings, and natural features, and varies with location. The Modified Mercalli scale expresses intensity of an earthquake; the scale is a subjective measure that describes how strong a shock 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 5.5-3 summarizes earthquake intensity as expressed by the Modified Mercalli scale. Table 5.5-4 displays the Modified Mercalli scale and peak ground acceleration equivalent.

Table 5.5-3. 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 their 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	Well-built buildings suffer slight damage. Poorly built structures suffer severe damage. 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, and 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.

Source: Michigan Tech University 2007

Table 5.5-4. Modified Mercalli Intensity and PGA Equivalents

Modified Mercalli Intensity	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

Source: Freeman et al. 2004
Note: PGA Peak Ground Acceleration

Modern intensity scales use terms that can be physically measured with seismometers, such as the acceleration, velocity, or displacements (movement) of the ground. The most common physical measure is peak ground acceleration (PGA). PGA expresses the severity of an earthquake and is a measure of how hard the earth shakes, or accelerates, in a given geographic area. PGA is expressed as a percent acceleration force of gravity (%g). For example, 1.0%g PGA in an earthquake (an extremely strong ground motion) means that objects accelerate sideways at the same rate as if they had been dropped from the ceiling. 10%g PGA means that the ground acceleration is 10% that of gravity (NJOEM 2011). Damage levels experienced in an earthquake vary with the intensity of ground shaking and with the seismic capacity of structures, as noted in Table 5.5-5.

Table 5.5-5. Damage Levels Experienced in Earthquakes

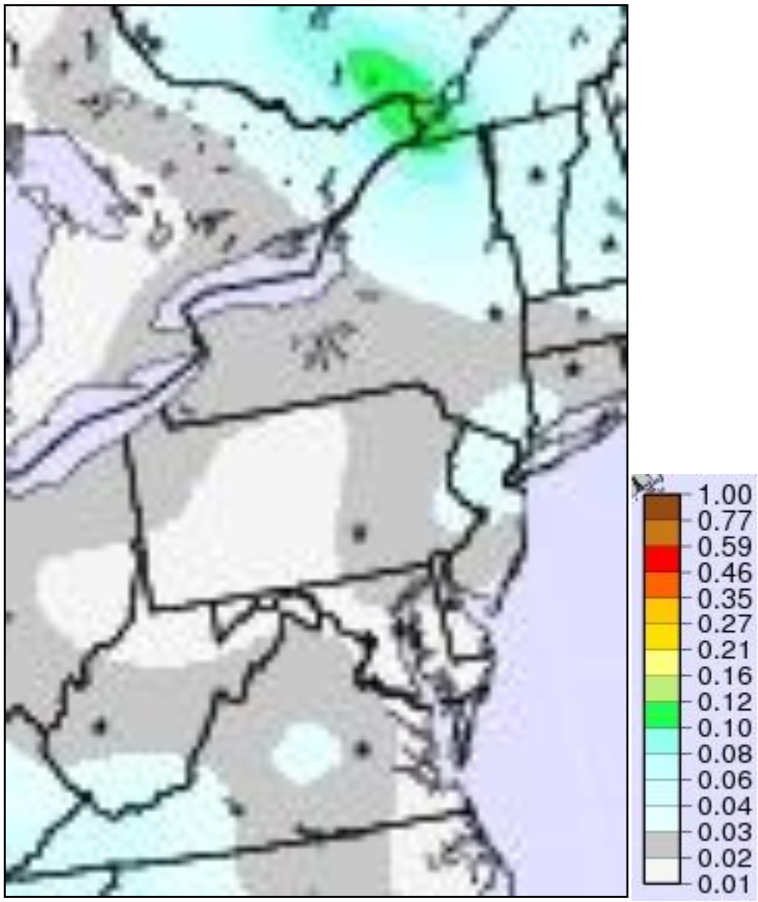
Ground Motion Percentage	Explanation of Damages
1-2%g	Motions are widely felt by people; hanging plants and lamps swing strongly, but damage levels, if any, are usually very low.
Below 10%g	Usually causes only slight damage, except in unusually vulnerable facilities.
10 - 20%g	May cause minor-to-moderate damage in well-designed buildings, with higher levels of damage in poorly designed buildings. At this level of ground shaking, only unusually poor buildings would be subject to potential collapse.
20 - 50%g	May cause significant damage in some modern buildings and very high levels of damage (including collapse) in poorly designed buildings.
≥50%g	May causes higher levels of damage in many buildings, even those designed to resist seismic forces.

Source: NJOEM 2011
Note: %g Peak Ground Acceleration

According to USGS Earthquake Hazards Program, PGA maps (also known as earthquake hazard maps) are used as planning tools when designing buildings, bridges, highways, and utilities so that they can withstand shaking associated with earthquake events. These maps are also used as planning tools for the development of building codes that establish construction requirements appropriate to preserve public safety.

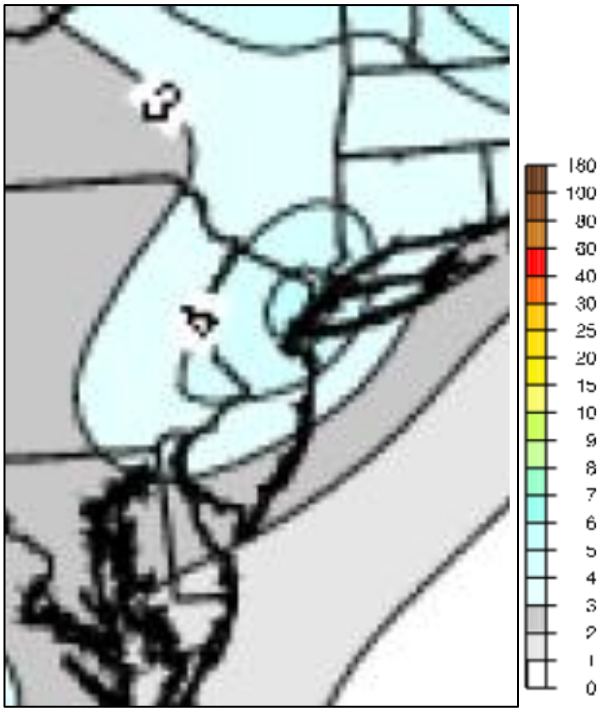
The USGS updated the National Seismic Hazard Maps in 2008, which supersede the 2002 maps. New seismic, geologic, and geodetic information on earthquake rates and associated ground shaking were incorporated into these revised maps. The 2008 map, presented as Figure 5.5-9, represents the best-available data as determined by the USGS (USGS 2008).

Figure 5.5-9. 2008 Seismic Hazard Map, PGA with 10% Probability of Exceedance in 50 Years



Source: USGS 2008
Note: The figure indicates that the State has PGA of 1%g - 4%g.
g% Percent acceleration force of gravity
PGA Peak ground acceleration

Figure 5.5-10. 2002 Seismic Hazard Map, PGA with 10% Probability of Exceedance in 50 Years



Source: USGS 2002
Note: The figure indicates that the State has PGA of 2%g - 5%g.
g% Percent acceleration force of gravity
PGA Peak ground acceleration

The 2002 Seismic Hazard Map shows that New Jersey has a PGA between 2%g and 5%g (Figure 5.5-10). The 2008 Seismic Hazard Map shows that New Jersey has a PGA between 1%g and 4%g (Figure 5.5-9). These maps are based on peak ground acceleration (%g) with 10% probability of exceedance in 50 years.

Previous Occurrences and Losses

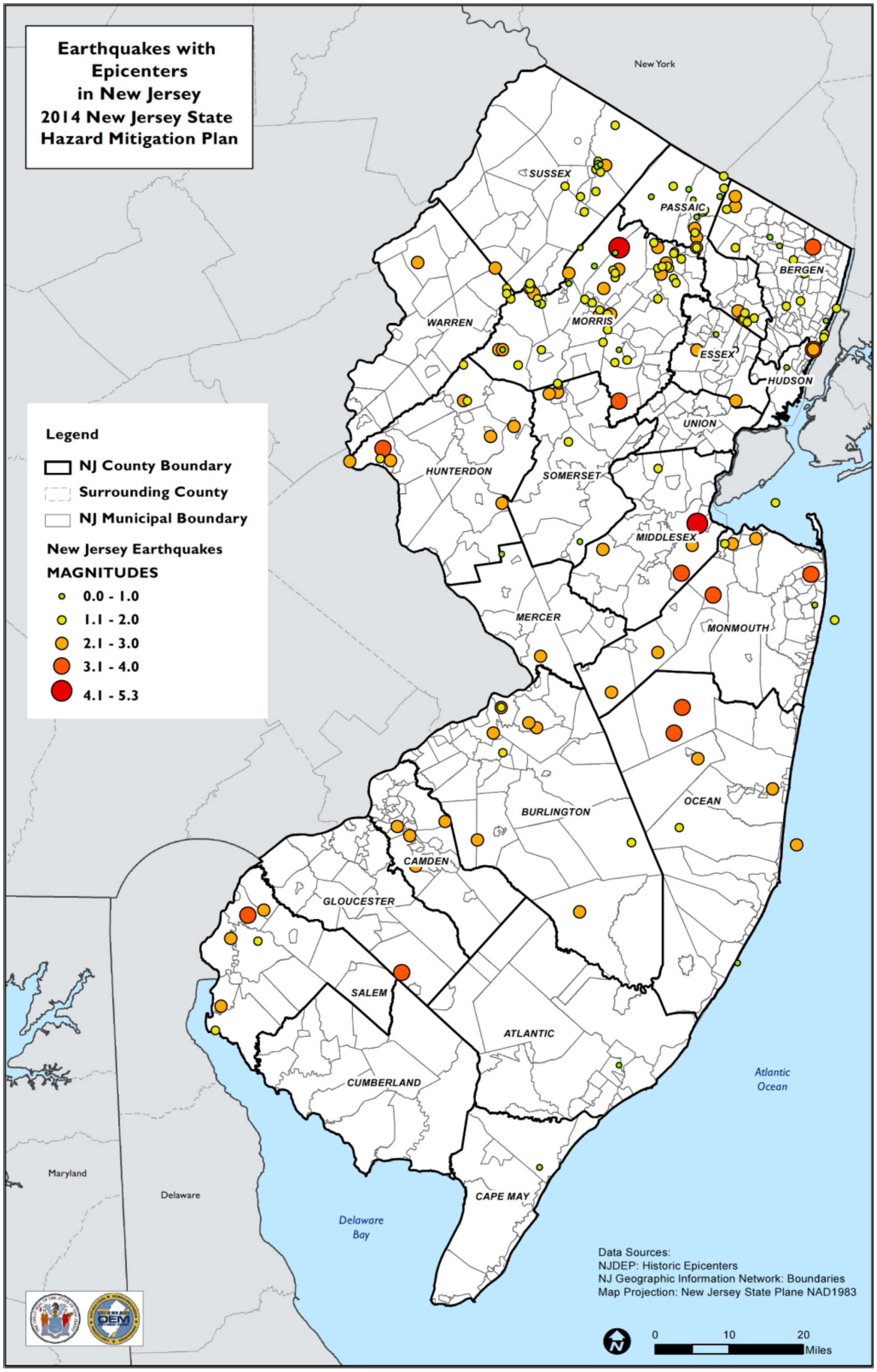
New Jersey has a fairly extensive history of earthquakes, mostly because of the factors discussed previously in the location section. Small earthquakes occur several times a year and generally do not cause significant damage. The largest earthquake to impact New Jersey occurred in 1783. That earthquake, a magnitude 5.3 quake, occurred west of New York City and was felt from New Hampshire to Pennsylvania (Stover and Coffman 1993).

