5.4.3 Earthquake

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

5.4.3.1 Hazard Profile

This section provides profile information including description, extent, location, previous occurrences and losses, climate change projections and the probability of future occurrences for the earthquake 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 1995). Most earthquakes occur at the boundaries where the Earth's tectonic plates meet (faults); less than 10 percent of earthquakes occur within plate interiors. 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 1995).

The location of an earthquake is commonly described by its focal depth and the geographic position of its epicenter. Focal depth of an earthquake is depth from 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 a great distance from the epicenter (FEMA 2001).

According to the U.S. 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. Liquefaction susceptibility is determined by the geological history, depositional setting, and topographic position of the soil. 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.
- *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).

Extent

An earthquake's magnitude and intensity are used to describe the severity and size of the event. intensity describes the overall felt severity of shaking during the event and magnitude describes the size at the focus of an earthquake. The earthquake's magnitude is a measure of the energy released at the source of the earthquake. Magnitude was formerly expressed by ratings on the Richter scale. Currently, it is now most commonly expressed using the moment magnitude (Mw) scale. This scale is based on the total moment release of the earthquake (the product of the distance a fault moved, and the force required to move it). The scale is as follows:

- Great Mw > 8
- Major Mw = 7.0 – 7.9
- Strong Mw = 6.0 – 6.9
- Moderate Mw = 5.0 – 5.9
- Light Mw = 4.0 – 4.9
- Minor Mw = 3.0 – 3.9
- Micro Mw = 3.0 – 3.9

The most commonly used intensity scale is the modified Mercalli intensity scale. Ratings of the scale, as well as the perceived shaking and damage potential for structures, are shown in Table 5.4.3-1. The modified Mercalli intensity scale is generally represented visually using shake maps, which show the expected ground shaking at any given location produced by an earthquake with a specified magnitude and epicenter. An earthquake has only one magnitude and one epicenter, but it produces a range of ground shaking at sites throughout the region. This shaking depends on the distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the earth's crust. A USGS shake map shows the variation of ground shaking in a region immediately following significant earthquakes. Table 5.4.3-2 displays the MMI scale and its relationship to the areas peak ground acceleration.

Table 5.4.3-1. Modified Mercalli Intensity Scale

Mercalli Intensity	Shaking	Description
I	Not Felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Source: USGS 2016c

Table 5.4.3-2. Modified Mercalli Intensity and PGA Equivalents

Modified Mercalli Intensity	Acceleration (%g) (PGA)	Perceived Shaking	Potential Damage
I	< 0.17	Not Felt	None
II	0.17–1.4	Weak	None
III	0.17–1.4	Weak	None
IV	1.4–3.9	Light	None
V	3.9–9.2	Moderate	Very Light
VI	9.2–18	Strong	Light
VII	18–34	Very Strong	Moderate
VIII	34–65	Severe	Moderate to Heavy
IX	65–124	Violent	Heavy
X	>124	Extreme	Very Heavy

Source: Freeman et al. (Purdue University) 2004
Note: PGA Peak Ground Acceleration

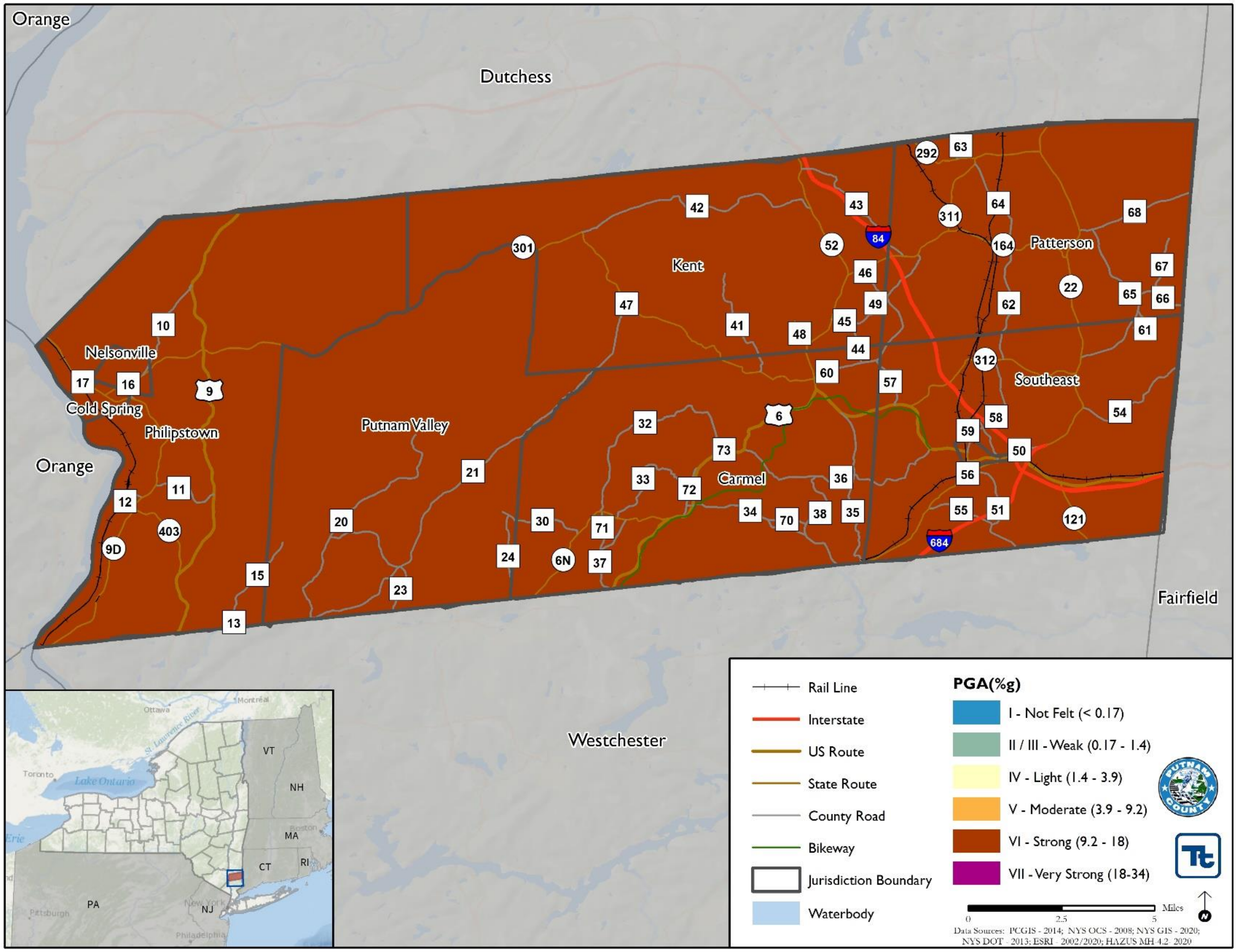
The ground experiences acceleration as it shakes during an earthquake. The peak ground acceleration (PGA) is a measure of how hard the earth shakes in a given geographic area. It is expressed as a percentage of the acceleration due to gravity (percent g). Horizontal and vertical PGA varies with soil or rock type. Earthquake hazard assessment involves estimating the annual probability that certain ground accelerations will be exceeded, and then summing the annual probabilities over a period of interest. Damage levels experienced in an earthquake vary with the intensity of ground shaking and with the seismic capacity of structures, as noted in Figure 5.4.3-1.

