9. EARTHQUAKE

9.1 HAZARD PROFILE

9.1.1 Hazard Description

An earthquake is the vibration of the earth's surface following a release of energy in the earth's crust. This energy can be generated by a sudden dislocation of the crust or by a volcanic eruption. Most destructive quakes are caused by dislocations of the crust. The crust may first bend and then, when the stress exceeds the strength of the rocks, break and snap to a new position. The process of breaking generates vibrations called seismic waves. These waves travel outward from the source of the earthquake at varying speeds and ultimately result in potentially damaging movement of the earth's surface.

Earthquake Geology

Tectonic Plates

The earth's crust, which is the rigid outermost shell of the planet, is broken into seven or eight major tectonic plates (depending on how they are defined) and many minor plates. Where the plates meet, they move in one of three ways along their mutual boundary: convergent (two plates moving toward one another), divergent (two plates moving apart), or transform (two plates moving parallel to one another). Earthquakes, volcanic activity, mountain-building, and oceanic trench formation occur along these plate boundaries. Subduction is a geological process that takes place at convergent boundaries of tectonic plate, in which one plate moves under another. Regions where this process occurs are known as subduction zones, and they have the potential to generate highly damaging earthquakes.

Faults

Geologists have found that earthquakes reoccur along faults, which are zones of weakness in the earth's crust. When a fault experiences an earthquake, there is no guarantee that all the stress has been relieved. Another earthquake can still occur. In fact, relieving stress along one part of a fault may increase it in another part.

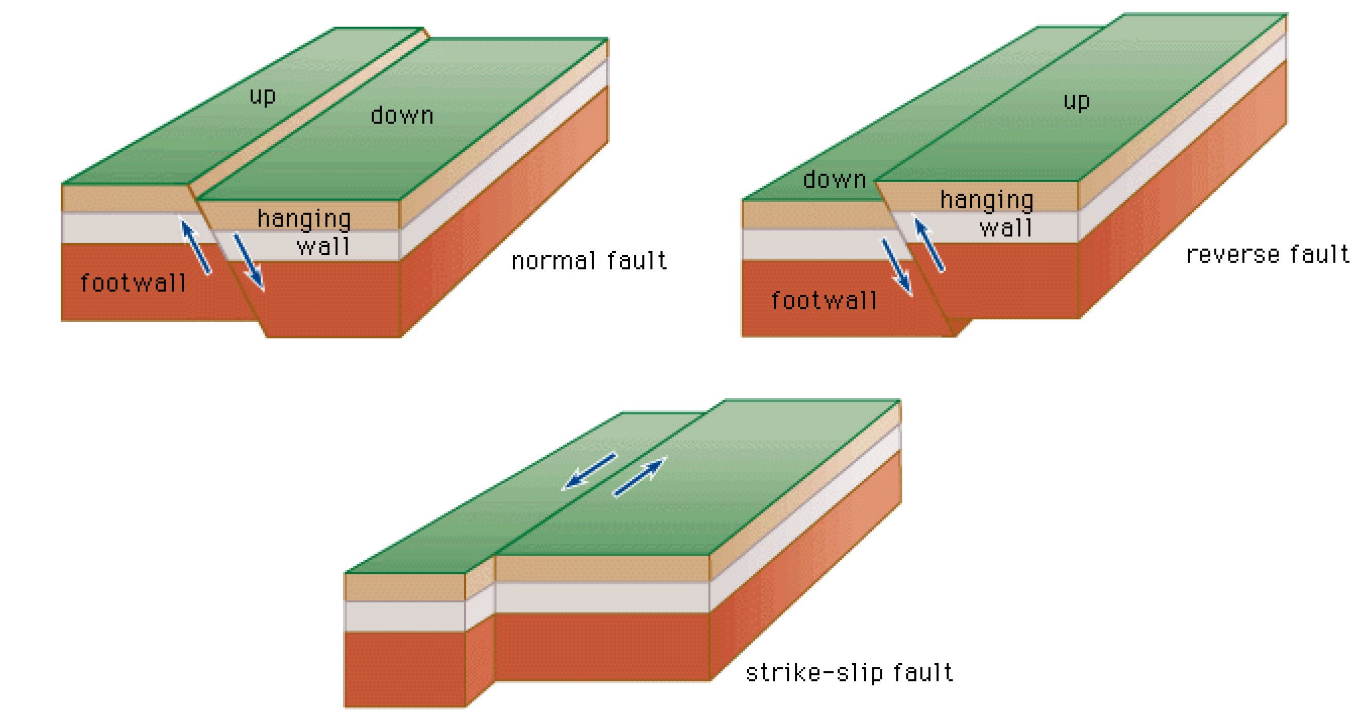
Faults are more likely to have future earthquakes on them if they have more rapid rates of movement, have had recent earthquakes along them, experience greater total displacements, and are aligned so that movement can relieve the accumulating tectonic stresses. Geologists classify faults by their relative hazards. "Active" faults, which represent the highest hazard, are those that have ruptured to the ground surface during the Holocene period (about the last 11,000 years). "Potentially active" faults are those that displaced layers of rock from the Quaternary period (the last 1,800,000 years) (Machette 2000).

Earthquake-Related Hazards

An earthquake hazard is anything associated with an earthquake that may affect people's normal activities. This includes the following (Earthquake Hazard Program n.d.):

- **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 12 miles. Figure 9-1 illustrates three types of surface faults.

Figure 9-1. Surface Fault Types



Source: Encyclopedia Britannica, Inc., 1994

- **Ground Motion (shaking)**—The movement of the earth's surface produced by waves that are generated by sudden slip on a fault and travel through the earth from the fault to the surface.
- **Liquefaction**—A process by which water-saturated soils temporarily lose strength and act as a fluid. Earthquake shaking can cause this effect. When liquefaction occurs, the strength of the soil decreases and the soil's ability to support foundations for buildings and bridges is reduced. Liquefaction has been responsible for tremendous amounts of damage in historical earthquakes around the world.

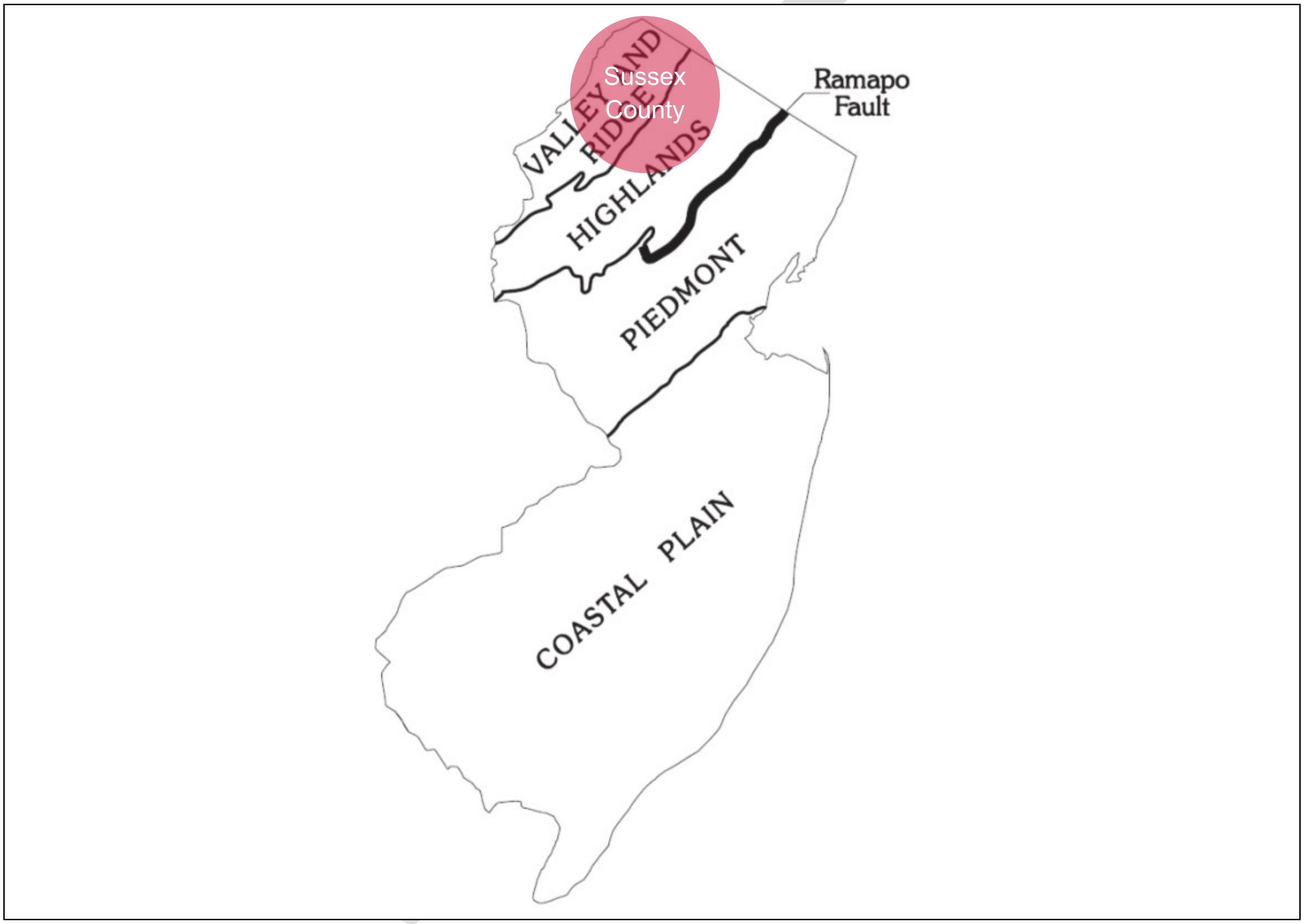
Shaking behavior and liquefaction susceptibility of soils are determined by their grain size, thickness, compaction, and degree of saturation. These properties, in turn, are determined by the geologic origin of the soils and their topographic position. Earthquake damage is least likely on rock or dense soils that resist motion and most likely on softer soils that can amplify ground shaking because they are susceptible to movement and liquefaction. One contributor to this amplification is the velocity at which the rock or soil transmits shear waves. The National Earthquake Hazard Reductions Program (NEHRP) has classified soils as follows, based on their shear-wave velocity:

