5.4.1 Earthquake

This section provides a profile and vulnerability assessment for the earthquake hazard.

5.4.1.1 Hazard Profile

This section provides profile information including description, extent, location, previous occurrences and losses and the probability of future occurrences.

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], 2013; Shedlock and Pakiser, 1997). Most earthquakes occur at the boundaries where the Earth's tectonic plates meet (faults); however, less than 10 percent of earthquakes occur within plate interiors. New York State is in an area where plate interior-related earthquakes occur. As plates continue to move and plate boundaries change over geologic 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 (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 U.S. Geological Society (USGS) Earthquake Hazards Program, an earthquake hazard is anything associated with an earthquake that may affect resident's normal activities. This includes surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, tsunamis, and seiches. A description of each of these is provided below.

- *Surface faulting*: Displacement that reaches the earth's surface during 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 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 when you wiggle your toes in the wet sand near the water at the beach. This effect can be caused by earthquake shaking.
- *Tectonic Deformation*: A change in the original shape of a material due to stress and strain.
- *Tsunami*: A sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or exploding volcanic islands.
- *Seiche*: The sloshing of a closed body of water from earthquake shaking (USGS, 2012).

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 (USGS, 1989). The Richter Scale is the most widely-known scale that measures the magnitude of earthquakes (Shedlock and Pakiser, 1997; USGS, 1989). 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 cause any damage (USGS, 1989). Table 5.4.1-1 presents the Richter Scale magnitudes and corresponding earthquake effects.

Table 5.4.1-1. Richter 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 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, 1989

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 strong a shock was felt at a particular location (Shedlock and Pakiser, 1997). The Modified Mercalli Scale expresses the intensity of an earthquake's effects in a given locality in values ranging from I to XII. Table 5.4.1-2 summarizes earthquake intensity as expressed by the Modified Mercalli Scale. Table 5.4.1-3 displays the Modified Mercalli Scale and peak ground acceleration equivalent.

Table 5.4.1-2. 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 moves, 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, 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(s): Michigan Tech University, 2007; Louie, J. N. Nevada Seismological Laboratory, 1996

Table 5.4.1-3. 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

Source: NYS DHSES, 2014

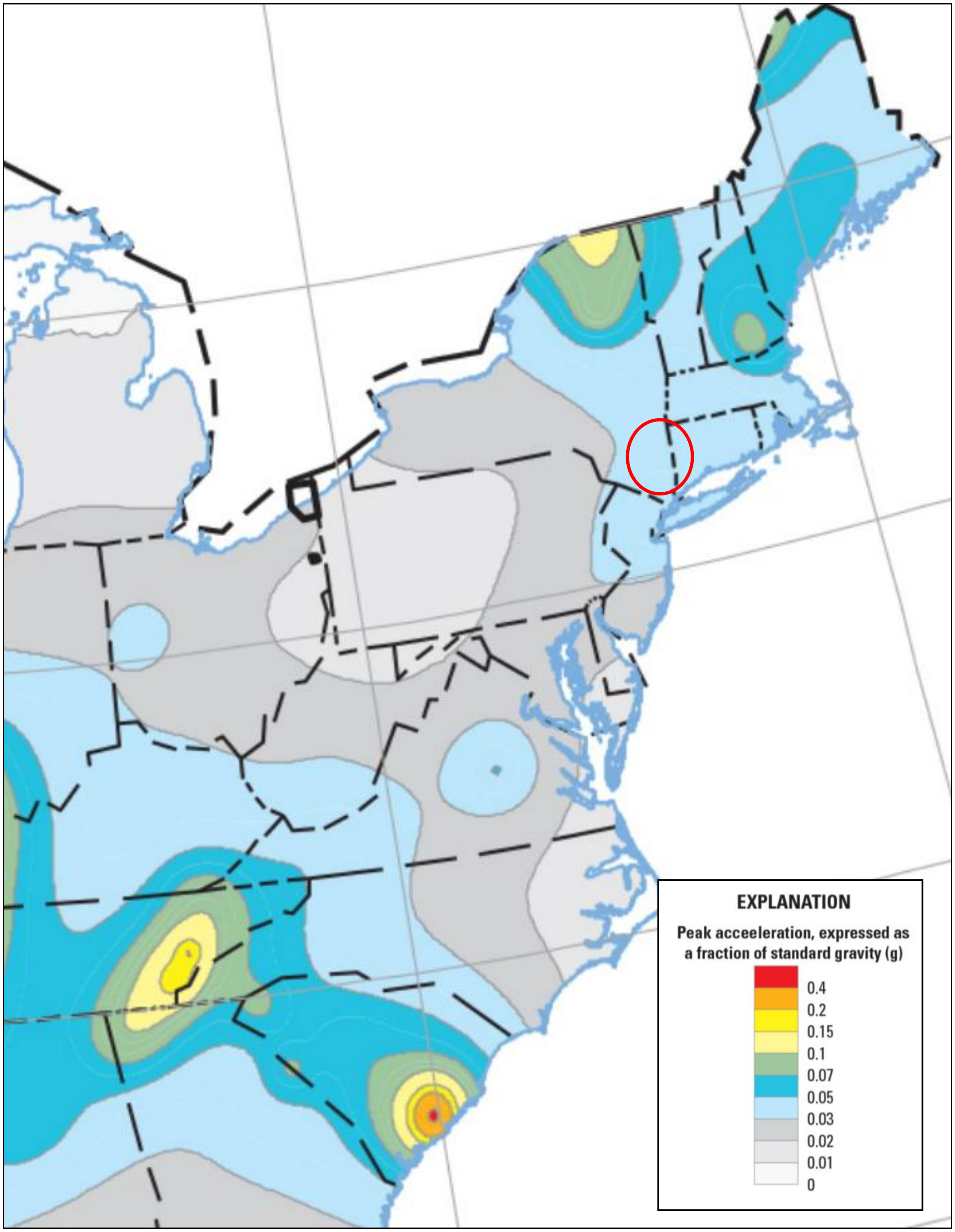
Seismic hazards are often expressed in terms of Peak Ground Acceleration (PGA) and Spectral Acceleration (SA). USGS defines PGA and SA as the following: 'PGA is what is experienced by a particle on the ground. Spectral Acceleration (SA) is approximately what is experienced by a building, as modeled by a particle mass on a massless vertical rod having the same natural period of vibration as the building' (USGS, 2012). 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 (NYS DHSES, 2014).

More specifically, PGA is a common earthquake measurement that 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 (NYS DHSES, 2014).

National maps of earthquake shaking hazards have been produced since 1948. They provide information essential to creating and updating the seismic design requirements for building codes, insurance rate structures, earthquake loss studies, retrofit priorities and land use planning used in the U.S. Scientists frequently revise these maps to reflect new information and knowledge. Buildings, bridges, highways and utilities built to meet modern seismic design requirements are typically able to withstand earthquakes better, with less damages and disruption. After thorough review of the studies, professional organizations of engineers update the seismic-risk maps and seismic design requirements contained in building codes (Brown et al., 2001).

The USGS updated the National Seismic Hazard Maps in 2014, which superseded the 2008 maps. New seismic, geologic, and geodetic information on earthquake rates and associated ground shaking were incorporated into these revised maps. The 2014 map represents the best available data as determined by the USGS (Petersen, et. al. 2014).

Figure 5.4.1-1. Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years (2014)

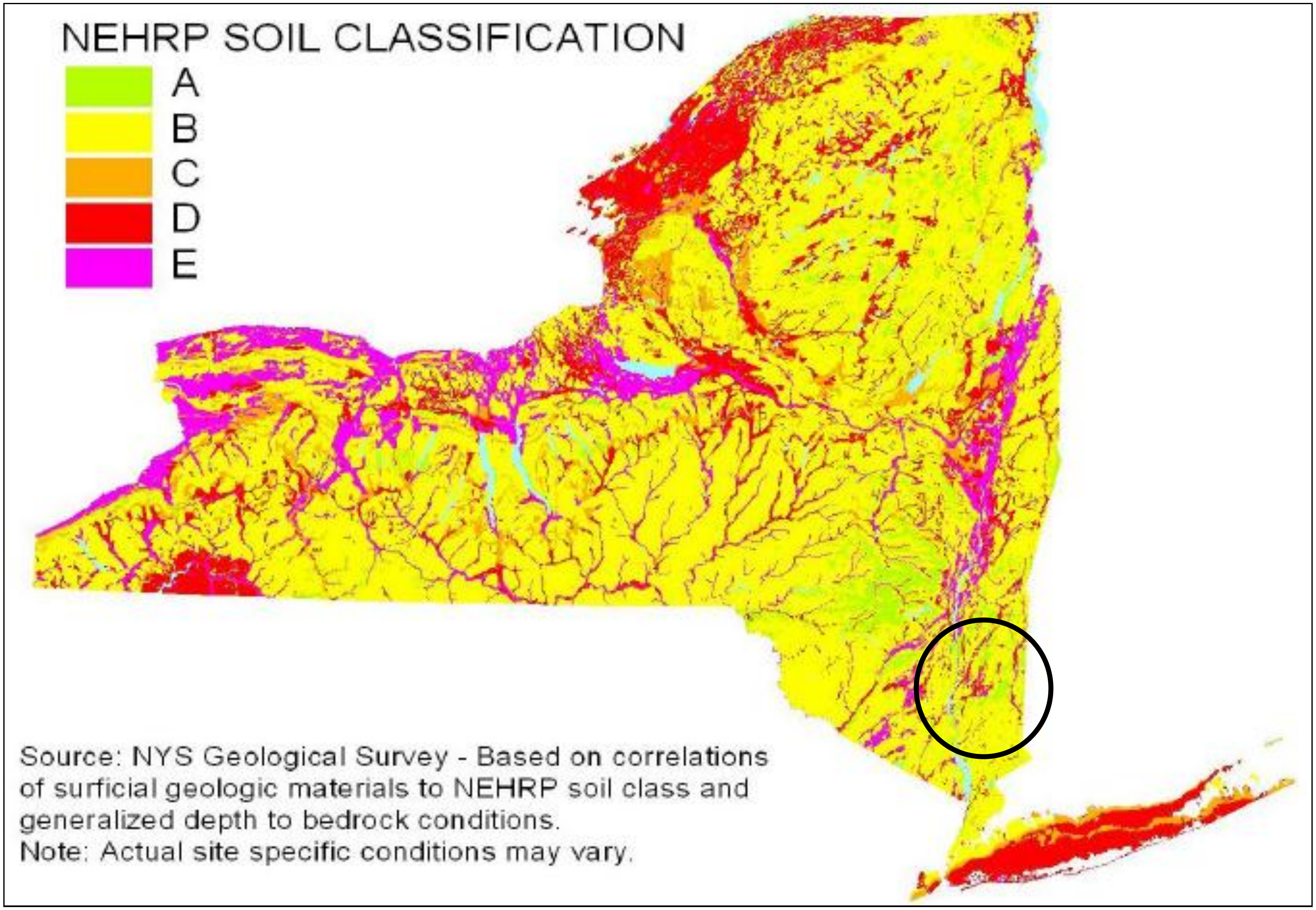


Source: *Petersen, et. al. 2014*
Note: *The red circle indicates the approximate location of Putnam County. The figure indicates that the County has a PGA between 3%g and 5%g.*

The 2014 Seismic Hazard Map shows that Putnam County has a PGA between 3 and 5% (Figure 5.4.1-1). This map is based on peak ground acceleration (%g) with 10% probability of exceedance in 50 years.