Table 5.4.3-3. **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.

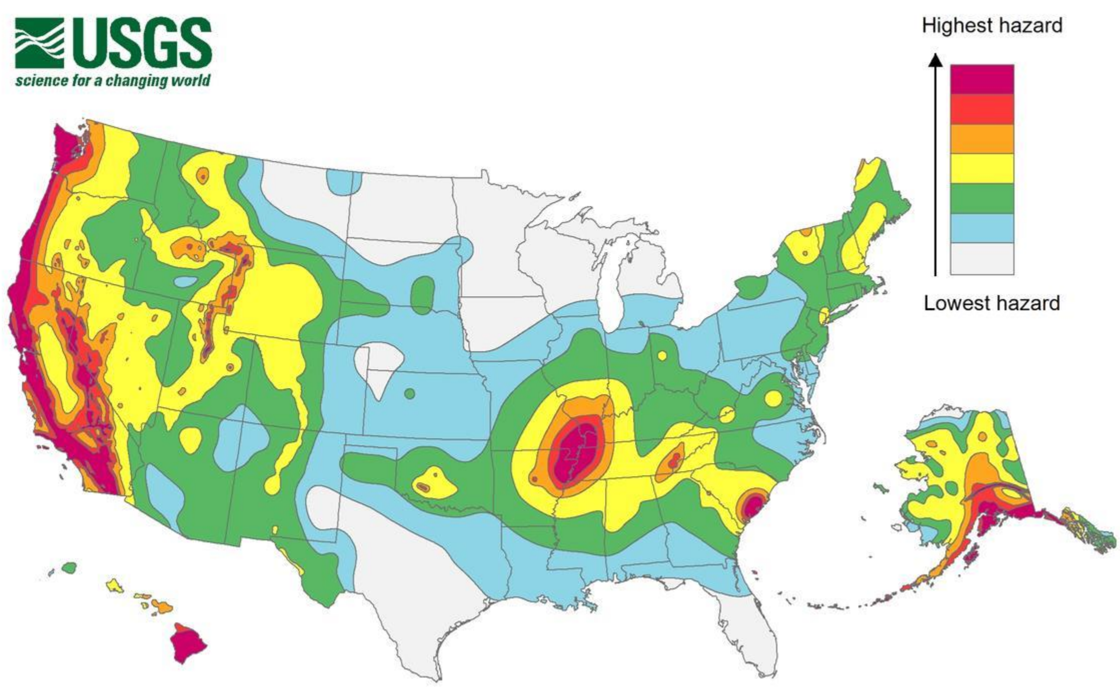
Source: NJOEM 2014
Note: %g Peak Ground Acceleration

Figure 5.4.3-1. Peak Ground Acceleration Modified Mercalli Scale for a 2,500-Year MRP Earthquake Event



National maps of earthquake shaking hazards provide information for creating and updating seismic design requirements for building codes, insurance rate structures, earthquake loss studies, retrofit priorities, and land use planning. 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 2018. New seismic, geologic, and geodetic information on earthquake rates and associated ground shaking were incorporated into these revised maps. The 2018 map represents the best available data, as determined by the USGS.

Figure 5.4.3-2. 2018 Long-Term National Seismic Hazard Map



The HAZUS-MH earthquake model was run for one mean return period (MRP) event in Putnam County to provide impacts 2,500-year MRP event. Figure 5.4.3-2 illustrates the geographic distribution of the Modified Mercalli Scale based on PGAs (*g*) across Putnam County at the census-tract level for this event. Strong shaking is projected for the across the whole county.

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 (Table 5.4.3-4). 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 Class A to Class E, as noted in Figure 5.4.3-3, where Class A represents hard rock that reduces ground motions from an earthquake and Class E represents soft soils that amplify and magnify ground shaking and increase building damage and losses. Class E soils include water-saturated mud and artificial fill. The strongest amplification of shaking due is expected for this soil type. Seismic waves travel faster through hard rock than through softer rock and sediments. As the waves pass from harder to softer rocks, the waves slow down, and their amplitude increases. Shaking tends to be stronger at locations with softer surface layers where seismic waves move more slowly. Ground motion above an unconsolidated landfill or soft soils can be more than 10 times stronger than at neighboring locations on rock for small ground motions (FEMA 2016).

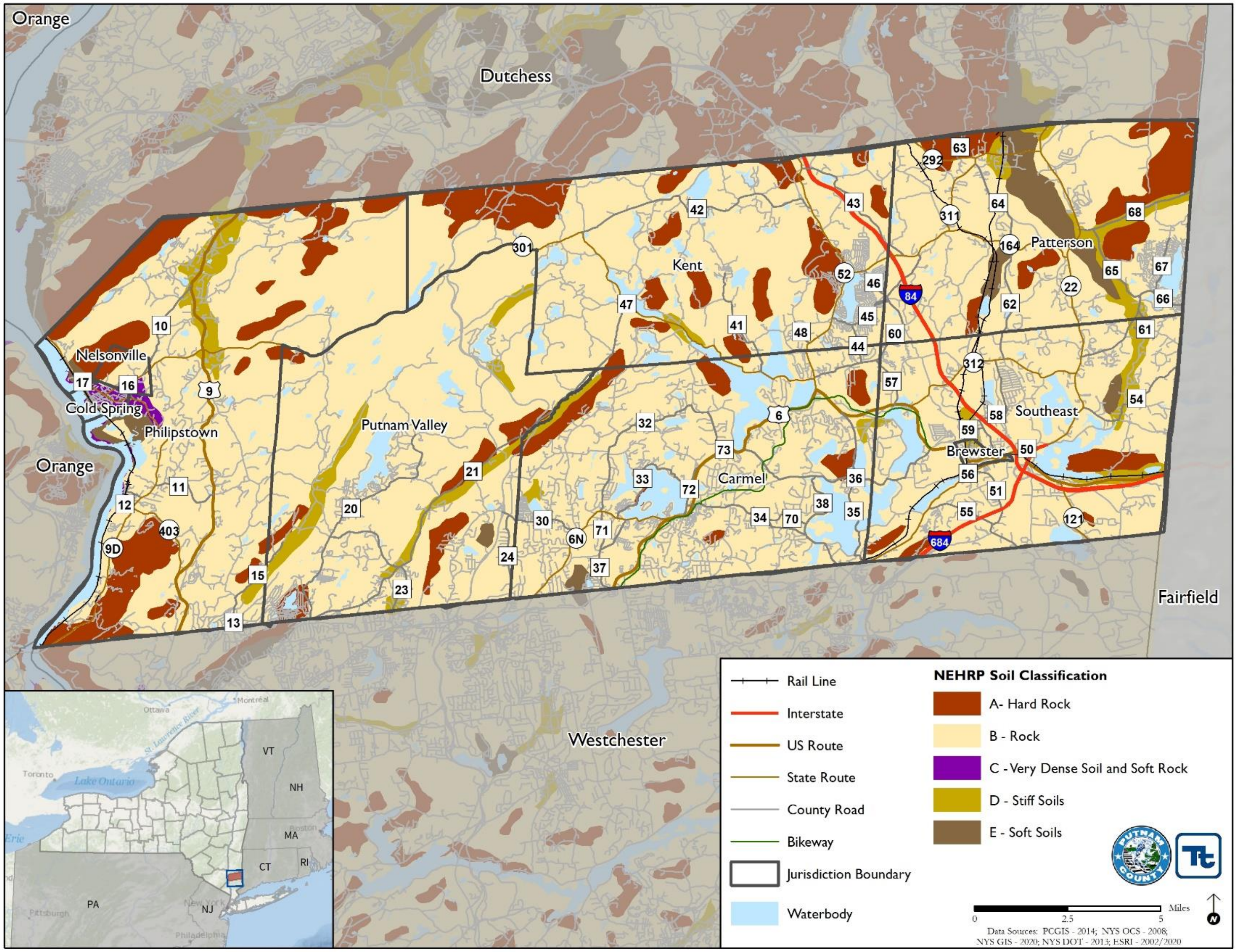
Table 5.4.3-4. NEHRP Soil Classifications