- A—Hard Rock (greatest shear-wave velocity and least amplification of earthquake impacts)
- B—Rock
- C—Very dense soil and soft rock
- D—Stiff soils
- E—Soft soils (lowest shear-wave velocity and greatest amplification of earthquake impacts)
- F—Special soil requiring site-specific analysis

9.1.2 Location

Earthquakes in New Jersey are most likely in the northern part of the state, including Sussex County, where significant fault lines are concentrated. Most earthquakes in the state have occurred along faults in the central and eastern Highlands, with the Ramapo fault being the most seismically active fault in the region. The Ramapo Fault separates the Piedmont and Highlands Physiographic Provinces, as shown in Figure 9-2. Although the fault line is not within Sussex County, the County may still feel the effects of an earthquake along the Ramapo Fault due to its proximity. The Reservoir Fault, which borders the Green Pond Mountain region, is another major fault line in the state and is even closer to Sussex County than the Ramapo Fault (Volkert and Witte 2015).

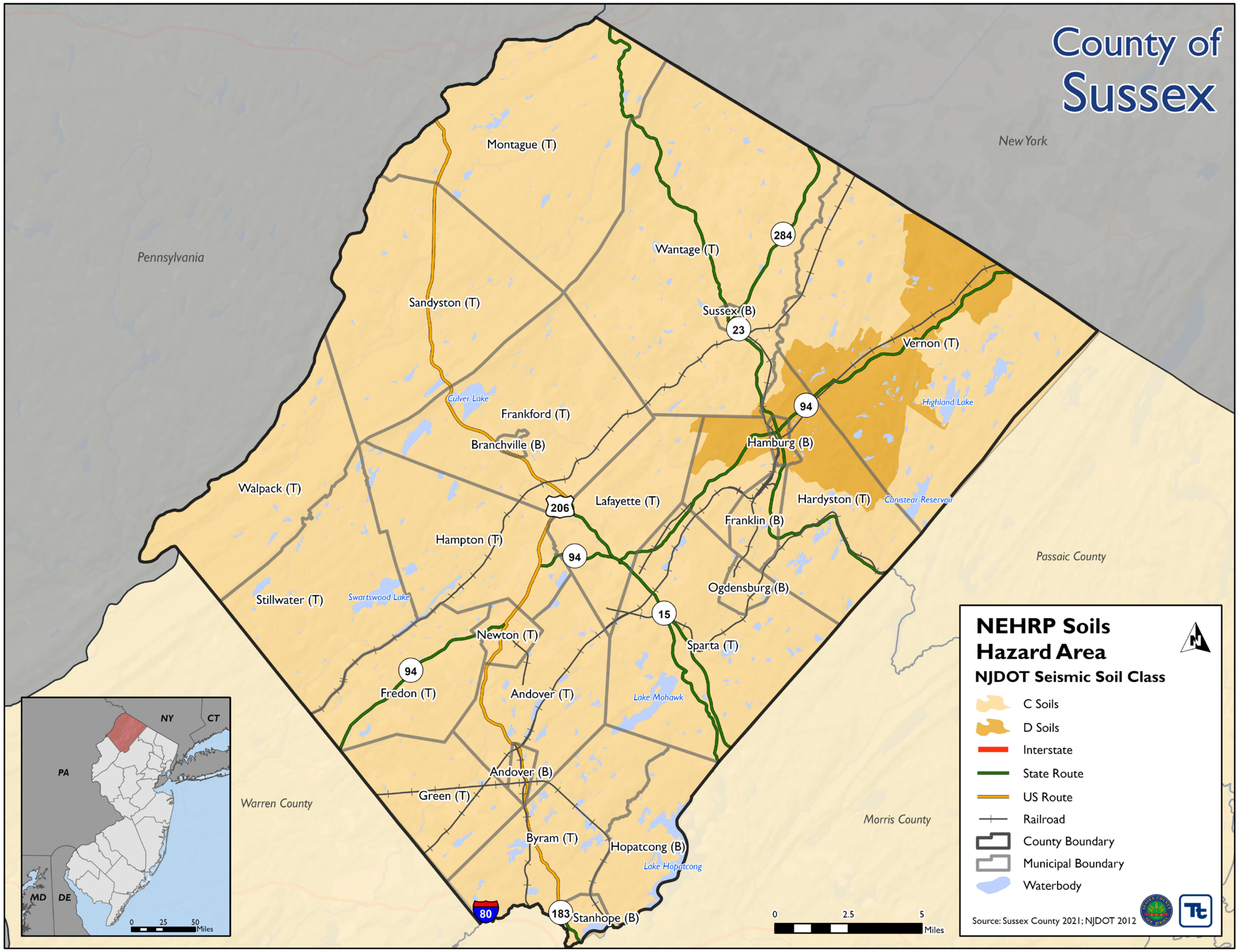
Figure 9-2. Physiographic Provinces of New Jersey and the Ramapo Fault Line



Source: Dombroski 1973 (revised 2005)

The New Jersey Department of Transportation (NJDOT) developed a Geotechnical Database Management System, which contains soil boring data across New Jersey. The soil boring logs were used to classify soil sites. Through this analysis, NJDOT developed a map of soil site classes according to ZIP codes in the state where each ZIP code was assigned a class based on its predominant soil condition. In Sussex County, most ZIP codes were classified as “C,” and a few were rated as “D”, as shown in Figure 9-3 (NJOEM 2019)

Figure 9-3. NEHRP Soils in Sussex County as Mapped by NJDOT



9.1.3 Extent

The severity of an earthquake can be determined by factors such as amount of seismic energy released; duration of shaking; depth of focus (hypocenter); distance from epicenter; geological, geographic, and topographic setting; population and building density; and even time of day (Reger 2023). These factors define earthquake magnitude and intensity. The magnitude is the energy released at the location of the earthquake-generating event. Intensity is the earthquake energy felt at any given location within the range of the earthquake's impacts. An earthquake has only one magnitude and one epicenter, but its intensity varies throughout the region, depending on the distance from the earthquake, local rock and soil conditions, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the earth's crust.

Magnitude

Earthquake magnitude is commonly expressed by ratings on the moment magnitude scale (M_W). 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 (U.S. Geological Survey 2021):

- 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

Historically, Sussex County has not experienced a major-magnitude earthquake. However, small earthquakes may occur several times a year and generally do not cause significant damage. The largest earthquake to impact Sussex County was a magnitude 5.3 with an epicenter located in New York City (NJOEM 2019).

