5.4.3 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 Burlington County.

2019 HMP UPDATE CHANGES

- The hazard profile has been significantly enhanced to include a detailed hazard description, location, extent, previous occurrences, probability of future occurrence, and potential change in climate and its impacts on the earthquake hazard is discussed.
- New and updated figures from federal and state agencies are incorporated. U.S. 2010 Census data was incorporated, where appropriate.
- Previous occurrences were updated with events that occurred between 2013 and 2018.
- A vulnerability assessment was conducted for the earthquake hazard that provides a quantitative analysis of exposure and potential losses to Burlington County.

5.4.3.1 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).

According to the U.S. Geological Society (USGS) Earthquake Hazards Program, an earthquake hazard is any disruption associated with an earthquake that may affect residents' normal activities. This includes surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, tsunamis, and seiches; each of these terms is defined below:

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

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

Location

Earthquakes are most likely to occur in the northern parts of New Jersey; however, low-magnitude events occur throughout the state, including Burlington County. 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 5.4.3-1, 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. Studies have not yet been conducted by NJGWS to determine the NEHRP classifications for Burlington County; however, other New Jersey agencies have compiled similar data on soil classification for the county.

Table 5.4.3-1. 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 2016

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 5.4.3-2.

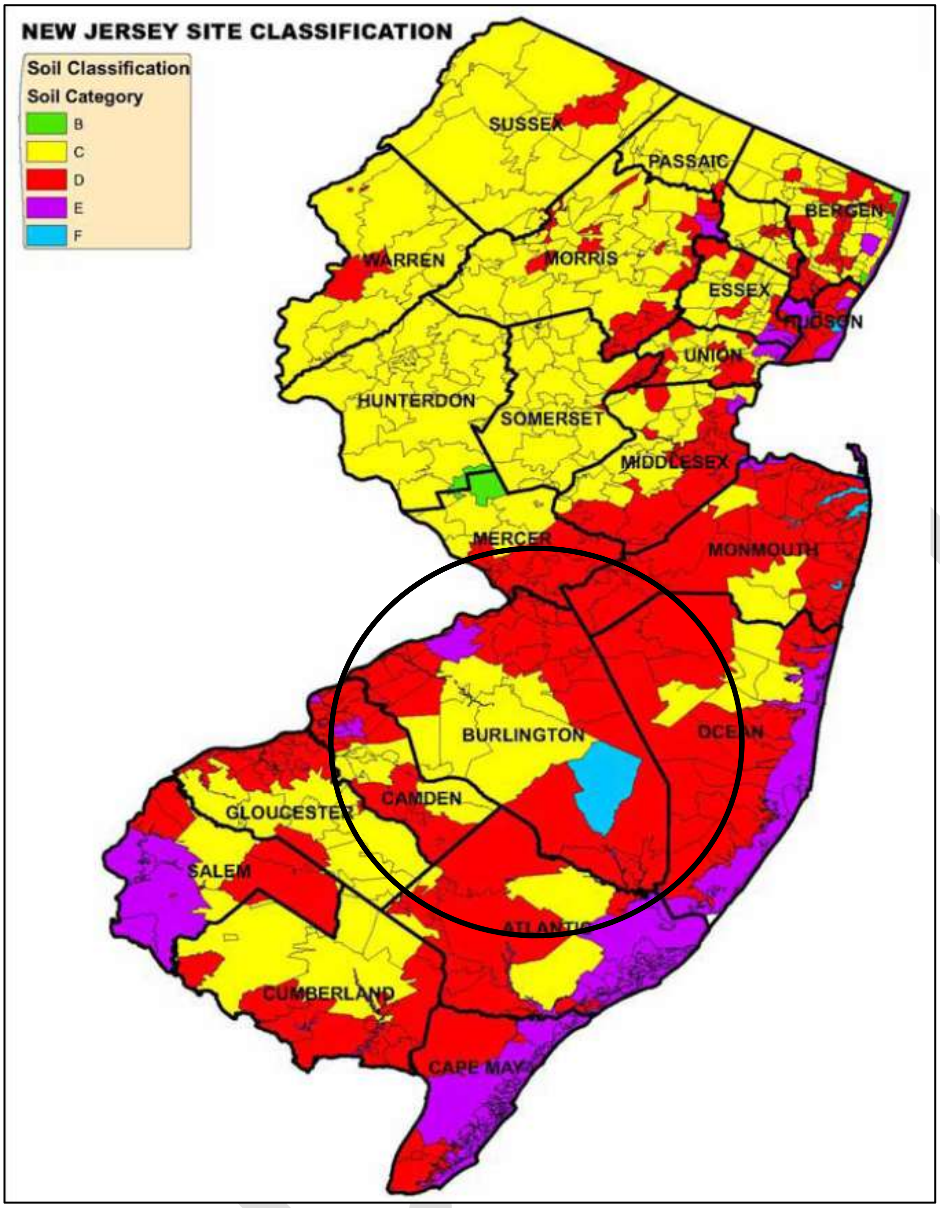
Table 5.4.3-2. NJDOT Soil Classifications

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 Burlington County, most ZIP codes were rated as a Categories C and D, and a few were rated as Categories E and F. Figure 5.4.3-1 provides a visual confirmation of this information.