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

Source: FEMA 2013

As illustrated in Figure 5.4.3-3, soils in Putnam County are primarily NEHRP Soil Classes A and B. The vast majority of the County has Class B soils. Smalls areas of Classes D and E are located throughout the County.

Figure 5.4.3-3. NEHRP Soils in Putnam County



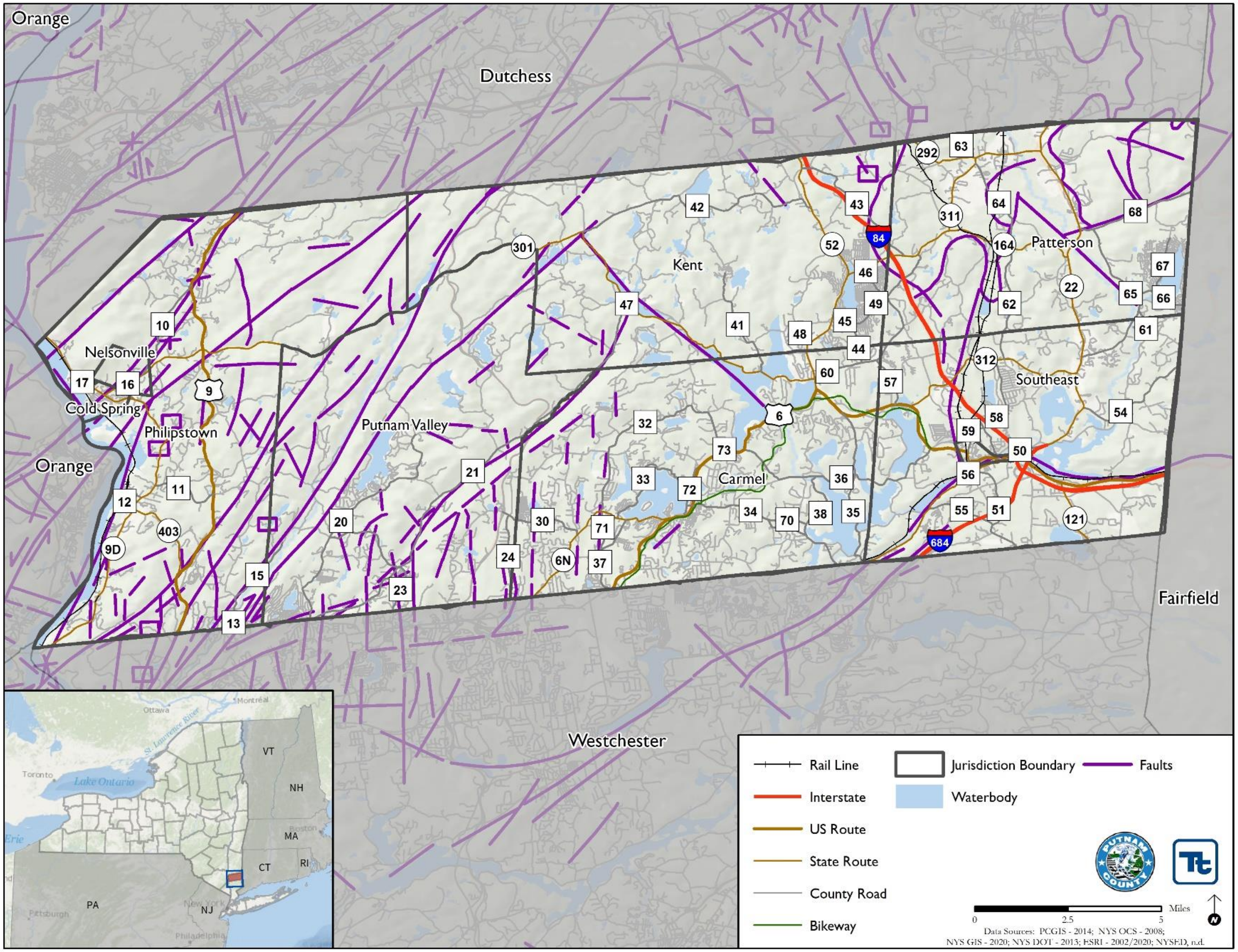
Location

There are three general regions in New York State that have a higher seismic risk compared to other parts of the state including the following:

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 and western Long Island.
3) The northwest corner, which includes Buffalo and its surrounding area.

Putnam County is in a region where a 2% in 50-year chance of peak ground accelerations between 9 and 17 are expected. (NYS DHSES 2019). Figure 5.4.3-4 shows the known faults within New York State with the Putnam County study area highlighted in yellow. According to this figure, there are several fault lines in the County, the densest cluster of which is found in the western section of Putnam County.

Figure 5.4.3-4. Fault Lines in Putnam County, New York



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 seven states, including New York. There are no seismic stations in Putnam County. There are stations in the region that service the county (LCSN 2014). In addition to the Lamont-Doherty Seismic Stations, the USGS operates a global network of seismic stations (GSN) 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.

