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 Essex County.

2019 HMP Update Changes

- All subsections have been updated using best available data.
- Previous occurrences were updated with events that occurred between 2015 and 2019.
- The New Jersey Geologic and Water Survey (NJGWS) updated liquefaction data has been integrated into the vulnerability assessment.
- Updated HAZUS-MH probabilistic modeling was conducted using updated inventory data.

4.3.4.1 Profile

Hazard Description

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

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

According to the 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 Essex 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 4.5.7 (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 Essex 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

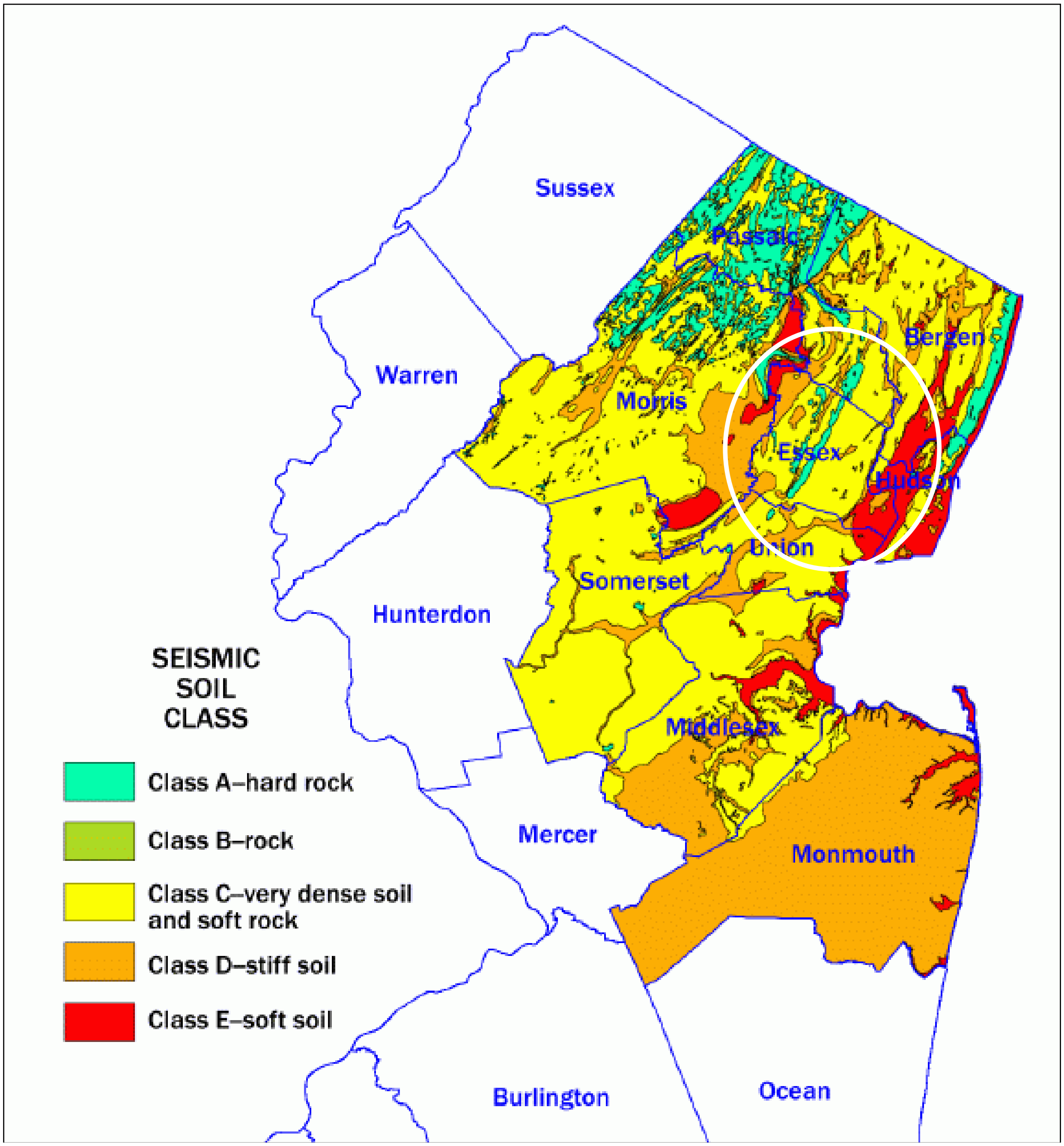
Soil Classification	Description
A	Hard Rock
B	Rock
C	Very dense soil and soft rock
D	Stiff soils
E	Soft soils

Source: FEMA 2013

Earthquakes are most likely to occur in the northern parts of New Jersey, where significant faults are concentrated; however, low-magnitude events can and do occur in many other areas of the State. Figure 4.3.4-1 illustrates the NEHRP soils located in the northeast quadrant the State. The data was available from the New Jersey Geologic and Water Survey. The available NEHRP soils information is incorporated into the HAZUS-

MH earthquake model for the risk assessment (discussed in further detail later in this section). According to this figure, Essex County is predominately underlain by Class C soils, with bands of Class A in the central portion of the County and areas of Class D in the western and southwestern areas.