The New York State Geological Survey conducted seismic shear-wave tests of the State's surficial geology (glacial deposits). Based on these test results, the surficial geologic materials of New York State were categorized according to the National Earthquake Hazard Reduction Program's (NEHRP) Soil Site Classifications (Figure 5.4.1-2). The NEHRP developed five soil classifications 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. Figure 5.4.1-3 illustrates the NEHRP soil classifications in Putnam County, as provided by NYSEMO (O'Brien, 2008). Table 5.4.1-4 summarizes the NEHRP soil classifications shown on Figure 5.4.1-3.

Figure 5.4.1-2. NEHRP Soils in New York



Source: NYS DHSES, 2014
Note: The black oval indicates the approximate location of Putnam County. The figure shows that the County's NEHRP soil classifications include B, C and D soils.

As illustrated in Figure 5.4.1-3, Putnam County is primarily comprised of NEHRP soil classes A through E. The majority of the County is soil class B.

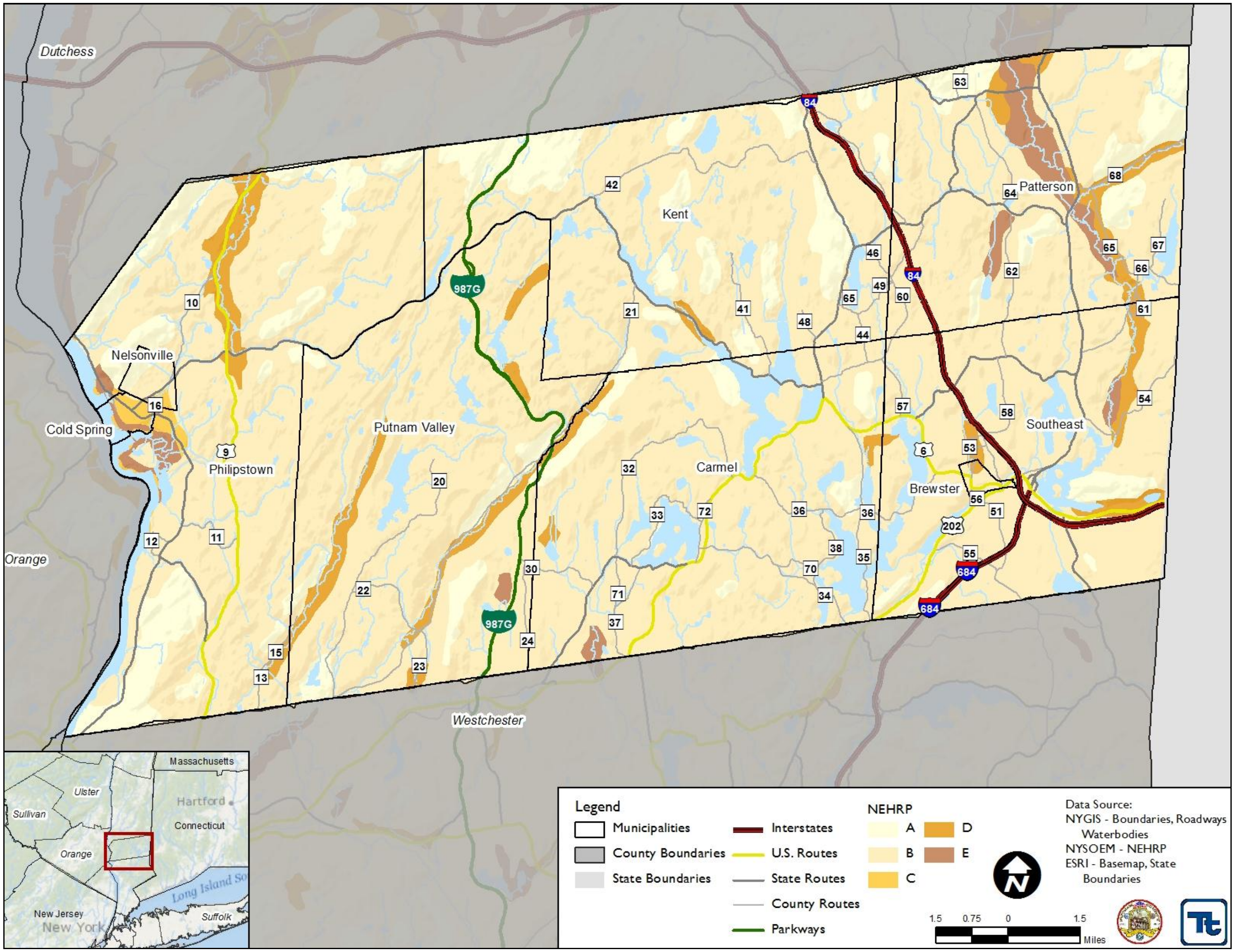
A probabilistic assessment was conducted for the 100-, 500- and 2,500-year mean return periods (MRP) through a Level 2 analysis in HAZUS-MH 2.1 to analyze the earthquake hazard for Putnam County. The HAZUS analysis evaluates the statistical likelihood that a specific event will occur and what consequences will occur. A 100-year MRP event is an earthquake with a less than 0.17% chance that the mapped ground motion levels (PGA) will be exceeded in any given year. For a 500-year MRP, there is a 1.4 to 3.9% chance the mapped PGA will be exceeded in any given year. For a 2,500-year MRP, there is a 9.2 to 18% chance the mapped PGA will be exceeded in any given year. Figure 5.4.1-4 through Figure 5.4.1-6 illustrates the geographic distribution of PGA (g) across Putnam County or 100-, 500- and 2,500-year MRP events at the Census-Tract level.

Table 5.4.1-4. NEHRP Soil Classifications

Soil Classification	Description
A	Very hard rock (e.g., granite, gneisses; and most of the Adirondack Mountains)
B	Rock (sedimentary) or firm ground
C	Stiff clay
D	Soft to medium clays or sands
E	Soft soil including fill, loose sand, waterfront, lake bed clays