Intensity

The Modified Mercalli Scale is the most commonly used scale of earthquake intensity. Ratings of the scale, as well as the perceived shaking and damage potential for structures, are shown in Table 9-1. Damage levels experienced in an earthquake vary with the intensity of ground shaking and with the seismic capacity of structures, as noted in Table 9-2.

Ground Motion

During an earthquake when the ground is shaking, it also experiences acceleration. Instruments called seismometers record levels of ground acceleration due to earthquakes at stations throughout a region. From this data, estimates are developed of the annual probability that certain ground motion accelerations will be exceeded (USGS 2019). The most commonly mapped ground motion parameters are horizontal and vertical peak ground accelerations (PGA) for a given soil type. PGA is a measure of how hard the earth shakes, or accelerates, in a given geographic area. PGA is measured as a percentage of the acceleration due to gravity (%g). These readings are recorded by state and federal agencies that monitor and predict seismic activity (USGS 2019).

Maps of PGA values form the basis of seismic zone maps that are included in building codes such as the International Building Code. Building codes that include seismic provisions specify the horizontal force due to lateral acceleration that a building should be able to withstand during an earthquake. Short-period seismic motions are of concern for smaller structures such as single-family dwellings. Longer period response components determine the lateral forces that damage larger structures (apartment buildings, factories, high-rises, bridges) (USGS 2019). Table 9-3 lists damage potential and perceived shaking by PGA factors, compared to the Mercalli scale.

Table 9-1. Modified Mercalli Scale

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

Source: USGS 1989

Table 9-2. Damage Levels Experienced in Earthquakes

Ground Motion	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 2019
Note: %g = Peak Ground Acceleration as a percentage of the acceleration due to gravity

Table 9-3. Modified Mercalli Scale and PGA Equivalents

Mercalli Intensity	PGA (%g)	Perceived Shaking	Potential Damage
I	<0.17%	Not Felt	None
II-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 - XII	>124%	Extreme	Very Heavy

Source: USGS 1989

Figure 9-4 and Figure 9-5 show geographic distributions of the Modified Mercalli Scale based on PGA across Sussex County for 500-year and 1,000-year mean return period (MRP) events at the census-tract level. A 500-year MRP event is an earthquake with 0.2-percent chance that mapped ground motion levels will be exceeded in any given year. A 1,000-year MRP is an earthquake with 0.1 percent chance that mapped PGAs will be exceeded in any given year.

National Seismic Hazard Map

USGS has developed National Seismic Hazard Maps. that provide information for creating and updating seismic design requirements for building codes, insurance rate structures, earthquake loss studies, retrofit priorities, and land use planning. The 2023 map, shown in Figure 9-6, represents the best currently available data as determined by the USGS.

Shake Maps

The USGS Earthquake Hazards Program produces maps called ShakeMaps that map ground motion and shaking intensity following significant earthquakes. ShakeMaps focus on the ground shaking caused by the earthquake, rather than on characteristics of the earthquake source, such as magnitude and epicenter. A ShakeMap shows the extent and variation of ground shaking across the surrounding region following significant earthquakes. Such mapping is derived from peak ground acceleration amplitudes recorded on seismic sensors, with interpolation where data is lacking based on estimated amplitudes. Color-coded instrumental intensity maps are derived from empirical relations between peak ground motions and Modified Mercalli intensity. In addition to the maps of recorded events, the USGS creates the following:

- Scenario ShakeMaps of hypothetical earthquakes of an assumed magnitude on known faults.
- Probabilistic ShakeMaps, based on predicted shaking from earthquakes over a 10,000-year period. In a probabilistic map, information is combined to make a forecast for the future. The maps indicate the ground motion at any given point that has a given probability of being exceeded in a given timeframe.

Figure 9-4. Peak Ground Acceleration 500-Year Mean Return Period for Sussex County

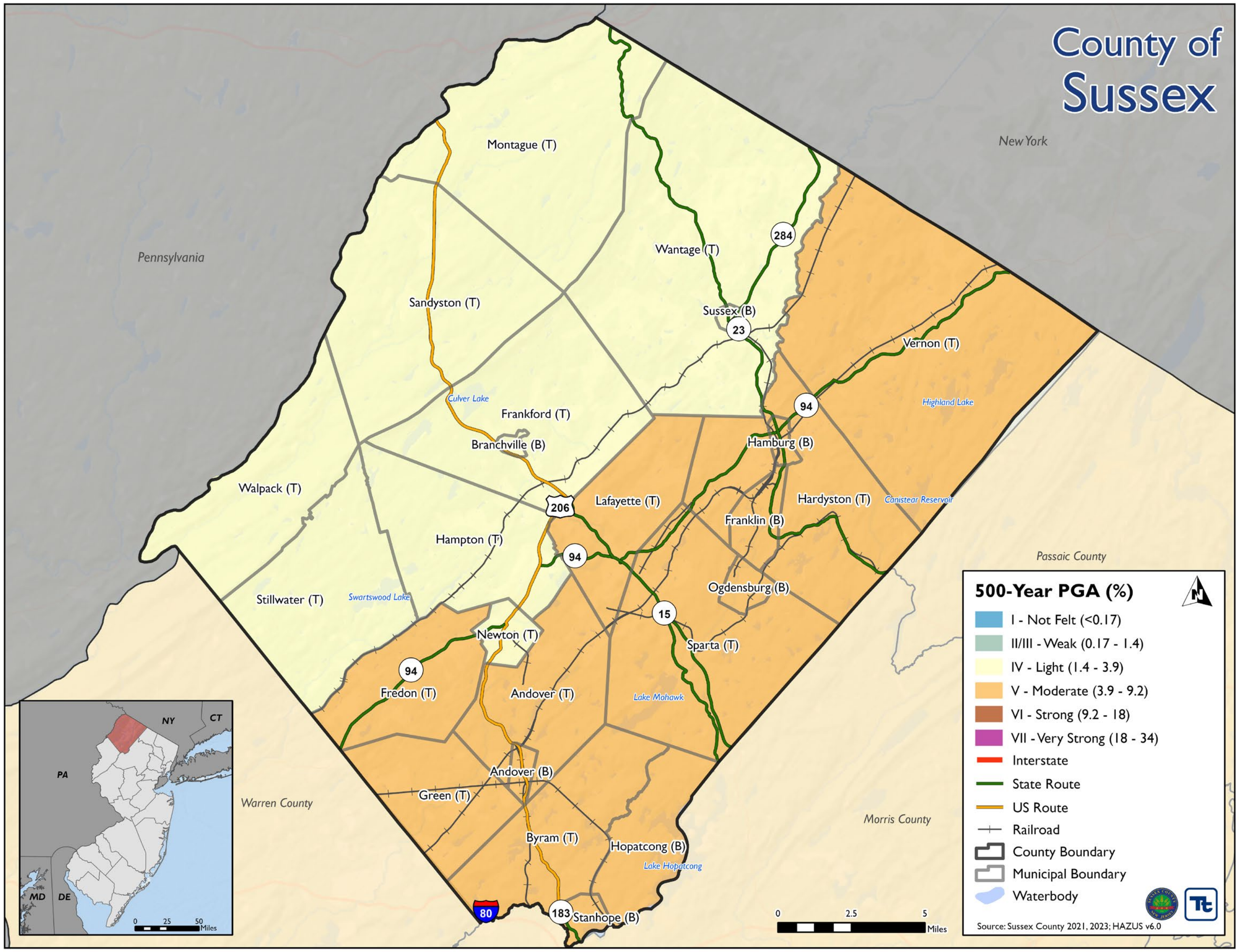


Figure 9-5. Peak Ground Acceleration 1,000-Year Mean Return Period for Sussex County