The Advanced National Seismic System (ANSS) is run by USGS. When earthquakes strike, ANSS delivers real-time information, providing situational awareness for emergency-response personnel. In regions with sufficient seismic stations, that information includes –within minutes–a ShakeMap showing the distribution of potentially damaging ground shaking, information used to target post-earthquake response efforts. ANSS stations are operated within the state at Lake Ozonia (St. Lawrence County) and the City of Binghamton (Broome County) (USGS 2018).

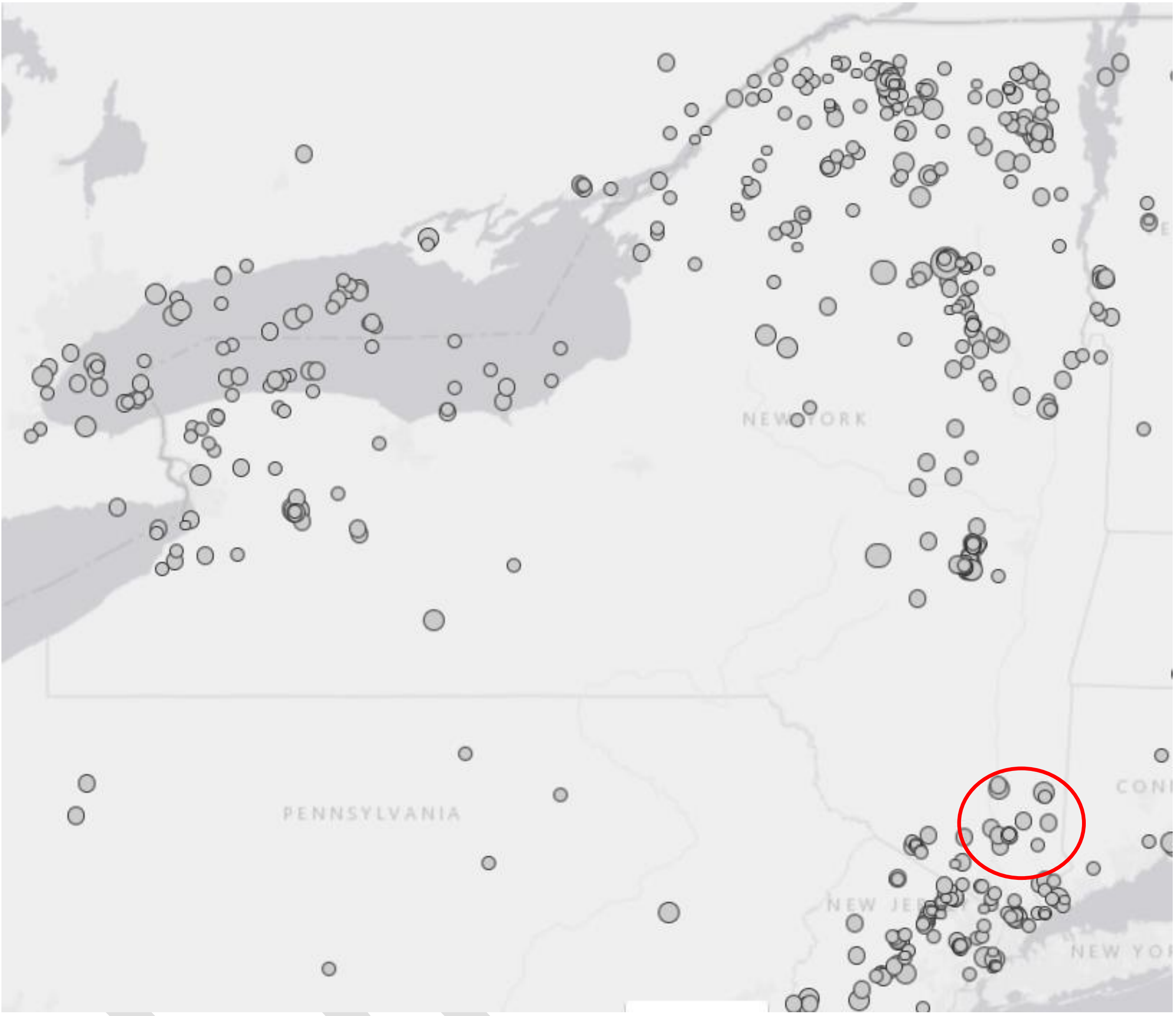
Previous Occurrences and Losses

New York State has a history of earthquake occurrences. According to the USGS earthquake catalog search, between 1950 and January 2019, the state has experienced over 500 earthquakes. Of those events, six low-magnitude earthquake epicenters were recorded in Putnam County (USGS 2020). Figure 5.4.3-5 illustrates the epicenters of earthquakes with epicenters within New York State and outside of the state. The earthquakes originating outside of the state have also been felt within the state. According to the NYS HMP, these events are considered significant for hazard mitigation planning because earthquakes such as those could inflict damage within the state in certain situations (NYS DHSES 2019).

Between 1954 and 2020, New York State was included in one earthquake-related major disaster (DR) or emergency (EM) declaration (DR-1415). The declaration occurred in 2002 and impacted Washington, Hamilton, Clinton, Warren, Essex, and Franklin counties in New York State. Generally, these disasters cover a wide region of the state and may have impacted many other counties. However, not all counties in the state were included in this disaster declaration and Putnam County was not included in any DR or EM declaration (FEMA 2020).

Known earthquakes events that have impacted New York State and Putnam County between 2015 and 2020 are identified in Table 5.4.3-5. For events prior to 2015, refer to Appendix E (Supplemental Data). Please note that many sources were researched for historical information regarding earthquake events in Putnam County; therefore, Table 5.4.3-5 might not include all earthquake events that impacted the county.

Figure 5.4.3-5. Earthquake Epicenters in the Northeast United States, January 1950 to April 2020



Source: USGS 2020d
Note: The red oval indicates the approximate location of Putnam County.

Table 5.4.3-5. Earthquake Events Impacting Putnam County, 2015 to 2020

Dates of Event	Event Type	Location	FEMA Declaration Number (if applicable)	County Designated?	Event Details*
April 10, 2017	Earthquake	Pawling, NY	N/A	N/A	A magnitude 1.3 earthquake occurred in Pawling just outside of Putnam County.
February 7, 2018	Earthquake	Putnam Valley, NY	N/A	N/A	A magnitude 2.2 earthquake with an epicenter southwest of the intersection of Oscawana Lake Road and Cimmarron Road struck in the morning of February 7th. Two aftershocks each measuring 1.3 struck approximately two minutes and two hours later.

Source(s): NYS DHSES 2020; USGS 2020d; FEMA 2020

**Many sources were consulted to provide an update of previous occurrences and losses; event details and loss/impact information may vary and has been summarized in the above table.*

Climate Change Projections

Global climate change has currently unknown impacts on earthquake probability. Some scientists believe that melting glaciers may 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 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 enable future earthquakes (Andersen et al. 2004).

Secondary impacts of earthquakes can be magnified by climate change. Soils saturated by repetitive storms could experience liquefaction during seismic activity due to the increased saturation. Dams that store 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.