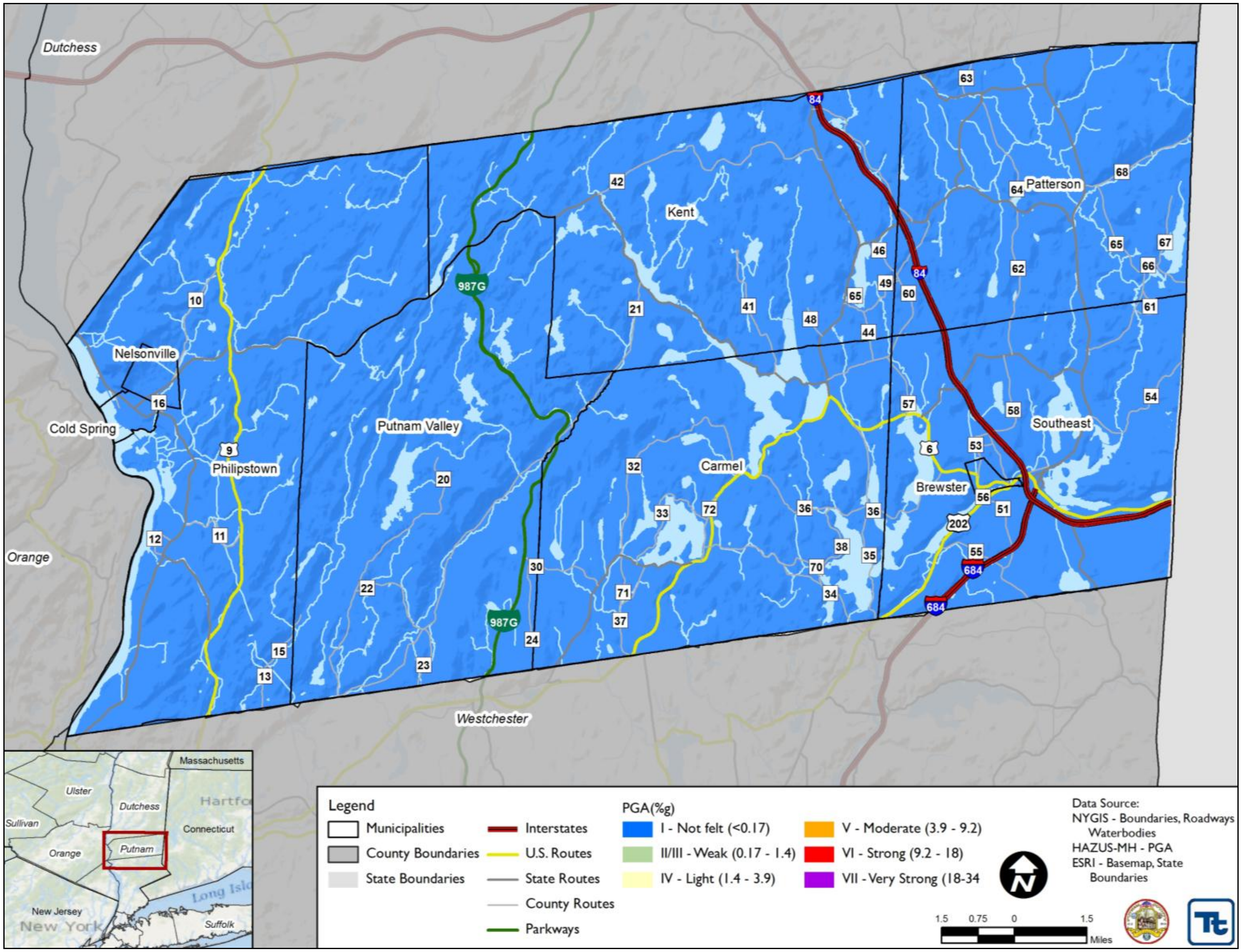
Source: NYS DHSES, 2014

Figure 5.4.1-3. NEHRP Soils in Putnam County



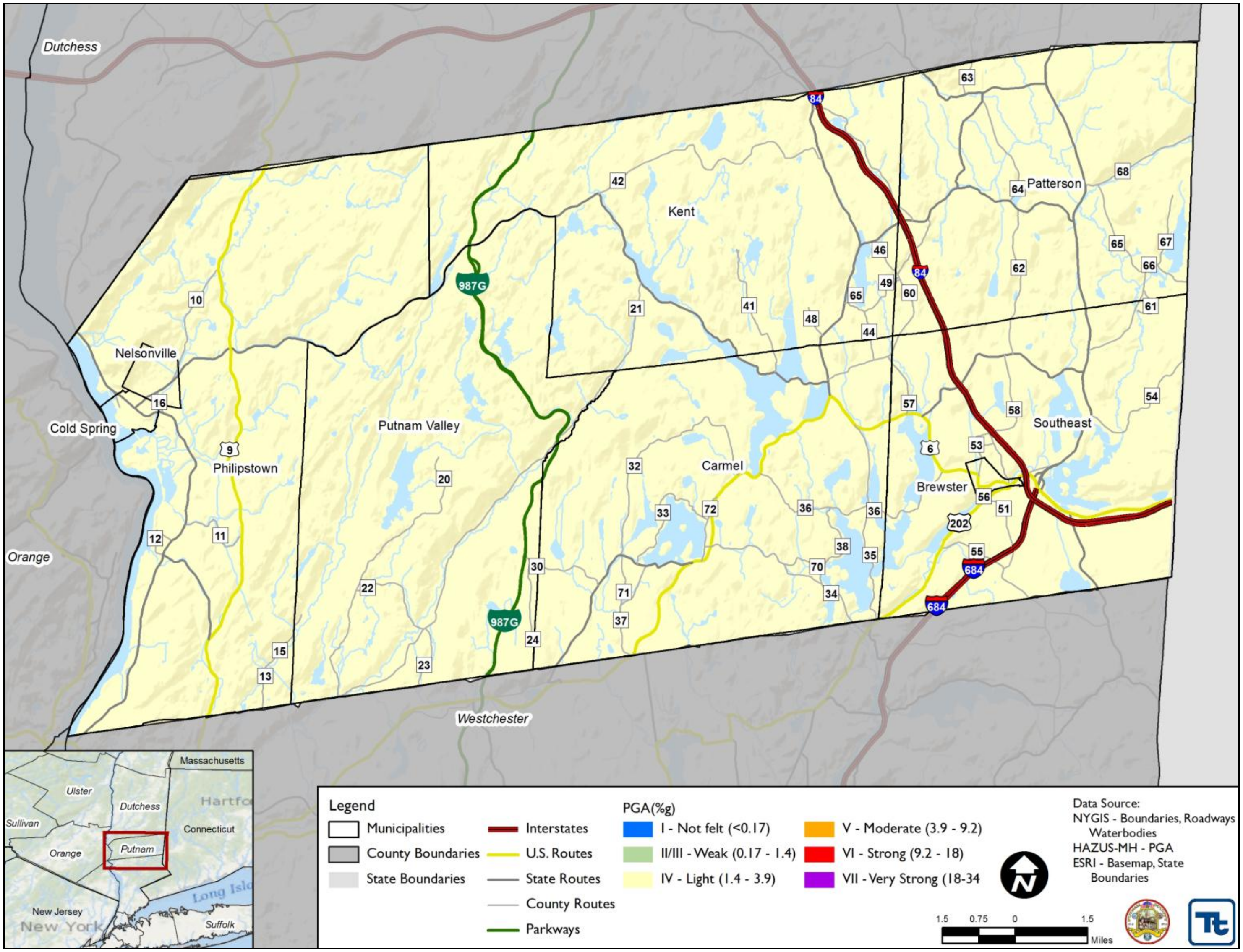
Source: HAZUS-MH 2.1

Figure 5.4.1-4. Peak Ground Acceleration Modified Mercalli Scale for a 100-Year MRP Earthquake Event



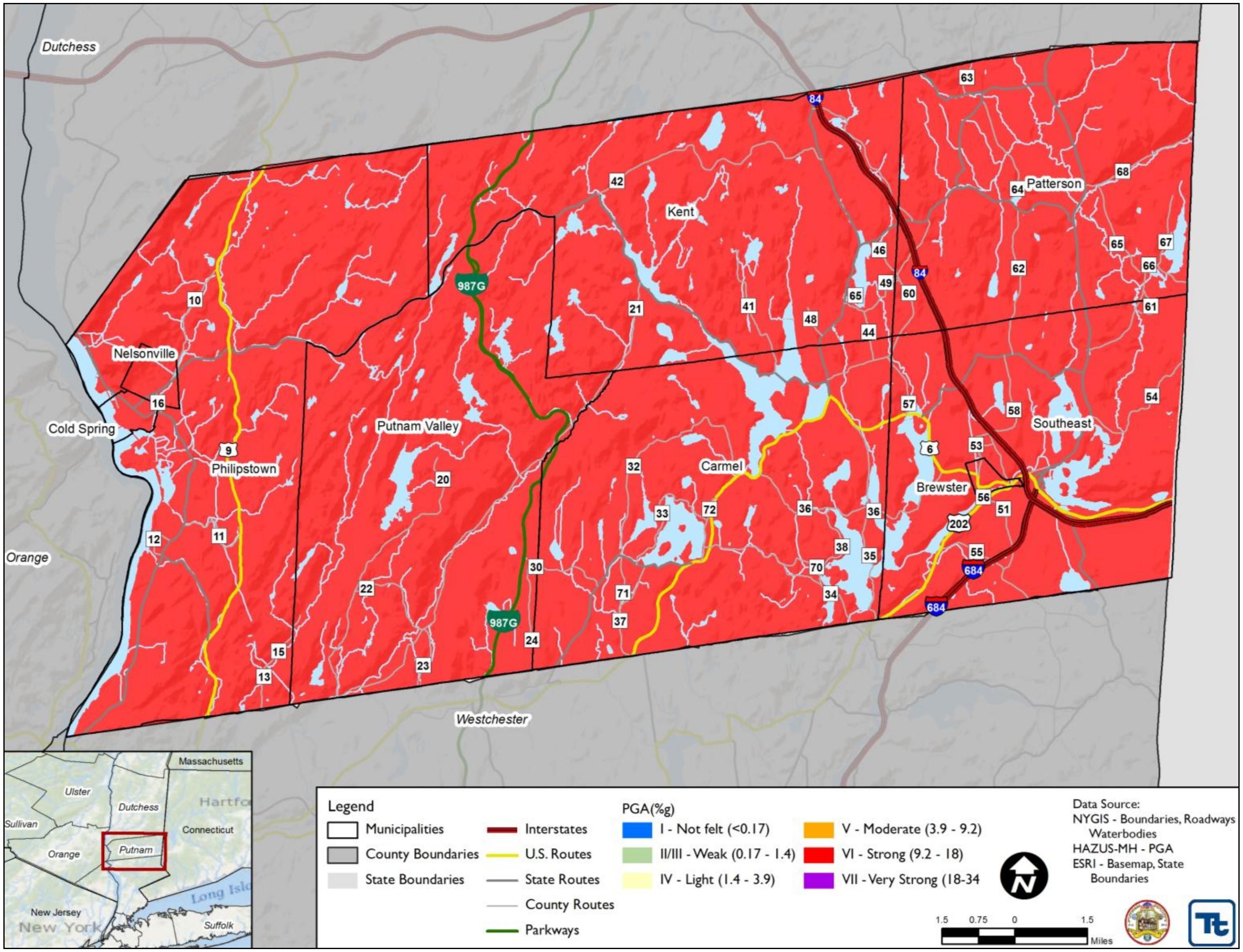
Source: *HAZUS-MH v2.1*
Note: *The peak ground acceleration for the 100-year MRP is <0.17 %g.*

Figure 5.4.1-5. Peak Ground Acceleration Modified Mercalli Scale for a 500-Year MRP Earthquake Event



Source: HAZUS-MH v2.1
Note: The peak ground acceleration for the 500-year MRP is 1.4 to 3.9 %g

Figure 5.4.1-6. Peak Ground Acceleration Modified Mercalli Scale for a 2,500-Year MRP Earthquake Event



Source: *HAZUS-MH v2.1*

Note: *The peak ground acceleration for the 2,500-year MRP is 9.2 to 18 %g*

Location

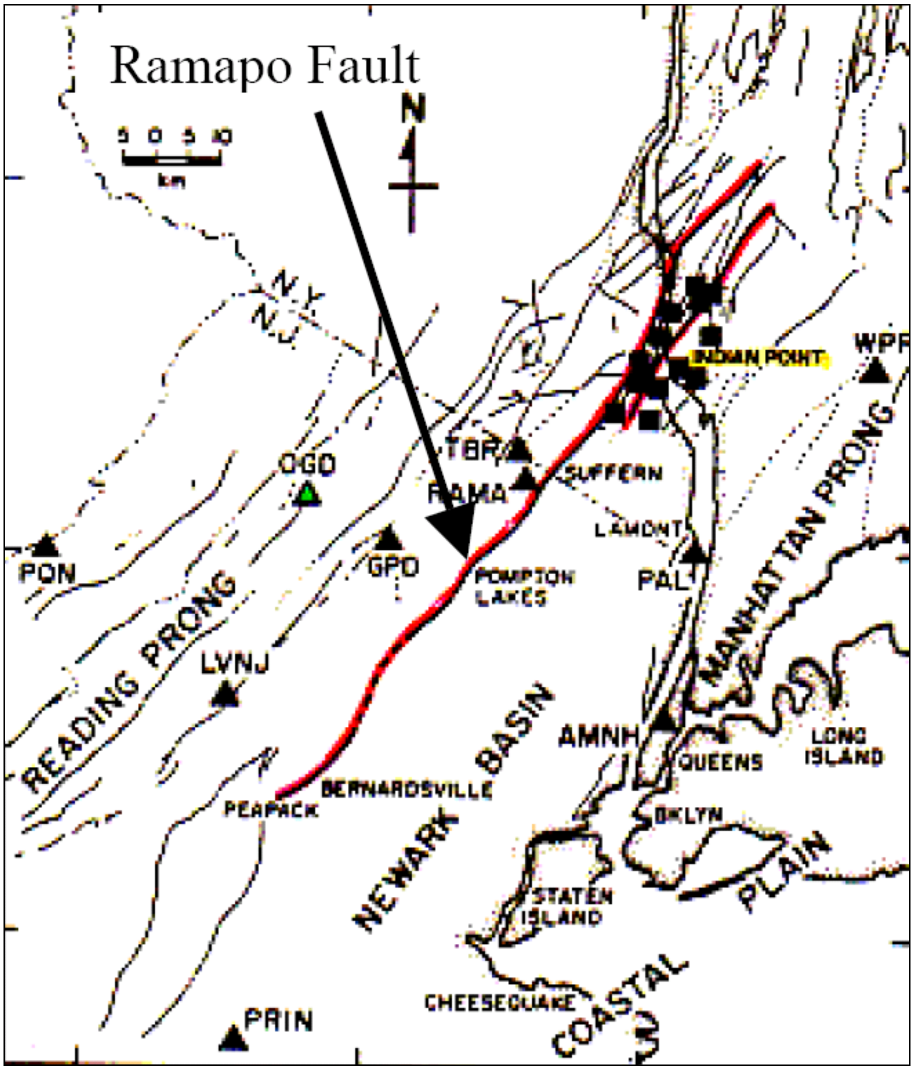
As noted in the NYS HMP, the importance of the earthquake hazard in New York State is often underestimated because other natural hazards (for example, hurricanes and floods) occur more frequently and because major floods and hurricanes have occurred more recently than a major earthquake event (NYS DHSES, 2011). However, the potential for earthquakes exists across all of New York State and the entire northeastern U.S. The New York City Area Consortium for Earthquake Loss Mitigation (NYCEM) ranks New York State as having the third highest earthquake activity level east of the Mississippi River (Tantala et al., 2003).