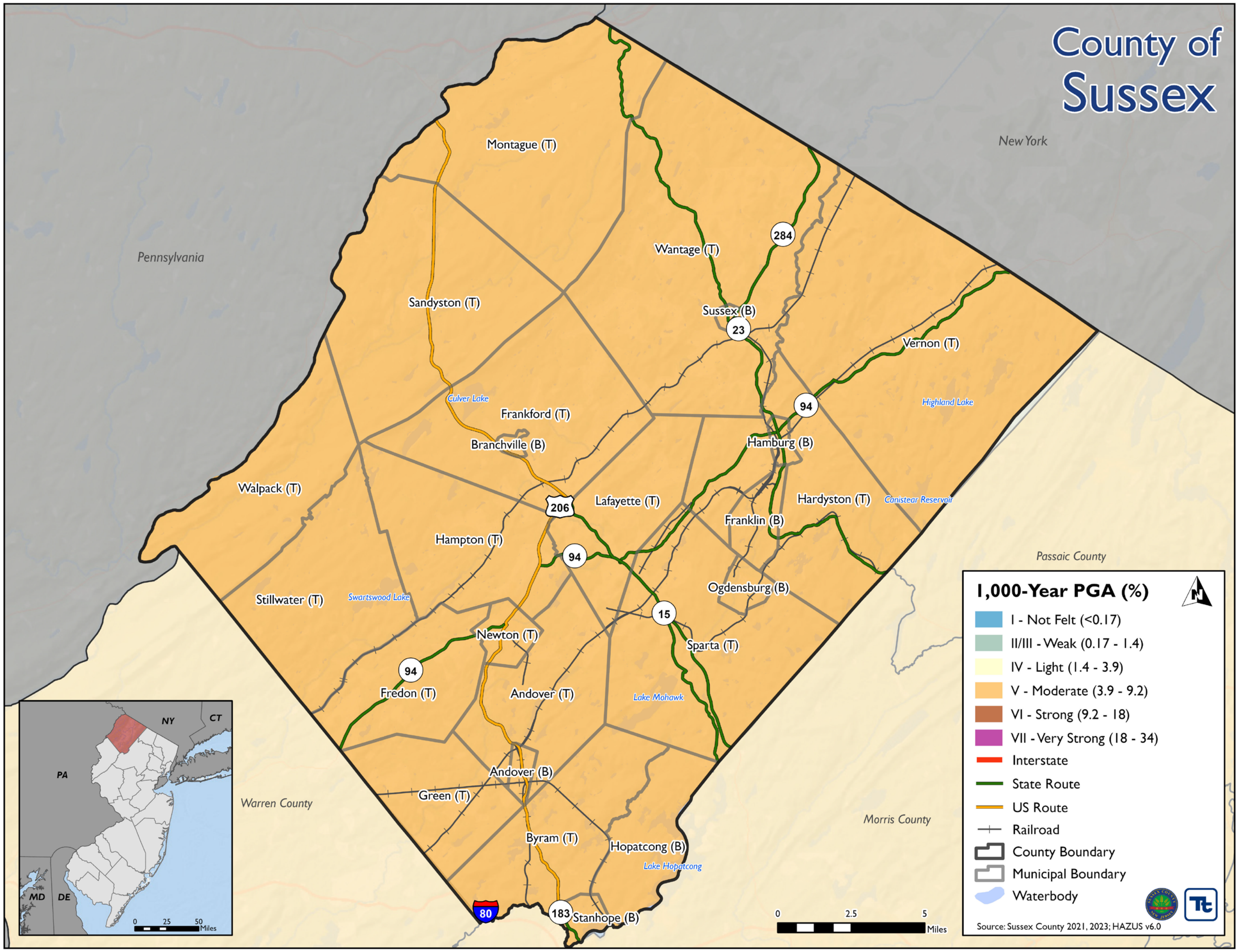
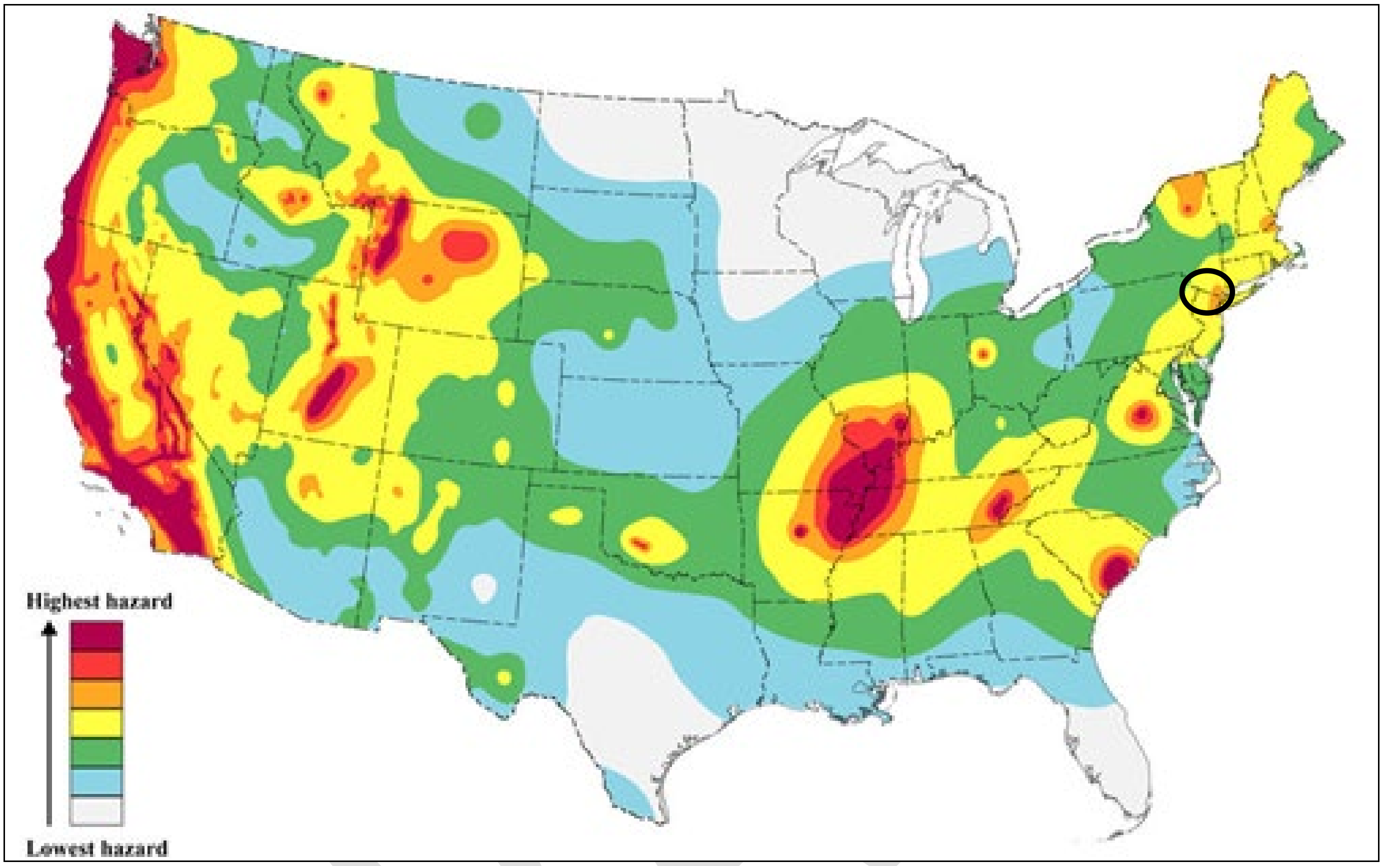


Figure 9-6. 2023 USGS National Seismic Hazard Map of the Contiguous United States



Source: USGS 2024
Note: Approximate location of Sussex County is indicated by the black circle

9.1.4 Previous Occurrences

FEMA Major Disaster and Emergency Declarations

Sussex County has not been included in any major disaster (DR) or emergency (EM) declarations for earthquake-related events (FEMA 2023).

USDA Declarations

The U.S. Secretary of Agriculture is authorized to designate counties as disaster areas to make emergency loans from the U.S. Department of Agriculture (USDA) to producers suffering losses in those counties and in contiguous counties. Since the previous Sussex County HMP, the County has not been included in any USDA earthquake-related agricultural disaster declarations (USDA 2024).

Previous Events

Figure 9-7 shows the locations of earthquake events that had epicenters in Sussex County. Known events that impacted Sussex County between January 2020 and June 2024 are discussed in Table 9-4. For events prior to 2020, refer to the 2021 Sussex County HMP.