Probability of Future Events

The New York City Area Consortium for Earthquake Loss Mitigation (NYCOEM) ranks New York State as having the third highest earthquake activity level east of the Mississippi River (Tantala et al. 2003). The New York State Disaster Preparedness Commission (NYS DPC) and probabilistic maps for Putnam County indicate that the potential for earthquakes does exist in the County (NYS DHSES 2019). The location of Putnam County and past events indicate that earthquakes will continue to occur. However, impacts to Putnam County may be limited. The probability of occurrence for earthquakes in the county is considered rare . Refer to Section 5.3 for additional information on the hazard ranking methodology and probability criteria.

5.4.3.2 Vulnerability Assessment

A probabilistic assessment was conducted for the 2,500-year MRPs through a Level 2 analysis in HAZUS-MH to analyze the earthquake hazard and provide a range of loss estimates. Figure 5.4.3-3 shows the geographic distribution of the NEHRP soil types in the County. Refer to Section 5.1 (Methodology and Tools) for additional details on the methodology used to assess earthquake risk.

Impact on Life, Health and Safety

Although the entire County may experience an earthquake, the degree of impact is dependent on many factors including the age and type of construction people live in, the soil types their homes are located on, the intensity of the earthquake. Whether directly or indirectly impacted, residents could be faced with business closures, road closures that could isolate populations, and loss of function of critical facilities and utilities. There is a higher risk to public safety for those inside buildings due to structural damage or people walking below building ornamentations and chimneys that may be shaken loose and fall because of an earthquake.

As noted earlier, NEHRP Soil Classes D and E can amplify ground shaking to damaging levels even during a moderate earthquake, and thus increase risk to the population. Populations within municipalities located on NEHRP Class D and E soils were estimated and are listed in Table 5.4.3-6.

Overall, approximately 5,137 residents (5.2-percent of the County's population) are located on NEHRP Class D and E soils. The Village of Brewster, Town of Putnam Valley, and Village of Cold Spring have the highest percentage of population among the 9 jurisdictions in the County with 14.7-percent, 13.2-percent, and 12.5-percent of its residents residing on the NEHRP D and E Class Soils, respectively.

Table 5.4.3-6. Approximate Population within NEHRP Class D Soil Areas

Jurisdiction	Total Population	Population Exposed to the Class D and E NEHRP Soil Hazard Area	
		Number of Persons	Percent of Total
Brewster (V)	2,087	307	14.7%
Carmel (T)	34,227	598	1.7%
Cold Spring (V)	1,862	232	12.5%
Kent (T)	13,325	19	0.1%
Nelsonville (V)	699	0	0.0%
Patterson (T)	11,922	911	7.6%
Philipstown (T)	7,163	949	13.2%
Putnam Valley (T)	11,654	975	8.4%
Southeast (T)	16,131	1,146	0.0%
Putnam County (TOTAL)	**99,070**	**5,137**	**5.2%**

Source: American Community Survey 2018, NYS n.d.
Note: T = Town, V = Village; NEHRP = National Earthquake Hazards Reduction Program

Populations considered most vulnerable are those located in/near the built environment, particularly those near unreinforced masonry structures. Of these most vulnerable populations, socially vulnerable populations, including the elderly (persons over age 65) and individuals living below the census poverty threshold, are most susceptible. Factors leading to this higher susceptibility include decreased mobility and financial ability to react or respond during a hazard, and the location and construction quality of their housing. There are 16,053 persons over the age of 65 and 5,191 persons living in poverty in Putnam County. The distribution of these vulnerable populations can be found in Section 4 (County Profile).

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 5.4.3-7 summarizes the households HAZUS-MH v4.2 estimates will be displaced and population that may require short-term sheltering as a result of the 2,500-year MRP earthquake events. HAZUS-MH v4.2 estimates are also summarized by jurisdiction for the 2,500-year MRP earthquake events in Table 5.4.3-8.

Table 5.4.3-7. Summary of Estimated Sheltering Needs for Putnam County

Scenario	Displaced Households	People Requiring Short-Term Shelter
2,500-Year Earthquake	7	4

Source: HAZUS-MH 4.2

Table 5.4.3-8. Estimated Displaced Households and Population Seeking Short-Term Shelter from the 2,500-year MRP Events by Jurisdiction

Jurisdiction	2,500-Year MRP	
	Displaced Households	People Requiring Short-Term Shelter
Brewster (V)	0	0
Carmel (T)	2	1
Cold Spring (V)	1	1
Kent (T)	0	0

Jurisdiction	2,500-Year MRP Displaced Households	People Requiring Short-Term Shelter
Nelsonville (V)	0	0
Patterson (T)	1	1
Philipstown (T)	0	0
Putnam Valley (T)	1	0
Southeast (T)	1	1
Putnam County (TOTAL)	**7**	**4**

Source: HAZUS-MH 4.2

According to the 1999-2003 NYCEM Summary Report (Earthquake Risks and Mitigation in the New York / New Jersey / Connecticut Region), a strong correlation exists between structural building damage and number of injuries and casualties from an earthquake event. Further, time of day also exposes different sectors of the community to the hazard. For example, HAZUS-MH v4.2 considers residential occupancy at its maximum at 2:00 AM, whereas educational, commercial, and industrial sectors are at their maximum at 2:00 PM, and peak commute time is at 5:00 PM. Whether directly impacted or indirectly impacted, the entire population will be affected to some degree. Business interruption could prevent people from working, road closures could isolate populations, and loss of utilities could impact populations that suffered no direct damage from an event.

Table 5.4.3-9 summarizes the County-wide injuries and casualties estimated for the 2,500-year MRP earthquake events.

Table 5.4.3-9. 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	4	16	9
Hospitalization	0	2	1
Casualties	0	0	0

Source: HAZUS-MH 4.2

Impact on General Building Stock

The entire County's general building stock is considered at risk and exposed to this hazard. As stated earlier, soft soils (NEHRP Soil Classes D and E) can amplify ground shaking to damaging levels even during a moderate earthquake (NYCEM 2003). Therefore, buildings located on NEHRP Classes D and E soils are at increased risk of damage from an earthquake. Table 5.4.3-10 summarizes the number and replacement cost value of buildings in Putnam County located on NEHRP Class D and E soils. Overall, approximately 5.4-percent of Putnam County's buildings are built on NEHRP Class D and E soils.

There is a strong correlation between PGA and damage a building might undergo (NYCEM 2003). The HAZUS-MH model is based on best available earthquake science and aligns with these statements. The HAZUS-MH probabilistic earthquake model was applied to analyze effects from the earthquake hazard on general building stock in Putnam County. See Figure 5.4.3-1 earlier in this profile which illustrates the geographic distribution of PGA (g) across the County for 2,500-year MRP events at the Census-tract level.