Figure 4.3.4-1. Seismic Soils in Northeastern New Jersey

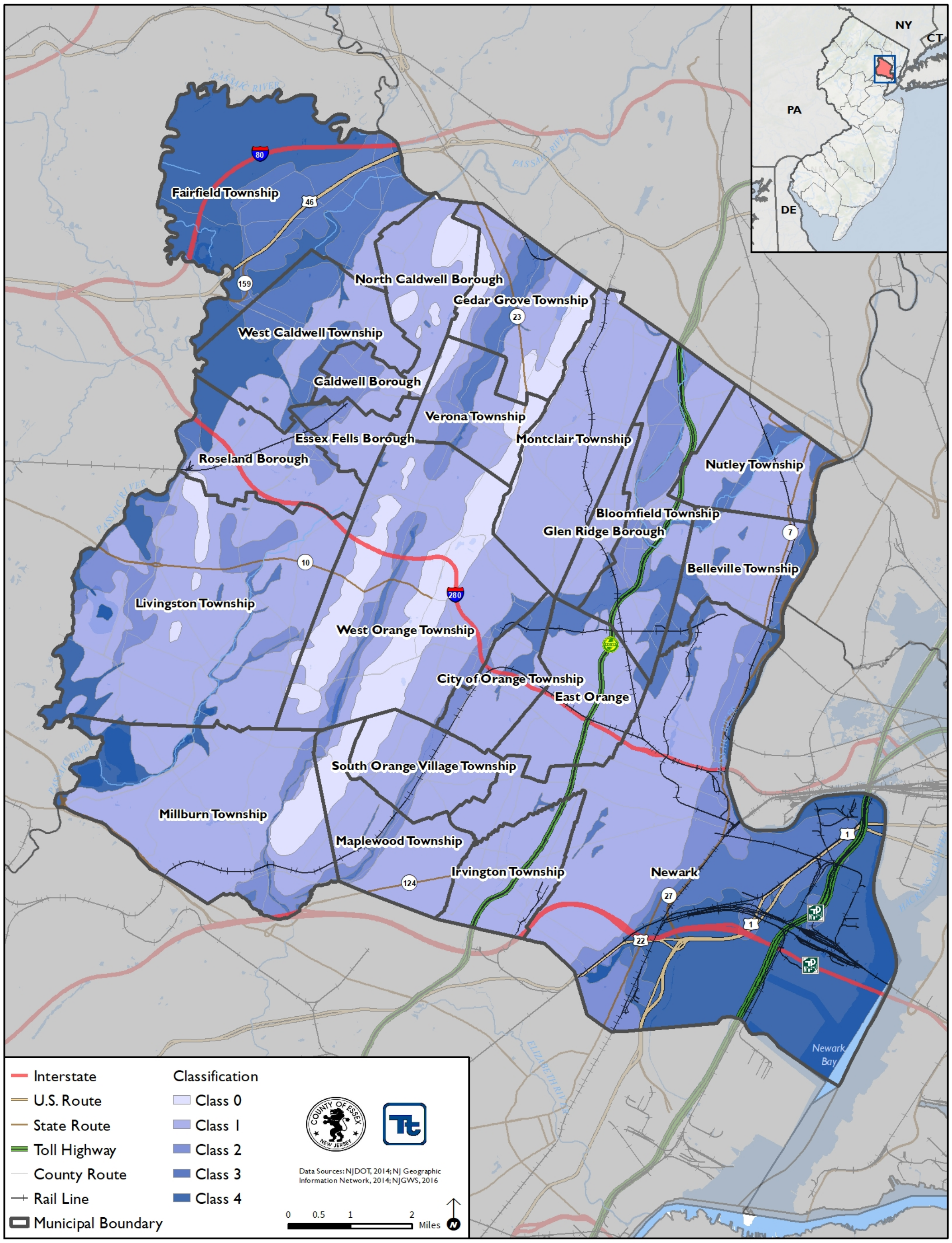


Source: New Jersey Geological and Water Survey (NJGWS) and New Jersey Department of Environmental Protection (NJDEP) 2011

Note: The white circle indicates the location of Essex County. The County contains mainly Class C soils, with areas of Class A, B, D, and E.

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. In terms of liquefaction susceptibility, the interior of the northwestern and southeastern corners and some parts in central and western Essex County have a medium susceptibility, and southeastern Essex County (City of Newark) and the western edge and northwest corner of the County along the Passaic River have a high liquefaction susceptibility (see Figure 4.3.4-2).

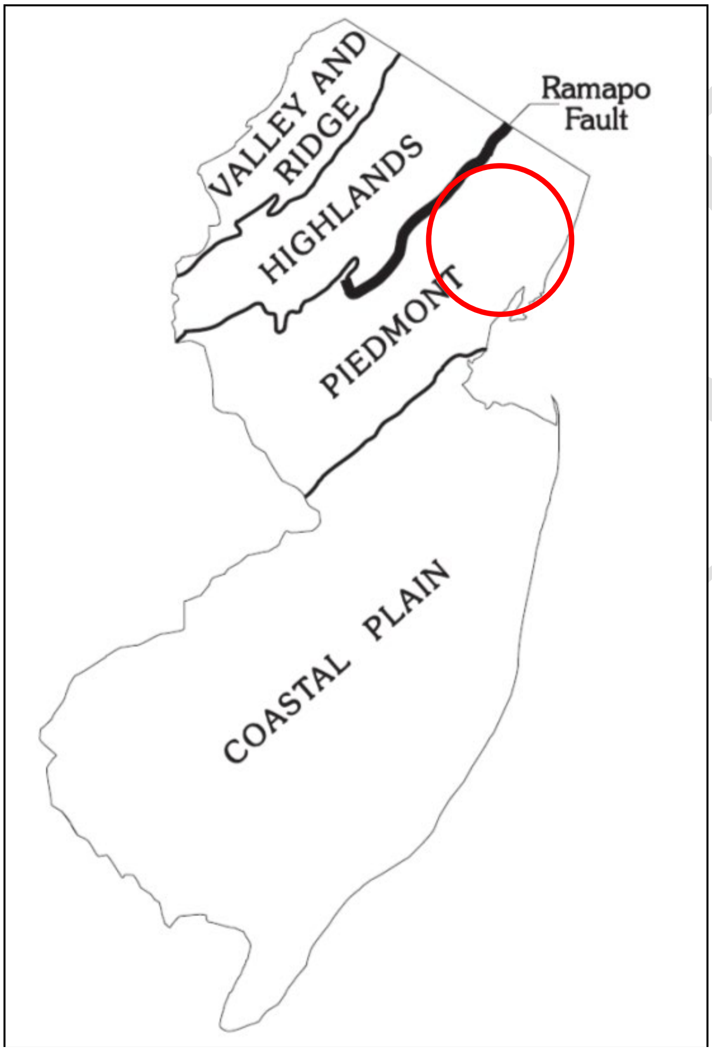
Figure 4.3.4-2. Liquefaction Susceptibility in Essex County



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

There are many faults in New Jersey; however, the Ramapo Fault, which separates the Piedmont and Highlands Physiographic Provinces, is best known. Numerous minor earthquakes have been recorded in the Ramapo Fault zone, a 10- to 20-mile-wide area lying adjacent to, and west, of the actual fault (Dombroski 1973 [revised 2005]). Figure 4.3.4-3 illustrates the relationship of the Ramapo fault line with the physiologic provinces of New Jersey. Essex County is located in the Piedmont Province and near the Ramapo Fault line.

Figure 4.3.4-3. Physiographic Provinces of New Jersey and the Ramapo Fault Line



Source: Dombroski 1973 (revised 2005)

Note: The red circle indicates the approximate location of Essex 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 4.3.4-2. 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 4.3.4-3 displays the MMI scale and its relationship to the areas peak ground acceleration (PGA).

Table 4.3.4-2. Modified Mercalli Intensity Scale

Mercalli Intensity	Description
I	Felt by very few people; barely noticeable.
II	Felt by few people, especially on upper floors.
III	Noticeable indoors, especially on upper floors, but may not be recognized as an earthquake.
IV	Felt by many indoors, few outdoors. May feel like passing truck.
V	Felt by almost everyone, some people awakened. Small objects 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 2016c

Table 4.3.4-3. 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 4.3.4-4.

Table 4.3.4-4. Damage Levels Experienced in Earthquakes

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

Source: NJOEM 2011
Note: %g Peak Ground Acceleration

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.

Figure 4.3.4-4 through Figure 4.3.4-6 illustrate geographic distributions of the Modified Mercalli Scale based on PGAs (%*g*) across Essex County for 100-, 500-, and 2,500-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. A 2,500-year MRP is an earthquake with 0.04 percent chance that mapped PGAs will be exceeded in any given year.

Figure 4.3.4-4. Peak Ground Acceleration 100-Year Mean Return Period for Essex County