Figure 9-7. Previous Earthquakes with Epicenters in Sussex County

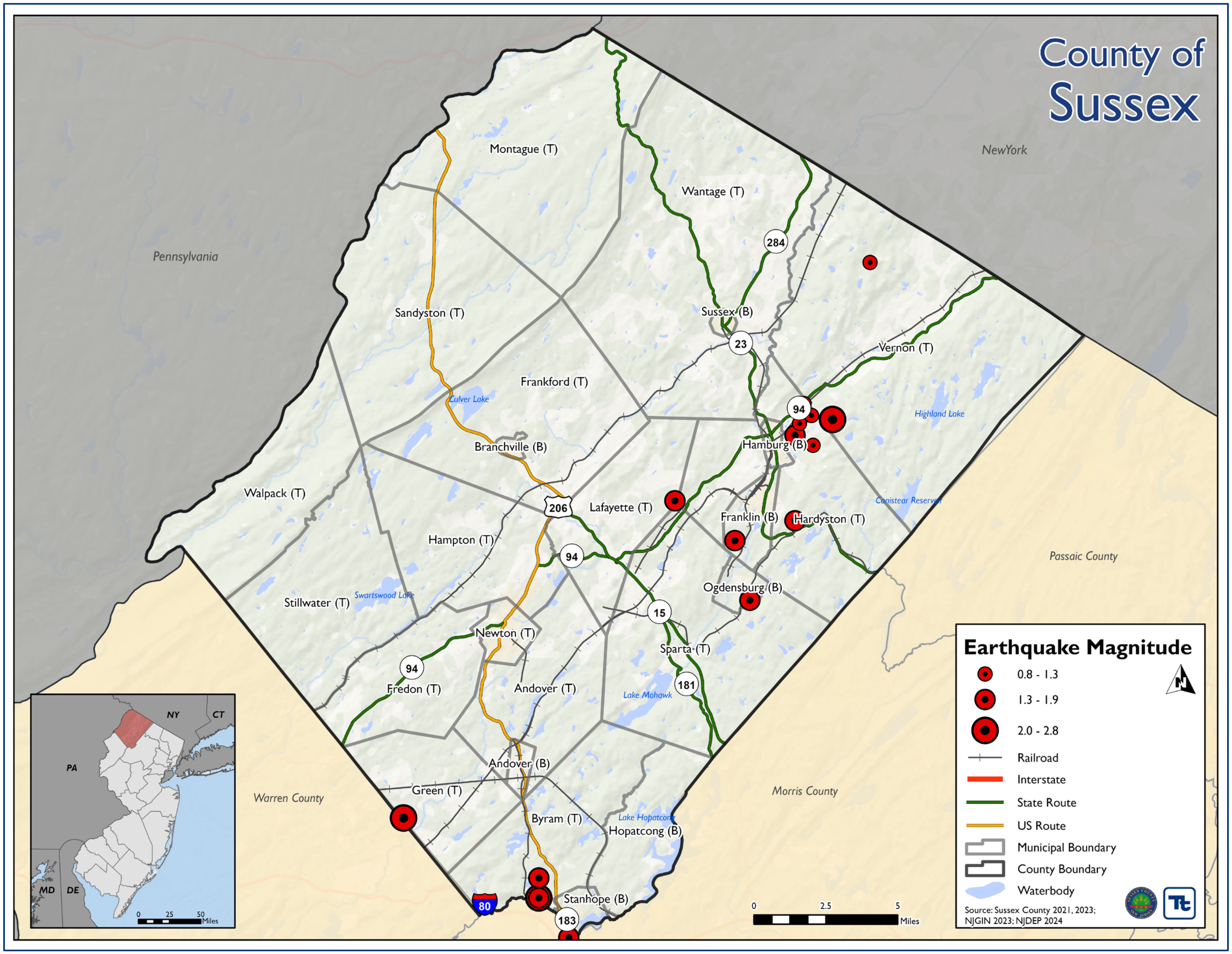


Table 9-4. Earthquake Events in Sussex County (2020 to 2024)

Event Date	FEMA Declaration or State Proclamation Number	Sussex County included in declaration?	Location Impacted	Description
September 9, 2020	N/A	N/A	Marlboro, NJ	A magnitude 3.1 earthquake in Marlboro, NJ was faintly felt in Sussex County.
April 5, 2024	N/A	N/A	Tewksbury Township, NJ	A magnitude 4.8 earthquake in Tewksbury Township, NJ was felt in Sussex County.

Source: NOAA-NCEI 2023; NJDEP 2024

9.1.5 Probability of Future Occurrences

Probability Based on Previous Occurrences

Information on previous earthquakes with an epicenter in the County was used to calculate the probability of future occurrence of such events, as summarized in Table 9-5. Based on historical records and input from the Steering Committee, the probability of occurrence for earthquake in the County is considered "rare."

Table 9-5. Probability of Future Earthquake Events in Sussex County

Hazard Type	Number of Occurrences Between 1977 and 2023	Percent Chance of Occurring in Any Given Year
Earthquake	20	42.55%

Source: NJDEP 2024
Note: The number of occurrences is restricted to earthquakes with an epicenter in Sussex County. The lowest magnitude recorded was a 0.8, and the highest magnitude recorded was a 2.8.

Effect of Climate Change on Future Probability

The only current science indicating possible impacts of climate change on the occurrence of earthquakes relates to melting glaciers. Some research has suggested 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 (NJOEM 2019). The lack of glaciers in New Jersey and the surrounding area make it unlikely that glacier retreat will increase the occurrence of earthquake in Sussex County. Therefore, no change in future probability is expected due to climate change.

9.1.6 Cascading Impacts on Other Hazards

Earthquakes can cause large and sometimes disastrous landslides and mudslides, as they create stresses that make weak slopes fail. Any steep slope is vulnerable to slope failure, often as a result of loss of cohesion in clay-rich soils.

Earthen dams and levees are highly susceptible to seismic events and the impacts of their eventual failures can be considered secondary risks for earthquakes. The most common mode of earthquake-induced dam failure is slumping or settlement of earth-fill dams where the fill has not been property compacted. If the slumping occurs when the dam is full, then overtopping of the dam, with rapid erosion leading to dam failure is possible. Dam failure is also possible if strong ground motions heavily damage concrete dams. Earthquake-induced landslides into reservoirs have also caused dam failures.

Unless properly secured, hazardous materials can be released during an earthquake, causing significant damage to the environment and people.

9.2 VULNERABILITY AND IMPACT ASSESSMENT

A vulnerability analysis was conducted for the county's assets using NEHRP soil data sourced from NJDOT and Sussex County (2012, 2021). The degree of direct earthquake impact on people and property depends on factors such as the age and construction type of residences and other buildings, the soil type that buildings are built on, and the intensity of the earthquake. Softer soils can amplify ground shaking to damaging levels even during a moderate earthquake, increasing the risk of personal harm and property damage. The vulnerability analysis defined the hazard area as all areas with Type C and D soil types (the two most vulnerable soil types present in Sussex County).

A probabilistic assessment to estimate potential losses for the 500-year and 1,000-year MRP events was conducted through a Level 2 analysis in Hazus v6.

9.2.1 Life, Health, and Safety

Overall Population

Overall, risk to public safety and loss of life in the County is minimal for the low-magnitude events common in New Jersey. People in or near the built environment, particularly those near unreinforced masonry construction, are at higher risk. According to a report by the New York City Area Consortium for Earthquake Loss Mitigation, a strong correlation exists between structural building damage and number of injuries and casualties from an earthquake event (NYCEM 2003). Those inside buildings can be harmed as a result of building structural damage. Also at risk are people walking below building ornamentations and chimneys that may be shaken loose and fall. All residents could be faced with indirect impacts: business interruption could prevent people from working, road closures could isolate populations, and loss of function of utilities could impact those who rely on those utilities.

As shown on Figure 9-3 the hazard area for this analysis, defined as areas of NEHRP Type C and D soils, covers all of Susex County. Therefore, the entire County population of 144,221 is vulnerable to the earthquake hazard (see Table 3-4).

The time of day exposes different sectors of the community to the earthquake hazard. Hazus considers residential occupancy to be at its maximum at 2:00 a.m., educational, commercial, and industrial sectors to be at their maximum at 2:00 p.m., and peak commute time to be at 5:00 p.m. Table 9-6 and Table 9-7 show the Hazus-estimated impacts on people for the 500-year and 1,000-year MRP earthquake events, respectively, based on the time of day of the event.