The closest plate boundary to the East Coast is the Mid-Atlantic Ridge, which is approximately 2,000 miles east of Putnam County. Over 200 million years ago, when the continent Pangaea rifted apart forming the Atlantic Ocean, the Northeast coast of America was a plate boundary. Being at the plate boundary, many faults were formed in the region. Although these faults are geologically old and are contained in a passive margin, they act as pre-existing planes of weakness and concentrated strain. When a strain exceeds the strength of the ancient fault, it ruptures causing an earthquake (Lehigh Earth Observatory, 2006).

There are three general regions in New York State that have a higher seismic risk compared to other parts of the State. These regions are: 1) the north and northeast third of the State, which includes the North Country/Adirondack region and a portion of the greater Albany-Saratoga region; 2) the southeast corner, which includes the greater New York City area (including Putnam County) and western Long Island; and 3) the northwest corner, which includes Buffalo and its surrounding area. Overall, these three regions are the most seismically active areas of the State, with the north-northeast portion having the higher seismic risk and the northwest corner of the State has the lower seismic risk (NYS DHSES, 2014).

The Ramapo Fault (Figure 5.4.1-7) is part of a system of northeast striking, southeast-dipping faults, which runs from southeastern New York to the Hudson River at Stony Point, through eastern Pennsylvania and beyond. The fault is a hairline fracture, 50 miles long, and is located 35 miles from New York City. Seismographic stations, part of the Advanced National Seismic System, are used to monitor earthquakes and ground motion near important buildings and critical infrastructure along this fault (Lamont-Doherty, 2004; Pasfield, Unknown). 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, 2005).

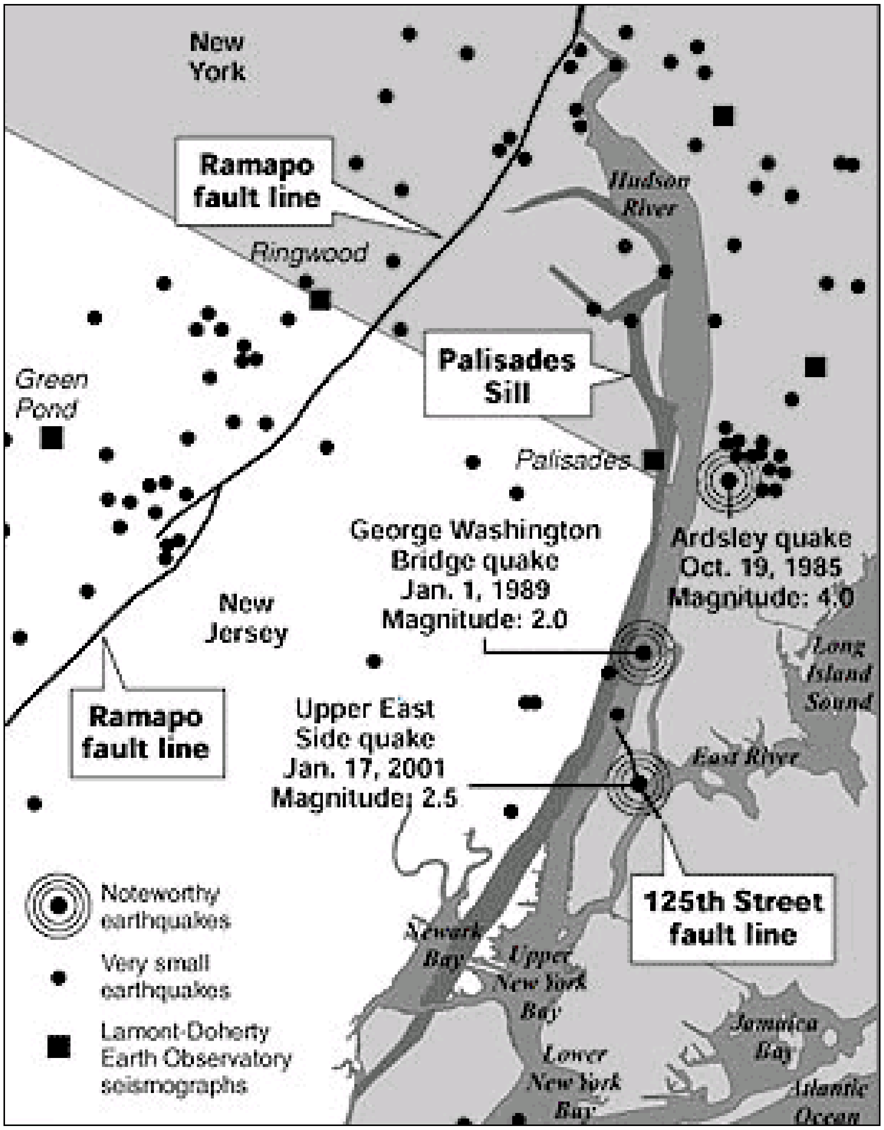
Figure 5.4.1-7. Ramapo Fault Line



Source: Rasmusson, 2003

Figure 5.4.1-8 shows the Ramapo Fault Line and the earthquakes that have occurred in the surrounding area of the fault.

Figure 5.4.1-8. Earthquake Occurrences Near the Ramapo Fault Line

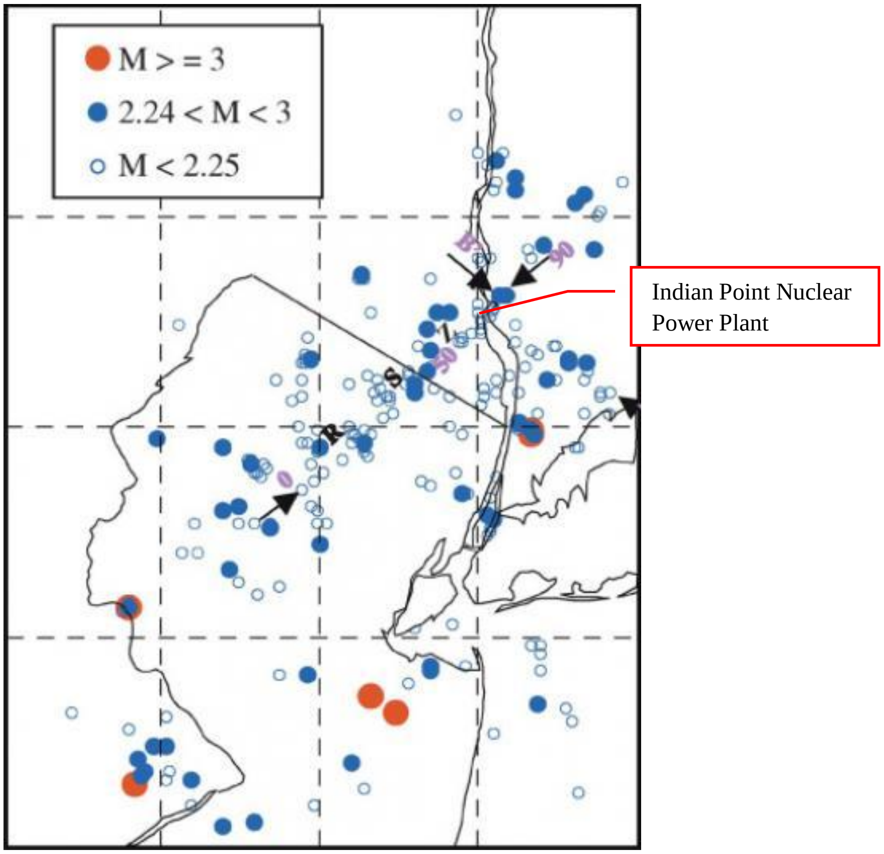


Source: Groves, 2001

According to a study conducted by the Lamont-Doherty Earth Observatory, research has found evidence of an active seismic zone running at least 25 miles from Stamford, Connecticut to the Hudson Valley's Town of Peekskill (Westchester County), known as the Stamford-Peekskill line. Small clusters of earthquake events are found along the length of the line and to its immediate southwest. Just north of the line, there are no recorded earthquakes. The Stamford-Peekskill line runs parallel to the other faults beginning at 125th Street and researchers believe this fault is in the same family capable of producing at least a magnitude 6.0 earthquake. This fault also intersects the Ramapo seismic zone (Sykes et al., 2008).

The study complied information from 383 earthquakes within a 15,000 square mile area around New York City since 1677 and analyzed 34 years of new data on tremors recorded by modern technology. Based on this research, magnitude 5 earthquakes should be expected in the region about every 100 years, with the most recent one in 1884 (Gardner, 2008; Neroulias, 2008; Environmental News Service, 2008. Figure 5.4.1-9 depicts the Stamford-Peekskill seismic zone, along with earthquakes between 1974 and 2007.

Figure 5.4.1-9. Stamford-Peekskill Seismic Zone.



Source: Sykes et al., 2008

Note: Quakes located by instruments 1974-2007. Arrows indicate the Peekskill-Stamford fault line and Ramapo seismic zone (RSZ), which intersect near Indian Point. Purple numerals indicate distance in kilometers.