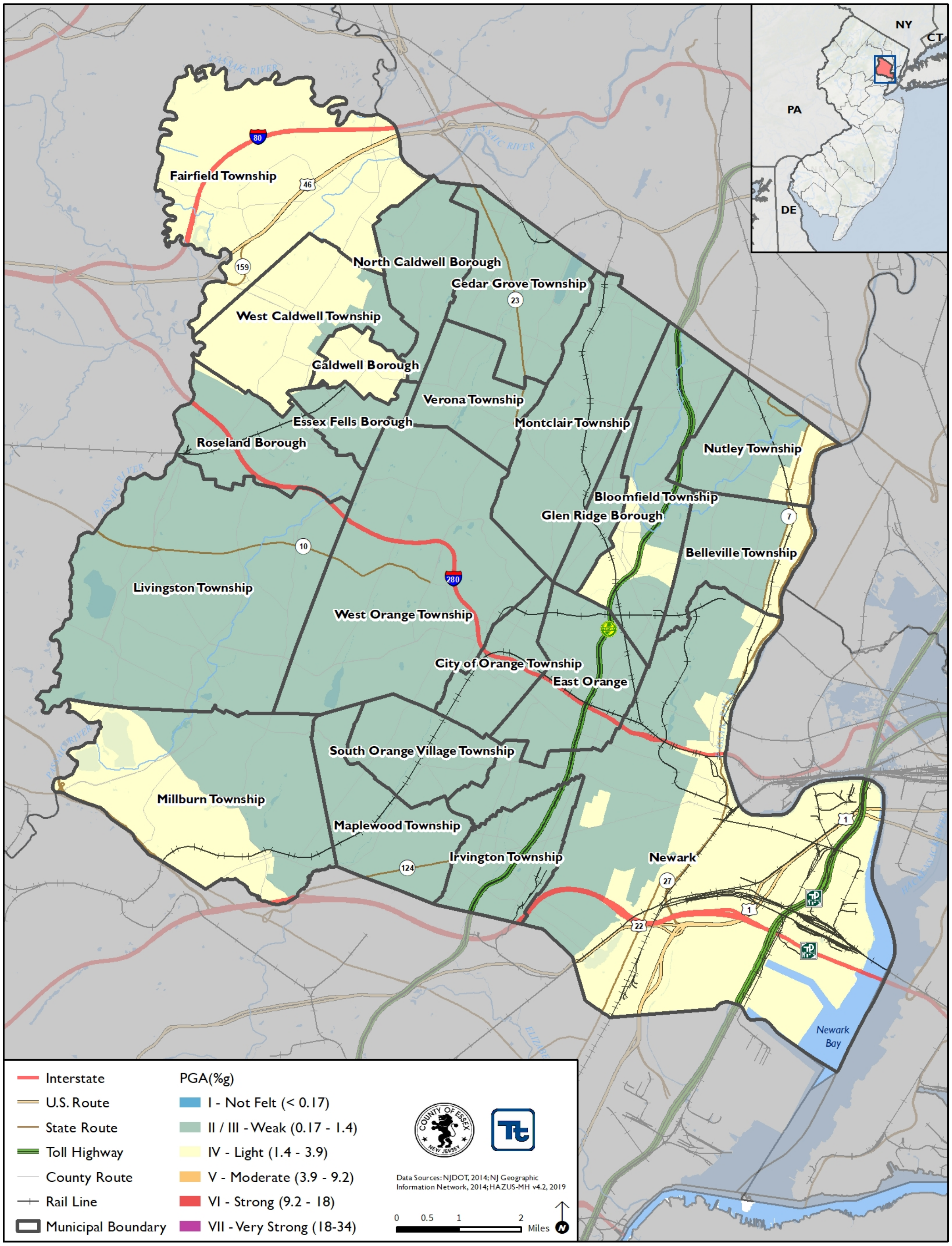


Figure 4.3.4-5. Peak Ground Acceleration 500-Year Mean Return Period for Essex County

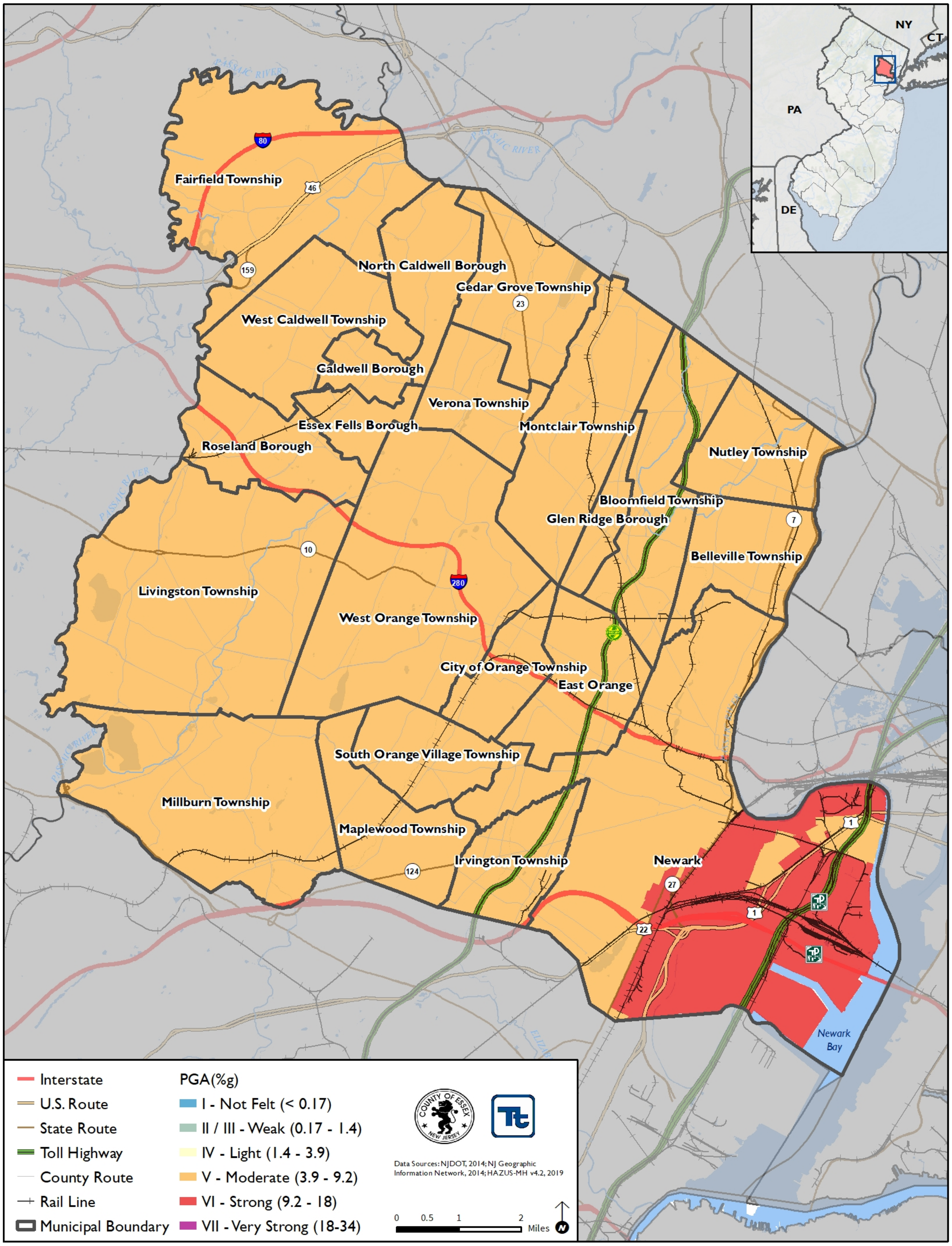
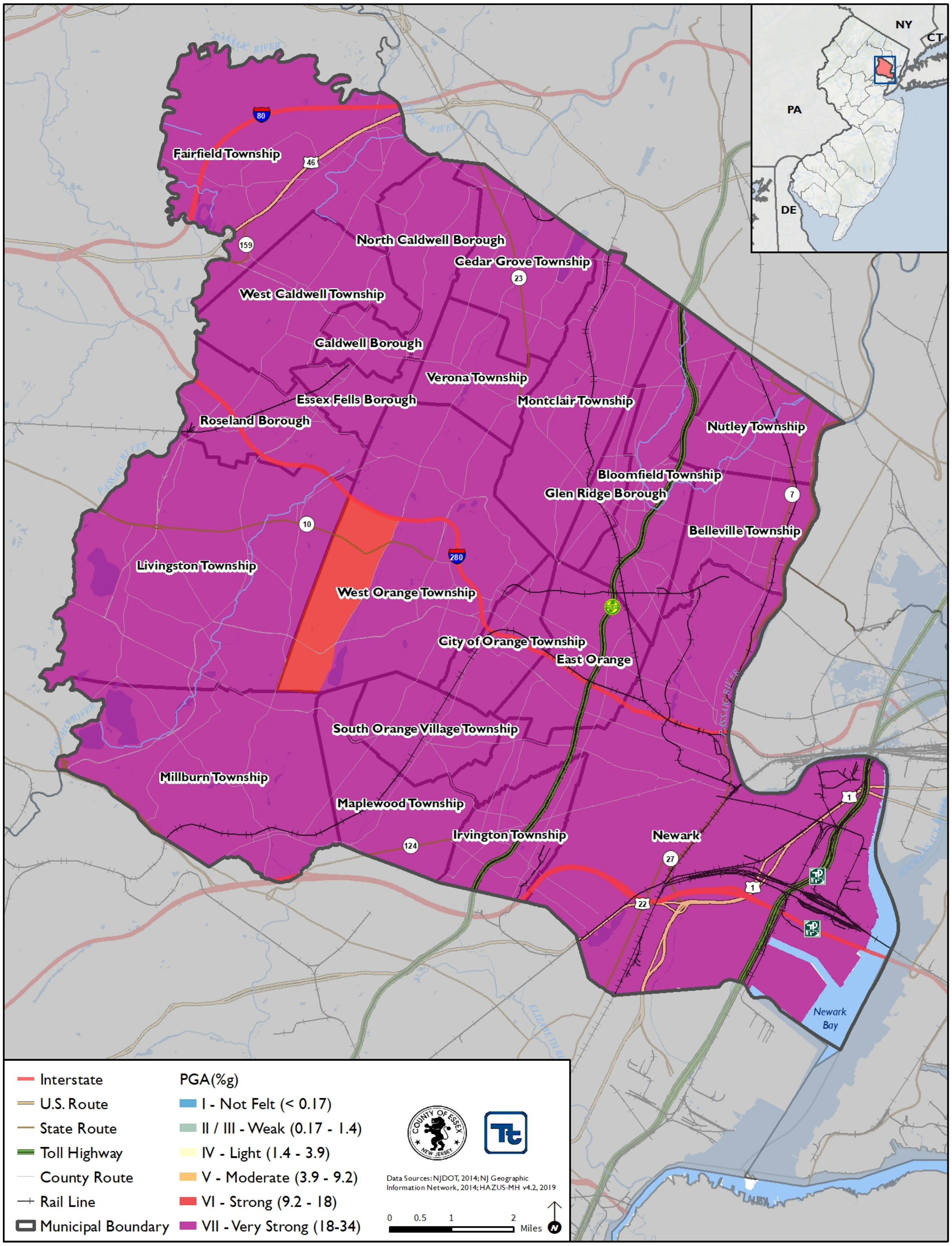