Many sources provided historical information regarding previous occurrences and losses associated with earthquake events throughout the State of New Jersey. With so many sources reviewed for the purpose of this HMP, loss and impact information for many events could vary depending on the source. Therefore, the accuracy of monetary figures discussed is based only on available information identified during research for this HMP update. Table 5.8-16 outlines the history of earthquake events in New Jersey.

The 2011 Plan did not discuss specific earthquake events; however, the 2011 Plan indicated that there have been four historic earthquakes that caused damage in the State: 1737 (New York City), 1783 (west of New York City), 1884 (New York City), and 1927 (New Jersey coast near Asbury). Damages in New Jersey were relatively minor from these events, including building damage such as chimney collapse and objects falling from shelves. The 2011 Plan also stated that New Jersey has felt several large earthquakes that caused major damage near their epicenters: 1755 (Cape Ann, Massachusetts), 1886 (Charleston, South Carolina), and three large earthquakes near New Madrid, Missouri (December 16, 1811; January 23, 1812; and February 7, 1812).

For this Plan update, earthquake events will be further discussed that occurred in the State between January 1, 2010 and December 31, 2012. Table 5.5-6 lists earthquakes that had epicenters in New Jersey from 1783 through 2012. Figure 5.5-11 maps these epicenters. Incidents occurring prior to 2010 are based on the previous HMP and other research, including events recorded by the New Jersey Geological and Water Survey (NJGWS) and United States Geological Survey (USGS).

Figure 5.5-11. Earthquakes with Epicenters in New Jersey, 1783 to 2012



Source: NJDEP 2012

Table 5.5-6. Earthquake Incidents that Impacted New Jersey, 1737 to 2012

Date(s) of Event	Magnitude	Location	Losses/Impacts
12/19/1737	5.2	Greater NYC Area*	Threw down chimneys
11/30/1783	5.3	North-Central New Jersey*	TwofForeshocks (11/24 and 11/30) and one aftershock (11/30); threw down chimneys
1/25/1841	0.0	West Orange, NJ	No reference and/or no damage reported.
10/26/1845	3.8	Greater NYC Area*	No reference and/or no damage reported.
9/9/1848	4.4	Greater NYC area*	No reference and/or no damage reported.
3/5/1861	0.0	Newark, NJ	No reference and/or no damage reported.
12/11/1874	3.4	Near Nyack and Tarrytown, NY	No reference and/or no damage reported.
9/10/1877	0.0	Burlington, NJ	No reference and/or no damage reported.
8/10/1880	0.0	Near Morristown, NJ	1 aftershock 9/1/1880.
8/10/1884	5.2	Greater NYC Area	Threw down chimneys; felt from Virginia to Maine
1/4/1885	3.4	Hudson Valley	No reference and/or no damage reported.
9/1/1895	4.1	Near High Bridge, NJ	Felt over a considerable area to the northeast and southwest. The total felt area covered points from Maine to Virginia in a long, narrow elliptical zone of about 92,000 square kilometers. Articles fell from shelves and buildings rocked (intensity VI) in several Hunterdon County towns. The shock was fairly sharp at Camden and Burlington. At Philadelphia, Pennsylvania, broken windows and overturned crockery were reported.
5/27/1902	0.0	Bayonne-Wayne, NJ	No reference and/or no damage reported.
8/11/1902	0.0	Bayonne-Wayne, NJ	No reference and/or no damage reported.
1/20/1905	4.5	Greater NYC Area*	Probably located offshore
4/23/1910	0.0	Near Atlantic City, NJ	No reference and/or no damage reported.
11/6/1912	0.0	Near Long Beach, NJ	No reference and/or no damage reported.
8/5/1919	0.0	Cinnaminson, NJ	No reference and/or no damage reported.
6/1/1927	3.9	Near Asbury Park, NJ	Occurred in the Asbury Park area. Three shocks were felt along the coast from Sandy Hook to Toms River. Maximum intensities of VII were observed at Asbury Park and Long Branch. Several chimneys fell, plaster cracked, and articles were thrown from shelves. The felt area extended over approximately 7,800 square kilometers.
1/25/1933	0.0	Near Trenton, NJ	A sharp jolt was felt over central New Jersey from Lakehurst to Trenton. Although there is some doubt whether the shock was of seismic origin, the event was felt most strongly at Lakehurst, where people reported they were rolled out of bed (intensity V). Other people reported pictures shaken from walls. The shock was also felt at Bordentown, Burlington, Columbus, Englishtown, Freehold, Hightstown, New Egypt, Robbinsville, and White Horse.
7/19/1937	3.5	Western Long Island, NY	One or few earthquakes beneath Long Island

Date(s) of Event	Magnitude	Location	Losses/Impacts
9/30/1937	0.0	Verona, NJ	No reference and/or no damage reported.
5/16/1938	0.0	Verona, NJ	No reference and/or no damage reported.
8/23/1938	3.8	Northeast of New Egypt, NJ	Caused minor damage at Gloucester City and Hightstown (intensity V). The total felt area was about 13,000 square kilometers, including bordering portions of Delaware and Pennsylvania. Glassware was broken at Gloucester City and Hightstown and some furniture was displaced at Pitman. A few windows and some glassware were reported broken at Ardmore, Pennsylvania. Four smaller shocks occurred on 8/23 and one on 8/26.
8/23/1938	4.0	Freehold, NJ	4 aftershocks felt.
12/6/1938	0.0	Verona, NJ	No reference and/or no damage reported.
9/13/1939	0.0	Union City, NJ	No reference and/or no damage reported.
11/15/1939	3.4	Salem County, NJ	The disturbance was reportedly felt from Trenton to Baltimore, Maryland, and from Cape May to Philadelphia and its adjoining counties. About 16,000 square kilometers were affected. Small objects were reported to have overturned at Deepwater, but little or no damage was noted.
4/1/1947	2.7	Pompton Lakes NJ	No reference and/or no damage reported.
10/16/1949	0.0	Hopewell, NJ	No reference and/or no damage reported.
9/3/1951	3.6	Rockland County, NY	Northeastern New Jersey experienced minor effects.
8/17/1953	3.2	Bergen County, NJ	No reference and/or no damage reported.
3/31/1954	0.0	Long Branch, NJ	No reference and/or no damage reported.
3/23/1957	2.9	Schooley's Mountain, NJ	A shock affected west-central New Jersey, near the site of the 1895 earthquake. Chimneys cracked (intensity VI), windows and dishes broke, and pictures fell at Lebanon. A cracked chimney was also reported from Hamden. At Long Valley, some walls were cracked and plaster fell. The felt area was small in comparison with the other shocks previously described.
12/27/1961	2.7	5 km W of Flemington, NJ	No reference and/or no damage reported.
10/13/1962	0.0	Pompton Lakes, NJ	No reference and/or no damage reported.
12/10/1968	2.7	Southeast of Camden, NJ	No reference and/or no damage reported.
4/25/1969	0.0	Near Sussex, NJ	No reference and/or no damage reported.
10/6/1969	0.0	Ogdensburg, NJ	No reference and/or no damage reported.
2/28/1973	3.5	East of Wilmington, DE	No reference and/or no damage reported.
7/10/1973	2.6	East of Wilmington, DE	No reference and/or no damage reported.
3/11/1976	2.8	Pompton Lakes, NJ	1 aftershock, some damage
4/13/1976	3.1	Near Ridgefield, NJ	The shock was felt widely.
12/5/1976	0.0	N/A	No reference and/or no damage reported.

