4.3.4 EARTHQUAKE

The following section provides the hazard profile (hazard description, location, extent, previous occurrences and losses, probability of future occurrences, and impact of climate change) and vulnerability assessment for the earthquake hazard in Sussex County.

2021 HMP Changes

- All subsections have been updated using best available data.
- Previous occurrences were updated with events that occurred between 2015 and 2020.
- The New Jersey Geologic and Water Survey (NJGWS) updated liquefaction data was included in the vulnerability assessment.
- Updated Hazus-MH probabilistic modeling using v4.2 was conducted using updated inventory data.
- Impacts on the environment are summarized in the vulnerability assessment.

Profile

Hazard Description

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

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

According to the U.S. Geological Survey (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; however, not all occur within the Sussex County planning area:

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

- *Seiche*: The sloshing of a closed body of water, such as a lake or bay, from earthquake shaking (USGS 2012a).

Earthquakes can cause large and sometimes disastrous landslides and mudslides. Any steep slope is vulnerable to slope failure, often as a result of loss of cohesion in clay-rich soils. Unless properly secured, hazardous materials can be released, causing significant damage to the environment and people. Earthen dams and levees are highly susceptible to seismic events and the impacts of their eventual failures can be considered secondary risks for earthquakes. Landslides are further discussed in Section 5.4.5 (Geologic Hazards) of this HMP update.

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

Another secondary effect of earthquakes that is often observed in low-lying areas near water bodies is ground liquefaction. Liquefaction is the conversion of water-saturated soil into a fluid-like mass. This can occur when loosely packed, waterlogged sediments lose their strength in response to strong shaking. Liquefaction effects may occur along the shorelines of the ocean, rivers, and lakes and they can also happen in low-lying areas away from water bodies in locations where the ground water is near the earth's surface.

Tsunamis are formed as a result of earthquakes, volcanic eruptions, or landslides that occur under the ocean. When these events occur, huge amounts of energy are released as a result of quick, upward bottom movement. A wave is formed when huge volumes of ocean water are pushed upward. A large earthquake can lift large portions of the seafloor, which will cause the formation of huge waves (U.S. Search and Rescue Task Force Date Unknown).

Location

Earthquakes are most likely to occur in the northern parts of New Jersey, which includes Sussex County, where significant faults are concentrated; however, low-magnitude events can and do occur in many other areas of the State. The National Earthquake Hazard Reduction Program (NEHRP) developed five soil classifications defined by their shear-wave velocity that impact the severity of an earthquake. The soil classification system ranges from A to E, as noted in Table 4.3.4-1, where A represents hard rock that reduces ground motions from an earthquake and E represents soft soils that amplify and magnify ground shaking and increase building damage and losses.

Table 4.3.4-1. NEHRP Soil Classifications

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

Source: FEMA 2013

The New Jersey Department of Transportation (NJDOT) compiled a report on seismic design consideration for bridges in New Jersey, dated March 2012. In the report, NJDOT classifies the seismic nature of soils according to the American Association of State Highway and Transportation Officials (AASHTO) Guide Specifications for Bridge Seismic Design (SGS). For the purpose of seismic analysis and design, sites can be classified into

Soil Classes A, B, C, D, E and F, ranging from hard rock to soft soil and special soils (similar to the NEHRP soil classifications with an additional class F); refer to Table 4.3.4-2.

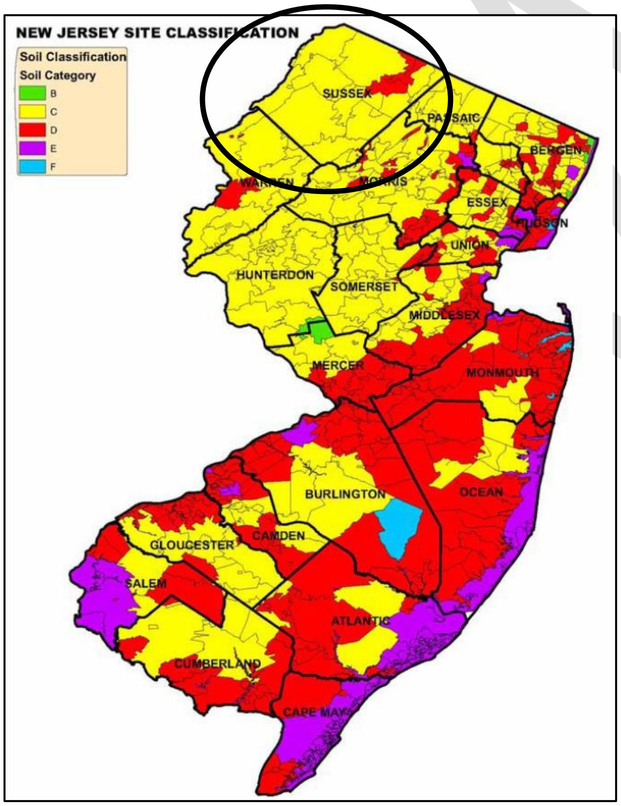
Table 4.3.4-2. NJDOT Soil Classifications

Soil Classification	Description
A-B	Rock sites
C	Very dense soil
D	Dense soil
E	Soft soil
F	Special soil requiring site-specific analysis

Source: NJDOT 2012

NJDOT also developed a Geotechnical Database Management System, which contains soil boring data across New Jersey. The soil boring logs were then used to classify soil sites. Through this analysis, NJDOT developed a map of soil site classes according to ZIP codes in New Jersey where each ZIP code was assigned a class based on its predominant soil condition. In Sussex County, most ZIP codes were rated as a Category C, and a few were rated as Category D; refer to Figure 4.3.4-1.