Figure 4.3.4-6. Peak Ground Acceleration 2,500-Year Mean Return Period for Essex County

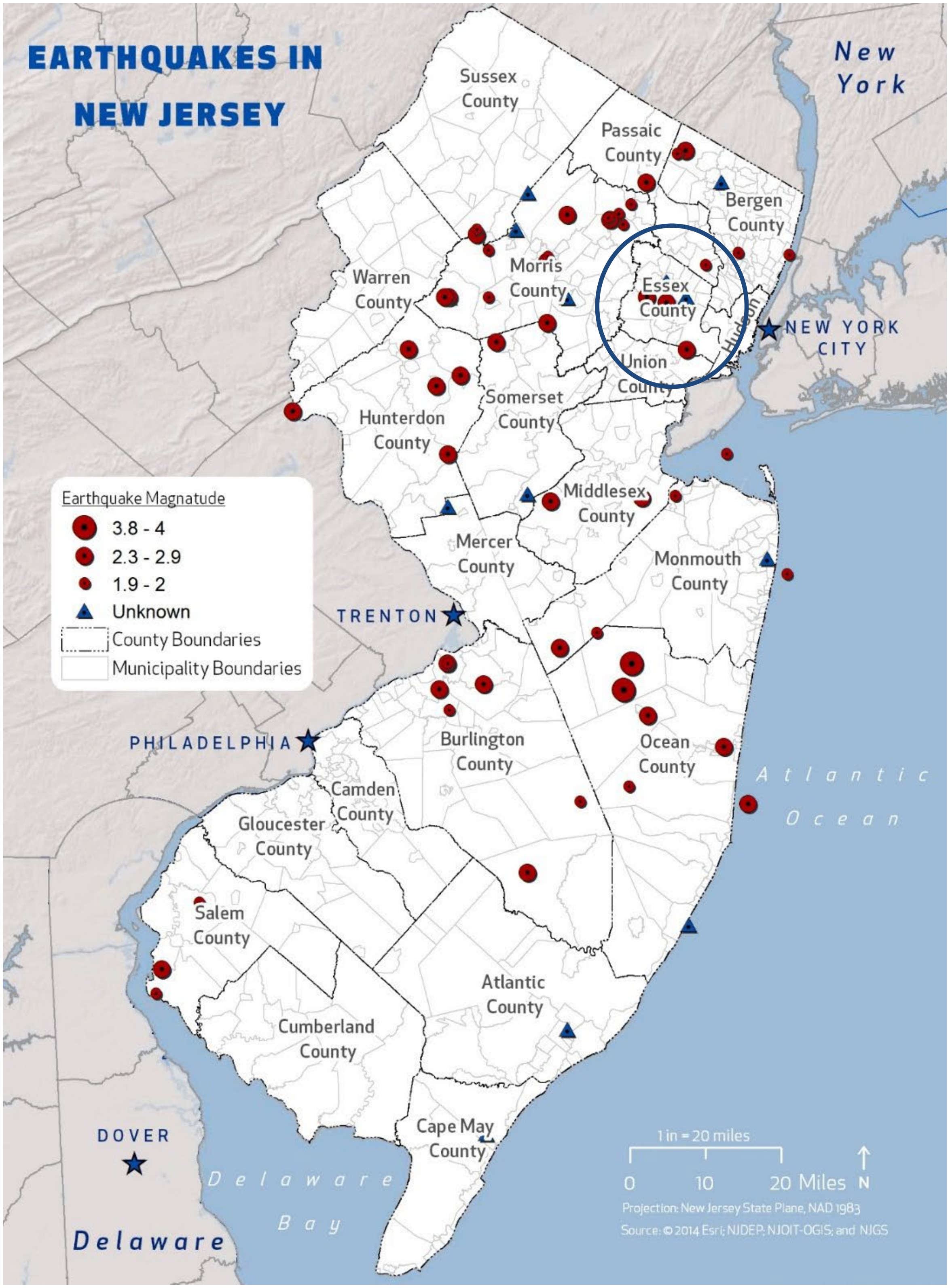


Previous Occurrences and Losses

New Jersey has a fairly extensive history of earthquakes. Small earthquakes occur several times a year and generally do not cause significant damage. The largest earthquake to impact New Jersey occurred in 1783. That earthquake, a magnitude 5.3 quake, occurred west of New York City and was felt from New Hampshire to Pennsylvania (Stover and Coffman 1993). Figure 4.3.4-7 illustrates earthquake events with epicenters located in New Jersey. Of the 178 events in the State, four earthquake epicenters were located in Essex County.

Earthquake events that have impacted Essex County between 2014 and 2019 are listed in Table 4.3.4-5. In the 2015 HMP, previous events were listed for the entirety of New Jersey. For the 2020 HMP, only events that impacted or could be felt in Essex County have been included. For events prior to 2014, refer to Appendix X (Risk Assessment Supplement). Please see Section 9 (Jurisdictional Annexes) for detailed information regarding impacts and losses to each municipality. The State of New Jersey has not been included in any FEMA disaster (DR) or emergency (EM) declarations for earthquake events.