Date(s) of Event	Magnitude	Location	Losses/Impacts
12/5/1976	1.8	Schooley's Mountain, NJ	1 aftershock felt on 12/07
1/21/1977	2.7	Lakehurst, NJ	No reference and/or no damage reported.
6/10/1977	1.1	High Bridge, NJ	No reference and/or no damage reported.
7/2/1977	2.3	Hampton, NJ	No reference and/or no damage reported.
10/27/1977	1.5	Sparta, NJ	No reference and/or no damage reported.
11/27/1977	1.8	Oakland, NJ	No reference and/or no damage reported.
12/23/1977	2.3	Schooley's Mountain, NJ	Five foreshocks felt between 12/4 to12/8, and five aftershocks felt on 12/23
2/15/1978	1.6	Boonton, NJ	No reference and/or no damage reported.
4/3/1978	2.0	Off Sandy Hook	No reference and/or no damage reported.
5/18/1978	1.5	Bloomingdale, NJ	No reference and/or no damage reported.
6/16/1978	0.0	Sparta, NJ	No reference and/or no damage reported.
6/30/1978	2.9	Mahwah-Oakland, NJ	1 aftershock on same day.
1/30/1979	3.5	Cheesequake, NJ	No reference and/or no damage reported.
2/2/1979	1.9	Chester, NJ	No reference and/or no damage reported.
2/23/1979	2.9	Chester, NJ	No reference and/or no damage reported.
3/10/1979 "Cheesequake Earthquake"	3.1	Bernardsville, NJ (epicenter in Morris County)	Felt by some people in Manhattan
3/25/1980	2.8	Hainesburg, NJ	No reference and/or no damage reported.
4/5/1980	2.9	South of Seaside, NJ	No reference and/or no damage reported.
8/2/1980	2.8	Keyport, NJ	No reference and/or no damage reported.
8/30/1980	3.0	Medford Lakes, NJ	No reference and/or no damage reported.
3/19/1981	2.0	Boonton, NJ	No reference and/or no damage reported.
5/18/1981	2.1	Ramsey, NJ	No reference and/or no damage reported.
6/21/1981	1.8	Denville, NJ	No reference and/or no damage reported.
4/12/1982	2.4	Mount Holly, NJ	No reference and/or no damage reported.
7/29/1982	2.4	Seaside Heights, NJ	No reference and/or no damage reported.
9/16/1982	1.6	Franklin, NJ	No reference and/or no damage reported.
2/19/1983	2.7	Oldwick, NJ	No reference and/or no damage reported.
6/1/1983	1.5	Dover, NJ	No reference and/or no damage reported.
9/6/1983	1.5	Fort Lee, NJ	No reference and/or no damage reported.

Date(s) of Event	Magnitude	Location	Losses/Impacts
9/15/1983	1.5	Ringwood, NJ	No reference and/or no damage reported.
3/12/1984	2.0	Asbury Park, NJ	No reference and/or no damage reported.
5/13/1984	2.1	Mount Hope, NJ	No reference and/or no damage reported.
6/3/1984	1.3	Kinnelon, NJ	No reference and/or no damage reported.
6/6/1984	1.7	Near Morristown, NJ	No reference and/or no damage reported.
8/2/1984	1.7	Mount Olive, NJ	No reference and/or no damage reported.
8/12/1984	2.4	Byram, NJ	No reference and/or no damage reported.
8/12/1984	2.1	Byram, NJ	No reference and/or no damage reported.
10/25/1984	2.0	Near Mount Olive, NJ	No reference and/or no damage reported.
12/3/1984	1.5	Byram, NJ	No reference and/or no damage reported.
12/13/1984	1.7	Byram, NJ	No reference and/or no damage reported.
12/14/1984	1.7	North of Milford, NJ	No reference and/or no damage reported.
12/15/1984	1.8	Byram, NJ	No reference and/or no damage reported.
12/17/1984	1.6	Byram, NJ	No reference and/or no damage reported.
10/19/1985	4	Ardsley, NY	Many people in the NYC area felt this earthquake.
2/8/1986	1.7	Flanders, NJ	No reference and/or no damage reported.
2/23/1986	1.8	Port Murray, NJ	No reference and/or no damage reported.
6/29/1986	1.5	Kinnelon, NJ	No reference and/or no damage reported.
7/15/1986	1.5	Franklin, NJ	No reference and/or no damage reported.
9/15/1986	2.3	Near New Egypt, NJ	No reference and/or no damage reported.
9/15/1986	1.9	Near Roebling, NJ	No reference and/or no damage reported.
11/23/1986	2.8	Tranquility, NJ	Felt in Sussex and Warren.
4/24/1987	1.9	South of Lake Mohawk, NJ	No reference and/or no damage reported.
5/16/1987	1.4	Near Paterson, NJ	No reference and/or no damage reported.
8/5/1987	1.7	Southwest of Newton, NJ	No reference and/or no damage reported.
8/6/1987	1.1	Southwest of Newton, NJ	No reference and/or no damage reported.
8/6/1987	1.1	Southwest of Newton, NJ	No reference and/or no damage reported.
12/6/1987	2.1	Burlington, NJ	No reference and/or no damage reported.
4/13/1988	1.4	Dover, NJ	No reference and/or no damage reported.
8/20/1988	1.0	10 km Northwest of Morristown, NJ	No reference and/or no damage reported.

Date(s) of Event	Magnitude	Location	Losses/Impacts
12/22/1988	1.0	Wanaque, NJ	No reference and/or no damage reported.
12/23/1988	1.1	Wanaque, NJ	No reference and/or no damage reported.
1/22/1989	2.0	Englewood, NJ	No reference and/or no damage reported.
1/27/1989	1.1	New York-New Jersey Border	No reference and/or no damage reported.
9/3/1989	2.0	South of Staten Island	No reference and/or no damage reported.
9/3/1989	2.5	South of Staten Island	No reference and/or no damage reported.
1/26/1990	1.0	Franklin, NJ	No reference and/or no damage reported.
5/10/1990	1.8	Mount Freedom, NJ	No reference and/or no damage reported.
8/21/1990	0.7	Wanaque, NJ	No reference and/or no damage reported.
10/23/1990	2.9	Hancock's Bridge, NJ	Felt in New Jersey, Delaware, and Pennsylvania
5/12/1991	1.3	Wanaque, NJ	No reference and/or no damage reported.
7/5/1991	1.3	Pompton Plains, NJ	No reference and/or no damage reported.
9/29/1991	2.2	Somerdale Borough, NJ	No reference and/or no damage reported.
1/9/1992	3.1	New Brunswick, NJ	No reference and/or no damage reported.
3/4/1992	1.4	Kinnelon, NJ	No reference and/or no damage reported.
6/7/1992	0.4	Jefferson Township, NJ	No reference and/or no damage reported.
10/13/1992	1.0	West Milford, NJ	No reference and/or no damage reported.
2/26/1993	2.5	Cherry Hill, NJ	No reference and/or no damage reported.
5/15/1993	2.6	Perrineville, NJ	No reference and/or no damage reported.
5/23/1994	1.6	Butler, NJ	No reference and/or no damage reported.
1/27/1995	2.3	Rockaway, NJ	No reference and/or no damage reported.
4/1/1995	1.5	Rockaway, NJ	No reference and/or no damage reported.
5/26/1995	1.5	Kinnelon, NJ	No reference and/or no damage reported.
10/27/1995	1.3	Northeast of Newton, NJ	No reference and/or no damage reported.
10/27/1995	1.4	Northeast of Newton, NJ	No reference and/or no damage reported.
2/18/1996	1.5	Ringwood, NJ	No reference and/or no damage reported.
2/19/1996	1.7	Ringwood, NJ	1 aftershock felt 22 minutes later
2/19/1996	0.8	5 km West Ringwood, NJ	No reference and/or no damage reported.
2/23/1996	0.8	6.4 km West of Ringwood, NJ	No reference and/or no damage reported.
2/26/1996	0.0	Near Mount Arlington, NJ	No reference and/or no damage reported.

Date(s) of Event	Magnitude	Location	Losses/Impacts
10/24/1996	2.0	9 km South Crestwood Village, NJ	No reference and/or no damage reported.
11/12/1996	1.3	21 km Northeast of Newton, NJ	No reference and/or no damage reported.
11/12/1996	0.8	21 km Northeast of Newton, NJ	No reference and/or no damage reported.
3/11/1997	0.0	3 km West of Rendall Park, NJ	No reference and/or no damage reported.
5/25/1997	0.5	1 km Northeast of Fort Lee, NJ	No reference and/or no damage reported.
6/27/1997	1.6	4.6 km North of Rockaway, NJ	No reference and/or no damage reported.
7/15/1997	2.3	12 km Northeast of Princeton, NJ	No reference and/or no damage reported.
10/21/1997	0.5	3 km Southwest Woodcliff Lake, NJ	No reference and/or no damage reported.
10/24/1997	0.5	3 km Southwest Secaucus, NJ	No reference and/or no damage reported.
3/25/1998	1.9	13 km South of Salem, NJ	No reference and/or no damage reported.
6/20/1998	1.2	2 km Southeast Kinnelon, NJ	No reference and/or no damage reported.
6/30/1998	1.9	3 km South of Butler, NJ	No reference and/or no damage reported.
1/12/1999	1.4	1 km Northwest of Clifton, NJ	No reference and/or no damage reported.
1/31/1999	1.5	2 km West of Emerson, NJ	No reference and/or no damage reported.
5/31/1999	2.3	8 km West of Fort Dix, NJ	No reference and/or no damage reported.
1/17/2001	2.4	Manhattan	Felt in the Upper East Side of Manhattan, Long Island City, and Queens, NY
7/14/2001	1.9	7.1 km Northeast of of Boonton, NJ	No reference and/or no damage reported.
10/17/2001	2.6	Manhattan	Felt in the Upper East Side of Manhattan, Long Island City, Astoria, and Queens, NY
8/9/2002	1.5	5.4 km North of Somerville, NJ (epicenter in Bridgewater)	No reference and/or no damage reported.
8/24/2003	1.5	6 km Southwest of Morris Plains,	No reference and/or no damage reported.
8/26/2003	3.5	3 km North of Milford, NJ	No reference and/or no damage reported.
3/22/2004	2.1	2 km Northeast of from Runnemede, NJ	No reference and/or no damage reported.
12/17/2004	2.0	6 km Southeast from Pennsville, NJ	No reference and/or no damage reported.
04/23/2005	1.9	1.3 km East of Lodi, NJ	No reference and/or no damage reported.
12/09/2005	2.1	16 km West of Franklin Lakes, NJ	Aftershock felt 55 minutes later
02/16/2006	2.6	22 km Northeast of Newton, NJ	No reference and/or no damage reported.
02/17/2006	0.9	20 km Northeast of Newton, NJ	No reference and/or no damage reported.
02/21/2006	1.3	20.4 km Northeast of Newton, NJ	No reference and/or no damage reported.