Figure 4.3.4-1. ZIP Code-Based Soil Site Class Map



Source: NJDOT 2012

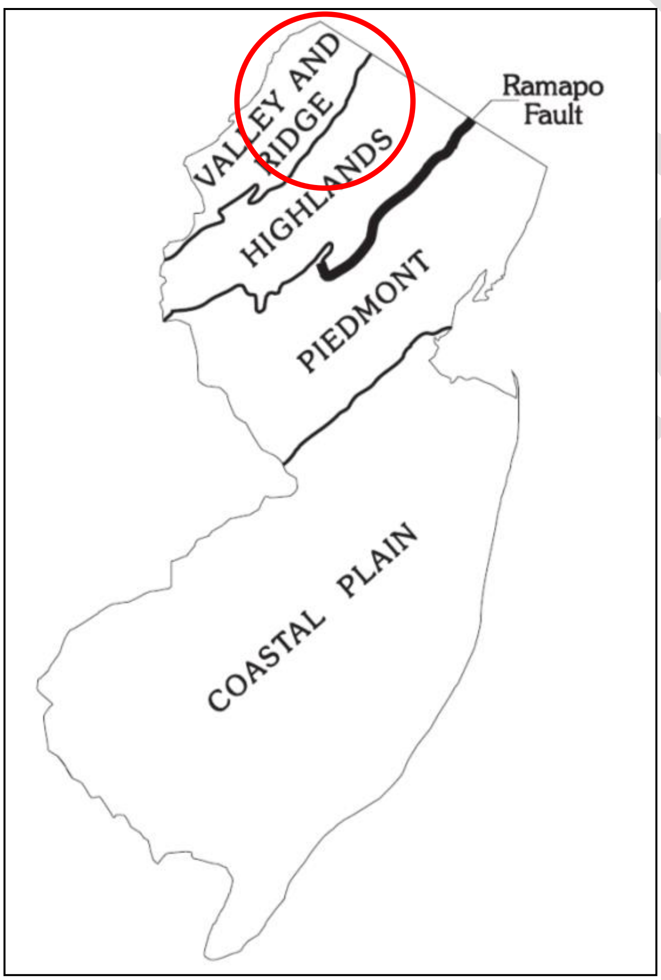
Note: Sussex County is indicated by the black circle.
Soil Classes A and B are rock sites
Soil Class C is very dense soil
Soil Class D is dense soil
Soil Class E is soft soil
Soil Class F is special soil requiring site-specific analysis

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.

Liquefaction occurs in saturated soils and when it occurs, the strength of the soil decreases and the ability of a soil deposit to support foundations for buildings and bridges is reduced. Shaking from earthquakes often triggers an increase in water pressure which can trigger landslides and the collapse of dams. For information regarding dam failures, refer to Section 4.3.1 (Dam Failure) and for landslides refer to Section 4.3.6 (Geologic). Earthquakes can also contribute to landslide hazards. Earthquakes create stresses that make weak slopes fail. Earthquakes of magnitude 4.0 or greater have been known to trigger landslides.

There are many faults in New Jersey; however, the Ramapo Fault, which separates the Piedmont and Highlands Physiographic Provinces, is best known. As indicated in Figure 4.3.4-2, Sussex County might feel the effects of an earthquake along the Ramapo Fault; however, the fault itself is not located within County borders. The Reservoir Fault, which borders the Green Pond Mountain region, is another major faultline in New Jersey and is closer to Sussex County borders than the Ramapo Fault (Volkert and Witte 2015).

Figure 4.3.4-2. Physiographic Provinces of New Jersey and the Ramapo Fault Line



Source: Dombroski 1973 (revised 2005)

Note: The red circle indicates the approximate location of Sussex County. The County is part of Piedmont Province.

Extent

An earthquake's magnitude and intensity are used to describe the size and severity of the event. Magnitude describes the size at the focal point of an earthquake, and intensity describes the overall severity of shaking felt during the event. 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 but 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 4.3.4-3. 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, depending 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 4.3.4-4 displays the MMI scale and its relationship to the areas peak ground acceleration (PGA).

Table 4.3.4-3. Modified Mercalli Intensity Scale

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

Mercalli Intensity	Description
XII	Almost everything is destroyed. Objects are thrown into the air. The ground moves in waves or ripples. Large amounts of rock may move.

Source: Michigan Tech University n.d.

Table 4.3.4-4. Modified Mercalli Intensity and PGA Equivalents

Modified Mercalli Intensity	Acceleration (%g) (PGA)	Perceived Shaking	Potential Damage
I	< .17	Not Felt	None
II	.17 – 1.4	Weak	None
III	.17 – 1.4	Weak	None
IV	1.4 – 3.9	Light	None
V	3.9 – 9.2	Moderate	Very Light
VI	9.2 – 18	Strong	Light
VII	18 – 34	Very Strong	Moderate
VIII	34 – 65	Severe	Moderate to Heavy

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

The ground experiences acceleration as it shakes during an earthquake. The peak ground acceleration (PGA) is the largest acceleration recorded by a monitoring station during an earthquake. 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 (%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 time 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 Table 4.3.4-5.

Table 4.3.4-5. Damage Levels Experienced in Earthquakes

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

Source: NJOEM 2019
Note: %g Peak Ground Acceleration

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 2014. New seismic, geologic, and geodetic information on earthquake rates and associated ground shaking were incorporated into these revised maps. The 2014 map represents the best available data, as determined by the USGS.