Figure 5.4.3-1. ZIP Code-Based Soil Site Class Map



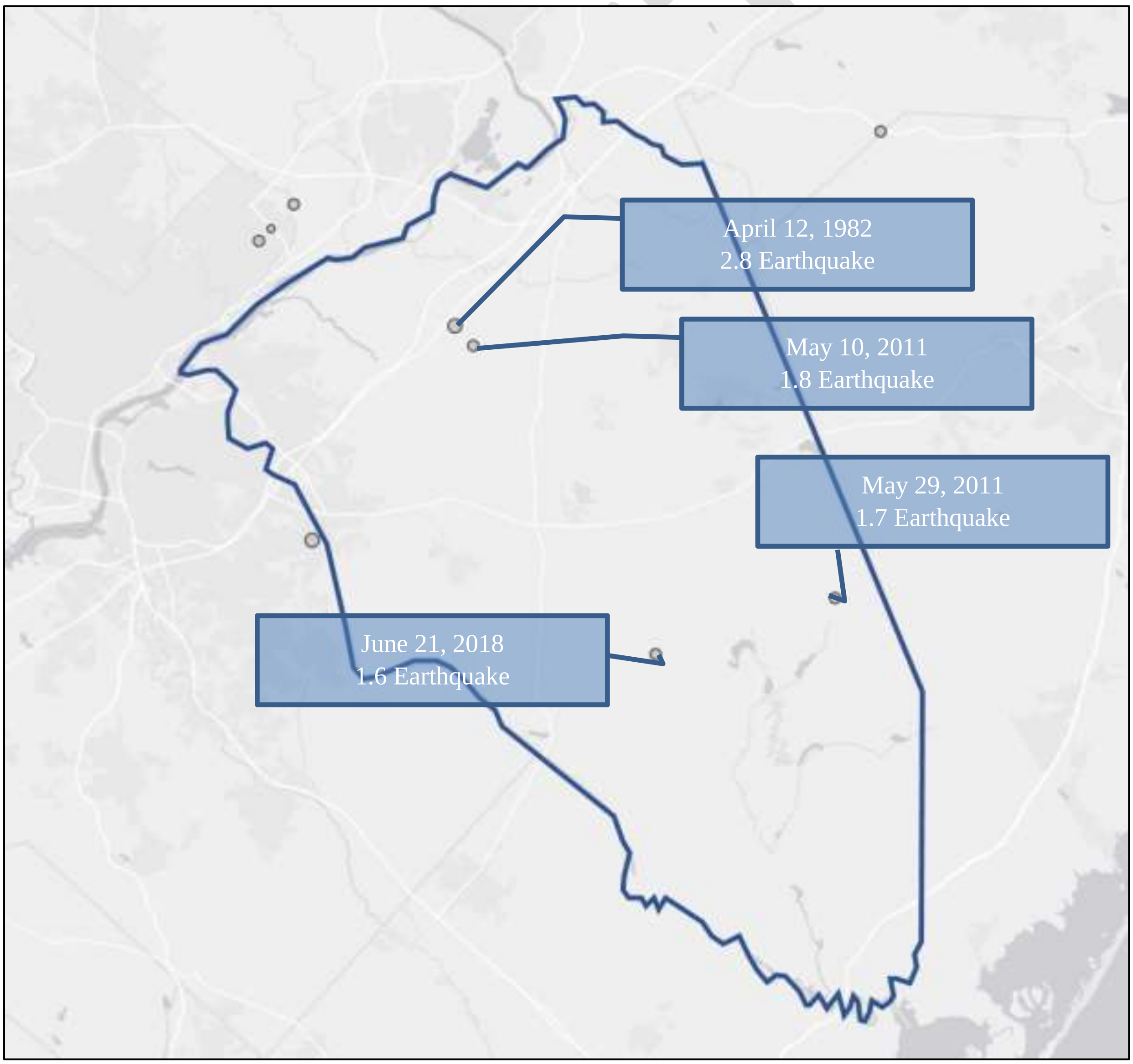
Source: *NJDOT 2012*
Note: *Burlington County is indicated by the black circle.*
Soil Classes A and B are rock sites
Soil Class C is very dense soil
Soil Class D is dense soil
Soil Class E is soft soil
Soil Class F is special soil requiring site-specific analysis

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. Although liquefaction susceptibility will vary throughout the County, the majority of the County most likely has a low to very low susceptibility (NJDOT 2012).

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 5.4.4 (Flood) and for landslides refer to Section 5.4.5 (Landslides). On the other side, earthquakes 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.