Date(s) of Event	Magnitude	Location	Losses/Impacts
05/15/2006	2.0	9 km South of Fair Lawn, NJ	No reference and/or no damage reported.
06/28/2007	2.1	7 km East of Fairfield, NJ	No reference and/or no damage reported.
02/03/2009	3.0	3.5km South-Southwest of Rockaway, NJ	There were reports of people having felt this earthquake throughout New Jersey.
02/14/2009	2.4	5 km North-Northeast of Boonton, NJ	There were reports of people having felt this earthquake throughout New Jersey.
2/18/2009	1.1	3 km South-Southwest of Kinnelon, NJ	No reference and/or no damage reported.
2/16/2009	1.4	1 km East-Southeast of Oradell, NJ	No reference and/or no damage reported.
2/16/2009	2.3	2 km South-Southeast of Dover, NJ	No reference and/or no damage reported.
07/01/2009	2.8	2.25km East-Southeast of Pennsville, NJ	There were reports of people having felt this earthquake throughout New Jersey.
12/21/2009	2.3	13 km South of Phillipsburg, NJ	No reference and/or no damage reported.
12/26/2009	2.0	8 km Northwest of Morris Plains, NJ	No reference and/or no damage reported.
02/05/2010	1.5	3 km Northwest of Far Hills, NJ	No reference and/or no damage reported.
02/07/2010	1.2	3 km Northwest of far Hills, NJ	No reference and/or no damage reported.
02/10/2010	2.2	1 km West of Wanaque	No reference and/or no damage reported.
02/21/2010	2.6	Gladstone, NJ	This earthquake hit just before 9 a.m. and prompted numerous phone calls to police. No damages were reported. Many people in New Jersey reported having felt this earthquake.
02/21/2010	2.3	Gladstone, NJ	This event was most likely an aftershock from the morning's earthquake. Numerous people in New Jersey reported having felt this earthquake.
06/06/2010	2.3	6 km Southeast of Sayreville, NJ	People reported having felt this earthquake throughout New Jersey.
12/25/2010	2.1	1 km West of Clifton, NJ	No reference and/or no damage reported.
05/08/2011	1.2	1 km Southwest of Clifton, NJ	No reference and/or no damage reported.
05/10/2011	1.9	2 km North of Mount Holly, NJ	No reference and/or no damage reported.
05/29/2011	1.3	3 km South of Fort Lee, NJ	No reference and/or no damage reported.
05/29/2011	1.9	24 km South-Southwest of Lakehurst, NJ	No reference and/or no damage reported.
06/09/2011	1.6	2 km Southeast of S. Plainfield, NJ	No reference and/or no damage reported.
08/23/2011	5.8	Central Virginia	A moderate earthquake occurred in central Virginia and was felt throughout most of the east, from Georgia to southern Canada and from Indiana to coastal Maine. It was followed by four aftershocks. In New Jersey, the intensity ranged from one to four (weak to light). Areas

Date(s) of Event	Magnitude	Location	Losses/Impacts
			underlain by thick silt and clay felt a stronger ground motion than did those where rock was very close to the surface. The quake was felt in South Brunswick and residents were calling 911 wanting to know what happened; some thought it was an explosion. It was also felt in the offices of Alcatel-Lucent in Murray Hill (Union County). Ceiling tiles fell out at a Sears store in Middletown. In Plainfield (Union County), employees in the Park Madison building were evacuated after the tremor. Union County's administration building in Elizabeth reported continuous shaking. In New Brunswick (Middlesex County), employees were evacuated from the County administration building. Atlantic City (Atlantic County) went into emergency mode with evacuations of high rises, hospitals, schools, casinos, and hotels. The County OEM received reports of a crack in a wall in a house and broken water pipe in a building. There were minor scattered power outages reported throughout the state.
07/17/2012	1.1	16 km Northwest of Morristown, NJ	No reference and/or no damage reported.
07/18/2012	1.1	18 km Northwest of Morristown, NJ	No reference and/or no damage reported.
08/23/2012	1.2	1.4 km East of Ringwood, NJ	No reference and/or no damage reported.
11/05/2012	2.0	3 km Southwest of Mahwah, NJ	People reported having felt this earthquake in various parts of New Jersey.
11/23/2012	2.2	Greater Philadelphia Area/New Jersey	Numerous reports of people having felt the earthquake in southwestern New Jersey.

Source: NJGWS 2013; USGS 2012d; Won-Young Kim, Lamont-Doherty Earth Observatory of Columbia University 1999
** Location very poorly determined; may be uncertain by 50 miles.*
km Kilometers
N/A Not Applicable/Not Available
NJ New Jersey
NYC New York City
OEM Office of Emergency Management

FEMA Disaster Declarations

Based on all sources researched, the State of New Jersey was not included in any FEMA disaster declarations for earthquake-related events.

Probability of Future Occurrences

Earthquakes cannot be predicted and may occur any time of the day or year. The probability of damaging earthquakes affecting New Jersey is low. However, there is a definite threat of major earthquakes that could cause widespread damage and casualties in New Jersey. Major earthquakes are infrequent in the State and may occur only once every few hundred years or longer, but the consequences of major earthquakes would be very high.

For the purposes of this Plan update, the probability of future occurrences is defined by the number of events over a specified period of time. There have been zero earthquake-related disasters declared for the State of New Jersey, therefore the entire historical record was consulted. The historical record indicates 178 earthquakes recorded for New Jersey from 1783 to 2012. Based on this statistic, the State may experience one earthquake of any magnitude each year.

Severity

The level of seismic hazard—the frequency and severity of earthquakes—is substantially lower in New Jersey than in more seismically active states such as California or Alaska. The level of seismic risk—the threat to buildings, infrastructure, and people—is significant in New Jersey, especially in the northern portion of the State. The level of seismic risk in New Jersey is higher than might be expected because the majority of buildings and infrastructure has been built with minimal or no consideration of earthquakes, making them more vulnerable to earthquake damage.

The NJGWS indicates that although the United States east of the Rocky Mountains has fewer and generally smaller earthquakes than the west, at least two factors increase risk in the eastern United States and New Jersey. Because of the geologic differences, eastern earthquakes affect areas 10 times larger than western ones of the same magnitude. Also, the eastern United States is more densely populated, with New Jersey being the most densely populated state in the country.

According to USGS data, damage caused by an earthquake will begin at a level of ground shaking of approximately 0.1g. The Modified Mercalli 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 State of New Jersey can be expected to have a low-to-moderate risk to earthquake damage as compared to other areas of the country. The relatively small difference in the level of impact from one area of the State to another does not justify differentiating risk levels from one portion of the State to another.

Warning Time

There is currently no reliable way to predict the day or month that an earthquake will occur at any given location. An Earthquake Early Warning System is being developed by the USGS for the west coast of the United States. This system uses existing seismic networks to detect moderate to large earthquakes very rapidly so that a warning can be sent before destructive seismic waves arrive to locations outside the area where the earthquake begins. These warnings will allow people to take protective action and can also trigger automatic responses to safeguard critical infrastructure. Under the Disaster Relief Act of 1974, the USGS has the federal responsibility to issue alerts for earthquakes, enhance public safety, and reduce losses through effective forecasts and warnings. USGS currently issues rapid, automatic earthquake information via the Internet, e-mail messages, text messages, and social media (USGS 2012b).

Secondary Hazards

Earthquakes can cause large and sometimes disastrous landslides and mudslides. Any steep slope is vulnerable to slope failure, often as a result of loss of cohesion in clay-rich soils. 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. Landslides are further discussed in Section 5.7 (Geologic Hazards) of this Plan update.

Earthquakes can also cause dam failures. The most common mode of earthquake-induced dam failure is slumping or settlement of earth-fill dams where the fill has not been property compacted. If the slumping occurs when the dam is full, then overtopping of the dam, with rapid erosion leading to dam failure is possible. Dam failure is also possible if strong ground motions heavily damage concrete dams. Earthquake-induced landslides into reservoirs have also caused dam failures. Dam failures are further discussed in Section 5.3 (Dam/Levee Failure) of this Plan update.

Another secondary effect of earthquakes 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 effects may occur along the shorelines of the ocean, rivers, and lakes and they can also happen in low-lying areas away from water bodies in locations where the ground water is near the earth's surface.

As per the United States Search and Rescue Task force, tsunamis are formed as a result of earthquakes, volcanic eruptions, or landslides that occur under the ocean. When these events occur, huge amounts of energy are released as a result of quick, upward bottom movement. A wave is formed when huge volumes of ocean water are pushed upward. A large earthquake can lift large portions of the seafloor, which will cause the formation of huge waves.

Climate Change Impacts

Providing projections of future climate change for a specific region is challenging. Shorter term projections are more closely tied to existing trends making longer term projections even more challenging. The further out a prediction reaches the more subject to changing dynamics it becomes. The potential 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. National Aeronautics and Space Administration (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 future climate change. Soils saturated by repetitive storms could experience liquefaction during seismic activity because of the increased saturation. Dams storing increased volumes of water from changes in the hydrograph could fail during seismic events. There are currently no models available to estimate these impacts.

5.5.2 Vulnerability Assessment

To understand risk, the assets exposed to earthquake hazard areas are identified in this section. For the earthquake hazard, the entire State of New Jersey is exposed. However, certain areas, buildings, and infrastructure are at greater risk than others because of the soils on which they are located and their manner of construction.

In the 2011 Plan, HAZUS was used to quantify loss estimates for several scenario earthquakes. Each scenario was run in seven counties in northeastern New Jersey. For each county, five scenario earthquakes were considered (with magnitudes 5.0, 5.5, 6.0, 6.5 and 7.0) with an epicenter at the centroid of the county at a depth of 10 kilometers. These scenarios were considered worst-case for the county of focus for the analysis.