Figures 4.3.4-3 and Figure 4.3.4-4 illustrate geographic distributions of the Modified Mercalli Scale based on PGAs (%*g*) across Sussex County for 100- and 500-year MRP events at the census-tract level. A 100-year mean return period (MRP) event is an earthquake with 1-percent chance that mapped ground motion levels (PGA) will be exceeded in any given year. A 500-year MRP is an earthquake with 0.2 percent chance that mapped PGAs will be exceeded in any given year.

Figure 4.3.4-3. Peak Ground Acceleration 100-Year Mean Return Period for Sussex County

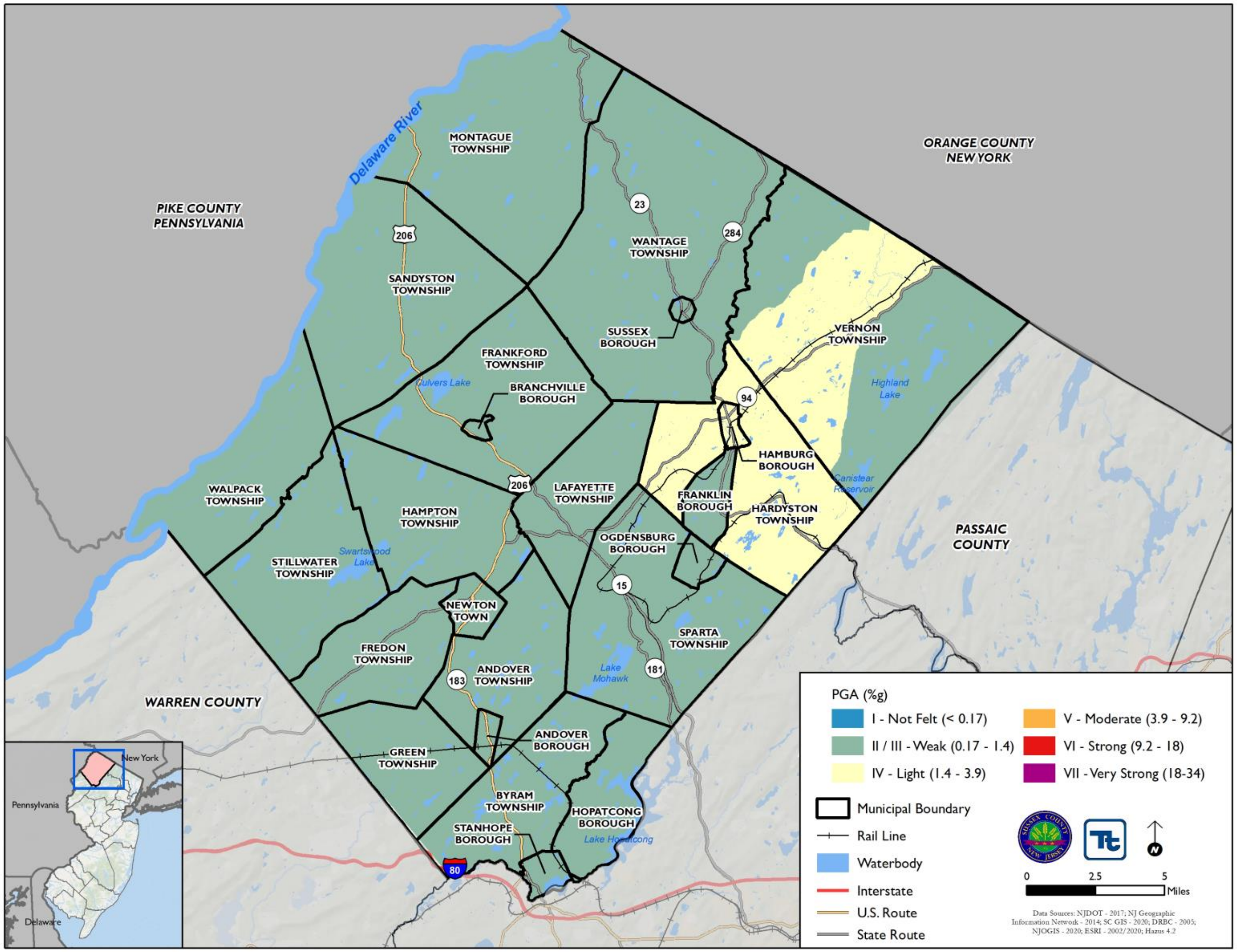
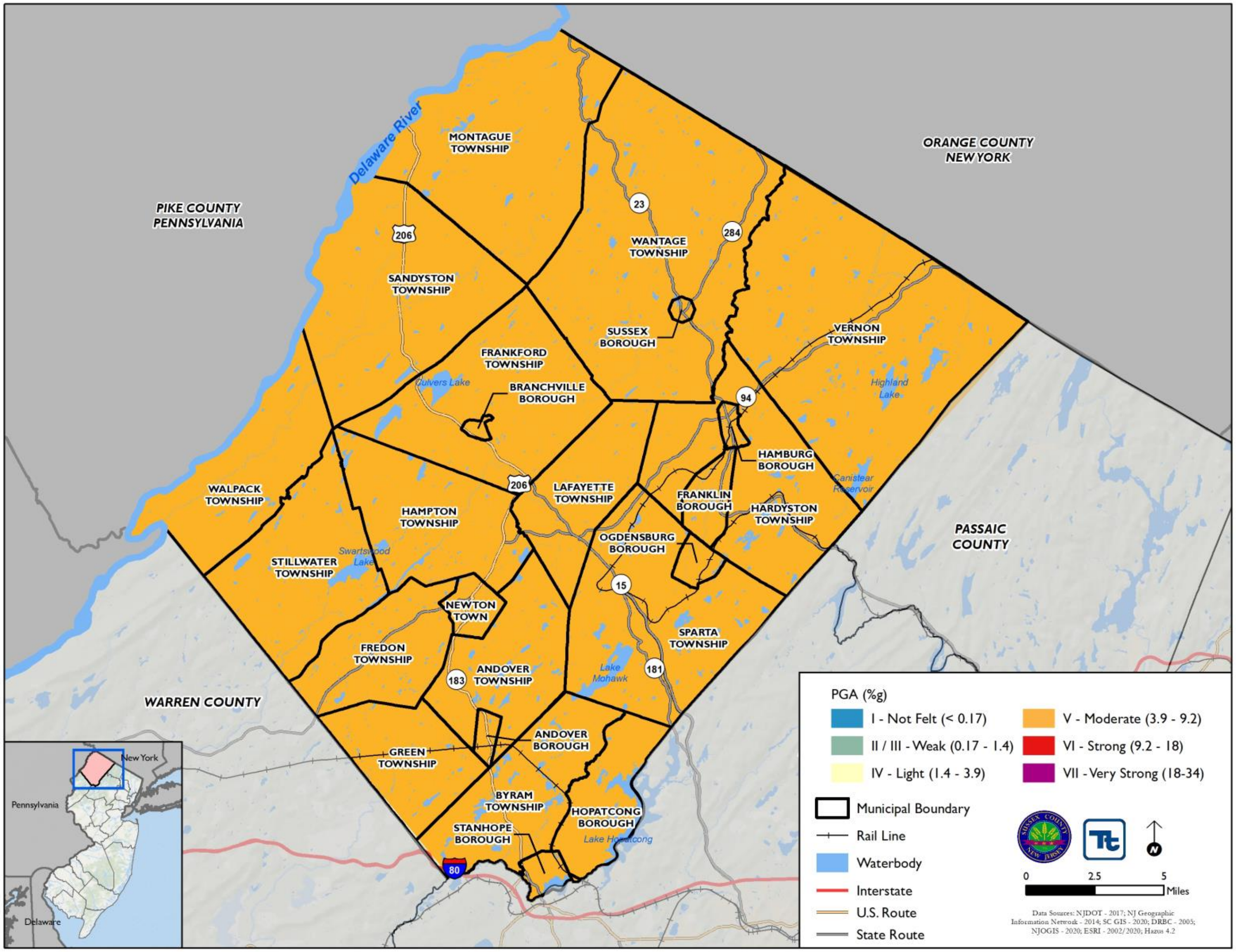