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 affect a building's capability to withstand an earthquake's force include its age, number of stories, and quality of construction. HAZUS-MH v4.2 considers building construction and age of building as part of the analysis., the Building ages and building types from the inventory were incorporated into the HAZUS-MH v4.2 model, as a custom general building stock was used for this HAZUS-MH v4.2 analysis.

Table 5.4.3-10. Number and Replacement Cost Value of Buildings within NEHRP Soil Areas

Jurisdiction	Total Number of Buildings	Total Replacement Cost Value (RCV)	Total (All Occupancies) Class D & E NEHRP Soils			
			Number of Buildings	Percent Total	Replacement Cost Value	Percent Total
Brewster (V)	406	$665,633,363	60	14.8%	$69,756,908	10.5%
Carmel (T)	10,170	$9,304,370,987	175	1.7%	$117,596,736	1.3%
Cold Spring (V)	679	$790,405,963	88	13.0%	$101,864,294	12.9%
Kent (T)	5,021	$2,983,284,562	7	0.1%	$7,429,887	0.2%
Nelsonville (V)	261	$209,404,256	0	0.0%	$0	0.0%
Patterson (T)	3,393	$2,927,865,178	291	8.6%	$372,801,470	12.7%
Philipstown (T)	2,767	$2,629,391,554	405	14.6%	$331,667,592	12.6%
Putnam Valley (T)	4,521	$3,314,750,529	382	8.4%	$349,977,601	10.6%
Southeast (T)	4,128	$4,717,511,487	298	7.2%	$318,574,721	6.8%
Putnam County (TOTAL)	**31,346**	**$27,542,617,878**	**1,706**	**5.4%**	**$1,669,669,209**	**6.1%**

Sources: American Community Survey 5-year Estimate, 2018; Putnam GIS 2014; RS Means 2019; NYS n.d.
Note: T = Town; V= Village

Potential building damage was evaluated using HAZUS-MH v4.2 across the following damage categories: none, slight, moderate, extensive, and complete. Table 5.4.3-11 provides definitions of these five categories of damage to a light wood-framed building; definitions of categories of damage to other building types appear in HAZUS-MH technical manual documentation.

Table 5.4.3-11. 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.
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

Building damage as a result of the 2,500-year MRP earthquake events was estimated using HAZUS-MH v4.2. Damage loss estimates include structural and non-structural damage to the building and loss of contents. Table 5.4.3-12 summarizes the estimated damages for the County by building type for the 2,500-year MRP earthquake events. HAZUS-MH estimates that 18 structures in the County will be face extensive damaged because of a 2,500-year earthquake event. The majority of these structures are wood building types. HAZUS-MH estimates that 231 structures will be moderately damaged, and majority of the buildings are wood (i.e., 172 total), followed by pre-cast concrete building types (i.e., 21 total). HAZUS-MH v4.2 also summarizes damage state estimates for buildings by general occupancy class. Table 5.4.3-12 summarizes the estimated structural damage state for buildings categorized by general building stock for the 2,500-year MRP earthquake events. Furthermore, Table 5.4.3-13 lists the severity of damage state structures will experience by the 2,500-year MRP earthquake event by general occupancy class. Table 5.4.3-14 also breaks down estimated damages by the structural general occupancy class for each jurisdiction.

Table 5.4.3-12. Estimated Number of Buildings Damaged by Building Type for 2,500-year MRP Earthquake Events

	Expected Number of Buildings Within Damage State Categories by Building Type 2,500-Year MRP				
Building Category	None	Slight	Moderate	Extensive	Complete
Wood	28,119	1,330	172	9	0
Steel	0	0	0	0	0
Concrete	906	60	24	2	0
Precast	277	27	21	5	0
Reinforced Masonry	0	0	0	0	0
Un-reinforced Masonry	334	32	14	2	0
Manufactured housing	10	1	0	0	0

Source: HAZUS-MH v4.2

Table 5.4.3-13. Estimated County-Wide Building Damage Severity by General Occupancy Class

			EQ 2,500-Year	
Occupancy Class	Total Number of Buildings in Occupancy	Severity of Expected Damage	Building Count	Percent Buildings in Occupancy Class
Residential Exposure (Single and Multi-Family Dwellings)	29,999	None	28,446	94.8%
		Minor	1,358	4.5%
		Moderate	184	0.6%
		Severe	11	0.0%
		Complete Destruction	0	0.0%
Commercial Buildings	944	None	841	89.1%
		Minor	63	6.6%
		Moderate	34	3.6%
		Severe	6	0.6%
		Complete Destruction	0	0.0%
Industrial Buildings	141	None	128	90.8%
		Minor	8	5.7%
		Moderate	4	2.8%
		Severe	1	0.7%
		Complete Destruction	0	0.0%
Government, Religion, Agricultural, and Education Buildings	262	None	231	88.2%
		Minor	21	8.1%
		Moderate	8	3.2%
		Severe	1	0.5%

Occupancy Class	Total Number of Buildings in Occupancy	Severity of Expected Damage	EQ 2,500-Year	
			Building Count	Percent Buildings in Occupancy Class
		Complete Destruction	0	0.0%

Source: HAZUS-MH v4.2

Table 5.4.3-14. Estimated Building Value (Building and Contents) By General Occupancy Classes and Estimated Damage in the 2,500-Year MRP Earthquake Events

Jurisdiction	Replacement Cost Value	Estimated Total Damage 2,500-Year	Percent of Total Building and Contents RCV 2,500-Year	Estimated Residential Damage 2,500-Year	Estimated Commercial Damage 2,500-Year	Estimated Damages for All Other Occupancies 2,500-Year
Brewster (V)	$665,633,363	$1,322,398	0.2%	$898,453	$184,040	$239,905
Carmel (T)	$9,304,370,987	$32,364,230	0.3%	$25,820,315	$3,915,594	$2,628,321
Cold Spring (V)	$790,405,963	$5,254,888	0.7%	$3,852,347	$535,870	$866,670
Kent (T)	$2,983,284,562	$7,797,013	0.3%	$6,652,698	$684,582	$459,732
Nelsonville (V)	$209,404,256	$2,020,321	1.0%	$1,481,269	$205,902	$333,149
Patterson (T)	$2,927,865,178	$12,687,197	0.4%	$9,233,441	$2,159,608	$1,294,148
Philipstown (T)	$2,629,391,554	$11,183,981	0.4%	$8,940,475	$1,594,497	$649,009
Putnam Valley (T)	$3,314,750,529	$13,895,337	0.4%	$12,337,116	$913,548	$644,673
Southeast (T)	$4,717,511,487	$17,437,282	0.4%	$11,494,720	$4,206,405	$1,736,157
Putnam County (TOTAL)	**$27,542,617,878**	**$103,962,645**	**0.4%**	**$80,710,835**	**$14,400,046**	**$8,851,764**

Source: HAZUS-MH v4.2
Notes: V = Village; T = Town

HAZUS-MH v4.2 estimates approximately $103.9 million of damage as a result of the 2,500-year MRP event. These damages account for less than 1-percent of total building replacement value in Putnam County for the 2,500-year MRP event. The sum of damages calculated in HAZUS-MH v4.2 include structural damage, non-structural damage, and loss of contents. Residential buildings account for majority of the building replacement cost damages.