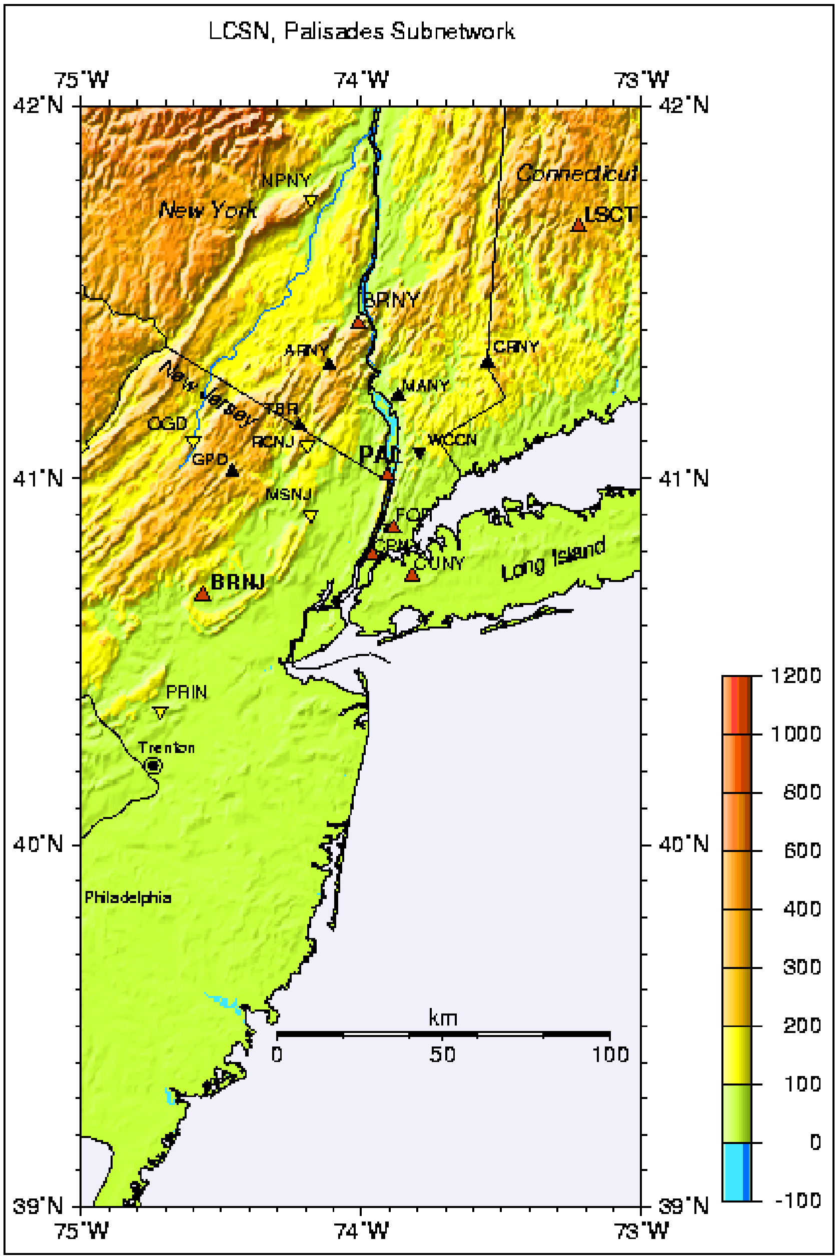
In the 1970s and 1980s, earthquake risk along the Ramapo Fault became more known due to its proximity to the Indian Point Nuclear Power Generating Station, operated by Entergy Nuclear and located in the Village of Buchanan, New York. The Stamford-Peekskill seismic zone passes less than one mile north of the Indian Point nuclear power plant. Seismic evidence confirms that Indian Point is situated at the intersection of both the Ramapo and Stamford-Peekskill seismic zones (Sykes et al., 2008). Approximately 20 million people live within 50 miles of Indian Point, which includes all of New York City.

The combination of New York State's geology and human footprint may increase the problem with earthquakes and Indian Point. Many New York earthquakes occur near the surface, withinin the upper mile of the extremely hard, rigid rocks underlying Manhattan and much of the lower Hudson Valley. These rocks can build large stresses, and then suddenly transmit engery over long distances. The region's major highways, commuter and long-distance rail lines, and the main gas, oil and power transmission lines all run parallel with active faults (Sykes et al., 2008).

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 52 seismographic stations in the following seven states: Connecticut, Delaware, Maryland, New Jersey, New York, Pennsylvania, and Vermont. There are no seismic stations in Putnam County; however, there are several within the vicinity of the County. Figure 5.4.1-10 shows the location of these stations in the

New York and New Jersey area. The network of stations is composed of broadband and short-period seismographic stations (LCSN 2014).

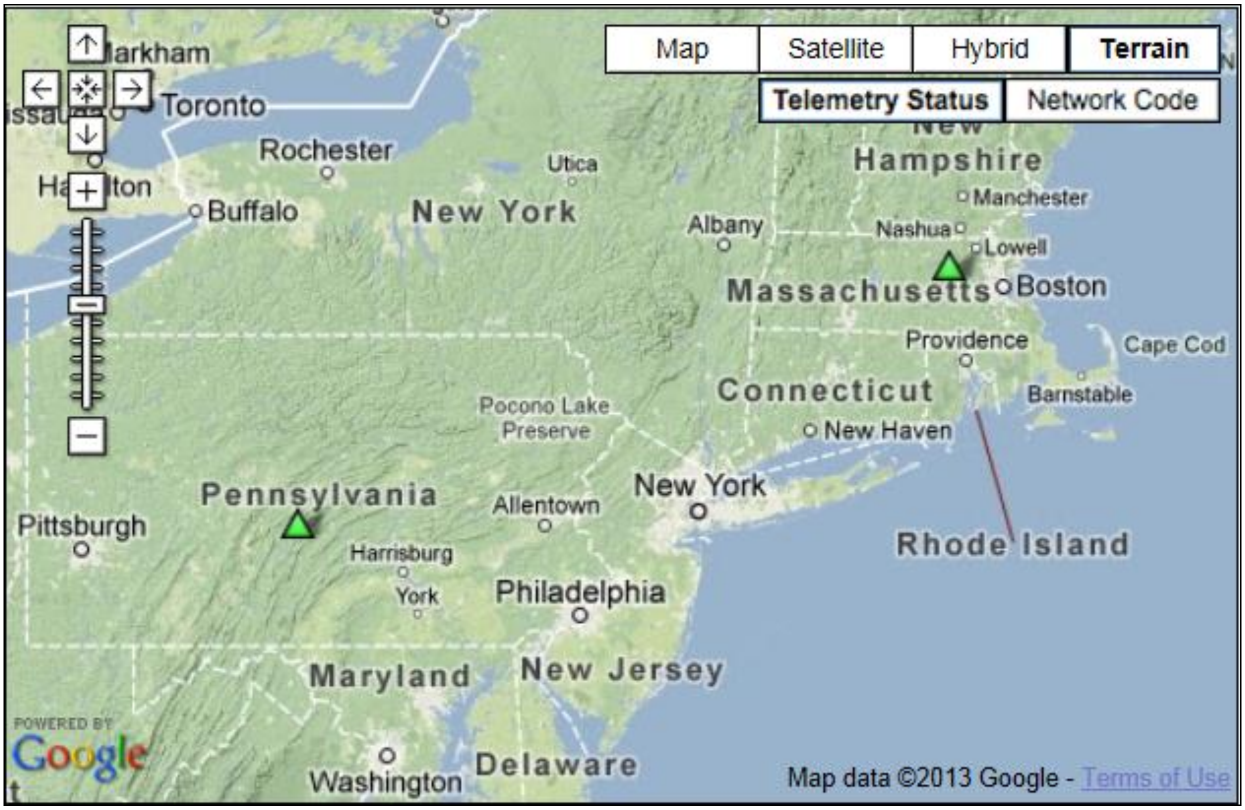
Figure 5.4.1-10. Lamont-Doherty Seismic Stations Locations in the New York-New Jersey Area



Source: LCSN 2014

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 York State, nearby stations are positioned in State College, Pennsylvania and Oak Ridge, Massachusetts. Figure 5.4.1-11 shows locations of USGS seismic stations near New York State.

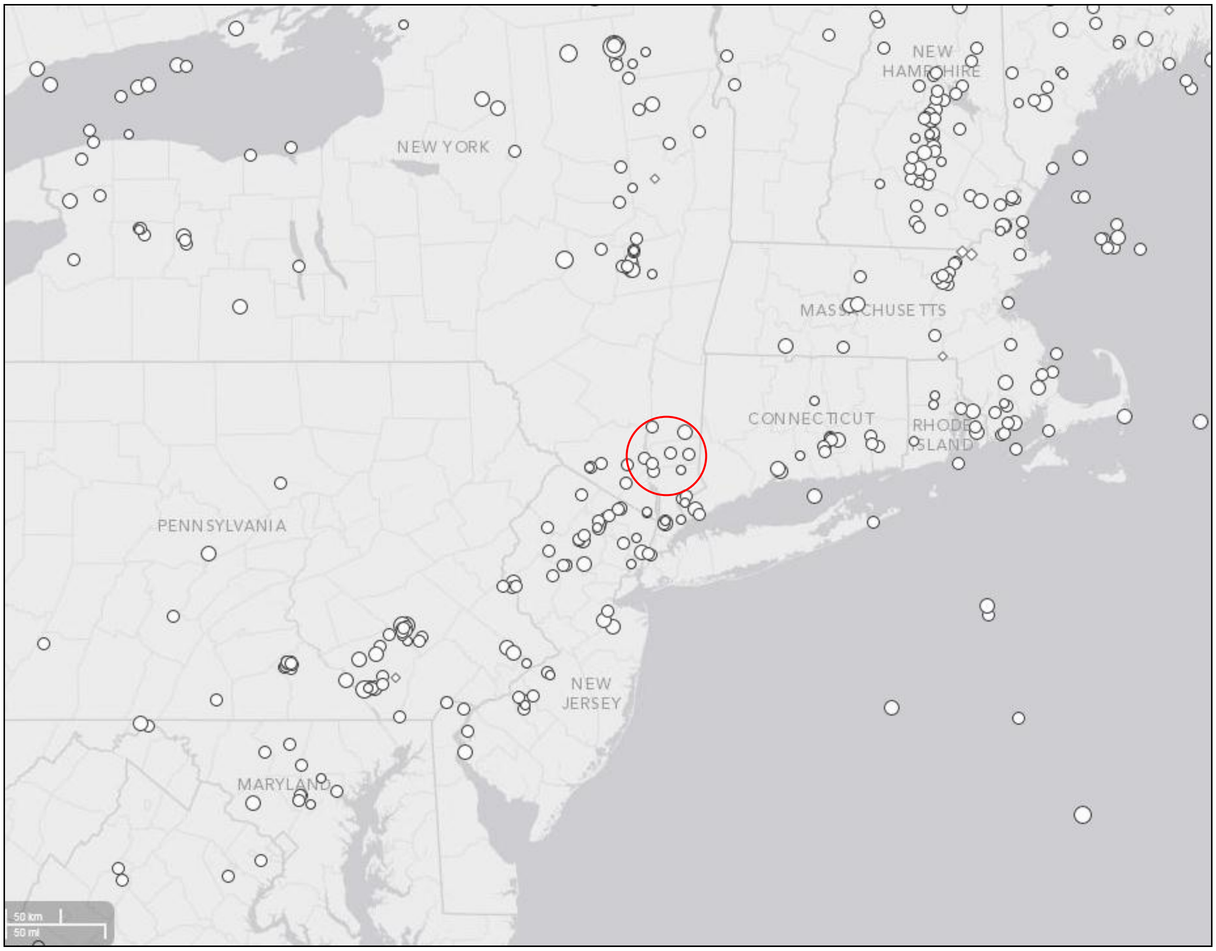
Figure 5.4.1-11. USGS Seismic Stations near New York State



Source: USGS 2012

Figure 5.4.1-12 illustrates historic earthquake epicenters across the northeast U.S. and New York State between October 1975 and July 2014. There have been multiple earthquakes originating outside New York's borders that have been felt within the State. These quakes have come from Quebec, Canada and Massachusetts. According to the NYS HMP, such events are considered significant for hazard mitigation planning because they could produce damage within the State in certain situations.

Figure 5.4.1-12. Earthquake Epicenters in the Northeast U.S., October 1975 to July 2014



Source: USGS, 2014
Note: The red oval indicates the location of Putnam County.