Figure 4.3.4-4. Peak Ground Acceleration 500-Year Mean Return Period for Sussex County



Previous Occurrences and Losses

FEMA Major Disasters and Emergency Declarations

Between 1954 and 2020, Sussex County has not been included in any declarations associated with earthquakes.

U.S. Department of Agriculture Disaster Declarations

The Secretary of Agriculture from the U.S. Department of Agriculture (USDA) is authorized to designate counties as disaster areas to make emergency loans to producers suffering losses in those counties and in counties that are contiguous to a designated county. Between 2015 and 2020, Sussex County was not included in any USDA declarations associated with earthquakes.

Earthquake Events

Earthquake events that have impacted Sussex County between 2015 and 2020 are identified in Table 4.3.4-6. With earthquake documentation for New Jersey and Sussex County being so extensive, not all sources have been identified or researched. Therefore, Table 4.3.4-6 may not include all events that have occurred in the County. Please see Section 9 (Jurisdictional Annexes) for detailed information regarding impacts and losses to each municipality.

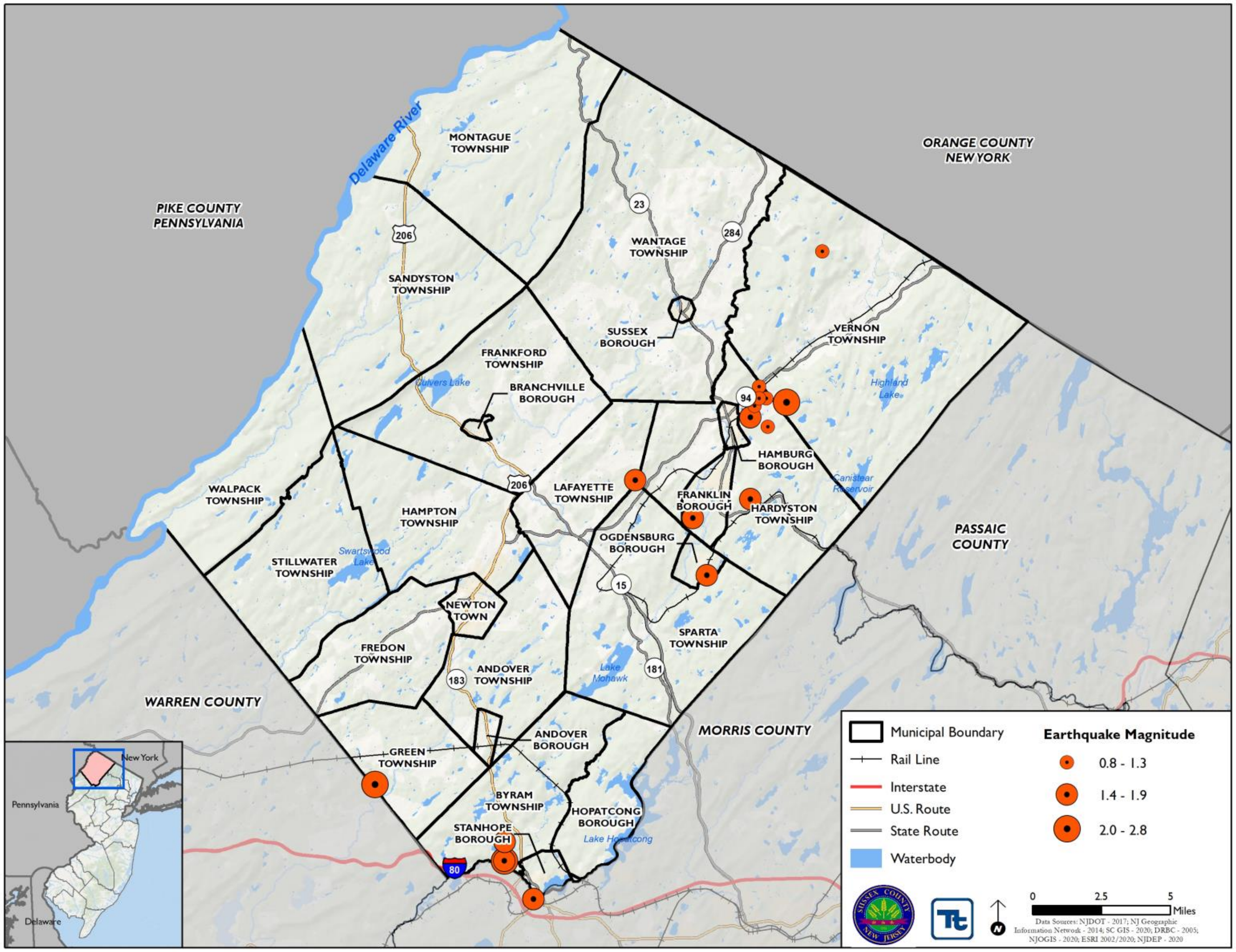
Table 4.3.4-6. Earthquake Events in Sussex County, 2015 to 2020

Date(s) of Event	Event Type	FEMA Declaration Number (if applicable)	Sussex County Designated?	Location	Description
January 2, 2016	Earthquake	N/A	N/A	Ringwood, NJ	A magnitude 2.1 earthquake in Ringwood, NJ was faintly felt in eastern areas of Sussex County.
November 30, 2017	Earthquake	N/A	N/A	Dover, DE	A magnitude 4.1 earthquake in Dover, DE was felt throughout the mid-Atlantic region. The quake was felt from central Virginia to Massachusetts.
September 9, 2020	Earthquake	N/A	N/A	Marlboro, NJ	A magnitude 3.1 earthquake in Marlboro, NJ was faintly felt in Sussex County.

Source: FEMA 2020; NOAA-NCEI 2020; NWS 2020; SPC 2020; NJOEM 2019
Note: Not all events that have occurred in Sussex County are included due to the extent of documentation and the fact that not all sources have been identified or researched.
K: Thousand
DR Disaster Declaration (FEMA)
FEMA Federal Emergency Management Agency
Mph miles per hour
N/A Not Applicable