For the 2014 plan update, a probabilistic Statewide 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 New Jersey. The HAZUS analysis evaluates the statistical likelihood that a specific event will occur and the related consequences. For example, a 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. The NEHRP soils and the landslide susceptibility classifications provided by the State Geologist were included in HAZUS for the earthquake analysis (Figures 5.5-1 and 5.5-2 presented earlier in this section illustrate NEHRP soil classifications of areas throughout New Jersey). Additional information on the landslide hazard is included in Section 5.7 (Geologic Hazards) of this HMP update and Appendix R, which contains landslide susceptibility maps for Bergen, Essex, Hudson, Middlesex, Monmouth, Morris, Passaic, Somerset, and Union Counties.

This section assesses vulnerability and estimates total losses by jurisdiction and to State-owned and leased facilities.

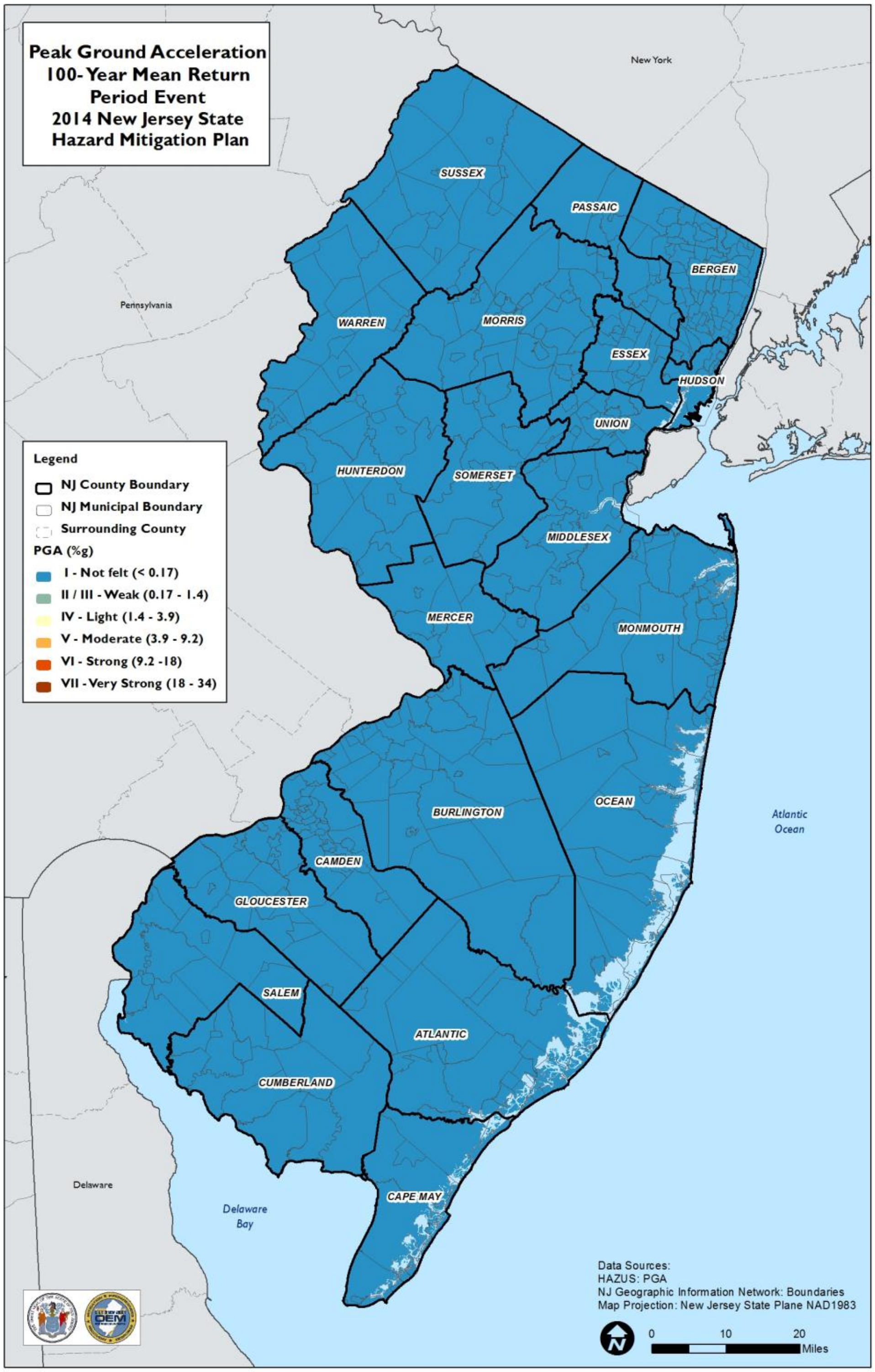
Assessing Vulnerability by Jurisdiction

All 21 New Jersey counties included earthquakes as a hazard of concern in their HMPs (listed in Table 5.1-2 in Section 5.1, State Risk Assessment Overview). A review of the historic record indicates earthquake epicenters have occurred in 20 of the 21 New Jersey Counties. As listed in Table 5.5-6 and illustrated in Figure 5.5-8 and Figure 5.5-11 earlier in this section, these greatest number of earthquake events with epicenters in New Jersey have been in the northern part of the State.

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. Spatial data were only available for nine counties as provided by the New Jersey Geologic and Water Survey. All nine counties with NEHRP soils delineated contain Class E soils, which amplify and magnify ground shaking and increase building damage and losses. (Figure 5.5-1 presented earlier in this profile illustrates soil classification area in New Jersey.)

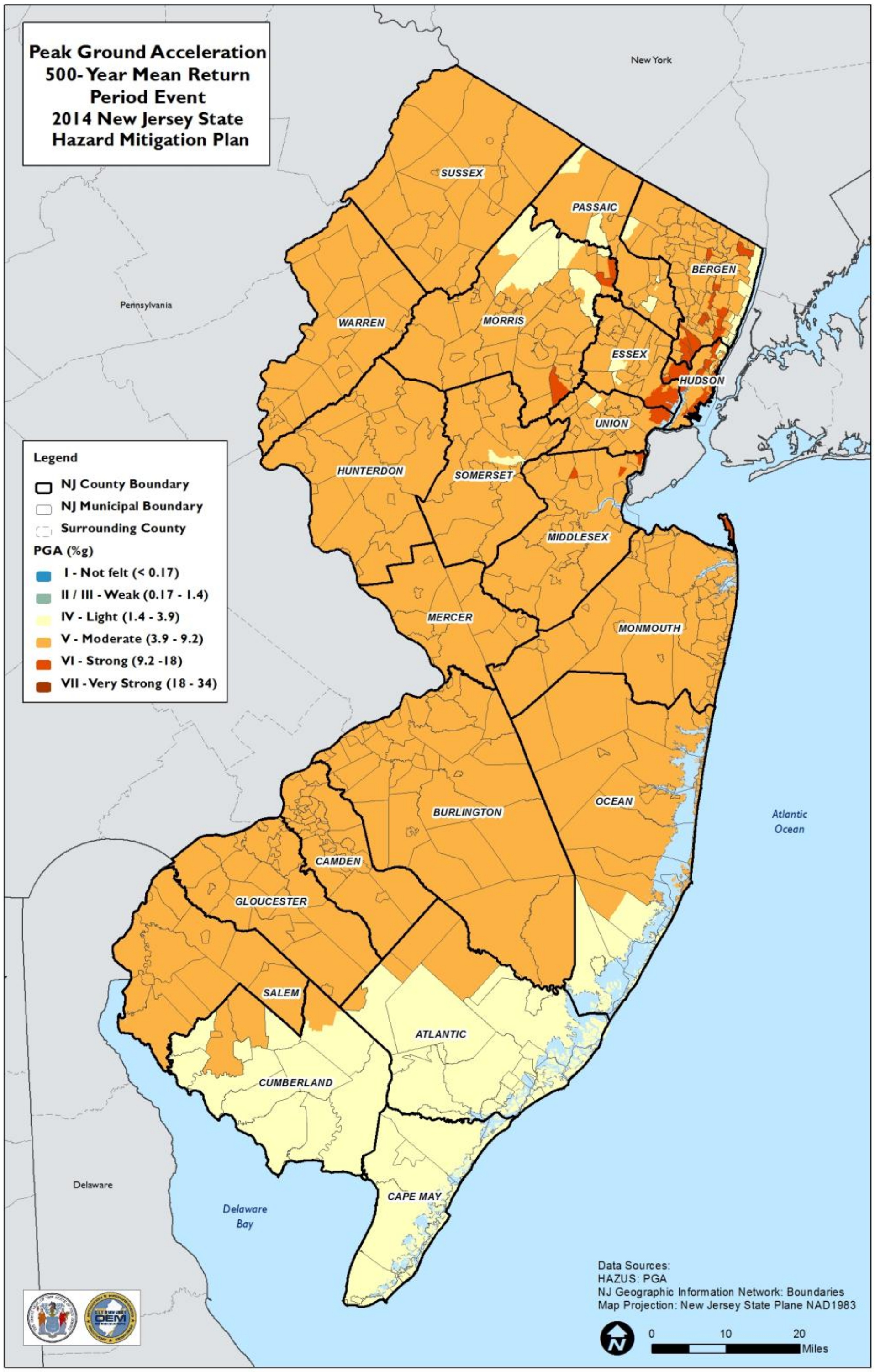
According to NYCEM, where earthquake risks and mitigation were evaluated in the New York, New Jersey, and Connecticut region, most damage and loss caused by an earthquake is directly or indirectly the result of ground shaking (NYCEM 2003). NYCEM indicates a strong correlation between PGA and the damage a building might experience. The HAZUS-MH model is based on the best-available earthquake science and aligns with these statements. The HAZUS-MH 2.1 methodology and model were used to analyze the earthquake hazard across the State. Figure 5.5-12 through Figure 5.5-15 illustrate the geographic distribution of PGA (%g) across New Jersey for 100-, 500-, 1,000- and 2,500-year MRP events at the United States 2000 Census-tract level.