Figure 5.4.3-2 illustrates historic earthquake epicenters in and surrounding Burlington County between 1950 and 2018. According to this figure, there have been four earthquakes with epicenters in Burlington County (April 1982, May 2011 [2], and June 2018). In addition to those in Burlington County, there have been numerous earthquakes originating outside of the county that may have been felt within the county. For details regarding these events, please refer to

Figure 5.4.3-2. Earthquake Epicenters in Burlington County and the Surrounding Area, 1950 – 2018



Source: USGS 2018
Note: Burlington County is outlined in blue

Extent

An earthquake's magnitude and intensity are used to describe the size and severity of the event. Magnitude is commonly expressed by ratings on the moment magnitude scale (M_W), the most common scale used today. It has replaced the Richter Scale. For very large earthquakes, moment magnitude gives the most reliable estimates of earthquake size. It measures earthquake strength based on the amount of energy released by calculating size of the fault, amount of movement, and type of rock (stiffness) (USGS 2018). 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

The most commonly used intensity scale is the modified Mercalli intensity scale (MMI). It expresses intensity of an earthquake and describes how strong a shock was felt at a particular location in values. Table 5.4.3-3 shows the ratings of the MMI as well as the perceived shaking and damage potential for structures.

Table 5.4.3-3. Mercalli Scale and Peak Ground Acceleration Comparison

Modified Mercalli Scale	Perceived Shaking	Potential Structure Damage		Estimated PGA (%g)
		Resistant Buildings	Vulnerable Buildings	
I	Not Felt	None	None	< .17
II	Weak	None	None	.17 – 1.4
III	Weak	None	None	.17 – 1.4
IV	Light	None	None	1.4 – 3.9
V	Moderate	Very Light	Light	3.9 – 9.2
VI	Strong	Light	Moderate	9.2 – 18
VII	Very Strong	Moderate	Moderate/Heavy	18 – 34
VIII	Severe	Moderate/Heavy	Heavy	34 – 65
IX	Violent	Heavy	Very Heavy	65-124
X	Extreme	Very Heavy	Very Heavy	>124

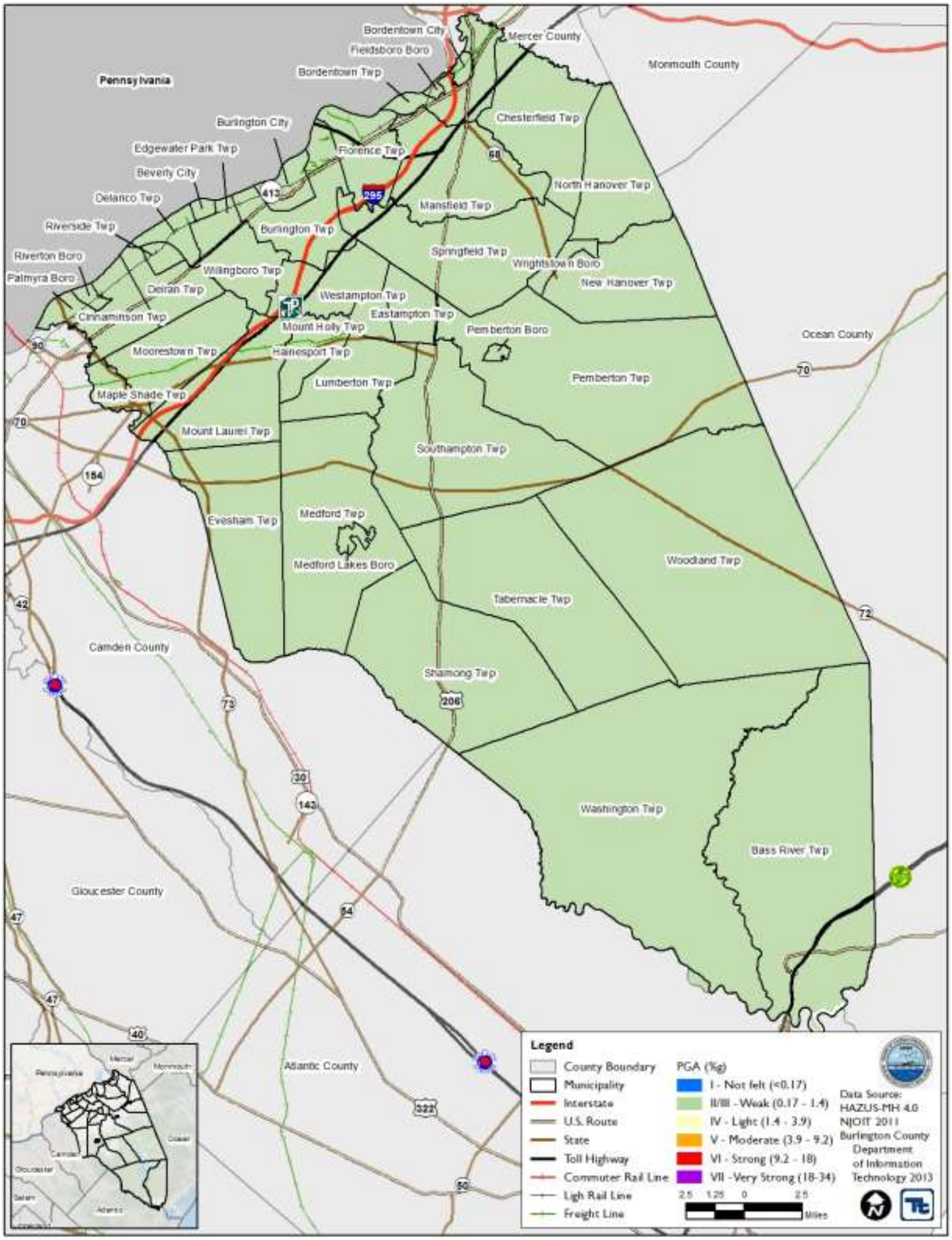
Source: USGS 2014; Freeman et al. (Purdue University) 2004
Note: PGA Peak Ground Acceleration