Historically, Sussex County has not experienced a major earthquake. However, there have been a number of earthquakes of relatively low intensity. The majority of earthquakes that have occurred in New Jersey have occurred along faults in the central and eastern Highlands, with the Ramapo fault being the most seismically active fault in the region (Volkert and Witte 2015); Sussex County can be impacted by earthquakes in the New Jersey Highlands. 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 earthquake that was epicentered west of New York City. It was felt from New Hampshire to Pennsylvania (Stover and Coffman 1993; NJGWS 2015). Figure 4.3.4-5 illustrates earthquake events where the epicenters were located in New Jersey.

Figure 4.3.4-5. Earthquakes with Epicenters in Sussex County



Probability of Future Occurrences

Earthquakes cannot be predicted and may occur any time of the day or year. Major earthquakes are infrequent in the State and County and may occur only once every few hundred years or longer, but the consequences of major earthquakes may potentially be very high. Based on the historic record, the future probability of damaging earthquakes impacting Sussex County is low.

In Section 4.4, the identified hazards of concern for Sussex County were ranked. The probability of occurrence, or likelihood of the event, is one parameter used for hazard rankings. Based on historical records and input from the Planning Committee, the probability of occurrence for earthquake in the County is considered 'rare' (between 1 and 10 percent annual probability of a hazard event occurring, as presented in Table 4.4-1). The ranking of the earthquake hazard for individual municipalities is presented in the jurisdictional annexes.

Climate Change Impacts

The potential impacts of global climate change on earthquake probability are unknown. Some scientists feel that melting glaciers could induce tectonic activity. As ice melts and water runs off, tremendous amounts of weight are shifted on the Earth's crust. As newly freed crust returns to its original, pre-glacier shape, it could cause seismic plates to slip and stimulate volcanic activity according to research into prehistoric earthquakes and volcanic activity. National Aeronautics and Space Administration (NASA) and USGS scientists found that retreating glaciers in southern Alaska might be opening the way for future earthquakes (NJOEM 2019).

Secondary impacts of earthquakes could be magnified by future climate change. Soils saturated by repetitive storms could experience liquefaction during seismic activity because of the increased saturation. Dams storing increased volumes of water from changes in the hydrograph could fail during seismic events. There are currently no models available to estimate these impacts (NJOEM 2019).