Figure 5.5-12. Peak Ground Acceleration Modified Mercalli Scale for a 100-Year MRP Earthquake Event



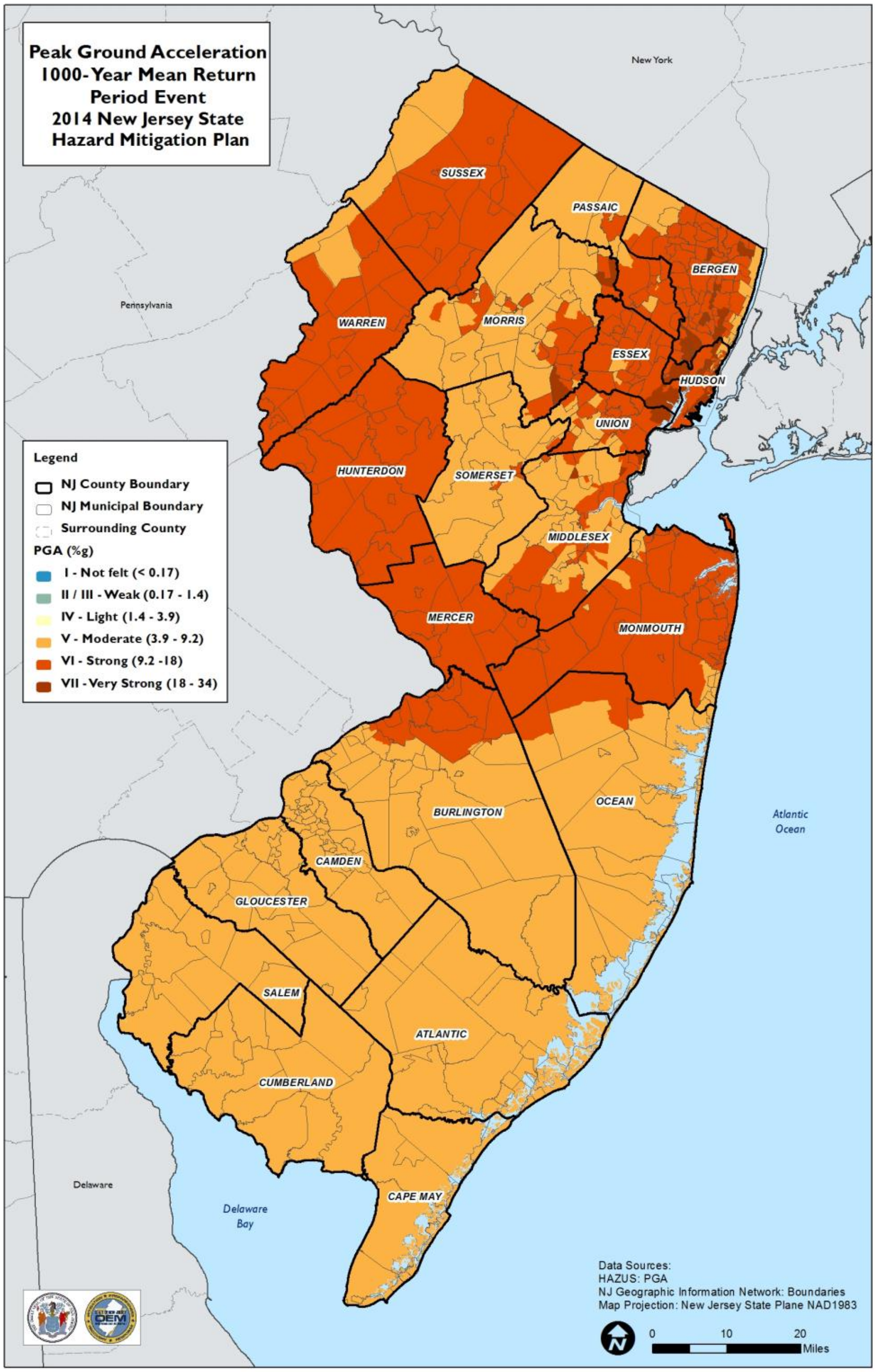
Source: HAZUS-MH 2.1

Figure 5.5-13. Peak Ground Acceleration Modified Mercalli Scale for a 500-Year MRP Earthquake Event



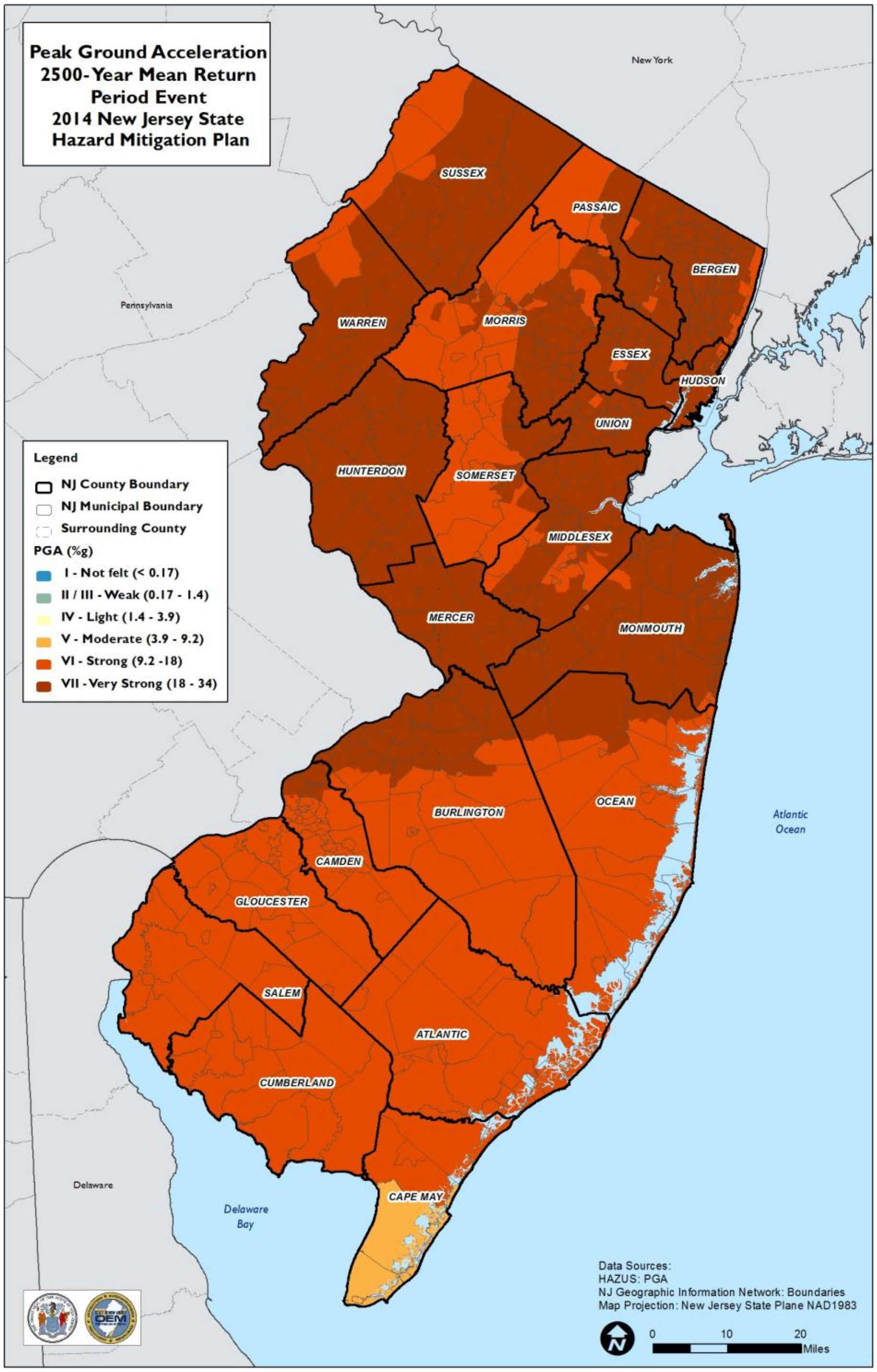
Source: HAZUS-MH 2.1

Figure 5.5-14. Peak Ground Acceleration Modified Mercalli Scale for a 1,000-Year MRP Earthquake Event



Source: HAZUS-MH 2.1

Figure 5.5-15. Peak Ground Acceleration Modified Mercalli Scale for a 2,500-Year MRP Earthquake Event



Source: *HAZUS-MH 2.1*

The entire population of New Jersey 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, and their proximity to fault locations.

In general the northern half of New Jersey is more vulnerable to potential damage from an earthquake. Bergen, Essex, Hudson, Hunterdon, Middlesex, Monmouth, Mercer, Passaic, Somerset, Sussex, and Union counties have the highest potential of sustaining damage during an event. The urban centers in Essex, Hudson, and Bergen Counties have the highest vulnerability to potential damage and have the potential to sustain heavy damage in a 1,000 year event. Only in a 2,500 year event would the remaining remainder of the counties listed above potentially sustain moderate to heavy damage.

Northern New Jersey, especially areas in proximity to the Ramapo Fault, have historically been the most active for instances of earthquakes; however, the average strength of earthquakes with epicenters in New Jersey is only 1.8 on the Richter scale. Earthquakes of this magnitude are usually not felt. Based on historical records, New Jersey is not particularly vulnerable to many instances of higher-magnitude earthquakes and the hazards associated with smaller-intensity earthquake events are minimal. Older buildings and infrastructure will likely be the most vulnerable to the hazards associated with earthquakes, as new buildings must meet the more stringent requirements of the Uniform Construction Code and International Building Code. New land development that takes place in northern New Jersey in proximity to the Ramapo Fault will likely have the most susceptibility to experiencing the effects of an earthquake and associated hazards.

Assessing Vulnerability to State Facilities

All State-owned and leased buildings are exposed to the earthquake hazard. Table 5.1-2 in Section 5.1 (Risk Assessment Overview) summarizes the total replacement cost value of all State-owned and leased buildings in the State.