Table 9-6.

Earthquake Population Impacts Based on Time of Day, 500-Year Mean Return Period

	2:00 a.m. Earthquake Event	2:00 p.m. Earthquake Event	5:00 p.m. Earthquake Event
Non-Hospitalized Injuries	0	1	0
Hospitalizations	0	0	0
Fatalities	0	0	0

Source: Hazus v6.0

Table 9-7. Earthquake Population Impacts Based on Time of Day, 1,000-Year Mean Return Period

	2:00 a.m. Earthquake Event	2:00 p.m. Earthquake Event	5:00 p.m. Earthquake Event
Non-Hospitalized Injuries	1	3	1
Hospitalizations	0	0	0
Fatalities	0	0	0

Source: Hazus v6.0

As a result of an earthquake event, residents may be displaced or require temporary to long-term sheltering. 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. The Hazus analysis of the 500-year and 1,000-year MRP events in Sussex County estimated no displaced households or persons requiring short-term sheltering.

Socially Vulnerable Population

Socially vulnerable populations are most susceptible to impacts from earthquakes due to decreased mobility and financial ability to react or respond during a hazard, and the location and construction quality of their housing. Because the hazard area for this analysis (NEHRP Type C and D soils) covers all of Sussex County, all socially vulnerable populations in the County are vulnerable to the hazard. Section 3.5.3 provides detailed data on socially vulnerable populations within the overall planning area. Table 9-8 summarizes highlights of this information.

9.2.2 General Building Stock

Buildings located on soft soils are at increased risk of damage from an earthquake. The entire general building stock inventory for Sussex County, as summarized in Table 9-9, is located within the defined NEHRP Type C and D soils hazard area. The distribution of these buildings by municipality is shown in Table 3-11.

The Hazus earthquake model analyzed earthquake impacts on the general building stock in Sussex County. The potential damage to buildings from an earthquake is estimated as losses to building structures and contents. There is a strong correlation between PGA and the damage a building might undergo (FEMA 2022). Figure 9-4 and Figure 9-5 show the geographic distribution of PGA across the County for 500-year and 1,000-year MRP events.

In estimating potential loss, Hazus considers building construction type and age. Additional attributes that affect a building's ability to withstand an earthquake include its age, number of stories, and quality of construction. This information was entered into the Hazus model as available from the custom general building inventory developed for this HMP. Hazus evaluates potential building damage in the following categories: none, slight, moderate, extensive, and complete. Table 9-10 provides definitions of these categories for a light wood-framed building.

Definitions for other building types are included in the Hazus technical manual documentation. Unreinforced masonry buildings are most at risk during an earthquake because the walls are prone to collapse outward; steel and wood buildings absorb more of the earthquake's energy.

Table 9-8. Distribution of Socially Vulnerable Populations by Municipality

Category	Sussex County Total		Municipality Highest in Category		Municipality Lowest in Category	
	Number	Percent	Number	Percent	Number	Percent
Population Over 65	**25,451**	**17.65%**	Vernon (Twp) **3,687**	Walpack (Twp) **100.00%**	Walpack (Twp) **7**	Sparta (Twp) **13.38%**
Population Under 5	**6,500**	**4.51%**	Sparta (Twp) **1,160**	Lafayette (Twp) **7.21%**	Walpack (Twp) **0**	Walpack (Twp) **0.00%**
Non-English-Speaking Population	**1,922**	**1.33%**	Hopatcong (B) **339**	Hamburg (B) **10.17%**	Andover, Frankford, Sandyston, Stanhope, Stillwater, Walpack **0**	Andover, Frankford, Sandyston, Stanhope, Stillwater, Walpack **0.00%**
Population With Disability	**15,697**	**10.88%**	Vernon (Twp) **2,318**	Franklin (B) **17.32%**	Walpack (Twp) **0**	Walpack (Twp) **0.00%**
Population Below Poverty Level	**7,320**	**5.08%**	Vernon (Twp) **877**	Sussex (B) **18.03%**	Walpack (Twp) **0**	Walpack (Twp) **0.00%**
Households Below ALICE Threshold	**14,428**	**21%**	Vernon (Twp) 1,833	Sussex (B0 **48%**	Branchville (B) 90	Green (Twp) **14%**

Note: B = Borough; Twp = Township

Table 9-9. Number and Total Replacement Cost Value of Structures on NEHRP Class C and D Soils

Occupancy Class	Number of Buildings	Replacement Cost Value
Residential	62,412	$30,074,691,358
Commercial	3,345	$24,000,040,348
Industrial	227	$1,581,124,500
Other (government, religion, agriculture, and education)	5,953	$12,855,233,999
Total	71,937	$68,511,090,204

Table 9-10. Example of Structural Damage State Definitions for a Light Wood-Framed Building

Damage	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	Description
Complete	Structure may have large permanent lateral displacement, may collapse, or may 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 Technical Manual

Building damage as a result of the 500-year and 1,000-year MRP earthquakes was estimated using Hazus, as summarized in Table 9-11. No buildings will be severely or completely destroyed by the 500-year MRP event; however, up to 13 will be moderately damaged and 214 will have minor damage. The majority of the losses are estimated to the residential occupancy class. No buildings will be severely or completely destroyed by the 1,000-year MRP event; however, up to 73 will be moderately damaged and 797 will have minor damage. The majority of the losses are estimated to the residential occupancy class.

Table 9-11. Estimated Building Damage (Structure and Contents) for the 500-Year MRP Earthquake Event

Occupancy Class	Total Number of Buildings in Occupancy	Severity of Expected Damage	500-Year MRP Event		1,000-Year MRP Event	
			Building Count	% of All Buildings in Occupancy Class	Building Count	% of All Buildings in Occupancy Class
Residential Exposure (Single and Multi-Family Dwellings)	62,412	None	62,221	99.7%	61,660	98.8%
		Minor	182	0.3%	691	1.1%
		Moderate	10	0.0%	61	0.1%
		Severe	0	0.0%	0	0.0%
		Complete Destruction	0	0.0%	0	0.0%
Commercial Buildings	3,345	None	3,335	99.7%	3,310	99.0%
		Minor	9	0.3%	29	0.9%
		Moderate	1	0.0%	5	0.1%
		Severe	0	0.0%	0	0.0%
		Complete Destruction	0	0.0%	0	0.0%
Industrial Buildings	227	None	223	98.4%	217	95.7%
		Minor	3	1.2%	7	3.1%
		Moderate	1	0.3%	2	1.0%
		Severe	0	0.0%	0	0.1%
		Complete Destruction	0	0.0%	0	0.0%
Government, Religion, Agricultural, and Education Buildings	5,953	None	5,931	99.6%	5,878	98.7%
		Minor	21	0.3%	70	1.2%
		Moderate	1	0.0%	5	0.1%
		Severe	0	0.0%	0	0.0%
		Complete Destruction	0	0.0%	0	0.0%

Source: Hazus v6.0; NJGIN 2023; Sussex County 2023.

The Hazus results for potential building damage by occupancy class are summarized in Table 9-12 for the 500-year MRP event. Hazus estimates that there will be $7,186,292 in damage to structures caused by the 500-year

MRP event, with the estimated residential damage being the most expensive at $3,313,410, or 46.1 percent of the total damage. Table 9-13 summarizes the damage to structures for the 1,000-year MRP event. Hazus estimates that there will be $39,538,281 in damage to structures caused by the 1,000-year MRP event, with the estimated residential damage being the most expensive at $16,924,411, or 42.8 percent of the total damage.