Vulnerability Assessment

A probabilistic assessment was conducted for the 100-year and 500-year MRP events through a Level 2 analysis in Hazus v4.2 to analyze the earthquake hazard and provide a range of loss estimates. Refer to Section 4.2 (Methodology) for additional details on the methodology used to assess earthquake risk.

Impact on Life, Health, and Safety

The entire County may experience an earthquake. However, 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, and 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.

Overall, risk to public safety and loss of life from an earthquake in the County is minimal for low magnitude events. However, 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. NEHRP Soil Classes D and E amplify ground shaking to damaging levels even during a moderate earthquake, and thus increase risk to the population. As Figure 4.3.4-1 demonstrates, softer soils are more prevalent in the northeast portion of the County, making the population in this area more vulnerable to an earthquake event.

Populations considered most vulnerable are those located in/near the built environment, particularly those near unreinforced masonry construction. Of these most vulnerable populations, socially vulnerable populations, including the elderly (persons over age 65) and individuals living below the poverty threshold, are most susceptible. Factors leadings 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. According to the 2014 – 2018 5-year American Community Survey (ACS) estimates, there are 7,191 total persons living below the poverty level and 22,889 persons over the age of 65 years in Sussex County.

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. Hazus estimates that there will be zero displaced households and zero persons seeking short-term sheltering caused by the 100-year and 500-year MRP events.

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, the time of day also exposes different sectors of the community to the hazard. For example, Hazus considers the residential occupancy at its maximum at 2:00 a.m., where the educational, commercial, and industrial sectors are at their maximum at 2:00 p.m., with peak commute time at 5:00 p.m. Whether directly impacted or indirectly impact, the entire population will have to deal with the consequences of earthquakes to some degree. Business interruption could prevent people from working, road closures could isolate populations, and loss of functions of utilities could impact populations that suffered no direct damage from an event itself. Overall, Hazus estimates that there are no injuries or casualties caused by the 100-year MRP event and seven injuries caused by the 500-year MRP event (i.e., one injury during the 2AM commute, four injuries during the 2PM commute, and two injuries during the 5PM commute).

Impact on General Building Stock

The entire County's general building stock is considered at risk and exposed to this hazard. Soft soils (NEHRP Soil Classes D and E) can amplify ground shaking to damaging levels even during a moderate earthquake.

Therefore, buildings located on NEHRP Classes D (Figure 4.3.4-1) soils are at increased risk of damage from an earthquake.

There is a strong correlation between PGA and damage a building might undergo (New Jersey 2019). The Hazus model is based on best available earthquake science and aligns with these statements. The Hazus probabilistic earthquake model was applied to analyze effects from the earthquake hazard on general building stock in Sussex County. Refer to Figures 4.3.4-3 and 4.3.4-4 earlier in this profile which illustrates the geographic distribution of PGA (g) across the County for 100-year and 500-year MRP events at the Census-tract level.

A building's construction determines how well it can withstand the force of an earthquake. 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 considers building construction and age of building as part of the analysis. Because a custom general building stock was used for this Hazus analysis, the building ages and building types from the inventory were incorporated into the Hazus model.

Potential building damage was evaluated by Hazus across the following damage categories: none, slight, moderate, extensive, and complete. Table 4.3.4-7 provides definitions of these five categories of damage for a light wood-framed building. Definitions for other building types are included in the Hazus technical manual documentation. The results of potential damage states for buildings in Sussex County categorized by general occupancy classes (i.e., residential, commercial, industrial, etc.) from Hazus are summarized in Table 4.3.4-8 for the 500-year MRP event. Hazus estimates that there are zero damages to structures caused by the 100-year MRP event.

Table 4.3.4-7 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 Technical Manual

Table 4.3.4-8. Estimated Buildings Damaged by General Occupancy for the 500-Year MRP Earthquake Event

Occupancy Class	Total Number of Buildings in Occupancy	Severity of Expected Damage	500-Year MRP Event	
			Building Count	Percent Buildings in Occupancy Class
Residential Exposure (Single and Multi-Family Dwellings)	62,429	None	61,844	99.1%
		Minor	535	0.9%
		Moderate	49	0.1%
		Severe	1	0.0%

Occupancy Class	Total Number of Buildings in Occupancy	Severity of Expected Damage	500-Year MRP Event	
			Building Count	Percent Buildings in Occupancy Class
		Complete Destruction	0	0.0%
Commercial Buildings	3,304	None	3,266	98.8%
		Minor	30	0.9%
		Moderate	7	0.2%
		Severe	1	0.0%
		Complete Destruction	0	0.0%
Industrial Buildings	258	None	249	96.5%
		Minor	7	2.7%
		Moderate	2	0.8%
		Severe	0	0.0%
		Complete Destruction	0	0.0%
Government, Religion, Agricultural, and Education Buildings	6,030	None	5,974	99.1%
		Minor	50	0.8%
		Moderate	6	0.1%
		Severe	0	0.0%
		Complete Destruction	0	0.0%

Source: Sussex County GIS 2020; Hazus; NJDOT 2012

Building damage as a result of the 100-year and 500-year MRP earthquakes were estimated for each municipality using Hazus. Hazus estimates that zero damages will occur to buildings and contents during the 100-year MRP event. Table 4.3.4-9 estimates total building and content losses caused by the 500-year MRP event by jurisdiction. This table also summarizes losses for structures categorized as residential, commercial, and all other occupancy classes. Less than 0.1-percent of the County's structures are impacted by the 500-year MRP event (i.e., approximately $22.1 million in replacement cost value). A majority of the losses are estimated to occur in the Township of Sparta ($3.2 million).