As mentioned earlier, the 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. Soft soils (NEHRP soil classed D and E) can amplify ground shaking to damaging levels even in a moderate earthquake (NYCEM 2003).

Tables 5.5-7 and 5.5-8 summarize the number of State-owned and leased buildings located on soil classes A through E (where data are available) by county and State agency, respectively.

Table 5.5-7. 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
Atlantic	-	-	-	-	-	x	-
Bergen	3	0	33	7	3	-	
Burlington	-	-	-	-	-	x	-
Camden	-	-	-	-	-	x	-
Cape May	-	-	-	-	-	x	-
Cumberland	-	-	-	-	-	x	-
Essex	0	0	31	5	38	-	

County	Class A	Class B	Class C	Class D	Class E	No data available	Total
Gloucester	-	-	-	-	-	x	-
Hudson	2	0	8	0	12	-	22
Hunterdon	-	-	-	-	-	x	-
Mercer	-	-	-	-	-	x	-
Middlesex	0	0	249	15	0	-	
Monmouth	0	0	5	155	2	-	162
Morris	1	0	61	39	3	-	104
Ocean	-	-	-	-	-	x	-
Passaic	5	0	61	5	0	-	71
Salem	-	-	-	-	-	x	-
Somerset	0	0	37	1	0	-	38
Sussex	-	-	-	-	-	x	-
Union	0	0	26	9	0	-	35
Warren	-	-	-	-	-	x	-
Total	**11**	**0**	**511**	**236**	**58**	**-**	**816**

Source: NJOMB 2013; NJGWS NEHRP 2002
Notes:
X = No data available
- = Not in study area

Table 5.5-8. Number of State-Owned and Leased Buildings per NEHRP Soil Class by Agency

Agency	Class A	Class B	Class C	Class D	Class E	Total
Agriculture		0	0	1	0	1
Banking and Insurance	0	0	0	0	0	0
Chief Executive	0	0	1	0	0	1
Children and Families	1	0	29	21	3	54
Community Affairs	0	0	2	2	0	4
Corrections	0	0	91	1	29	121
Education	0	0	8	3	0	11
Environmental Protection	2	0	9	30	6	47
Health	0	0	0	0	0	0
Human Services	1	0	67	1	0	69
Judiciary	0	0	1	1	0	2
Juvenile Justice Commission	1	0	92	0	0	93
Labor and Work Force Dev.	0	0	2	1	0	3
Law and Public Safety	0	0	2	3	0	5
Legislature	0	0	0	0	0	0
Military and Veterans Affairs	0	0	52	80	2	134
Miscellaneous Commissions	0	0	0	0	0	0
Motor Vehicles Commission	1	0	12	15	1	29
Personnel	0	0	0	0	0	0
State	0	0	0	1	0	1
State Police	2	0	17	12	4	35
Transportation	3	0	124	63	13	203
Treasury	0	0	2	1	0	3
Total	**11**	**0**	**511**	**236**	**58**	**816**

Source: NJOMB 2013; NJGWS NEHRP 2002
Notes:
X = No data available
- = Not in study area

As mentioned earlier in this section, NJDOT in cooperation with the United States Department of Transportation (USDOT) has created liquefaction vulnerability maps for standard and critical bridges within each New Jersey County (USDOT 2012). These liquefaction maps indicate there is a high potential for liquefaction to impact bridges within portions of Bergen, Essex, Hudson, Middlesex, Ocean, and Union Counties.

Estimating Potential Losses by Jurisdiction

The entire population of New Jersey is exposed to the risk posed by an earthquake event; however, populations considered most vulnerable include the elderly (persons over the age of 65) and individuals living below the United States 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 because of limited ability to stockpile supplies. Section 4, State Profile, of this HMP summarizes the State's demographics by county.

Residents may be displaced or may require temporary to long-term sheltering because of an earthquake 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; results of these analyses are summarized in Table 5.5-9.

HAZUS-MH 2.1 estimates the number of people that may potentially be injured and/or killed by an earthquake depending on the time of day the event occurs. These estimates are provided for three times of day (2:00 a.m., 2:00 p.m. and 5:00 p.m.), representing the periods of the day that different sectors of the community are at their peak. The 2:00 am estimate considers the residential occupancy at its maximum; the 2:00 p.m. estimate considers the educational, commercial, and industrial sector at their maximum; and the 5:00 p.m. estimate represents peak commuter time.

No injuries or casualties are estimated for the 100-year event. Table 5.5-10 summarizes the injuries and casualties estimated for the 100-, 500-, 1,000-, and 2,500-year MRP earthquake events.

Table 5.5-9. Estimated Shelter Requirements HAZUS-MH Probabilistic Scenario

County	100-Year MRP		500-Year MRP		1,000-Year MRP		2,500-Year MRP	
	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs
Atlantic	0	0	9	6	35	25	152	108
Bergen	1	1	115	69	460	274	2,561	1,530
Burlington	0	0	21	12	83	49	439	258
Camden	0	0	27	20	107	77	586	419
Cape May	0	0	2	1	10	5	44	25
Cumberland	0	0	5	4	18	16	83	75
Essex	1	1	129	117	525	476	2,878	2,603
Gloucester	0	0	9	6	35	22	196	126
Hudson	2	1	181	126	727	507	3,947	2,754
Hunterdon	0	0	6	3	26	14	121	66
Mercer	0	0	30	21	127	89	601	418
Middlesex	0	0	64	44	268	182	1,451	989
Monmouth	0	0	42	26	181	111	921	564
Morris	0	0	35	20	140	79	750	423
Ocean	0	0	17	11	65	43	357	233
Passaic	0	0	56	49	226	201	1,244	1,100
Salem	0	0	2	2	9	6	51	35
Somerset	0	0	16	10	68	41	355	214
Sussex	0	0	8	4	29	17	132	76
Union	0	0	54	42	222	174	1,224	957
Warren	0	0	8	4	30	17	134	78
Total	**4**	**2**	**836**	**597**	**3,393**	**2,427**	**18,228**	**13,051**

Source: HAZUS-MH v2.1 (United States Census 2000)
Note: MRP = Mean return period

Table 5.5-10. Estimated Injuries and Casualties

Level of Severity	500-Year MRP Event			1,000-Year MRP Event			2,500-Year MRP Event		
	2:00 AM	2:00 PM	5:00 PM	2:00 AM	2:00 PM	5:00 PM	2:00 AM	2:00 PM	5:00 PM
Injuries	287	297	261	988	1,036	907	4,162	4,794	4,116
Hospitalization	32	37	33	129	152	138	705	929	894
Casualties	4	5	4	18	23	20	123	174	155

Source: HAZUS-MH v2.1
MRP Mean Return Period

HAZUS-MH estimates the direct building losses to repair or replace the damage caused to the building. According to NYCEM, a building's construction determines how well it can withstand the force of an earthquake. The NYCEM report indicates that unreinforced masonry buildings are most at risk during an earthquake because the walls are prone to collapse outward, whereas steel and wood buildings absorb more of the earthquake's energy. Additional attributes that contribute to a building's capability to withstand an earthquake's force include its age, number of stories, and quality of construction. HAZUS-MH considers building construction and the age of buildings as part of the analysis. Because the default general building stock was used for this HAZUS-MH analysis, the default building ages and building types already incorporated into the inventory were used. Table 5.5-11 summarizes the estimated potential losses to all of the buildings in the State per earthquake scenario per county.

Table 5.5-11. 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
Atlantic	$0	$12,284,628	$51,781,912	$225,109,153
Bergen	$809,531	$171,687,912	$687,673,786	$2,899,261,622
Burlington	$0	$43,471,185	$185,484,958	$842,902,037
Camden	$0	$45,983,158	$190,847,704	$902,972,070
Cape May	$0	$5,401,287	$22,472,592	$104,494,337
Cumberland	$0	$7,695,787	$31,606,422	$141,318,997
Essex	$422,733	$117,454,130	$487,185,416	$2,112,079,620
Gloucester	$0	$19,717,284	$81,414,573	$396,423,786
Hudson	$1,232,789	$141,969,855	$542,331,844	$2,059,986,351
Hunterdon	$0	$21,926,559	$90,391,550	$357,786,063
Mercer	$0	$52,154,385	$229,903,636	$938,638,708
Middlesex	$0	$93,709,809	$414,289,536	$1,857,499,054
Monmouth	$0	$84,944,802	$381,691,957	$1,624,089,441
Morris	$163,806	$77,965,746	$318,144,986	$1,348,785,366
Ocean	$0	$43,112,218	$178,587,253	$826,376,130
Passaic	$0	$53,325,887	$232,195,728	$1,072,610,312
Salem	$0	$4,295,308	$17,856,547	$88,958,159
Somerset	$0	$29,421,532	$135,319,633	$625,982,861
Sussex	$0	$22,368,750	$86,739,266	$333,863,404
Union	$62,000	$66,788,422	$290,714,217	$1,327,112,754
Warren	$0	$13,624,734	$54,712,697	$215,873,326
Total	**$2,690,859**	**$1,129,303,379**	**$4,711,346,212**	**$20,302,123,551**

Source: Default general building stock data in HAZUS-MH v. 2.1
Notes: Building losses include structural and non-structural damage estimates.
MRP = Mean Return Period

Earthquakes have the potential to impact economies at both the local and regional scale. Losses can include structural and non-structural damage to buildings, loss of business function, damage to inventory, relocation costs, wage loss, and rental loss caused by the repair and 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 could be exposed to potential breakage and failure.

Lifeline-related losses include the direct repair cost to transportation and utility systems; losses 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 includes business interruption losses associated with the inability to operate a business because of damage sustained during an earthquake, as well as temporary living expenses for those displaced. These losses are presented in Table 5.5-12.