Table 9-12. Estimated Building Damage by General Occupancy from the 500-Year MRP Earthquake Event

	Replacement Cost Value (RCV)	Estimated Total Damage	Percent of Total Building and Contents Replacement Cost Value	Estimated Residential Damage	Estimated Commercial Damage	Estimated Damages for All Other Occupancies
Andover (B)	$693,607,785	$100,821	<0.1%	$37,717	$48,352	$14,752
Andover (Twp)	$4,012,892,721	$932,184	<0.1%	$281,712	$475,932	$174,541
Branchville (B)	$598,388,025	$40,229	<0.1%	$15,572	$12,498	$12,159
Byram (Twp)	$3,162,144,222	$259,577	<0.1%	$130,788	$96,504	$32,286
Frankford (Twp)	$3,491,793,002	$326,176	<0.1%	$166,027	$89,944	$70,206
Franklin (B)	$2,227,977,138	$227,133	<0.1%	$102,129	$81,662	$43,342
Fredon (Twp)	$1,542,422,915	$196,205	<0.1%	$100,923	$14,408	$80,874
Green (Twp)	$1,821,582,867	$467,710	<0.1%	$254,531	$33,512	$179,667
Hamburg (B)	$1,809,235,911	$122,314	<0.1%	$37,700	$45,609	$39,005
Hampton (Twp)	$2,474,023,610	$205,171	<0.1%	$92,061	$52,956	$60,155
Hardyston (Twp)	$3,681,458,622	$294,839	<0.1%	$157,175	$75,526	$62,138
Hopatcong (B)	$3,432,619,929	$335,526	<0.1%	$238,025	$53,527	$43,974
Lafayette (Twp)	$2,142,628,709	$245,571	<0.1%	$83,855	$51,257	$110,459
Montague (Twp)	$1,659,675,648	$80,023	<0.1%	$37,835	$17,521	$24,667
Newton (T)	$5,699,120,027	$504,321	<0.1%	$164,258	$204,201	$135,862
Ogdensburg (B)	$954,409,603	$94,700	<0.1%	$39,915	$33,453	$21,332
Sandyston (Twp)	$1,350,071,503	$106,454	<0.1%	$36,788	$19,265	$50,401
Sparta (Twp)	$10,316,900,290	$983,465	<0.1%	$404,896	$399,837	$178,731
Stanhope (B)	$1,228,753,628	$112,081	<0.1%	$56,851	$17,069	$38,161
Stillwater (Twp)	$1,611,608,775	$125,162	<0.1%	$74,711	$15,821	$34,631
Sussex (B)	$2,187,092,184	$155,528	<0.1%	$50,390	$71,830	$33,309
Vernon (Twp)	$6,816,863,576	$809,756	<0.1%	$522,622	$104,331	$182,804
Walpack (Twp)	$68,015,712	$3,558	<0.1%	$1,229	$644	$1,684
Wantage (Twp)	$5,527,803,803	$457,786	<0.1%	$225,700	$59,748	$172,338
Sussex County (Total)	$68,511,090,205	$7,186,292	<0.1%	$3,313,410	$2,075,406	$1,797,476

Source: Hazus v6.0; Sussex County 2023; RS Means 2022; NJOGIS, Civil Solutions, Spatial Data Logic
Notes: B – Borough; T – Town; Twp. – Township

Table 9-13. Estimated Building Damage by General Occupancy from the 1,000-Year MRP Earthquake Event

	Replacement Cost Value (RCV)	Estimated Total Damage	Percent of Total Building and Contents Replacement Cost Value	Estimated Residential Damage	Estimated Commercial Damage	Estimated Damages for All Other Occupancies
Andover (B)	$693,607,785	$478,833	0.1%	$164,738	$250,543	$63,553
Andover (Twp)	$4,012,892,721	$4,460,683	0.1%	$1,222,152	$2,404,961	$833,570
Branchville (B)	$598,388,025	$244,227	<0.1%	$80,261	$81,285	$82,681
Byram (Twp)	$3,162,144,222	$1,580,750	<0.1%	$736,834	$654,780	$189,136
Frankford (Twp)	$3,491,793,002	$1,794,558	0.1%	$791,311	$551,371	$451,876
Franklin (B)	$2,227,977,138	$1,302,051	0.1%	$535,619	$537,610	$228,822
Fredon (Twp)	$1,542,422,915	$1,017,955	0.1%	$472,218	$76,107	$469,630
Green (Twp)	$1,821,582,867	$2,040,882	0.1%	$1,043,128	$155,009	$842,745
Hamburg (B)	$1,809,235,911	$791,552	<0.1%	$244,739	$344,427	$202,385
Hampton (Twp)	$2,474,023,610	$1,166,735	<0.1%	$481,222	$333,202	$352,310
Hardyston (Twp)	$3,681,458,622	$1,786,272	<0.1%	$874,075	$556,912	$355,285
Hopatcong (B)	$3,432,619,929	$1,920,998	0.1%	$1,314,048	$371,383	$235,568
Lafayette (Twp)	$2,142,628,709	$1,382,449	0.1%	$403,884	$330,925	$647,639
Montague (Twp)	$1,659,675,648	$507,280	<0.1%	$239,206	$124,607	$143,467
Newton (T)	$5,699,120,027	$2,884,589	0.1%	$866,201	$1,358,706	$659,682
Ogdensburg (B)	$954,409,603	$532,187	0.1%	$222,219	$210,256	$99,711
Sandyston (Twp)	$1,350,071,503	$585,352	<0.1%	$182,320	$127,102	$275,931
Sparta (Twp)	$10,316,900,290	$5,817,335	0.1%	$2,191,932	$2,723,971	$901,432
Stanhope (B)	$1,228,753,628	$655,717	0.1%	$332,042	$121,615	$202,061
Stillwater (Twp)	$1,611,608,775	$709,536	<0.1%	$382,225	$101,022	$226,288
Sussex (B)	$2,187,092,184	$955,724	<0.1%	$263,571	$543,554	$148,599
Vernon (Twp)	$6,816,863,576	$4,312,587	0.1%	$2,719,241	$666,044	$927,302
Walpack (Twp)	$68,015,712	$19,563	<0.1%	$6,093	$4,248	$9,222
Wantage (Twp)	$5,527,803,803	$2,590,469	<0.1%	$1,155,131	$406,890	$1,028,447
Sussex County (Total)	$68,511,090,205	$39,538,281	0.1%	$16,924,411	$13,036,531	$9,577,339

Source: Hazus v6.0; Sussex County 2023; RS Means 2022; NJOGIS, Civil Solutions, Spatial Data Logic
Notes: B – Borough; T – Town; Twp. – Township

Historically, Building Officials Code Administration regulations in the northeast states were developed to address local concerns such as heavy snow loads and wind. Seismic requirements for design criteria are not as stringent as those of the west coast of the United States, which rely on the more seismically focused Uniform Building Code. As such, a smaller earthquake can cause more structural damage in the northeast than an equivalent event would cause in the west.

9.2.3 Community Lifelines and Other Critical Facilities

All critical facilities in Sussex County, as described in Section 3.8 of this HMP, are located on NEHRP Type C or D soils and are therefore vulnerable to the earthquake hazard. The Hazus earthquake model was used to assign average probability of each damage category to the critical facilities in Sussex County for the 500-year and 1,000-year MRP events.

In addition, Hazus estimates the time to restore critical facilities to fully functional use. Results are presented as a probability of being functional at specified time increments (days after the event). For example, Hazus might estimate that a facility has 5 percent chance of being fully functional at Day 3, and a 95 percent chance of being fully functional at Day 90.

As shown in Table 9-14, Hazus estimates that community lifelines will be nearly 100 percent functional immediately after of a 500-year MRP event. Across the community lifeline categories, the average chance of receiving slight or no damage from the 500-year MRP event ranges from 99.3 percent to 100 percent.

As shown in Table 9-15, Hazus estimates that community lifelines will be nearly 100 percent functional by Day 7 after of a 1,000-year MRP event. Across the community lifeline categories, the average chance of receiving slight or no damage from the 1,000-year MRP event ranges from 98.1 percent to 99.9 percent.

9.2.4 Economy

Earthquakes impacts on the economy include loss of business function, damage to inventory, relocation costs, wage loss, and rental costs during to the repair or replacement of buildings. Roads and railroad tracks 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. Earthquake events can significantly affect bridges, many of which provide the only access to certain neighborhoods. Because softer soils generally follow floodplain boundaries, bridges that cross watercourses are particularly vulnerable. Potential impacts on facilities and infrastructure will depend on their age, which correlates with standards in place at times of construction.

Hazus estimates the volume of debris that may be generated as a result of an earthquake event to enable the study region to manage debris removal and disposal. Debris estimates are divided into two categories: reinforced concrete and steel that require special equipment to break up before being transported, and brick, wood, and other debris that can be loaded directly onto trucks with bulldozers (FEMA 2022).