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

The USGS updated the National Seismic Hazard Maps in 2014, which superseded the 2008 maps. New seismic, geologic, and geodetic information on earthquake rates and associated ground shaking were incorporated into these revised maps. The 2014 map represents the best available data as determined by the USGS. According to the data, Burlington County has a PGA between 2%g and 3%g (USGS 2014). The 2014 PGA map can be found at https://earthquake.usgs.gov/hazards/hazmaps/conterminous/index.php#2014

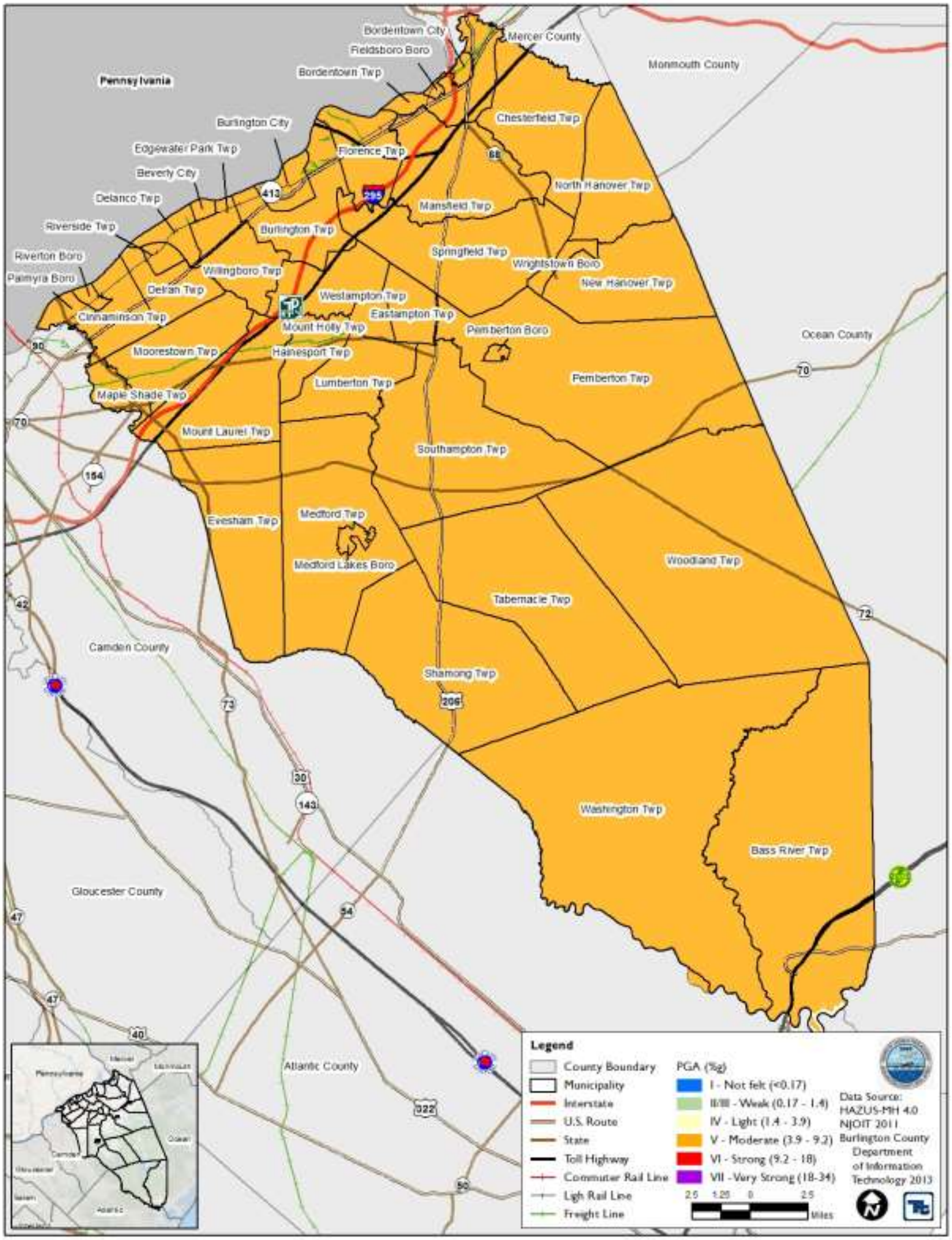
A probabilistic assessment was conducted for the 100-, 500- and 2,500-year mean return periods (MRP) in HAZUS-MH 2.2 to analyze the earthquake hazard for Burlington County. The HAZUS analysis evaluates the statistical likelihood that a specific event will occur and what consequences will occur. Figure 5.4.3-3 through Figure 5.4.3-5 illustrates the geographic distribution of PGA (*g*) across the County or 100-, 500- and 2,500-year MRP events by Census-tract.