Figure 4.3.4-7. Earthquakes with Epicenters in New Jersey, 1783 to 2017



Source: *NJDEP 2017*

Note: *The blue circle indicates the location of Essex County. The figure shows that several earthquakes have been epicentered in Essex County.*

Table 4.3.4-5. Earthquake Events impacting Essex County, 2014 to 2019

Dates of Event	Event Type	FEMA Declaration Number	County Designated?	Location	Losses/Impacts
March 27, 2015	1.1 Earthquake	N/A	N/A	Clifton, New Jersey	A magnitude 1.1 earthquake took place just south of Clifton, NJ at the border of Essex and Passaic County.
August 14, 2015	2.6 Earthquake	N/A	N/A	Bernardsville, New Jersey	A magnitude 2.6 earthquake took place in Bernardsville, NJ. The quake was faintly felt in Essex County.
August 22, 2015	1.2 Earthquake	N/A	N/A	Fairfield	A magnitude 1.2 earthquake took place in Fairfield at the border of Essex and Morris County.
January 2, 2016	2.1 Earthquake	N/A	N/A	Ringwood, New Jersey	A magnitude 2.1 earthquake took place in Ringwood, NJ. The quake was faintly felt in Essex County.
July 31, 2016	0.8 Earthquake	N/A	N/A	Brookdale	A magnitude 0.8 earthquake took place in Brookdale.
November 30, 2017	4.1 Earthquake	N/A	N/A	Dover, Delaware	Essex County residents felt ground shake from nearby 4.1 magnitude earthquake in Dover, Delaware. The quake was felt from central Virginia to Massachusetts.
April 12, 2019	1.8 Earthquake	N/A	N/A	Clifton, New Jersey	A magnitude 1.8 earthquake took place in Clifton, NJ. The quake was faintly felt in the western portion of Essex County.

Source: NJGWS 2019; USGS 2019
N/A Not Applicable/Not Available
NJ New Jersey

Probability of Future Occurrences

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

In Section 4.4 (Hazard Ranking), the identified hazards of concern for Essex 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 Steering Committee and Planning Committee, the probability of occurrence for earthquake events in the County is considered 'occasional'.

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).

4.3.4.2 Vulnerability Assessment

Earthquake vulnerability data was generated using HAZUS. A probabilistic assessment was conducted for the 100-, 500- and 2,500-year MRPs through a Level 2 analysis in HAZUS-MH to analyze the earthquake hazard and provide a range of loss estimates. Figure 4.3.4-8 shows the geographic distribution of the NEHRP soil types in the County. Figure 4.3.4-9 shows the geographic distribution of the liquefaction soil types in the County. Refer to Section 4.2 (Methodology and Tools) for additional details on the methodology used to assess earthquake risk.

Impact on Life, Health and Safety

The entire population of Essex County is exposed to the direct and indirect impacts from earthquakes. The degree of exposure is dependent on many factors including the age and type of construction people live in, the soil types their homes are located on, the intensity of the earthquake. Whether directly or indirectly impacted, residents could be faced with business closures, road closures that could isolate populations, and loss of function of critical facilities and utilities.

According to the 2017 American Community Survey annual estimate, Essex County had a population of 800,401 people. Overall, risk to public safety and loss of life from an earthquake in the County is minimal. 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.

As noted earlier, NEHRP Soil Classes D and E and liquefaction Class 4 soils can amplify ground shaking to damaging levels even during a moderate earthquake, and thus increase risk to the population. Populations within municipalities located on NEHRP Class D and E soils and high liquefaction susceptible soils were estimated and are listed in Table 4.3.4-6 below. Overall, approximately 121,736 people (15.2% of the County's population) are located on NEHRP class "D" and "E" soils. In addition, 8,942 people (1.1% of the County's population) are located in areas of high susceptibility to liquefaction. The Township of Fairfield has the greatest percent of its population exposed to both hazard areas (NEHRP Class D and E: 82.6%; Liquefaction Class 4: 23.6%). In the 2015 HMP, only the City of Newark had exposure to Class 4 soils; however, the 2016 NJGWS expanded these areas and indicated increased susceptibility to liquefaction along the Passaic River throughout communities in eastern and western Essex County.