Previous Occurrences and Losses

Many sources provided historical information regarding previous occurrences and losses associated with earthquakes throughout New York State. Therefore, with so many sources reviewed for the purpose of this HMP, loss and impact information for many events could vary depending on the sources. According to the New York State 2014 HMP, between 1973 and 2012, 189 earthquakes were epicentered in New York State. Of those 189 earthquakes, four were reported in Putnam County.

Between 1954 and 2014, New York State was included in one earthquake-related major disaster (DR) or emergency (EM) declaration. Generally, these disasters cover a wide region of the State; therefore, they may have impacted many counties. However, not all counties were included in the disaster declaration. Putnam County was not included in any DRs or EMs (FEMA, 2014).

For this HMP, known earthquakes events that have impacted New York State and Putnam County between 1950 and 2014 are identified in Table 5.4.1-5. Many sources were researched for historical information regarding earthquake events in Putnam County; therefore, Table 5.4.1-5 may not include all earthquake events that have impacted the County.

Table 5.4.1-5. Earthquake Events Impacting Putnam County, 1950 to 2014

Dates of Event	Event Type	Location	FEMA Declaration Number	County Designated?	Losses / Impacts
May 23, 1971	Earthquake 3.5 – 4.1	Blue Mountain Lake, NY	N/A	N/A	No reference and/or no damage reported.
June 7, 1974	Earthquake 3.0	Wappingers Falls, NY	N/A	N/A	Windows broken
June 9, 1975	Earthquake 3.5	Plattsburgh, NY	N/A	N/A	Chimneys and fireplaces cracked
December 30, 1979	Earthquake 2.5	Armonk, NY	N/A	N/A	No reference and/or no damage reported.
January 17, 1980	Earthquake 2.9	Peekskill, NY	N/A	N/A	No reference and/or no damage reported.
February 2, 1983	Earthquake 3.0	Scarsdale-Lagrangeville	N/A	N/A	Chimneys cracked
January 26, 1985	Earthquake 2.2	Greenville, NY	N/A	N/A	No reference and/or no damage reported.
October 1985	Earthquake 4.0	Greenburgh, between Ardsley and Yonkers	N/A	N/A	Tremors shook the metropolitan area and were felt in Philadelphia, southern Canada, and Long Island
October 19, 1985	Earthquake 2.0	Greenville, NY	N/A	N/A	No reference and/or no damage reported.
October 19, 1985	Earthquake 3.6	Greenville, NY	N/A	N/A	No reference and/or no damage reported.
October 21, 1985	Earthquake 2.8	Greenville, NY	N/A	N/A	No reference and/or no damage reported.
January 4, 1986	Earthquake 1.8	Greenville, NY	N/A	N/A	No reference and/or no damage reported.
April 22, 1986	Earthquake 2.7	Greenville, NY	N/A	N/A	No reference and/or no damage reported.

Table 5.4.1-5. Earthquake Events Impacting Putnam County, 1950 to 2014

Dates of Event	Event Type	Location	FEMA Declaration Number	County Designated?	Losses / Impacts
December 20, 1986	Earthquake 1.9	Greenville, NY	N/A	N/A	No reference and/or no damage reported.
November 1988	Earthquake 6.0	90 miles north of Quebec, Canada	N/A	N/A	This earthquake was felt in the Lower Hudson Valley and in New York City.
June 1991	Earthquake 4.4	West of Albany	N/A	N/A	Rattled homes throughout the area
April 12, 1991	Earthquake 2.0-2.7	Westchester County, NY and Fairfield, CT	N/A	N/A	Last just five seconds and caused no damage
August 22, 2000	Earthquake 2.5	Carmel, NY	N/A	N/A	Numerous residents in Putnam County reported having felt this earthquake.
January 17, 2001	Earthquake 2.4	Upper East Side of Manhattan, NY	N/A	N/A	No reference and/or no damage reported.
April 20, 2002	Earthquake 5.2	Au Sable Forks, NY	DR-1415	No	Some roads, bridges, chimneys and water lines damaged in Clinton and Essex Counties. Many buildings in the area had cracked walls and foundations, broken windows and small items knocked from shelves. Maximum intensity (VII) at Au Sable Forks. Felt from New Brunswick and Maine to Ohio and Michigan and from Ontario and Quebec to Maryland.
January 2003	Earthquake 1.2 and 1.4	Hastings-on-Hudson	N/A	N/A	No reference and/or no damage reported.
March 2006	Earthquake 1.1 and 1.3	Rockland, NY	N/A	N/A	Two earthquakes struck Rockland County. The first, 1.1, struck 3.3 miles southwest of Pearl River and the second, 1.3, was centered in the West Nyack-Blauvelt-Pearl River area.
February 18, 2009	Earthquake 2.3	Greater New York Area	N/A	N/A	No reference and/or no damage reported.
June 23, 2013	Earthquake 2.1	Greater New York Area	N/A	N/A	No reference and/or no damage reported.
February 1, 2014	Earthquake 1.8	Rye Brook, NY	N/A	N/A	No reference and/or no damage reported.
May 11, 2014	Earthquake 1.7	Heritage Hills, NY	N/A	N/A	No reference and/or no damage reported.

Table 5.4.1-5. Earthquake Events Impacting Putnam County, 1950 to 2014

Dates of Event	Event Type	Location	FEMA Declaration Number	County Designated?	Losses / Impacts
July 5, 2014	Earthquake 2.5	5.2 miles from Peekskill	N/A	N/A	No reference and/or no damage reported.

Source(s): *NYS DHSES, 2014; USGS, 2014; Kim, 1999; Stover and Coffman, 1989; Journal News Online 2011; PIX11 News 2014 ; FEMA 2014*
CT *Connecticut*
DR *Major Disaster Declaration (FEMA)*
FEMA *Federal Emergency Management Agency*
N/A *Not Applicable*
NY *New York*
USGS *U.S. Geological Survey*

Probability of Future Events

Earthquake hazard maps illustrate the distribution of earthquake shaking levels that have a certain probability of occurring over a given time period. According to the USGS, in 2014 (the date of the most recent analysis), Putnam County had a PGA of 3-5%g for earthquakes with a 10-percent probability of occurring within 50 years.

The NYSDPC indicates that the earthquake hazard in New York State is often understated because other natural hazards occur more frequently (for example: hurricanes, tornadoes and flooding) and are much more visible. However, the potential for earthquakes does exist across the entire northeastern U.S., and New York State is no exception (NYS DHSES, 2014).

Earlier in this section, the identified hazards of concern for Putnam County were ranked. NYS DHSES conducts a similar ranking process for hazards that affect the State. The probability of occurrence, or likelihood of the event, is one parameter used for ranking hazards. Based on historical records and input from the Planning Committee, the probability of occurrence for earthquakes in the County is considered 'frequent' (likely to occur more than once every 25 years, as presented in Table 5.3-3). It is anticipated that the County will experience indirect impacts from earthquakes that may affect the general building stock, local economy and may induce secondary hazards such ignite fires and cause utility failure.

Climate Change

The impacts of global climate change on earthquake probability are unknown. Some scientists say 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 may be opening the way for future earthquakes (NASA, 2004).

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.

5.4.1.2 Vulnerability Assessment

To understand risk, a community must evaluate what assets are exposed or vulnerable in the identified hazard area. For the earthquake hazard, the entire County has been identified as exposed to the hazard. Therefore, all assets in Putnam County (population, structures, critical facilities and lifelines), as described in the County Profile (Section 4), are exposed and potentially vulnerable. The following section includes an evaluation and estimation of the potential impact of the earthquake hazard on Putnam County including the following:

- Overview of vulnerability
- Data and methodology used for the evaluation
- Impact on: (1) life, health and safety of residents, (2) general building stock, (3) critical facilities, (4) economy, and (5) future growth and development
- Effect of climate change on vulnerability
- Further data collections that will assist understanding this hazard over time

Overview of Vulnerability

Earthquakes usually occur without warning and can impact areas a great distance from their point of origin. The extent of damage depends on the density of population and building and infrastructure construction in the area shaken by the quake. Some areas may be more vulnerable than others based on soil type, the age of the buildings and building codes in place. Compounding the potential for damage – historically, Building Officials Code Administration (BOCA) used in the Northeast were developed to address local concerns including heavy snow loads and wind; seismic requirements for design criteria are not as stringent compared to the west coast's reliance on the more seismically-focused Uniform Building Code). As such, a smaller earthquake in the Northeast can cause more structural damage than if it occurred out west.

The entire population and general building stock inventory of the County is at risk of being damaged or experiencing losses due to impacts of an earthquake. Potential losses associated with the earth shaking were calculated for Putnam County for three probabilistic earthquake events, the 100-year, 500- and 2,500-year mean return periods (MRP). The impacts on population, existing structures, critical facilities and the economy within Putnam County are presented below, following a summary of the data and methodology used.

Data and Methodology

A probabilistic assessment was conducted for Putnam County for the 100-, 500- and 2,500-year MRPs through a Level 2 analysis in HAZUS-MH 2.1 to analyze the earthquake hazard and provide a range of loss estimates for Putnam County. The probabilistic method uses information from historic earthquakes and inferred faults, locations and magnitudes, and computes the probable ground shaking levels that may be experienced during a recurrence period by Census tract.

As noted in the HAZUS-MH Earthquake User Manual '*Uncertainties are inherent in any loss estimation methodology. They arise in part from incomplete scientific knowledge concerning earthquakes and their effects upon buildings and facilities. They also result from the approximations and simplifications that are necessary for comprehensive analyses. Incomplete or inaccurate inventories of the built environment, demographics and economic parameters add to the uncertainty. These factors can result in a range of uncertainly in loss estimates produced by the HAZUS Earthquake Model, possibly at best a factor of two or more*.' However, HAZUS' potential loss estimates are acceptable for the purposes of this HMP.

The occupancy classes available in HAZUS-MH 2.1 were condensed into the following categories (residential, commercial, industrial, agricultural, religious, government, and educational) to facilitate the analysis and the presentation of results. Residential loss estimates address both multi-family and single family dwellings. Impacts to critical facilities and utilities were also evaluated.