Figure 5.4.3-3. Peak Ground Acceleration 100-Year Mean Return Period for Burlington County



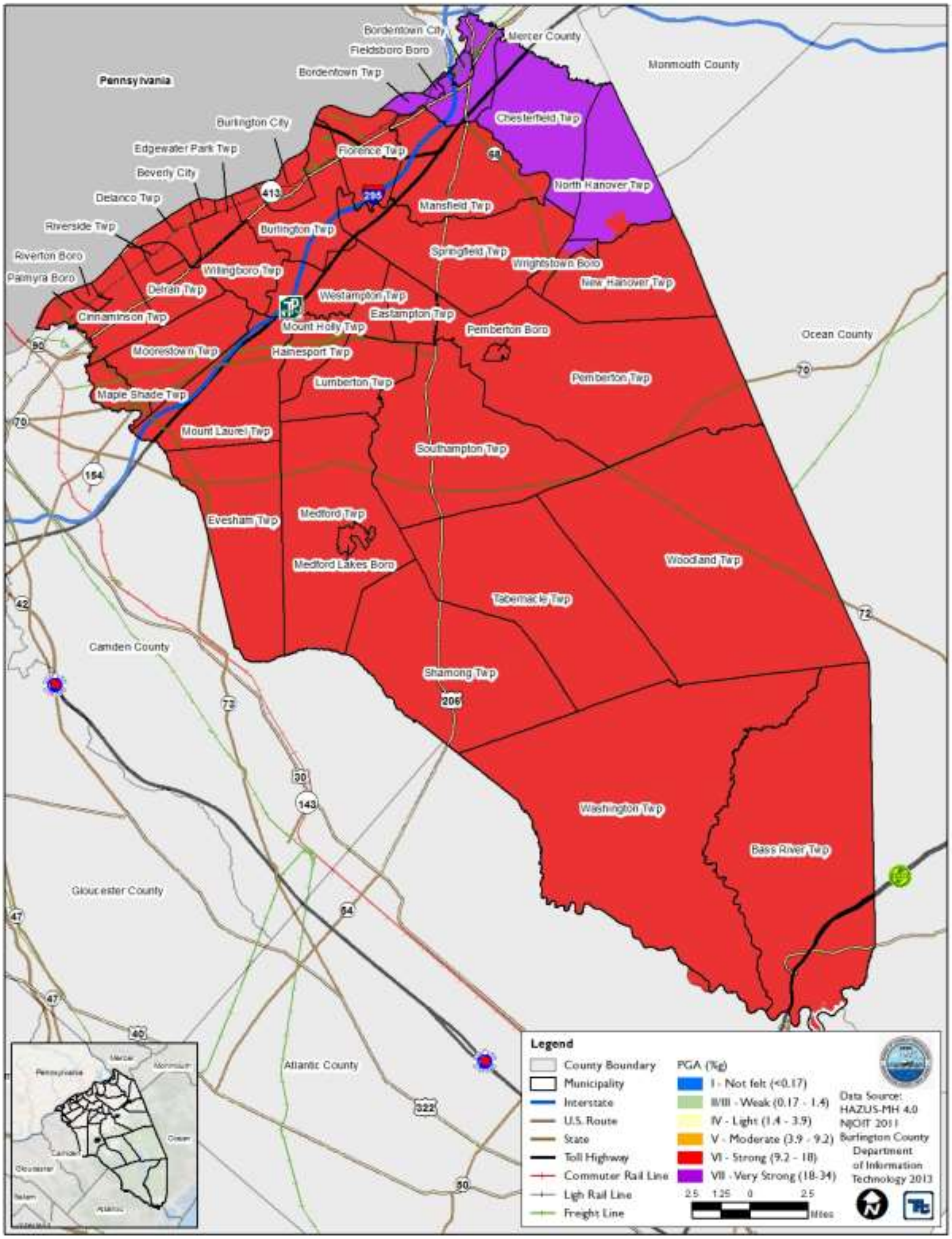
Note: The peak ground acceleration for the 100-year MRP is 1.24 to 1.40 %g.

Figure 5.4.3-4. Peak Ground Acceleration 500-Year Mean Return Period for Burlington County



Note: The peak ground acceleration for the 500-year MRP is 4.43 to 5.58 %g.

Figure 5.4.3-5. Peak Ground Acceleration 2,500-Year Mean Return Period for Burlington County



Note: The peak ground acceleration for the 2,500-year MRP is 13.43 to 18.66 %g.

Previous Occurrences and Losses

Historically, New Jersey and Burlington County have not experienced a major earthquake. Between 1954 and 2017, the State of New Jersey was not included in any FEMA earthquake-related major disaster (DR) or emergency (EM) declarations (FEMA 2018). 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). Small earthquakes may occur several times a year and generally do not cause significant damage. The strongest earthquake with an epicenter in Burlington County was a 3.0 quake in Medford Lakes in 1980.