Figure 4.3.4-8. NEHRP Soils Types in Essex County

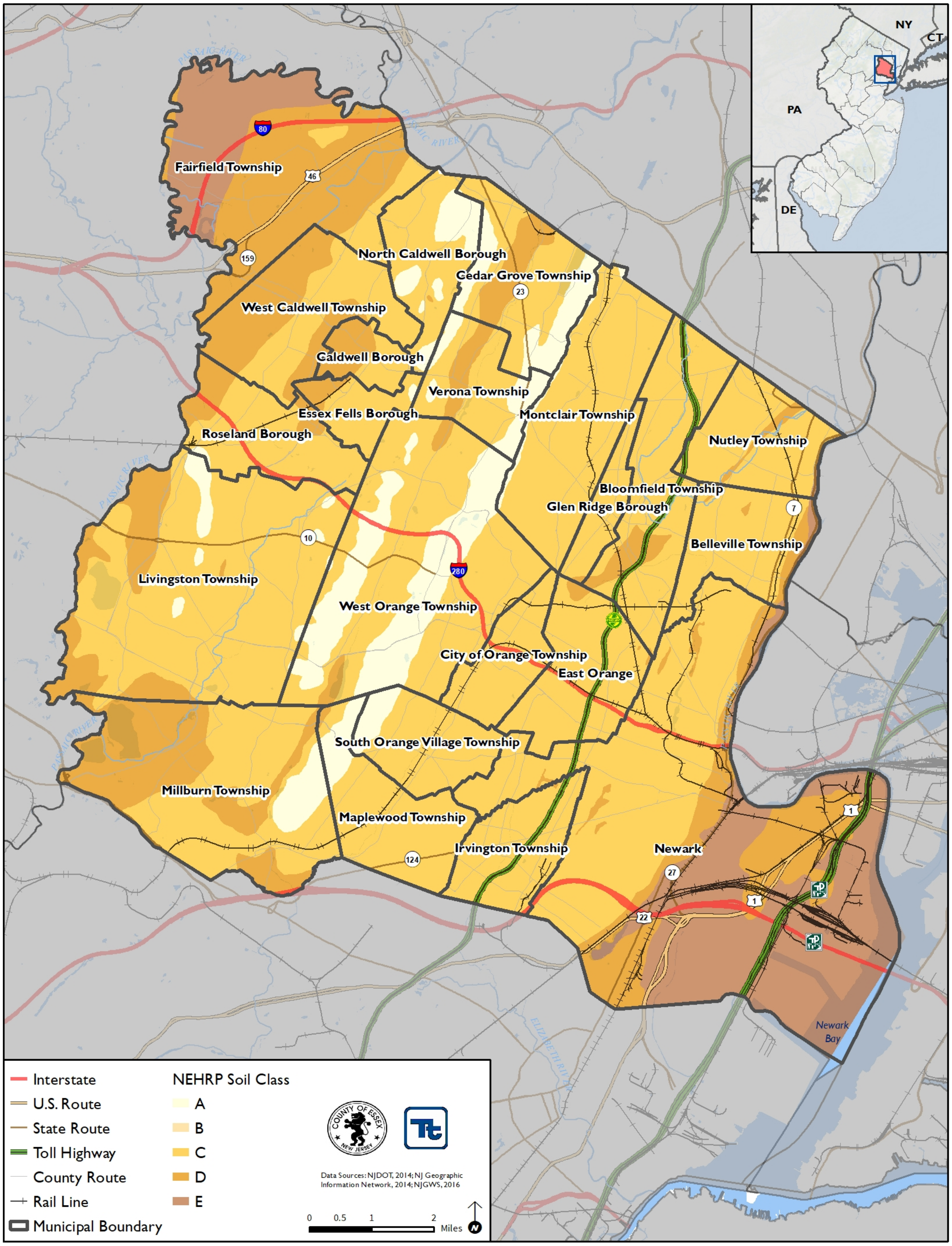


Table 4.3.4-6. Approximate Population within NEHRP and Liquefaction Areas

Municipality	American Community Survey (2013-2017) Population	Population NEHRP Class "D" and "E" Soils		Population Liquefaction Class 4	
		Number	%	Number	%
Township of Belleville	36,383	2,368	6.5%	179	<1%
Township of Bloomfield	48,892	5,085	10.4%	0	0.0%
Borough of Caldwell	8,032	4,808	59.9%	0	0.0%
Township of Cedar Grove	12,638	2,411	19.1%	0	0.0%
City of East Orange	65,151	1,469	2.3%	0	0.0%
Borough of Essex Fells	2,095	176	8.4%	0	0.0%
Township of Fairfield	7,671	6,337	82.6%	1,807	23.6%
Borough of Glen Ridge	7,668	197	2.6%	0	0.0%
Township of Irvington	54,715	219	<1%	0	0.0%
Township of Livingston	29,955	1,022	3.4%	40	<1%
Township of Maplewood	24,706	0	0.0%	0	0.0%
Township of Millburn	20,387	5,560	27.3%	27	<1%
Township of Montclair	38,572	0	0.0%	0	0.0%
City of Newark	282,803	82,555	29.2%	6,610	2.3%
Borough of North Caldwell	6,637	13	<1%	0	0.0%
Township of Nutley	28,829	1,358	4.7%	87	<1%
City of Orange Township	30,731	0	0.0%	0	0.0%
Borough of Roseland	5,907	916	15.5%	3	<1%
Township of South Orange Village	16,503	0	0.0%	0	0.0%
Township of Verona	13,585	3,056	22.5%	0	0.0%
Township of West Caldwell	10,932	3,700	33.8%	190	1.7%
Township of West Orange	47,609	486	1.0%	0	0.0%
Essex County (Total)	**800,401**	**121,736**	**15.2%**	**8,942**	**1.1%**

Sources: American Community Survey 5-year Estimate, 2017; NJGWS, 2016

Populations considered most vulnerable are those located in/near the built environment, particularly those near unreinforced masonry structures. Of these most vulnerable populations, socially vulnerable populations, including the elderly (persons over age 65) and individuals living below the census poverty threshold, are most susceptible. Factors leading to this higher susceptibility include decreased mobility and financial ability to react or respond during a hazard, and the location and construction quality of their housing. Within the NEHRP Class D and E soils, there are 13,913 people over the age of 65 and 21,775 people below the poverty level. Within liquefaction Class 4 soils, there are 786 people over the age of 65 and 1,046 people below the poverty level.

Residents may be displaced or require temporary to long-term sheltering due to an earthquake event. The number of people requiring shelter is generally less than the number displaced as some displaced persons use hotels or stay with family or friends following a disaster event. Table 4.3.4-7 summarizes the households HAZUS-MH v4.2 estimates will be displaced and population that may require short-term sheltering as a result of the 100-, 500- and 2,500-year MRP earthquake events.

Table 4.3.4-7. Summary of Estimated Sheltering Needs for Essex County

Scenario	Displaced Households	Persons Seeking Short-Term Shelter
100-Year Earthquake	1	1
500-Year Earthquake	202	162
2,500-Year Earthquake	2,742	2,224

Source: HAZUS-MH v4.2

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

Table 4.3.4-8 summarizes the County-wide injuries and casualties estimated for the 100-, 500-, and 2,500-year MRP earthquake events.

Table 4.3.4-8. Estimated Number of Injuries and Casualties from the 100-, 500-, and 2,500-Year MRP Earthquake Events

Level of Severity	Time of Day		
	2:00 AM	2:00 PM	5:00 PM
100-year MRP			
Injuries	0	0	1
Hospitalization	0	0	3
Casualties	0	0	0
500-year MRP			
Injuries	30	43	32
Hospitalization	4	6	8
Casualties	1	1	1
2,500-year MRP			
Injuries	325	448	332
Hospitalization	59	91	75
Casualties	11	18	14

Source: HAZUS-MH v4.2

Impact on General Building Stock

The entire County's general building stock is considered at risk and exposed to this hazard. As stated earlier, soft soils (NEHRP Soil Classes D and E) can amplify ground shaking to damaging levels even during a moderate earthquake (NYCEM 2003). Therefore, buildings located on NEHRP Classes D and E soils and high liquefaction susceptible soils are at increased risk of damage from an earthquake. Table 4.3.4-9 summarizes the number and replacement cost value of buildings in Essex County located on NEHRP Soils Classes D and E and liquefaction Class 4 soils.

Table 4.3.4-9. Number and Replacement Cost Value of Buildings within NEHRP and Liquefaction Areas

Municipality	Total Number of Buildings	Total RCV (Structure and Contents)	Buildings NEHRP Class "D" and "E" Soils			Buildings Liquefaction Class 4		
			Number	RCV	% of Total RCV	Number	RCV	% of Total RCV
Township of Belleville	7,910	$4,483,250,138	504	$550,476,187	12.3%	37	$80,430,934	1.8%
Township of Bloomfield	11,720	$6,021,089,887	1035	$694,069,667	11.5%	0	$0	0.0%
Borough of Caldwell	1,738	$1,183,204,981	1002	$615,988,955	52.1%	0	$0	0.0%
Township of Cedar Grove	3,944	$3,008,045,785	740	$843,004,854	28.0%	0	$0	0.0%
City of East Orange	7,908	$6,090,766,912	282	$110,922,535	1.8%	0	$0	0.0%
Borough of Essex Fells	766	$527,629,662	64	$34,459,982	6.5%	0	$0	0.0%
Township of Fairfield	3,121	$6,082,819,367	2578	$5,349,810,165	87.9%	735	$1,563,613,990	25.7%
Borough of Glen Ridge	2,256	$1,095,474,263	58	$19,937,181	1.8%	0	$0	0.0%
Township of Irvington	7,934	$5,384,838,816	30	$17,026,564	0.3%	0	$0	0.0%
Township of Livingston	9,795	$7,691,376,811	310	$519,221,451	6.8%	12	$69,128,114	0.9%
Township of Maplewood	6,738	$3,575,395,600	0	$0	0.0%	0	$0	0.0%
Township of Millburn	6,437	$5,241,567,136	1762	$1,974,304,439	37.7%	9	$11,628,704	0.2%
Township of Montclair	9,436	$5,845,976,130	0	$0	0.0%	0	$0	0.0%
City of Newark	43,085	$40,970,549,425	11,579	$20,174,784,407	49.2%	1,091	$6,759,796,576	16.5%
Borough of North Caldwell	2,095	$1,727,767,442	4	$3,009,682	0.2%	0	$0	0.0%
Township of Nutley	7,945	$3,841,553,722	414	$262,081,308	6.8%	15	$26,609,238	0.7%
City of Orange Township	3,890	$3,520,865,708	0	$0	0.0%	0	$0	0.0%
Borough of Roseland	1,794	$1,955,487,279	278	$255,621,702	13.1%	1	$4,648,900	0.2%
Township of South Orange Village	4,188	$2,877,374,186	0	$0	0.0%	0	$0	0.0%
Township of Verona	4,113	$2,213,338,613	925	$477,765,931	21.6%	0	$0	0.0%
Township of West Caldwell	3,730	$3,533,044,820	1267	$1,540,696,116	43.6%	66	$271,015,777	7.7%
Township of West Orange	11,845	$8,358,783,858	133	$89,133,008	1.1%	0	$0	0.0%
Essex County	**162,388**	**$125,230,200,542**	**22,965**	**33,532,314,136**	**26.8%**	**1,966**	**8,786,872,232**	**7.0%**

Sources: American Community Survey 5-year Estimate, 2017; Microsoft, 2018, Open Street Map, 2019; NJOIT, 2018; NJGWS, 2016
RCV Replacment Cost Value.

There is a strong correlation between PGA and damage a building might undergo (NYCEM 2003). The HAZUS-MH model is based on best available earthquake science and aligns with these statements. The HAZUS-MH probabilistic earthquake model was applied to analyze effects from the earthquake hazard on general building stock in Essex County. See Figure 4.3.4-4 through Figure 4.3.4-6 earlier in this profile which illustrates the geographic distribution of PGA (g) across the County for 100-, 500- and 2,500-year MRP events at the Census-tract level.