Table 4.3.4-9. Estimated Building Damages (Structure and Contents) from the 500-year MRP Earthquake Event

Jurisdiction	Replacement Cost Value (RCV)	500-Year MRP				
		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)	$628,463,030	$138,206	<0.1%	$41,366	$75,478	$21,362
Andover (Twp)	$3,609,679,724	$1,211,956	<0.1%	$295,663	$687,218	$229,075
Branchville (B)	$532,377,368	$137,604	<0.1%	$40,001	$50,678	$46,924
Byram (Twp)	$2,746,550,446	$912,777	<0.1%	$379,598	$409,542	$123,637
Frankford (Twp)	$3,129,888,305	$849,244	<0.1%	$315,353	$291,281	$242,610
Franklin (B)	$1,921,211,856	$733,079	<0.1%	$274,199	$299,511	$159,369
Fredon (Twp)	$1,372,050,934	$373,196	<0.1%	$167,578	$34,723	$170,895
Green (Twp)	$1,598,635,804	$464,353	<0.1%	$221,292	$36,158	$206,903
Hamburg (B)	$1,588,049,291	$1,375,141	0.1%	$300,503	$768,323	$306,315
Hampton (Twp)	$2,196,131,598	$648,121	<0.1%	$239,795	$212,162	$196,163
Hardyston (Twp)	$3,183,033,542	$1,619,332	0.1%	$613,578	$678,706	$327,048
Hopatcong (B)	$2,888,571,676	$1,055,355	<0.1%	$651,629	$239,749	$163,977
Lafayette (Twp)	$1,958,174,065	$568,466	<0.1%	$149,711	$145,237	$273,518
Montague (Twp)	$1,459,611,020	$382,419	<0.1%	$154,030	$112,671	$115,718
Newton (T)	$5,093,275,807	$1,781,932	<0.1%	$409,696	$931,264	$440,971
Ogdensburg (B)	$819,879,629	$332,147	<0.1%	$116,702	$126,672	$88,773
Sandyston (Twp)	$1,212,626,664	$311,623	<0.1%	$87,694	$74,144	$149,785
Sparta (Twp)	$9,070,094,285	$3,166,510	<0.1%	$1,095,870	$1,556,912	$513,728
Stanhope (B)	$1,051,183,581	$434,431	<0.1%	$181,702	$107,122	$145,606
Stillwater (Twp)	$1,417,579,398	$345,260	<0.1%	$181,040	$53,910	$110,310
Sussex (B)	$1,945,578,916	$696,643	<0.1%	$145,135	$463,241	$88,267

Jurisdiction	Replacement Cost Value (RCV)	500-Year MRP				
		Estimated Total Damage	Percent of Total Building and Contents Replacement Cost Value	Estimated Residential Damage	Estimated Commercial Damage	Estimated Damages for All Other Occupancies
Vernon (Twp)	$5,658,971,163	$3,107,545	0.1%	$1,679,595	$649,630	$778,320
Walpack (Twp)	$63,691,550	$10,401	<0.1%	$2,927	$2,475	$4,999
Wantage (Twp)	$4,877,543,885	$1,488,367	<0.1%	$539,289	$365,878	$583,200
Sussex County (Total)	**$60,022,853,539**	**$22,144,106**	**<0.1%**	**$8,283,949**	**$8,372,687**	**$5,487,470**

Source: Sussex County GIS 2020; RS Means 2020; Hazus; NYS n.d.
Notes: B – Borough; T – Town; Twp. – Township; % - Percent

Historically, Building Officials Code Administration (BOCA) regulations in the northeast states were developed to address local concerns, including 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 in the northeast can cause more structural damage than if it would occur in the west.

Impact on Critical Facilities

All critical facilities in Sussex County are considered exposed to the earthquake hazard. Refer to subsection "Critical Facilities" in Section 3 (County Profile) of this HMP for a complete inventory of critical facilities in Sussex County.

The Hazus earthquake model was used to assign the range or average probability of each damage state category to the critical facilities in Sussex County for the 100-year and 500-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% chance of being fully functional at Day 3, and a 95% 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 100-year MRP event, Hazus estimates that critical facilities will be nearly 100-percent functional with negligible damages. Therefore, the impact to critical facilities is not significant for the 100-year MRP event. Whereas, for the 500-year MRP events, functionality can approximately decrease as low as 4.2-percent. Table 4.3.4-10 summarizes the damage state probabilities for critical facilities during the 500-year MRP event.

Table 4.3.4-10. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities in Sussex County for the 500-Year MRP Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Critical Facilities									
EOC	99.1-99.3%	0.8%	0.1%	0.0%	0.0%	99.2%	99.9%	99.9%	99.9%
Medical	99.2%	0.8%	0.0%	0.0%	0.0%	99.1%	99.9%	99.9%	99.9%
Police	95.9-97.7%	1.4-2.4%	0.8-1.5%	0.1-0.3%	0.0%	95.9-97.6%	98.1-99.0%	99.8%	99.9%
Fire	95.9-97.9%	1.2-2.4%	0.7-1.5%	0.1-0.3%	0.0%	95.9-97.9%	98.1-99.1%	99.8%	99.9%
Schools	97.4-98.6%	1.0-1.8%	0.3-0.8%	0.1%	0.0%	97.3-98.6%	99.5%	99.9%	99.9%
Utilities									
Potable Water	95.9-98.0%	1.2-2.3%	0.7-1.5%	0.1-0.3%	0.0%	97.7-99.2%	99.8%	99.9%	99.9%
Waste Water	96.1-97.7%	1.4-2.3%	0.8-1.4%	0.1-0.3%	0.0%	96.9-98.2%	99.8%	99.9%	99.9%
Communication	95.8-99.2%	0.7-2.8%	0.0-1.2%	0.0%-0.1%	0.0%	99.9%	99.9%	99.9%	99.9%
Electric Power	96.1-98.0%	1.2-2.3%	0.7-1.4%	0.1-0.3%	0.0%	97.3-98.6%	99.9%	99.9%	99.9%
Natural Gas Facility	97.2%	0.1%	0.0%	0.0%	0.0%	98.9%	99.9%	99.9%	99.9%
Transportation									
Airport Facility	99.2%	0.8%	0.0%	0.0%	0.0%	99.9%	99.9%	99.9%	99.9%