According to the New Jersey Geological and Water Survey (NJGWS), records for the New York City area, which have been kept for 300 years, provide good information for estimating the frequency of earthquakes in New Jersey. Earthquakes with a maximum intensity of VII have occurred in the New York City area in 1737, 1783, and 1884. One intensity VI, four intensity V's, and at least three intensity III shocks have also occurred in the New York area over the last 300 years. Figure 5.4.3-6 illustrates earthquake events where the epicenters were located in Burlington County. The figure shows that 10 earthquakes had epicenters in the county (NJGWS 2018).

In Burlington County, between 2013 and 2018, there was one earthquake that had an epicenter in the County. In addition, a 4.4 quake in Dover, Delaware in 2017 was felt in Burlington County. For events prior to 2013, refer to the 2013 Burlington County HMP. Please note that many sources were researched for historical information regarding earthquake events in Burlington County; therefore, not all earthquake events that have impacted the County may be included. Additionally, not all sources may have been identified or researched. Loss and impact information could vary depending on the source.

Figure 5.4.3-6. Earthquakes with Epicenters in Burlington County, 1877 to 2018

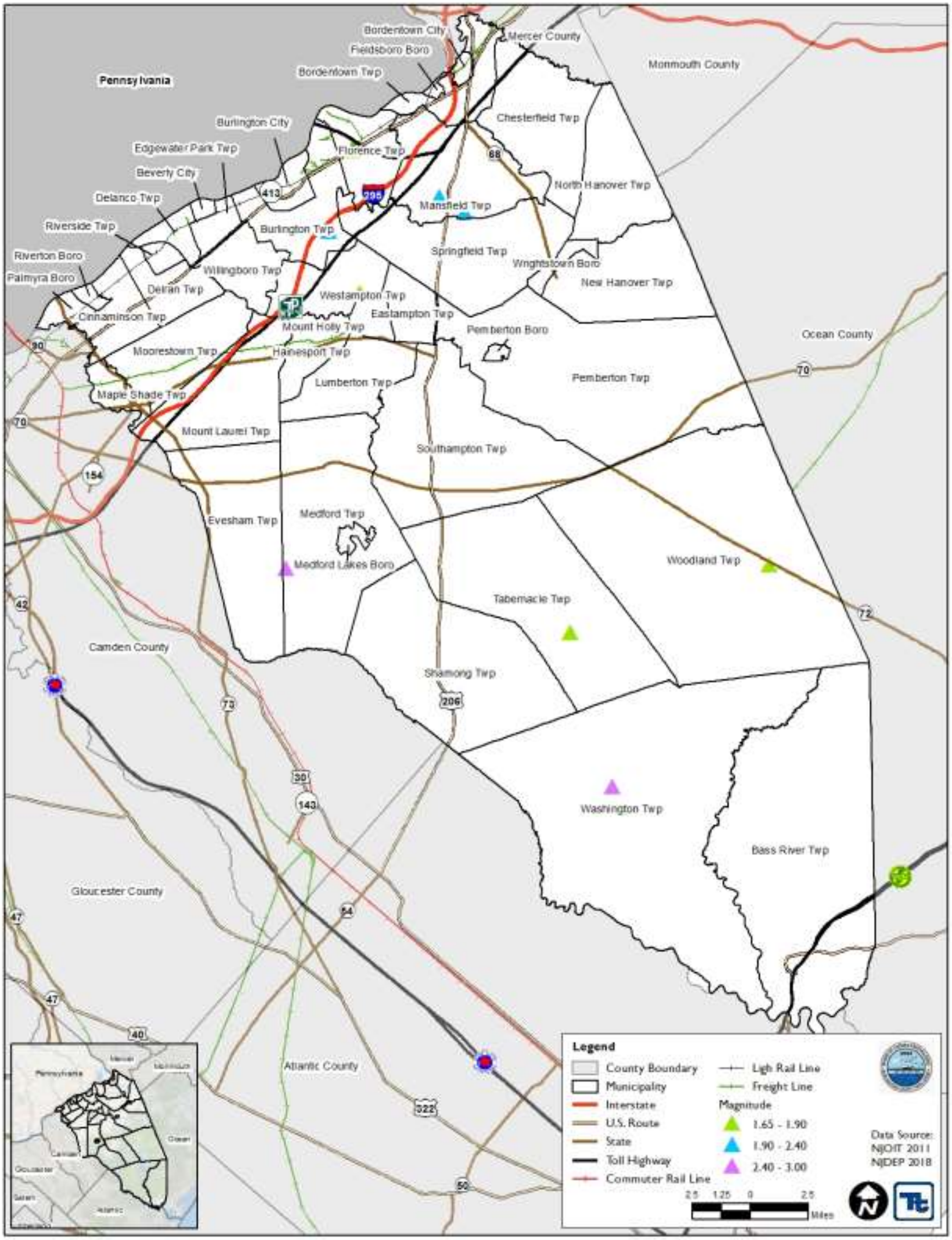


Table 5.4.3-4. Earthquake Events Impacting Burlington County, 2013 to 2017

Dates of Event	Event Type	Location	FEMA Declaration Number (if applicable)	County Designated?	Losses / Impacts
November 30, 2017	4.1 Earthquake	Dover, Delaware	N/A	N/A	Burlington County residents felt ground shake from nearby 4.1 magnitude earthquake in Dover, Delaware. The quake was felt from central Virginia to Massachusetts.
June 21, 2018	1.6 Earthquake	Tabernacle Township	N/A	N/A	A “microquake” was centered near Southampton. No damage was reported.
September 17, 2018	1.2 Earthquake	Washington Township	N/A	N/A	No losses and/or damages reported for this event