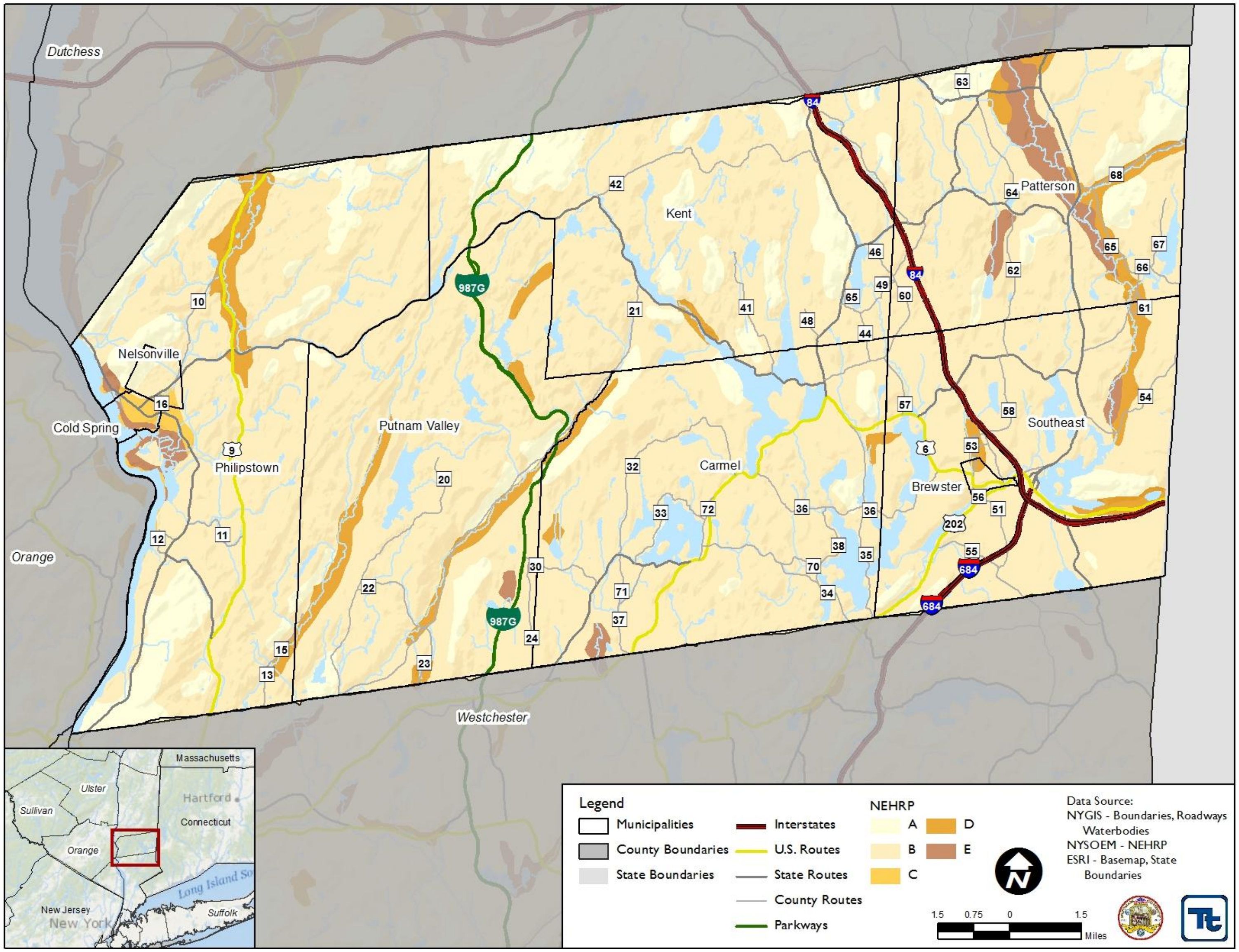
Ground shaking is the primary cause of earthquake damage to man-made structures and soft soils amplify ground shaking. One contributor to the site amplification is the velocity at which the rock or soil transmits shear waves (S-waves). The NEHRP developed five soil classifications defined by their shear-wave 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.

Figure 5.4.1-13 shows the geographic distribution of the NEHRP soil types in the County. When unchanged, HAZUS-MH default soil types are class "D". However, for this analysis HAZUS-MH was updated with the specific NEHRP soil types for Putnam County as provided by the New York State Office of Emergency Management. As stated earlier, soft soils (NEHRP soil classed D and E) can amplify ground shaking to damaging levels even in a moderate earthquake (NYCEM, 2003). Therefore, buildings located on NEHRP soil classes D and E have an increased risk of damages from an earthquake.

As Figure 5.4.1-13 illustrates, Putnam County consists of all NEHRP soil types. In general, softer soils follow riverine reaches. For example, Class 'E' soils are located along the East Branch of the Croton River and the Hudson River near Cold Spring.

Data used to assess this hazard include data available in the HAZUS-MH 2.1 earthquake model, USGS data, data provided by NYS DHSES, professional knowledge, and information provided by the County's Planning Committee.

Figure 5.4.1-13. NEHRP Soils Types in Putnam County



Source: O'Brien (NYS DHSES), 2008

Impact on Life, Health and Safety

Overall, the entire population of Putnam County is exposed to the earthquake hazard event. The impact of earthquakes on life, health and safety is dependent upon the severity of the event. Risk to public safety and loss of life from an earthquake in Putnam County is minimal with higher risk occurring in buildings as a result of damage to the structure, or people walking below building ornamentation and chimneys that may be shaken loose and fall as a result of the quake.

Populations considered most vulnerable are those located in/near the built environment, particularly near unreinforced masonry construction. In addition, the vulnerable population includes the elderly (persons over the age of 65) and individuals 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 and the location and construction quality of their housing. Refer to Section 4 (County Profile) for the vulnerable population statistics in Putnam County.

An exposure analysis was performed using the NEHRP soils data and the 2010 Census population data. The sum of the population by Census Block within the NEHRP class "D" and "E" soil types were calculated and summarized in Table 5.4.1-6 below. Overall, approximately 5-percent of the County's population is located on NEHRP class "D" and "E" soils.

Table 5.4.1-6. Approximate Population within NEHRP 'D" and 'E' Soils

Municipality	Total Population (2010 Census)	Population NEHRP Class "D" and "E" Soils	
		Number	%
Village of Brewster	2,390	0	0
Town of Carmel	34,305	1,095	3.2
Village of Cold Spring	2,013	407	20.2
Town of Kent	13,507	0	0
Village of Nelsonville	628	0	0
Town of Patterson	12,023	1,297	10.8
Town of Philipstown	7,021	710	10.1
Town of Putnam Valley	11,809	1,040	8.8
Town of Southeast	16,014	667	4.2
Putnam County	99,710	5,216	5.2

Sources: NYS DHSES 2008; U.S. Census 2010

Residents may be displaced or require temporary to long-term sheltering due to 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. Table 5.4.1-7 summarizes the households HAZUS-MH 2.1 estimates will be displaced and population that may require short-term sheltering as a result of the 100-, 500- and 2,500-year MRP earthquake events.

Table 5.4.1-7. Summary of Estimated Sheltering Needs for Putnam County

Scenario	Displaced Households	Persons Seeking Short-Term Shelter
100-Year Earthquake	0	0
500-Year Earthquake	1	1

Table 5.4.1-7. Summary of Estimated Sheltering Needs for Putnam County

Scenario	Displaced Households	Persons Seeking Short-Term Shelter
2,500-Year Earthquake	33	19

Source: HAZUS-MH 2.1

According to the 1999-2003 NYCEM Summary Report (*Earthquake Risks and Mitigation in the New York / New Jersey / Connecticut Region*), there is a strong correlation between structural building damage and the number of injuries and casualties from an earthquake event. 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.

There are no injuries or casualties estimated for the 100-year event. There are one to two injuries estimated as a result of the 500-year. Table 5.4.1-8 summarizes the County-wide injuries and casualties estimated for 2,500-year MRP earthquake event.

Table 5.4.1-8. Estimated Number of Injuries and Casualties from the 2,500-Year MRP Earthquake Event

Level of Severity	Time of Day		
	2:00 AM	2:00 PM	5:00 PM
Injuries	20	12	14
Hospitalization	3	2	2
Casualties	0	0	0

Source: HAZUS-MH 2.1

Impact on General Building Stock

After considering the population vulnerable to the earthquake hazard, the value of general building stock exposed to and damaged by 100-, 500- and 2,500-year MRP earthquake events was evaluated. In addition, annualized losses were calculated using HAZUS-MH 2.1. The entire County's general building stock is considered at risk and exposed to this hazard.

As stated earlier, soft soils (NEHRP soil classed D and E) can amplify ground shaking to damaging levels even in a moderate earthquake (NYCEM, 2003). Therefore, buildings located on NEHRP soil classes D and E have an increased risk of damages from an earthquake. Table 5.4.1-9 summarizes the number and value of buildings in Putnam County on the approximately located NEHRP soils classed D and E.

Table 5.4.1-9. Number and Improvement Value of Buildings within NEHRP 'D' and 'E' Soils

Municipality	Total Number of Buildings	Total RCV (Structure and Contents)	Buildings NEHRP Class "D" and "E" Soils		
			Number	RCV	% of Total RCV
Village of Brewster	406	$333,167,631	14.8	$37,916,566	11.4
Town of Carmel	10,170	$6,097,638,257	1.7	$80,755,250	1.3
Village of Cold Spring	679	$442,869,640	13.0	$58,633,576	13.2

Table 5.4.1-9. Number and Improvement Value of Buildings within NEHRP 'D' and 'E' Soils

Municipality	Total Number of Buildings	Total RCV (Structure and Contents)	Buildings NEHRP Class "D" and "E" Soils		
			Number	RCV	% of Total RCV
Town of Kent	5,021	$2,066,530,876	<1	$3,703,504	<1
Village of Nelsonville	261	$121,130,957	0	$0	0
Town of Patterson	3,393	$1,897,944,173	8.6	$240,994,151	12.7
Town of Philipstown	2,768	$1,669,292,142	14.6	$239,568,024	14.4
Town of Putnam Valley	4,520	$2,091,379,851	8.5	$207,678,181	9.9
Town of Southeast	4,128	$3,155,126,947	7.2	$218,575,553	6.9
Putnam County	31,346	$17,875,080,474	5.4	$1,087,824,805	6.1

Sources: NYS DHSES 2008, U.S. Census 2010
Note: RCV is the estimated replacement cost value of both structure and contents.

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 there is 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. HAZUS-MH 2.1 methodology and model were used to analyze the earthquake hazard for the general building stock for Putnam County. See Figure 5.4.1-4 through Figure 5.4.1-6earlier in this profile which illustrate the geographic distribution of PGA (g) across the County for 100-, 500- and 2,500-year MRP events at the Census-Tract level.

In addition, according to NYCEM, a building's construction determines how well it can withstand the force of an earthquake. The NYCEM report indicates that un-reinforced 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.

Potential building damage was evaluated by HAZUS-MH 2.1 across the following damage categories (none, slight, moderate, extensive and complete). Table 5.4.1-10 provides definitions of these five categories of damage for a light wood-framed building; definitions for other building types are included in HAZUS-MH technical manual documentation. General building stock damage for these damage categories by occupancy class and building type on a County-wide basis is summarized below for the 100-, 500- and 2,500-year events.

Table 5.4.1-10. Example of Structural Damage State Definitions for a Light Wood-Framed Building

Damage Category	Description
Slight	Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.
Moderate	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
Extensive	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of room-over-garage or other soft-story configurations.

Damage Category	Description
Complete	Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks.

Source: HAZUS-MH Technical Manual

Table 5.4.1-11 summarizes the damage estimated for the 100-, 500- and 2,500-year MRP earthquake events. Damage loss estimates include structural and non-structural damage to the building and loss of contents.