A building's construction determines how well it can withstand the force of an earthquake. The NYCEM report indicates that unreinforced masonry buildings are most at risk during an earthquake because the walls are prone to collapse outward, whereas steel and wood buildings absorb more of the earthquake's energy. Additional attributes that affect a building's capability to withstand an earthquake's force include its age, number of stories, and quality of construction. HAZUS-MH v4.2 considers building construction and age of building as part of the analysis. Because a custom general building stock was used for this HAZUS-MH v4.2 analysis, the building ages and building types from the inventory were incorporated into the HAZUS-MH v4.2 model.

Potential building damage was evaluated using HAZUS-MH v4.2 across the following damage categories: none, slight, moderate, extensive, and complete. Table 4.3.4-10 provides definitions of these five categories of damage to a light wood-framed building; definitions of categories of damage to other building types appear in HAZUS-MH technical manual documentation.

Table 4.3.4-10. Example of Structural Damage State Definitions for a Light Wood-Framed Building

Damage Category	Description
None	No damage recorded.
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 might have large permanent lateral displacement, can collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system; some structures can slip and fall off the foundations; large foundation cracks.

Source: HAZUS-MH Technical Manual

Building damage as a result of the 100-, 500- and 2,500-year MRP earthquake events was estimated using HAZUS-MH v4.2. Table 4.3.4-11 lists the estimated numbers of buildings damaged (within general occupancy categories) from the 500- and 2,500-year MRP earthquake events. Damage loss estimates include structural and non-structural damage to the building and loss of contents. Table 4.3.4-12 lists estimated replacement cost values (RCVs) of buildings and contents damaged by the 100-, 500- and 2,500-year MRP earthquake events.

Table 4.3.4-11. Estimated Buildings Damaged by General Occupancy for 100-year and 1,000-year MRP Earthquake Events

	Expected Building Damage by Occupancy									
	500-Year MRP					2,500-Year MRP				
Category	None	Slight	Moderate	Extensive	Complete	None	Slight	Moderate	Extensive	Complete
Residential	139,909 (86.2%)	2,384 (1.5%)	528 (<1%)	67 (<1%)	7 (<1%)	118,927 (73.2%)	18,049 (11.1%)	4,939 (3.0%)	839 (<1%)	141 (<1%)

Category	Expected Building Damage by Occupancy									
	500-Year MRP					2,500-Year MRP				
	None	Slight	Moderate	Extensive	Complete	None	Slight	Moderate	Extensive	Complete
Commercial	8,272 (5.1%)	321 (<1%)	111 (<1%)	14 (<1%)	1 (<1%)	6,358 (3.9%)	1,253 (<1%)	849 (<1%)	223 (<1%)	35 (<1%)
Industrial	1,718 (1.2%)	103 (<1%)	45 (<1%)	7 (<1%)	0 (0%)	1,094 (<1%)	332 (<1%)	310 (<1%)	119 (<1%)	19 (<1%)
Education, Government, Religious and Agricultural	8,478 (5.5%)	303 (<1%)	106 (<1%)	13 (<1%)	1 (<1%)	6,637 (4.1%)	1,195 (<1%)	808 (<1%)	225 (<1%)	36 (<1%)

Source: HAZUS-MH v4.2

Table 4.3.4-12. Estimated Value (Building and Contents) Damaged by the 100-, 500- and 2,500-Year MRP Earthquake Events

Municipality	Estimated Total Damages (All Occupancies)				Percent of Total RCV
	Annualized Loss	100-Year	500-Year	2,500-Year	2,500-Year
Township of Belleville	$72,807	$0	$4,616,521	$71,094,612	1.6%
Township of Bloomfield	$78,743	$0	$4,910,094	$80,412,843	1.3%
Borough of Caldwell	$18,907	$0	$1,229,842	$18,524,023	1.6%
Township of Cedar Grove	$32,457	$0	$1,941,799	$33,539,291	1.1%
City of East Orange	$75,554	$0	$4,678,812	$77,459,497	1.3%
Borough of Essex Fells	$6,428	$0	$395,156	$6,762,432	1.3%
Township of Fairfield	$214,267	$0	$14,229,766	$183,862,678	3.0%
Borough of Glen Ridge	$12,784	$0	$779,516	$13,407,246	1.2%
Township of Irvington	$65,105	$0	$3,990,827	$66,871,152	1.2%
Township of Livingston	$90,202	$0	$5,568,549	$92,818,762	1.2%
Township of Maplewood	$38,688	$0	$2,343,955	$40,300,317	1.1%
Township of Millburn	$72,377	$0	$4,590,624	$72,940,336	1.4%
Township of Montclair	$67,158	$0	$4,134,051	$69,557,125	1.2%
City of Newark	$1,434,514	$1,195,466	$86,036,956	$1,213,542,653	3.0%
Borough of North Caldwell	$14,448	$0	$829,243	$15,482,457	<1%
Township of Nutley	$49,476	$0	$3,082,906	$51,088,073	1.3%
City of Orange Township	$42,905	$0	$2,661,345	$43,623,386	1.2%
Borough of Roseland	$25,932	$0	$1,626,070	$26,072,734	1.3%
Township of South Orange Village	$29,585	$0	$1,796,487	$30,830,217	1.1%
Township of Verona	$22,253	$0	$1,323,391	$23,452,748	1.1%
Township of West Caldwell	$60,846	$0	$3,880,288	$59,314,601	1.7%
Township of West Orange	$72,542	$0	$4,195,584	$77,204,865	<1%
Essex County (Total)	**$2,597,976**	**$1,195,466**	**$158,841,784**	**$2,368,162,046**	**1.9%**

Source: HAZUS-MH v4.2 **Total Damages is sum of damages for all occupancy classes (residential, commercial, industrial, agricultural, educational, religious and government).*

The City of Newark is the only municipality that is estimated to experience building damages as a result of the 100-year MRP event ($1,195,466). It is estimated that there would be nearly $159 million in damages to buildings in the County as a result of a 500-year earthquake event. This includes structural damage, non-structural damage and loss of contents, representing less than one-percent of the total replacement value for general building stock in Essex County. For a 2,500-year MRP earthquake event, HAZUS-MH estimates nearly $2.4 billion, approximately 1.9-percent of the total general building stock replacement value. Residential buildings account for 8-percent, 31-percent, and 35.2-percent of the total losses for the 100-, 500- and 2,500-year MRP events, respectively and commercial losses account for 16.7-percent, 17.1-percent, and 15.8-percent of the total losses for the 100-, 500- and 2,500-year MRP events.

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 Essex 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 Essex County. Of the 1,118 critical facilities exposed countywide, the City of Newark has the greatest number of critical facilities located on NEHRP Classes D or E soils (96 facilities), followed by the Township of Fairfield with 28 facilities. Of the 96 facilities in the City of Newark, two were identified as lifeline facilities, and of the 28 facilities in Fairfield, 13 were identified as lifeline facilities. Table X-2 and Table X-2 in Appendix X (Supplemental Data) summarizes the number of critical facilities, by type, located on NEHRP Soil Classes D or E and liquefaction Class 4 soils.

The HAZUS-MH v4.2 earthquake model was used to assign a probability of each damage state category defined in Table 4.3.4.-10, to every critical facility in the planning area, which was then averaged across the facility category. In addition, HAZUS-MH v4.2 estimates the time to restore critical facilities to fully functional use. Results are presented as probability of being functional at specified time increments (days after the event). For example, HAZUS-MH v4.2 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. Results for the 500- and 2,500-year events are summarized in Table 4.3.4-13 and Table 4.3.4-14. As a result of a 100-year MRP event, HAZUS-MH v4.2 estimates that critical facilities will be nearly 100% functional with negligible damages. Therefore, the impact to critical facilities is not significant for the 100-year event. For percent probability of sustaining damage, the minimum and maximum damage estimated value for that facility type is presented.