Sources: FEMA 2018; USGS 2018; NJGWS 2018, Press of AC 2018
FEMA Federal Emergency Management Agency
USGS United States Geological Survey
NJGWS New Jersey Geological and Water Survey

Probability of Future Occurrences

Earthquakes cannot be predicted and may occur any time of the day or year. The probability of damaging earthquakes affecting Burlington County is low. However, there is a definite threat of major earthquakes that could cause widespread damage and casualties in the county and throughout New Jersey. 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 would be very high.

Earthquake hazard maps illustrate the distribution of earthquake shaking levels that have a certain probability of occurring over a given time period. According to the USGS, in 2014 (the date of the most recent analysis), Burlington County had a PGA of 2-3%g for earthquakes with a 10-percent probability of occurring within 50 years.

According to USGS and NJGWS, Burlington County has experienced 10 earthquakes with epicenters in the county. The table below shows these statistics, as well as the annual average number of events and the percent chance of earthquakes occurring in Burlington County in future years (USGS 2018; NJGWS 2018). In addition to earthquakes centered within the county, numerous earthquakes located outside of the county have also directly and indirectly impacted Burlington County. However, since impacts of these earthquakes are difficult to quantify, they are not considered in Table 5.4.3-5.

Table 5.4.3-5. Probability of Future Occurrence of Earthquake Events

Hazard Type	Number of Occurrences Between 1877 and 2018	Rate of Occurrence or Annual Number of Events (average)	Recurrence Interval (in years) (# Years/Number of Events)	Probability of Event in any given year	Percent chance of occurrence in any given year
Earthquake with Epicenter inside County	10	0.15	6.90	0.14	14.49%

Source: NJGWS 2015

Earlier in this section, the identified hazards of concern for Burlington County were ranked. The probability of occurrence, or likelihood of the event, is one parameter used for ranking hazards. Based on historical records and input from the Planning Committee, the probability of occurrence for earthquakes in the County is considered "occasional" (is likely to occur within 100 years as presented in Table 5.3-3). It is anticipated that the County will experience indirect impacts from earthquakes that may affect the general building stock, local economy and may induce secondary hazards such as sporadic ignition of fires and utility failure.

Climate Change Impacts

Providing projections of future climate change for a specific region is challenging. Shorter term projections are more closely tied to existing trends making longer term projections even more challenging. The further out a prediction reaches the more subject to changing dynamics it becomes. 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 (New Jersey State HMP 2014).

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 (New Jersey State HMP 2014).

5.4.3.2 VULNERABILITY ASSESSMENT

Earthquake vulnerability data was generated using a HAZUS analysis. A probabilistic assessment was conducted for the 100-, 500- and 2,500-year MRPs through a Level 2 analysis in HAZUS-MH 4.0 to analyze the earthquake hazard and provide a range of loss estimates. Refer to Section 5.1 for additional details on the methodology used to assess earthquake risk.

Impact on Life, Health and Safety

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

According to the 2010 U.S. Census, Burlington County had a population of 448,734 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 loose and fall as a result of an earthquake.

Populations considered most vulnerable are those located in/near the built environment, particularly near unreinforced masonry construction. In addition, the vulnerable population includes the elderly (persons over the age of 65) and individuals living below the U.S. Census poverty threshold. These socially vulnerable populations are most susceptible, based on a number of factors including their physical and financial ability to react or respond during a hazard and the location and construction quality of their housing. Refer to Section 4 (County Profile) for the vulnerable population statistics in Burlington County.

Residents may be displaced or require temporary to long-term sheltering due to the 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. HAZUS-MH 4.0 estimated sheltering needs for the earthquake hazard. HAZUS-MH 4.0 estimates there will be no displaced households or people seeking short-term shelter as a result of the 100-year event. Table 5.4.3-6 summarizes the population HAZUS-MH estimates will be displaced or will require short-term sheltering for 500- and 2,500-year MRP by municipality.

Table 5.4.3-6. Summary of Estimated Sheltering Needs for Burlington County

Scenario	Displaced Households	Persons Seeking Short-Term Shelter
100-Year Earthquake	0	0
500-Year Earthquake	33	18
2,500-Year Earthquake	382	211

Source: HAZUS-MH 4.0
Note: The number of displaced households and persons seeking shelter was calculated using the 2010 U.S. Census data (HAZUS-MH 4.0 default demographic data).

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

There are no injuries or casualties estimated for the 100-year event. Table 5.4.3-7 summarizes the County-wide injuries and casualties estimated for the 500- and 2,500-year MRP earthquake events.