Table 5.4.1-11. Estimated Value (Building and Contents) Damaged by the 100-, 500- and 2,500-Year MRP Earthquake Events

Municipality	Total RCV (Structure and Contents)	Estimated Total Damages*			Percent of Total Building and Contents **		
		100-Year	500-Year	2,500-Year	100-Year	500-Year	2,500-Year
Village of Brewster and Town of Southeast	$3,488,294,578	$0	$1,052,806	$20,528,822	0	<1	<1
Town of Carmel	$6,097,638,257	$0	$1,974,862	$38,999,184	0	<1	<1
Town of Kent	$2,066,530,876	$0	$562,101	$10,706,395	0	<1	<1
Villages of Cold Spring and Nelsonville	$564,000,597	$0	$175,544	$3,371,718	0	<1	<1
Town of Patterson	$1,897,944,173	$0	$571,753	$10,824,733	0	<1	<1
Town of Philipstown	$1,669,292,142	$0	$402,364	$8,286,973	0	<1	<1
Town of Putnam Valley	$2,091,379,851	$0	$690,845	$13,724,018	0	<1	<1
Putnam County	$17,875,080,474	$0	$5,430,277	$106,441,843	0	<1	<1

Source: HAZUS-MH 2.1
**Total Damages is sum of damages for all occupancy classes (residential, commercial, industrial, agricultural, educational, religious and government).*
Improved value was used
Please note the Census Tracts do not align exactly with municipal boundaries; therefore, the Village of Brewster and Town of Southeast have been combined and presented as one total, and the Villages of Cold Spring and Nelsonville have been combined and presented as one total.

It is estimated that there would be nearly $5.5 million in damages to buildings in the County during a 500-year earthquake event. This includes structural damage, non-structural damage and loss of contents, representing less than one-percent of the total replacement value for general building stock in Putnam County. For a 2,500-year MRP earthquake event, HAZUS-MH estimates nearly $106 million, less than one-percent of the total general building stock replacement value. Residential and commercial buildings account for most of the damage for earthquake events.

Earthquakes can cause secondary hazard events such as fires. No fires are anticipated as a result of the 100-, 5 500-year and 2,500-year MRP events.

Impact on Critical Facilities

After considering the general building stock exposed to, and damaged by, 100-, 500- and 2,500-year MRP earthquake events, critical facilities were evaluated. All critical facilities (essential facilities, transportation systems, lifeline utility systems, high-potential loss facilities and user-defined facilities) in Putnam County are considered exposed and potentially vulnerable to the earthquake hazard. Refer to subsection "Critical Facilities" in Section 4 (County Profile) of this Plan for a complete inventory of critical facilities in the County.

To estimate critical facility exposure to the potential impacts of an earthquake an exposure analysis was performed using the NEHRP soils data to determine the critical facility's location in relation to these areas. The critical facilities and utilities in the areas were calculated and summarized in Table 5.4.1-12 below.

Table 5.4.1-12. Number of Critical Facilities Located in the NEHRP Soil Class D and E

Municipality	Facility Types															
	Boat	Commercial	Communication	Dam	Electric	Emergency Center	Fire Station	Government	Highway Bridge	Natural Gas	Rail Facility	Recreation	School	Transportation	UDF	Wastewater
Village of Brewster	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Town of Carmel	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	3
Village of Cold Spring	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
Town of Kent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Village of Nelsonville	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Town of Patterson	0	1	1	1	1	0	1	4	3	2	1	1	2	0	0	5
Town of Philipstown	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0
Town of Putnam Valley	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Town of Southeast	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0
Putnam County	**1**	**2**	**2**	**3**	**2**	**1**	**2**	**6**	**3**	**2**	**2**	**1**	**2**	**1**	**1**	**10**

Source: Putnam County Committees; NYS DHSES, 2008
Note: UDF = User Defined Facility

HAZUS-MH 2.1 estimates the probability that critical facilities may sustain damage as a result of 100-, 500- and 2,500-year MRP earthquake events. Additionally, HAZUS-MH estimates percent functionality for each facility days after the event. Table 5.4.1-13 and Table 5.4.1-14 list the percent probability of critical facilities sustaining the damage category as defined by the column heading and percent functionality after the event for the 500-year and 2,500-year MRP earthquake events.

Table 5.4.1-13. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities in for the 500-Year MRP Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Critical Facilities									
EOC	99%	<1%	<1%	0%	0%	99-100%	99-100%	100%	100%
Medical	99%	<1%	<1%	0%	0%	99-100%	99-100%	100%	100%
Police	99%	<1%	<1%	0%	0%	99-100%	99-100%	100%	100%
Fire	99%	<1%	<1%	0%	0%	99-100%	99-100%	100%	100%
Schools	99%	<1%	<1%	0%	0%	99-100%	99-100%	100%	100%
Utilities									
Potable Water	99%	<1%	<1%	0%	0%	99-100%	100%	100%	100%
Wastewater	99%	<1%	<1%	0%	0%	99-100%	100%	100%	100%
Electric Power	99%	<1%	<1%	0%	0%	99-100%	100%	100%	100%
Communication	99%	<1%	<1%	0%	0%	99-100%	100%	100%	100%

Source: HAZUS-MH 2.1

Table 5.4.1-14. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities for the 2,500-Year MRP Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Critical Facilities									
EOC	64%	17%	17%	<1%	<1%	64%	81%	100%	100%
Medical	93%	5%	<1%	0%	0%	93%	98%	100%	100%
Police	78 – 93%	5 – 12%	<1 – 8%	0 - <1%	0 - <1%	78 – 93%	79 – 98%	100%	100%
Fire	42– 93%	3– 20%	1 - 16%	0 - <1%	0 - <1%	42 – 93%	62 – 98%	100%	100%
Schools	78 – 90%	5 – 10%	3 – 9%	<1%	0%	78 – 90%	89 – 96%	100%	100%
Utilities									
Potable Water	60 – 93%	5 – 32%	1 – 8%	0 - <1%	0%	99 – 100%	100%	100%	100%
Wastewater	41 – 93%	3 – 17%	2 – 30%	0 - <2%	0 - <1%	99 – 100%	100%	100%	100%
Electric Power	64 – 93%	3 – 17%	< 1 – 16%	0%	0%	99 – 100%	100%	100%	100%
Communication	64 – 93%	3 – 17%	< 1 – 16%	0 - <1%	0 - <1%	99 – 100%	100%	100%	100%

Source: HAZUS-MH 2.1

Impact on 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. A Level 2 HAZUS-MH analysis 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. This is reported in the "Impact on General Building Stock" subsection discussed earlier in this section. 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 includes 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 discussed below.

It is significant to note that for the 500-year event, HAZUS-MH 2.1 estimates the County will incur nearly $1.3 million in income losses (wage, rental, relocation and capital-related losses) in addition to the 500 –year event structural, non-structural, content and inventory losses ($5.4 million).

For the 2,500-year event, HAZUS-MH 2.1 estimates the County will incur approximately $14 million in income losses, mainly to the residential and commercial occupancy classes associated with wage, rental, relocation and capital-related losses. In addition, the 2,500-year event structural, non-structural, content and inventory losses equate to greater than an estimated $106 million.

Roadway segments and railroad tracks may experience damage due to ground failure and regional transportation and distribution of these materials will be interrupted as a result of an earthquake event. Losses to the community that result from damages to lifelines can be much greater than the cost of repair (HAZUS-MH 2.1 Earthquake User Manual, 2012).

Earthquake events can significantly impact road bridges. These are important because they often provide the only access to certain neighborhoods. Since softer soils can generally follow floodplain boundaries, bridges that cross watercourses should be considered vulnerable. A key factor in the degree of vulnerability will be the age of the facility or infrastructure, which will help indicate to which standards the facility was built. HAZUS-MH estimates the long-term economic impacts to the County for 15-years after the earthquake event. In terms of the transportation infrastructure, HAZUS-MH estimates $520,000 in direct repair costs to highway bridges as a result of a 2,500-year event.

HAZUS-MH 2.1 also estimates the volume of debris that may be generated as a result of an earthquake event to enable the study region to prepare and rapidly and efficiently manage debris removal and disposal. Debris estimates are divided into two categories: (1) reinforced concrete and steel that require special equipment to break it up before it can be transported, and (2) brick, wood and other debris that can be loaded directly onto trucks with bulldozers (HAZUS-MH Earthquake User's Manual).

For the 100-year MRP event, HAZUS-MH 2.1 does not estimate any debris will be generated. For the 500-year MRP event, HAZUS-MH 2.1 estimates greater than 2,500 tons of debris will be generated. For the 2,500-year MRP event, HAZUS-MH 2.1 estimates nearly 25,000 tons of debris will be generated.

Table 5.4.1-15. Estimated Debris Generated by the 500- and 2,500-year MRP Earthquake Events

Municipality	500-Year		2,500-Year	
	Brick/Wood (tons)	Concrete/Steel (tons)	Brick/Wood (tons)	Concrete/Steel (tons)

Municipality	500-Year		2,500-Year	
	Brick/Wood (tons)	Concrete/Steel (tons)	Brick/Wood (tons)	Concrete/Steel (tons)
Village of Brewster and Town of Southeast	447	113	3,722	1,488
Town of Carmel	789	171	6,792	2,294
Town of Kent	224	44	1,939	591
Villages of Cold Spring and Nelsonville	$4	18	623	238
Town of Patterson	233	52	1,951	690
Town of Philipstown	164	33	1,467	457
Town of Putnam Valley	262	51	2,298	688
Putnam County	2,193	482	18,793	6,446

Source: HAZUS-MH 2.1

Future Growth and Development

As discussed in Section 4, areas targeted for future growth and development have been identified across the County. It is anticipated that the human exposure and vulnerability to earthquake impacts in newly developed areas will be similar to those that currently exist within the County. Current building codes require seismic provisions that should render new construction less vulnerable to seismic impacts than older, existing construction that may have been built to lower construction standards.

New development located in areas with softer NEHRP soil classes may be more vulnerable to the earthquake hazard. Refer to Section 4, and the jurisdictional annexes in Section 9 for potential new development and approximate NEHRP soil class areas in Putnam County.

Effect of Climate Change on Vulnerability

Providing projections of future climate change for a specific region is challenging. 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.

Additional Data and Next Steps

A Level 2 HAZUS-MH earthquake analysis was conducted for Putnam County using the default model data, with the exception of the updated building and critical facility inventories which included user-defined data, and NEHRP soil data. Additional data needed to further refine the County's vulnerability assessment include: (1) updated demographic data to update the default data in HAZUS-MH; and (2) soil liquefaction data. Additionally, the County can identify un-reinforced masonry critical facilities and privately-owned buildings (i.e., residences) using local knowledge and/or pictometry/orthophotos. These buildings may not withstand earthquakes of certain magnitudes and plans to provide emergency response/recovery efforts for these properties can be set in place. Further mitigation actions include training of County and municipal personnel to provide post-hazard event rapid visual damage assessments, increase of County and local debris management and logistic capabilities, and revised regulations to prevent additional construction of non-reinforced masonry buildings.