Impacts on Critical Facilities

Approximately 9.1-percent of the critical facilities in Putnam County are considered exposed to the earthquake hazard. Refer to subsection "Critical Facilities" in Section 4 (County Profile) of this HMP for a complete inventory of critical facilities in Putnam County. Of the 419 critical facilities in the county, 38 are located on NEHRP Class D and E soils. Of the 38 critical facilities located on NEHRP Class D and E soils, 33 are considered lifelines for the County. The Town of Patterson has the greatest number of critical facilities exposed to the earthquake hazard area, and majority of the exposed critical facilities are government facilities. Table 5.4.3-15 summarizes the number of critical facilities by type per jurisdiction in Putnam County located on NEHRP Soil Class D and E hazard areas. Table 5.4.3-16 summarizes the number of lifelines summarized by FEMA's lifeline categories exposed to NEHRP Class D and E Soils.

Table 5.4.3-15. Number of Critical Facilities within the NEHRP Class D and E Soil Hazard Area

Jurisdiction	Facility Types													
	Commercial	Communication	Electric	Fire Station	Government	Highway Bridge	Marina	Natural Gas Facility	Oil Facility	Potable Water	Rail Facility	Recreation	School Facility	Wastewater Facility
Brewster (V)	1	0	0	0	0	0	0	0	1	0	0	0	1	0
Carmel (T)	0	0	1	0	1	0	0	0	0	1	0	0	0	2
Cold Spring (V)	0	0	0	0	0	0	1	0	0	0	1	0	0	2
Kent (T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nelsonville (V)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Patterson (T)	0	1	1	1	3	3	0	2	0	0	1	1	2	5
Philipstown (T)	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Putnam Valley (T)	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Southeast (T)	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Putnam County (TOTAL)	**1**	**2**	**3**	**2**	**7**	**3**	**1**	**2**	**1**	**1**	**2**	**1**	**3**	**9**

Source: Putnam County GIS 2020, NYS n.d
Notes: T= Town; V= Village

Table 5.4.3-16. Number of Lifelines Exposed to NEHRP D and E Soils

FEMA Lifeline Category	Number of Lifelines	Number of Lifelines Exposed to NEHRP Class D and E Soils
Communications	21	2
Energy	23	6
Food, Water, Shelter	150	10
Health and Medical	18	0
Safety and Security	114	9
Shelter	1	1
Transportation	35	5
Putnam County (TOTAL)	**362**	**33**

Source: Putnam County GIS 2020; NYS n.d.

The HAZUS-MH v4.2 earthquake model was used to assign a probability of each damage state category defined in Table 5.4.3-17 to every critical facility in the planning area for the 2,500-year MRP event, which was then averaged across the facility category. In addition, HAZUS-MH v4.2 estimates the time to restore critical facilities to fully functional use. Results are presented as the probability of being functional at specified time increments (days after the event). For example, HAZUS-MH v4.2 might estimate that a facility has a 5-percent chance of being fully functional at Day 3, and a 95-percent chance of being fully functional at Day 90. For percent probability of sustaining damage, the minimum and maximum damage estimated value for that facility type is presented. As a result of a 2,500-year MRP event, HAZUS-MH v4.2 estimates that critical facilities will be nearly 100-percent functional with negligible damages with the exception of fire stations, schools, and wastewater facilities that have lost 46.8-percent, 17.8-percent, and 46.9-percent functionality at Day 1, respectively. Almost all critical facilities will be nearly 100-percent function by Day 30 or Day 90.

Table 5.4.3-17. Estimated Damage and Loss of Functionality for Critical Facilities, Utilities, and Transportation Facilities in Putnam County 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	96.1%	3.4%	0.4%	<0.1%	0.0%	96.1%	99.4%	99.9%	99.9%
Medical	97.7%	2.2%	0.1%	0.0%	0.0%	97.6%	99.8%	99.9%	99.9%
Police	80.5%-93.5%	3.6%-9.3%	2.4%-7.9%	0.4%-2.2%	<0.1%	80.5%-93.5%	89.6%-97.0%	97.7%-99.5%	98.9%-99.7%
Fire	53.2%-93.5%	3.6%-17%	2.4%-20.3%	0.5%-9.2%	0.0%-0.2%	53.2%-93.5%	69.8%-97.0%	90.5%-99.5%	95.1%-99.7%
Schools	82.2%-95.5%	2.9%-9.2%	1.4%-7.2%	0.1%-1.4%	0.0%	82.2%-95.5%	91.1%-98.3%	99.7%	99.8%
Utilities									
Communication Facilities	58.2%-91.9%	5%-17.2%	2.7%-18.8%	0.3%-5.5%	0.0%	85.8%-98.3%	97%-99.8%	99.9%	99.9%
Electric Power Facilities	72.7%-93.5%	3.6%-12.1%	2.4%-11.4%	0.5%-3.7%	0.0%	79.9%-95.5%	98%-99.7%	99.9%	99.9%
Natural Gas Facilities	75.9%-93.6%	3.6%-11.0%	2.4%-10.0%	0.5%-3.0%	0.0%	85.3%-96.3%	96.9%-99.4%	99.9%	99.9%
Oil Facilities	-	-	-	-		0.0%	0.0%	0.0%	0.0%
Potable Water Facilities	-	-	-	-	-	0.0%	0.0%	0.0%	0.0%
Wastewater Facilities	44.3%-93.6%	3.6%-18.2%	2.4%-24.2%	0.5%-12.7%	0.0%-0.6%	53.1%-95%	84.9%-99.5%	88.7%-99.8%	98.4%-99.9%
Transportation									
Bus Facilities	93.4%	3.7%	2.5%	0.5%	0.0%	98.0%	99.5%	99.6%	99.8%
Railway Facilities	50.6%-97.7%	2.2%-33.9%	0.1%-14.4%	0.2%	0%-0.2%	92.6%-99.9%	99.6%	99.7%	99.8%
Highway Bridges	99.9%	0.0%-0.6%	0%-0.2%	0%-0.1%	0.0%	99.9%	99.9%	99.9%	99.9%
Rail Bridges	100.0%	0.0%	0.0%	0.0%	0.0%	99.9%	99.9%	99.9%	99.9%

Source: HAZUS-MH 4.2
Notes: EOC = Emergency Operation Center

Impact on Economy

Earthquakes also impact the economy, including loss of business function, damage to inventory (buildings, transportation, and utility systems), relocation costs, wage loss, and rental loss due to repair and replacement of buildings. HAZUS-MH v4.2 estimates building-related economic losses, including income losses (wage, rental, relocation, and capital-related losses) and capital stock losses (structural, non-structural, content, and inventory losses). Economic losses estimated by HAZUS-MH v4.2 are summarized in Table 5.4.3-18.