Table 4.3.4-13. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities 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									
Medical	78-91	6-13	3-7	0-2	<1	78-91	90-97	98-100	99-100
Police	78-90	6-13	3-7	0-2	<1	78-90	90-97	98-100	99-100
Fire	78-96	3-13	1-7	0-2	<1	78-96	91-99	98-100	99-100
EOC	94-96	3-5	1	<1	<1	94-96	98-99	100	100

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
School	97-99	1-9	0-4	0-1	<1	87-99	96-100	99-100	100
Utilities									
Potable Water	97-100	0-2	<1	<1	0	99-100	100	100	100
Wastewater	93-100	0-5	0-2	<1	<1	95-100	100	100	100
Electric Power	93-100	0-5	0-2	<1	<1	98-100	100	100	100
Communication	98-100	0-2	<1	<1	0	100	100	100	100

Source: HAZUS-MH v4.2

Table 4.3.4-14. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities for the 2,500-Year MRP Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Critical Facilities									
Medical	31-65	18-23	12-25	4-13	1-9	31-65	53-83	79-96	85-98
Police	26-65	18-23	12-25	4-13	1-24	26-65	44-89	65-96	71-98
Fire	29-92	11-23	6-25	1-13	0-15	29-92	50-93	74-99	80-99
EOC	60-75	14-19	8-12	2-3	0-7	60-75	79-90	90-98	92-99
School	39-91	7-25	2-21	0-7	0-12	39-91	62-97	81-100	85-100
Utilities									
Potable Water	61-98	2-14	0-10	0-1	0-18	71-99	84-100	85-100	91-100
Wastewater	36-98	2-16	0-23	0-5	0-21	44-98	75-100	76-100	81-100
Electric Power	36-98	2-16	0-23	0-5	0-21	58-99	77-100	80-100	95-100
Communication	74-98	2-14	0-11	0-1	0-1	93-100	99-100	99-100	100

Source: HAZUS-MH 4.2

Impact on Economy

Earthquakes also impact the economy, including loss of business function, damage to inventory (buildings, transportation, and utility systems), relocation costs, wage loss, and rental loss due to repair and replacement of buildings. HAZUS-MH v4.2 estimates building-related economic losses, including income losses (wage, rental, relocation, and capital-related losses) and capital stock losses (structural, non-structural, content, and inventory losses). Economic losses estimated by HAZUS-MH v4.2 are summarized in Table 4.3.4-15.

Table 4.3.4-15. Building-Related Economic Losses from the 100-, 500- and 2,500-Year MRP Earthquake Events

Level of Severity	100yr	500yr	2500yr
Income Losses			
Wage	$129,800	$5,565,700	$57,136,300
Capital Related	$20,300	$1,708,500	$17,574,400
Rental	$107,200	$6,200,700	$65,604,200
Relocation	$277,000	$16,589,900	$181,423,000

Level of Severity	100yr	500yr	2500yr
Subtotal	**$515,000**	**$30,064,800**	**$321,737,900**
Capital Stock Losses			
Structural	$547,100	$32,551,600	$349,663,300
Non-Structural	$538,400	$88,311,900	$1,323,203,200
Content	$109,100	$37,977,700	$695,294,800
Inventory	$3,800	$1,146,200	$17,692,600
Subtotal	**$1,198,400**	**$159,987,400**	**$1,198,400**

Source: HAZUS-MH v4.2

Although the HAZUS-MH v4.2 analysis did not compute estimates of damage to roadway segments and railroad tracks, assumedly these features would undergo damage due to ground failure—resulting in interruptions of regional transportation and of distribution of materials. Losses to the community that would result from damage to lifelines could exceed costs of repair (FEMA 2012).

Earthquake events can significantly affect road bridges, many of which provide the only access to certain neighborhoods. Because softer soils generally follow floodplain boundaries, bridges that cross watercourses should be considered vulnerable. Another key factor in degree of vulnerability is age of facilities and infrastructure, which correlates with standards in place at times of construction of these. HAZUS-MH v4.2 estimated economic impacts to Essex County for 15-years after the earthquake event, including impacts to transportation infrastructure. $30 million in damages were estimated as a result of a 500-year event and $1.2 billion as a result of a 2,500-year event for damages to highway bridges.

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

HAZUS-MH v4.2 estimated the generation of over 1,000 tons of total debris during the 100-year MRP event, over 55,000 tons of debris during the 500-year MRP event, and over 565,000 tons of debris during the 2,500-year MRP event. Table 4.3.4-16 below lists estimated debris generated by the 100-, 500- and 2,500-year MRP events.

Table 4.3.4-16. Estimated Debris Generated by the 250- and 1,000-year MRP Earthquake Events

Mean Return Period	Brick/Wood (tons)	Concrete/Steel (tons)
100-Year	739	320
500-Year	36,877	18,682
2,500-Year	268,745	297,192

Source: HAZUS-MH 4.2

Future Changes that May Impact Vulnerability

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

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

Projected Development

As discussed in Section 3 (County Profile), areas targeted for future growth and development have been identified across the County.

New development located in areas with softer NEHRP soil classes and high liquefaction susceptibility may be more vulnerable to the earthquake hazard. Information regarding new development, both recent and expected development, within Essex County was received during the planning process. Any development location that could be located using an address or Parcel ID were geocoded and overlaid with the NEHRP Class D and E soils spatial layer to determine vulnerability. In total, there are 10 new development sites located on NEHRP Class D and E soils. 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.

Specific areas of development are indicated in tabular form in the jurisdictional annexes in Volume II, Section 9 (Jurisdictional Annexes). Please refer to Figure 4.3.4-9 for the potential new development in the County and the NEHRP soil class and high liquefaction susceptibility areas.

Projected Changes in Population

According to population projections from the State of New Jersey Department of Labor and Workforce Development, Essex County will experience an increase in population through 2034 (approximately 40,000 people between 2017 and 2034). As noted above, vulnerability greatly depends upon the location residents reside. The HAZUS-MH earthquake model indicates the City of Newark is vulnerable to greater ground shaking and building impacts as a result of more frequent events such as the 100-year MRP event. Populations moving to Essex County and living in older buildings may be vulnerable to this hazard. 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 the earthquakes are not well understood, a change in the County's vulnerability is difficult to determine. However, climate change has the potential to magnify secondary impacts of earthquakes. As a result of the climate change projections discussed above, the County's assets located on areas of saturated soils and on or at the base of steep slopes, are at a higher risk of landslides/mudslides because of seismic activity. Refer to Section 4.3.7 for additional discussion of the geological hazard. Failure of a dam storing increased volumes of water would result in flooding of the county's assets located in the inundation area.

Change of Vulnerability Since 2015 HMP

Overall, the entire County continues to be vulnerable to earthquakes. Several differences exist between the 2015 plan and this update. For the 2020 plan update, an updated general building stock based upon replacement cost value from MODIV tax assessment data and 2019 RS Means, and an updated critical facility inventory were used to assess the County's risk to the hazard areas. In addition, the 2017 American Community Survey population estimates were used and estimated at a structural level in place of the 2010 U.S. Census blocks. Updated hazard areas were used as well; since the 2015 Plan, the NJGWS has released updated NEHRP and liquefaction susceptible soils data. The updated data was used for the exposure analysis and to update HAZUS-MH's default earthquake data. The largest increase in vulnerability reported is attributed to the availability of updated data which expands the delineated liquefaction Class 4 soils throughout the western and eastern borders of the County along the Passaic River. For the 2015 plan, these soils were only present in the City of Newark. The updated vulnerability assessment provides a more current exposure analysis for the county.

Figure 4.3.4-9. Potential New Development in Essex County and NEHRP Soil Types