Table 5.5-12. Estimated Potential Economic Losses for New Jersey

	100-Year MRP	500-Year MRP	1,000-Year MRP	2,500-Year MRP
Income Losses				
Wage	$260,000	$59,600,000	$207,693,300	$902,094,000
Capital-Related	$210,000	$44,230,000	$154,858,800	$678,635,000
Rental	$380,000	$71,000,000	$237,331,300	$950,454,300
Relocation	$460,000	$108,910,000	$387,968,100	$1,636,949,800
Subtotal	**$1,310,000**	**$283,740,000**	**$987,850,000**	**$4,168,130,000**
Capital Stock Losses				
Structural	$910,000	$206,990,000	$700,196,900	$2,803,382,800
Non-Structural	$1,550,000	$687,720,000	$2,837,881,800	$12,069,027,100
Content	$230,000	$234,600,000	$1,173,266,700	$5,429,713,000
Inventory	$10,000	$8,340,000	$37,592,100	$150,581,100
Subtotal	$2,700,000	$1,137,640,000	$4,748,940,000	$20,452,700,000
Total	**$4,010,000**	**$1,421,380,000**	**$5,736,790,000**	**$24,620,840,000**

Source: HAZUS-MH v. 2.1
Note:
MRP Mean return period.

Estimating Potential Losses to State Facilities

HAZUS-MH does not estimate potential dollar losses to facilities at this time. When this capability is available, the State can enhance this section of the State HMP. For the purposes of the 2014 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. A total risk exposure would be equal to the full replacement value of each State facility exposed.

Table 5.5-13 summarizes the replacement cost value of the State-owned and leased buildings located on each NEHRP soil class by county. Table 5.5-14 summarizes the replacement cost value of buildings located on each NEHRP soil class by State agency.

Table 5.5-13. State-Owned and Leased Building Replacement Cost Value and Associated NEHRP Soil Class by County

County	Class A	Class B	Class C	Class D	Class E	No data available	Total
Atlantic	-	-	-	-	-	x	-
Bergen	$1,493,542	$0	$99,721,839	$69,618,088	$48,590,300	-	$219,423,769
Burlington	-	-	-	-	-	x	-
Camden	-	-	-	-	-	x	-
Cape May	-	-	-	-	-	x	-
Cumberland	-	-	-	-	-	x	-
Essex	$0	$0	$145,080,311	$330,127,271	$199,260,205	-	
Gloucester	-	-	-	-	-	x	-
Hudson	$2,890,112	$0	$100,666,537	$0	$60,652,970	-	$164,209,619
Hunterdon	-	-	-	-	-	x	-
Mercer	-	-	-	-	-	x	-
Middlesex	$0	$0	$594,268,956	$57,116,257	$0	-	
Monmouth	$0	$0	$1,165,417	$245,502,596	$707,031	-	$247,375,044
Morris	$1,762,920	$0	$363,513,822	$86,283,956	$7,472,186	-	$459,032,884
Ocean	-	-	-	-	-	x	-
Passaic	$13,385,815	$0	$271,154,865	$8,327,398	$0	-	$292,868,078
Salem	-	-	-	-	-	x	-
Somerset	-	-	$178,664,413	$54,667,285	-	x	-
Sussex	-	-	-	-	-	x	-
Union	-	-	$73,947,504	$11,310,080	-	x	-
Warren	-	-	-	-	-	x	-
Total	**$19,532,389**	**$0**	**$1,828,183,665**	**$862,952,931**	**$316,682,693**	**-**	**$3,027,351,677**

Source: NJOMB, 2013; NJGWS NEHRP, 2002

Note:

NEHRP National Earthquake Hazards Reduction Program

RCV Replacement cost value (structure and contents)

Table 5.5-14. State-Owned and Leased Building Replacement Cost Value and Associated NEHRP Soil Classes, by State Agency

Agency	Class A	Class B	Class C	Class D	Class E	Total
Agriculture	$0	$0	$0	$2,876,615	$0	$2,876,615
Banking and Insurance	$0	$0	$0	$0	$0	$0
Chief Executive	$0	$0	$12,653,376	$0	$0	$12,653,376
Children and Families	$8,015,914	$0	$348,670,198	$45,474,219	$69,076,319	$471,236,650
Community Affairs	$0	$0	$45,523,323	$21,919,317	$0	$67,442,640
Corrections	$0	$0	$249,086,473	$3,105,138	$175,557,607	$427,749,219
Education	$0	$0	$51,564,930	$20,671,578	$0	$72,236,508
Environmental Protection	$1,908,864	$0	$4,304,989	$52,036,905	$33,218,408	$91,469,166
Health	$0	$0	$0	$0	$0	$0
Human Services	$1,762,920	$0	$449,986,842	$54,667,285	$0	$506,417,047
Judiciary	$0	$0	$7,518,425	$97,198,793	$0	$104,717,218
Juvenile Justice Commission	$309,295	$0	$106,963,746	$0	$0	$107,273,041
Labor and Work Force Dev.	$0	$0	$39,993,339	$6,398,751	$0	$46,392,090
Law and Public Safety	$0	$0	$20,407,534	$181,402,277	$0	$201,809,811
Legislature	$0	$0	$0	$0	$0	$0
Military and Veterans Affairs	$0	$0	$249,926,420	$184,061,857	$220,378	$434,208,655
Miscellaneous Commissions	$0	$0	$0	$0	$0	$0
Motor Vehicles Commission	$2,744,167	$0	$143,309,835	$36,498,105	$4,962,410	$187,514,518
Personnel	$0	$0	$0	$0	$0	$0
State	$0	$0	$0	$16,530,054	$0	$16,530,054
State Police	$3,297,686	$0	$26,212,849	$36,757,286	$18,297,846	$84,565,667
Transportation	$1,493,542	$0	$58,215,587	$57,137,011	$15,349,723	$132,195,864
Treasury	$0	$0	$13,845,798	$46,217,741	$0	$60,063,539
Total	**$19,532,389**	**$0**	**$3,151,143,495**	**$796,975,566**	**$316,682,693**	**$4,284,334,142**

Source: NJOMB, 2013; NJGWS NEHRP, 2002

NEHPR = National Earthquake Hazards Reduction Program

RCV = Replacement cost value (structure and contents)

All critical facilities in the planning area are exposed to the earthquake hazard. In addition, increased risk is 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.

As mentioned earlier, softer soils can amplify and magnify ground shaking and increase building damage and losses. Table 5.5-15 summarizes the critical facilities located on NEHRP soil classes D and E (where data are available).

Table 5.5-15. Number of Critical Facilities Exposed to NEHRP Soil Classes D and E

County	Total Count	Airport	Special Needs	Communication	Correctional Institutions	Dam	Electric Power	EMS	EOC	Ferry	Fire	Highway Bridge	Highway Tunnel	Light Rail Facility	Medical	Military	Natural Gas	Oil	Police	Port	Potable Water	Rail Facility	Rail Tunnel	School	Shelter	Storage of Critical Records	Wastewater
Atlantic	388	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bergen	1,148	1	14	0	1	23	2	25	0	1	32	0	0	0	1	0	0	0	17	0	2	12	0	86	52	0	3
Burlington	747	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Camden	701	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cape May	229	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cumberland	251	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Essex	784	2	5	0	2	11	1	6	0	0	10	2	0	7	3	0	0	0	11	3	2	4	0	44	11	0	4
Gloucester	346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hudson	493	0	2	1	1	0	2	7	0	8	12	3	1	11	3	0	1	0	7	4	2	6	1	30	12	0	4
Hunterdon	328	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mercer	538	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Middlesex	816	0	15	0	0	14	3	32	1	0	26	5	0	0	2	0	0	1	11	0	2	2	0	92	40	0	0
Monmouth	905	1	52	1	1	120	1	122	1	2	115	0	0	0	7	2	0	0	52	1	3	13	0	307	47	0	9
Morris	913	1	24	0	1	31	3	33	0	0	30	0	0	0	3	1	0	0	16	0	1	8	0	95	28	0	11
Ocean	621	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Passaic	648	0	4	1	0	7	0	10	0	0	9	0	0	0	0	0	0	0	4	0	1	5	0	30	13	0	3
Salem	201	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Somerset	539	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sussex	542	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Union	607	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

County	Total Count	Airport	Special Needs	Communication	Correctional Institutions	Dam	Electric Power	EMS	EOC	Ferry	Fire	Highway Bridge	Highway Tunnel	Light Rail Facility	Medical	Military	Natural Gas	Oil	Police	Port	Potable Water	Rail Facility	Rail Tunnel	School	Shelter	Storage of Critical Records	Wastewater
Warren	351	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**12,096**	**5**	**116**	**3**	**6**	**206**	**12**	**235**	**2**	**11**	**234**	**10**	**1**	**18**	**19**	**3**	**1**	**1**	**118**	**8**	**13**	**50**	**1**	**684**	**203**	**0**	**34**

Source: NJOMB, 2013; NJGWS NEHRP, 2002

Notes: Please note these results only reflect locations where NEHRP soil data are available. Figure 5.5-1 earlier in this section illustrates NEHRP soil classification areas throughout New Jersey.

HAZUS-MH estimates the extent of damage and cost to repair highway bridges as a result of each probabilistic scenario. Although no bridges are estimated to be completely destroyed, HAZUS-MH estimates slight, moderate and extensive damages as a result of the 500-, 1,000- and 2,500-year probabilistic events. Table 5.5-16 summarizes the estimated total loss to highway bridges across the State for each probabilistic scenario.

Table 5.5-16. Estimated Cost to Repair Highway Bridges for Probabilistic Earthquake Events

Scenario	100-Year	500-Year	1,000-Year	2,500-Year
Number Completely Destroyed	0	0	0	0
Damage Loss	$0	$31,290,000	$228,202,800	$1,460,710,000

Source: HAZUS-MH v. 2.1

Environmental Impacts

Earthquakes can cause disastrous environmental impacts. In summary, earthquake events may trigger landslides, mudslides, slope failure, dam failures, and tsunamis. Each of these secondary events can also be devastating to the environment. Refer to the Secondary Hazards subsection presented earlier for a more detailed discussion of these secondary events and their impacts on the environment. Further, refer to Sections 5.3 (Dam and Levee Failure) and 5.7 (Geologic Hazards) for additional information.