Source: Hazus; Sussex County GIS 2020
Notes: EOC = Emergency Operations Center; MRP = Mean Return Period; % - Percent

Impact on Economy

Earthquakes also have impacts on the economy, including loss of business function, damage to inventory, relocation costs, wage loss, and rental loss due to the repair/replacement of buildings. Hazus 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 are summarized in Table 4.3.4-11.

Table 4.3.4-11. Economic Losses for Earthquake MRP Events

Mean Return Period (MRP)	Inventory Loss	Relocation Loss	Building and Content Losses	Wages Losses	Rental Losses	Capital-Related Loss
100-year MRP	$0	$0	$0	$0	$0	$0
500-year MRP	$172,600	$1,213,800	$22,143,500	$551,600	$643,000	$322,700

Source: Hazus; RS Means 2020

Although the Hazus 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. Earthquake events can also 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 times of construction.

Hazus also estimates the volume of debris that may be generated as a result of an earthquake event to enable the study region to prepare and rapidly and efficiently manage debris removal and disposal. Debris estimates are divided into two categories: (1) reinforced concrete and steel that require special equipment to break it up before it can be transported, and (2) brick, wood, and other debris that can be loaded directly onto trucks with bulldozers (Hazus-MH Earthquake User's Manual 2020).

For the 100-year MRP event, Hazus estimates that zero tons of debris will be generated. For the 500-year MRP event, Hazus estimates a total of 3,596 tons of debris will be generated county-wide. Table 5.4.4-4.3.5-6 and Table 5.4.4-4.3.5-6 summarizes the estimated debris generated as a result of these events by municipality.

Table 4.3.4-12. Estimated Debris Generated by the 500-Year MRP Earthquake Events

Jurisdiction	500-Year	
	Brick/Wood (tons)	Concrete/Steel (tons)
Andover (B)	11	9
Andover (Twp)	97	69
Branchville (B)	11	4
Byram (Twp)	71	37
Frankford (Twp)	77	25
Franklin (B)	126	23
Fredon (Twp)	34	15
Green (Twp)	67	10

Jurisdiction	500-Year	
	Brick/Wood (tons)	Concrete/Steel (tons)
Hamburg (B)	209	82
Hampton (Twp)	85	26
Hardyston (Twp)	157	71
Hopatcong (B)	113	31
Lafayette (Twp)	57	11
Montague (Twp)	47	16
Newton (T)	313	100
Ogdensburg (B)	67	10
Sandyston (Twp)	48	10
Sparta (Twp)	363	68
Stanhope (B)	62	42
Stillwater (Twp)	42	6
Sussex (B)	101	36
Vernon (Twp)	423	75
Walpack (Twp)	2	0
Wantage (Twp)	159	78
Sussex County (Total)	**2,741**	**855**

Source: Hazus
Notes: B – Borough; T – Town; Twp. – Township

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.

Future Growth and Development

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 and illustrated in Section 3 (County Profile), areas targeted for future growth and development have been identified across the County. Development built in areas with softer NEHRP soil classes, liquefaction, and landslide-susceptible areas may experience shifting or cracking in the foundation during earthquakes because of the loose soil characteristics of these soil classes. However, current building codes require seismic provisions that should render new construction less vulnerable to seismic impacts than older, existing construction that may have been built to lower construction standards. Refer to Section 3, and Volume II Section 9 for more information about the potential new development in Sussex County.

Projected Changes in Population

Sussex County has experienced population decline since 2010. According to the U.S. Census Bureau, the County's population has decreased 4.7-percent between 2010 and 2018 (U.S. Census Bureau 2020). The Township of Walpack and the Borough of Sussex have experienced the greatest decline with a decrease of 62.5-percent and 13.0-percent, respectively. The population is expected to continue to decrease as residents move away from the suburbs and towards urban centers (Stirling 2018). Even though the population has decreased, any 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. As noted earlier, if moving into new construction, current building codes require seismic provisions that should render new construction less vulnerable to seismic impacts.

Climate Change

Because the impacts of climate change on earthquakes are not well understood, a change in the County's vulnerability as the climate continues to change 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. Refer to Section 4.3.6 for additional discussion of the geological hazard.

Vulnerability Change Since the 2016 HMP

Overall, the entire County continues to be vulnerable to earthquakes. For the 2021 HMP, the exposure analyses were conducted using 2014-2018 American Community Survey 5-year population estimates. The building inventory was updated using RS Means 2020 values, which is more current and reflects replacement cost versus the building stock improvement values reported in the 2016 HMP. Additional building stock updates include updates to the critical facility inventory provided by Sussex County. Furthermore, since the 2016 HMP, an updated version of Hazus was released (v4.2). This updated model includes longer historical records to pull from to generate probabilistic events. Further, a NEHRP boundary was created for NEHRP soil class D using the NJDOT Soil Classification map (Figure 4.3.4-1).