Table 5.4.3-18. Building-Related Economic Losses from the 2,500-Year MRP Earthquake Event

Level of Severity	Mean Return Period 2,500-year
Income Losses	
Wage	$2,792,500
Capital Related	$2,240,400
Rental	$1,805,200
Relocation	$3,783,200

Level of Severity	Mean Return Period 2,500-year
Subtotal	**$10,621,300**
Capital Stock Losses	
Structural	$9,332,900
Non-Structural	$64,385,000
Content	$30,243,800
Inventory	$224,700
Subtotal	**$104,186,400**

Source: HAZUS-MH v4.2

Although the HAZUS-MH v4.2 analysis did not compute damage estimates for individual roadway segments and railroad tracks, assumedly these features would undergo damage due to ground failure resulting in interruptions of regional transportation and of distribution of materials. Losses to the community that would result from damage to lifelines could exceed costs of repair (FEMA 2012). Earthquake events can significantly affect road bridges, many of which provide the only access to certain neighborhoods. Because softer soils generally follow floodplain boundaries, bridges that cross watercourses should be considered vulnerable. Another key factor in degree of vulnerability is age of facilities and infrastructure, which correlates with standards in place at time of construction.

Additionally, HAZUS-MH v4.2 estimates volume of debris that may be generated as a result of an earthquake event to enable the study region to prepare for and rapidly and efficiently manage debris removal and disposal. Debris estimates were divided into two categories: (1) reinforced concrete and steel that require special equipment to break up before transport can occur, and (2) brick, wood, and other debris that can be loaded directly onto trucks by use of bulldozers (HAZUS-MH Earthquake User's Manual).

HAZUS-MH v4.2 estimated the generation of over 7,941 tons of total debris during the 2,500-year MRP event, and Table 5.4.3-19 below lists estimated debris generated by the 2,500-year MRP event.

Table 5.4.3-19 Estimated Debris Generated by the 2,500-year MRP Earthquake Event

Jurisdiction	2,500-Year	
	Brick/Wood (tons)	Concrete/Steel (tons)
Brewster (V)	68	61
Carmel (T)	1,312	968
Cold Spring (V)	331	222
Kent (T)	290	190
Nelsonville (V)	127	85
Patterson (T)	544	684
Philipstown (T)	372	323
Putnam Valley (T)	460	225
Southeast (T)	593	1,086
Putnam County (TOTAL)	**4,098**	**3,843**

Source: HAZUS-MH v4.2

Impact on the Environment

According to USGS, earthquakes can cause damage to the surface of the Earth in various forms depending on the magnitude and distribution of the event (USGS 2020). Surface faulting is one of the major seismic components to earthquakes that can create wide ruptures in the ground. Ruptures can have a direct impact on the landscape and natural environment because it can disconnect habitats for miles isolating animal species or tear apart plant roots.

Furthermore, ground failure as a result of soil liquefaction can have an impact on soil pores and retention of water resources (USGS 2020). The greater the seismic activity and liquefaction properties of the soil, the more likely drainage of groundwater can occur which depletes groundwater resources. In areas where there is higher pressure of groundwater retention, the pores can build up more pressure and make soil behave more like a fluid rather than a solid increasing risk of localized flooding and deposition or accumulation of silt (USGS 2020).

Cascading Impacts to Other Hazards

The Global Geoengineering Research Group in USGS has been investigating the relationship earthquakes have with ground deformation and ground failure (USGS 2019). As mentioned in earlier sections, soft and loose soils are more susceptible to earthquake events. Ground failure can become exacerbated due to earthquake events, causing landsliding. Areas of steep slopes are at greater risk of ground failure and potential erosion during earthquakes (USGS 2019).

Further, residual impacts from earthquakes could alter the floodplain extent for the County if ground failure and erosion occur. Damage to coastal levees or canals may become breached as a result of an earthquake event, which could create flooding in the impacted areas. Refer to Section 5.4.4 (Flood) for more information about the flood hazard area.

Future Changes That May Impact Vulnerability

Understanding future changes that effect vulnerability in the County can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. The County considered the following factors to examine potential conditions that may affect hazard vulnerability:

- Potential or projected development
- Projected changes in population
- Other identified conditions as relevant and appropriate, including the impacts of climate change

Projected Development

As discussed in Section 4, areas targeted for future growth and development have been identified across the County. Any areas of growth located in the defined earthquake hazard areas could be potentially impacted by earthquakes. There are 3 new development sites located within the earthquake hazard area.

It is recommended that the County and municipal partners implement design strategies that follow the New York State Department of Transportation Geotechnical Design Manual (2015) for all development projects (NYSDOT 2015). Please refer to Figure 5.4.3-6 for potential new development in the County and their proximity to the earthquake hazard areas.

Projected Changes in Population

According to the U.S. Census Bureau, the population in Putnam County has decreased by approximately 0.7-percent between 2010 and 2018 (US Census Bureau 2020). Estimated population projections provided by the

2017 Cornell Program on Applied Demographics indicates that the County's population will increase slowly into 2040, increasing the total population to approximately 100,435 persons (Cornell University Program on Applied Demographics 2017). Persons that move into older structures in the County are at greater risk of being impacted by earthquake events because older structures are more vulnerable to ground shaking. Refer to Section 4 (County Profile), which includes a more thorough discussion about population trends for the County.

Climate Change

Because the impacts of climate change on the earthquakes are not well understood, a change in the County's vulnerability is difficult to determine. However, climate change has the potential to magnify secondary impacts of earthquakes. As a result of the climate change projections discussed above, the County's assets located on areas of saturated soils and on or at the base of steep slopes, are at a higher risk of landslides/mudslides because of seismic activity.

Change of Vulnerability Since 2015 HMP

Several differences exist between the 2015 plan and this update. For this hazard mitigation plan, the general building stock from 2015 was updated using structural and content replacement cost values from RS Means 2019. Updated critical facility inventory was provided by the County and was used to assess the County's risk to the hazard areas. In addition, the 2018 American Community Survey population estimates were used and estimated at a structural level in place of the 2010 U.S. Census blocks. Finally, an updated version of HAZUS-MH was used to assess the estimated damages from probabilistic earthquake hazard events (i.e., v4.2).

Identified Issues

Identified issues associated with an earthquake in Putnam County include the following:

- Critical facility owners should be encouraged to create or enhance a continuity of operations plan using the information on risk and vulnerability contained in this plan update.
- Identifying assets built prior to the uniform application of seismic provisions in the state will provide a basis to better understand the vulnerability of building stock in the County.

Figure 5.4.3-6. New Development and NEHRP Soil Types in Putnam County