Table 9-16 show Hazus-estimated debris quantities for the 500-year MRP event, including 1,054 tons of debris generated county-wide. The Township of Sparta will generate the most brick/wood debris (132 tons) and the most total debris (145 tons). The Town of Newton will generate the most concrete/steel debris (14 tons). For the 1,000-year MRP event, shown in Table 9-17, Hazus estimates a total of 3,583 tons of debris county-wide; with the greatest quantities in all categories generated in the Township of Sparta—452 tons of brick/wood debris, 14 tons of concrete/steel debris, and 513 tons of total debris.

Table 9-14. Estimated Damage and Loss of Functionality for Community Lifelines in Sussex County for the 500-Year MRP Earthquake Event

	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Communications	97.3%	2.0%	0.6%	0.1%	0.0%	97.3%	99.2%	99.9%	99.9%
Energy	98.4%	1.2%	0.3%	<0.1%	0.0%	98.4%	99.6%	99.9%	99.9%
Food, Hydration, Shelter	98.5%	1.2%	0.3%	<0.1%	0.0%	98.4%	99.6%	99.9%	99.9%
Hazardous Materials	98.5%	1.1%	0.3%	<0.1%	0.0%	98.5%	99.6%	99.9%	99.9%
Health and Medical	99.9%	<0.1%	<0.1%	0.0%	0.0%	99.9%	99.9%	99.9%	99.9%
Safety and Security	98.4%	1.2%	0.3%	<0.1%	0.0%	98.4%	99.6%	99.9%	99.9%
Transportation	97.3%	2.0%	0.6%	0.1%	0.0%	97.2%	99.2%	99.9%	99.9%

Source: Hazus v6.0; NJGIN 2023; Sussex County 2021, 2023
Notes: MRP = Mean Return Period

Table 9-15. Estimated Damage and Loss of Functionality for Community Lifelines in Sussex County for the 1,000-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
Communications	93.4%	4.7%	1.7%	0.2%	0.0%	93.3%	98.0%	99.7%	99.9%
Energy	95.7%	3.2%	1.0%	0.1%	0.0%	95.6%	98.8%	99.8%	99.9%
Food, Hydration, Shelter	95.8%	3.1%	1.0%	0.1%	0.0%	95.7%	98.8%	99.8%	99.9%
Hazardous Materials	95.8%	3.1%	1.0%	0.1%	0.0%	95.8%	98.8%	99.8%	99.9%
Health and Medical	99.7%	0.2%	<0.1%	0.0%	0.0%	99.7%	99.9%	99.9%	99.9%
Safety and Security	95.6%	3.2%	1.0%	0.1%	0.0%	95.6%	98.7%	99.8%	99.9%
Transportation	93.4%	4.7%	1.7%	0.2%	0.0%	93.3%	98.0%	99.7%	99.9%

Source: Hazus v6.0; NJGIN 2023; Sussex County 2021, 2023
Notes: MRP = Mean Return Period

Table 9-16. Estimated Debris Generated by the 500-Year MRP Earthquake Event

	Debris Generated by the 500-Year MRP Earthquake Event		
	Brick/Wood (tons)	Concrete/Steel (tons)	Total Debris (tons)
Andover (B)	10	1	11
Andover (Twp)	80	9	90
Branchville (B)	4	0	4
Byram (Twp)	20	1	22
Frankford (Twp)	32	3	35
Franklin (B)	37	4	41
Fredon (Twp)	25	2	27
Green (Twp)	73	8	80
Hamburg (B)	24	2	26
Hampton (Twp)	31	3	33
Hardyston (Twp)	38	3	41
Hopatcong (B)	34	2	36
Lafayette (Twp)	26	2	28
Montague (Twp)	11	1	12
Newton (T)	116	14	130
Ogdensburg (B)	17	2	19
Sandyston (Twp)	19	2	21
Sparta (Twp)	132	12	145
Stanhope (B)	26	3	28
Stillwater (Twp)	10	1	11
Sussex (B)	30	3	33
Vernon (Twp)	107	9	117
Walpack (Twp)	1	0	1
Wantage (Twp)	56	5	61
Sussex County (Total)	960	93	1,054

Source: Hazus v6.0; Sussex County 2023; NJOGIS, Civil Solutions, Spatial Data Logic
Notes: B – Borough; T – Town; Twp. – Township

Table 9-17. Estimated Debris Generated by the 1,000-Year MRP Earthquake Event

	Debris Generated by the 1,000-Year MRP Earthquake Event		
	Brick/Wood (tons)	Concrete/Steel (tons)	Total Debris (tons)
Andover (B)	31	5	37
Andover (Twp)	245	42	287
Branchville (B)	13	2	14
Byram (Twp)	78	9	86
Frankford (Twp)	108	14	122
Franklin (B)	122	17	139
Fredon (Twp)	83	9	92
Green (Twp)	210	30	240
Hamburg (B)	88	10	99
Hampton (Twp)	107	13	120
Hardyston (Twp)	134	16	149
Hopatcong (B)	127	14	141
Lafayette (Twp)	86	11	96
Montague (Twp)	42	5	47
Newton (T)	351	55	406
Ogdensburg (B)	58	7	65
Sandyston (Twp)	63	8	71
Sparta (Twp)	452	61	513
Stanhope (B)	91	11	102
Stillwater (Twp)	36	3	40
Sussex (B)	90	13	104
Vernon (Twp)	364	42	407
Walpack (Twp)	2	0	2
Wantage (Twp)	185	21	205
Sussex County (Total)	3,165	417	3,583

Source: Hazus v6.0; Sussex County 2023; NJOGIS, Civil Solutions, Spatial Data Logic
Notes: B – Borough; T – Town; Twp. – Township

9.2.5 Natural, Historic and Cultural Resources

Natural

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. Surface faulting can create wide ruptures in the ground that can disconnect habitats for miles, isolating animal species or tearing apart plant roots (USGS n.d.).

Furthermore, ground failure as a result of soil liquefaction can have an impact on soil pores and retention of water resources. 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 than a solid, increasing risk of localized flooding and accumulation of silt (USGS n.d.).

Earthquake-caused landslides or mudslides that fall into streams may significantly impact fish and wildlife habitat, as well as affecting water quality. Hillsides that provide wildlife habitat can be lost for prolonged periods due to landslides.

Historic

Earthquake events could damage property in and around historical landmarks. Many historical buildings and homes may not be built to withstand earthquakes and are more vulnerable than other structures.

Cultural

Earthquake events could bring damage to areas in and around cultural landmarks.

9.3 CHANGE OF VULNERABILITY SINCE 2021 HMP

Overall, the County's vulnerability to the earthquake hazard has not changed, and the entire County will continue to be vulnerable to this hazard. Any change in vulnerability since the previous HMP would be attributed to changes in population density and new development. This updated HMP used updated building stock and critical asset inventories to assess the County's risk to these assets. The building inventory was updated using RSMeans 2022 values, which are more current and reflect replacement cost rather than the building stock improvement values reported in the 2021 HMP. Further, the 2021 5-year population estimates from the American Community Survey were used to evaluate the population exposed to the hazard areas.

9.4 FUTURE CHANGES THAT MAY AFFECT RISK

Understanding future changes that affect vulnerability can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. The following sections examine potential conditions that may affect hazard vulnerability.

9.4.1 Potential or Planned Development

As discussed in Chapter 3, areas targeted for future growth have been identified across the County. Development in areas with softer NEHRP soil classes, liquefaction, and landslide-susceptibility may experience shifting or cracking in the foundation during earthquakes because of loose soils. However, seismic provisions in current building codes should render new construction less vulnerable to seismic impacts than older construction that may have been built to lower construction standards.

9.4.2 Projected Changes in Population

Changes in the density of population can impact the number of persons exposed to the earthquake hazard. Persons that move into older buildings may increase their overall vulnerability to earthquakes. Those moving into newer construction may decrease their vulnerability.

The New Jersey Department of Labor and Workforce Development produced population projections by County from 2014 to 2019, 2024, 2029, and 2034. Sussex County is projected to have a decrease in population in the upcoming years. These projections estimate a population of 140,400 by 2024, 137,300 by 2029, and 136,600 by 2034 (State of New Jersey 2017).

9.4.3 Climate Change

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. County assets in 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. There are currently no models available to estimate these impacts (NJOEM 2019).