Table 5.4.3-7. Estimated Number of Injuries and Casualties from the 500 and 2,500-Year MRP Earthquake Events

Level of Severity	Time of Day		
	2:00 AM	2:00 PM	5:00 PM
500-year			
Injuries	12	18	13
Hospitalization	1	2	2
Casualties	0	0	0
2,500-Year			
Injuries	108	169	123
Hospitalization	18	30	21
Casualties	3	5	4

Source: HAZUS-MH 4.0

Impact on General Building Stock

The entire county's general building stock is considered at risk and exposed to this hazard. The HAZUS-MH 4.0 model estimates the value of the exposed building stock and the loss (in terms of damage to the exposed stock). Refer to the County Profile (Section 4) for general building stock statistics (structure and contents).

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 model was applied to analyze effects from the earthquake hazard on general building stock in Burlington County. See Figure 5.4.3-3 through Figure 5.4.3-5 earlier in this profile that 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 un-reinforced masonry buildings are most at risk during an earthquake because the walls are prone to collapse outward, whereas steel and wood buildings absorb more of the earthquake's energy. Additional attributes that contribute to a building's capability to withstand an earthquake's force include its age, number of stories and quality of construction. HAZUS-MH considers building construction and the age of buildings as part of the analysis.

Potential building damage was evaluated by HAZUS-MH 4.0 across the following damage categories (none, slight, moderate, extensive and complete). Table 5.4.3-8 provides definitions of these five categories of damage for a light wood-framed building; definitions for other building types are included in HAZUS-MH technical manual documentation. General building stock damage for these damage categories by occupancy class and building type on a county-wide basis is summarized below for the 100-, 500- and 2,500-year events.

Table 5.4.3-8. 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 may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks.

Source: HAZUS-MH Technical Manual

The value of general building stock exposed to and damaged by 100-, 500-, and 2,500-year MRP earthquake events were evaluated and annualized losses were calculated via HAZUS-MH. Table 5.4.3-9 below lists estimated numbers of buildings damaged (within general occupancy categories) during 500- and 2,500-year MRP earthquake events; no building damages are expected as a result of the 100-year MRP event. Damage loss estimates include structural and non-structural damage to the building and loss of contents. Table 5.4.3-10 summarizes the damage estimated for the 500- and 2,500-year MRP earthquake events. No damages are estimated as a result of the 100-year MRP earthquake event. Damage loss estimates include structural and non-structural damage to the building and loss of contents. The total cost of all damage estimates for both mean return periods is less than 1% of total replacement cost value for each municipality.

Table 5.4.3-9. Estimated Number Buildings Damaged by the 500-year and 2,500-year MRP Earthquake Events

	Average Damage State									
	500-Year MRP					2,500-Year MRP				
Category	None	Slight	Moderate	Extensive	Complete	None	Slight	Moderate	Extensive	Complete
Residential	145,155 (83.9%)	1,959 (1.1%)	440 (<1%)	50 (<1%)	5 (<1%)	129,799 (75.0%)	13,676 (7.9%	3,480 (2.0%)	532 (<1%)	71 (<1%)
Commercial	7,231 (4.2%)	201 (<1%)	60 (<1%)	7 (<1%)	0 (0%)	5,887 (3.4%	977 (<1%)	535 (<1%)	92 (<1%)	9 (<1%)
Industrial	1,460 (<1%)	44 (<1%)	15 (<1%)	2 (<1%)	0 (0%)	1,164 (<1%)	202 (<1%)	127 (<1%)	26 (<1%)	2 (<1%)
Education, Government, Religious and Agricultural	15,887 (9.2%)	437 (<1%)	128 (<1%)	15 (<1%)	0 (0%)	12,933 (7.5%)	2,175 (1.3%	1,136 (<1%)	205 (<1%)	19 (<1%)

Source: HAZUS-MH 4.0

Table 5.4.3-10. Estimated Buildings Damaged (Replacement Cost) for the 500- and 2,500-Year MRP Earthquake Events

Municipality	Total Replacement Cost Value (Structure and Contents)	Estimated Total Damages*		
		Annualized Loss	500-Year	2,500-Year
Bass River Township-Washington Township-Woodland Township	$3,282,092,309	$23,023	$1,492,383	$21,157,418
Beverly City	$471,487,138	$3,736	$256,547	$3,789,551
Bordentown City	$1,244,995,904	$14,478	$928,772	$13,957,621
Bordentown Township	$916,111,126	$10,648	$686,415	$10,318,820
Bordentown Township-Fieldsboro Borough	$2,043,301,247	$23,292	$1,489,167	$22,126,226
Burlington City	$3,215,233,092	$30,491	$2,015,192	$29,455,384
Burlington Township	$8,013,259,672	$73,275	$4,851,686	$72,052,936
Chesterfield Township	$2,443,294,418	$28,424	$1,772,693	$26,984,602
Cinnaminson Township	$5,703,895,752	$50,443	$3,303,408	$48,658,473
Delanco Township	$1,422,201,479	$11,462	$776,057	$11,537,751
Delran Township	$5,145,622,596	$44,132	$2,951,059	$43,245,088
Eastampton Township	$1,687,017,512	$14,701	$979,820	$14,449,572
Edgewater Park Township	$2,307,285,215	$21,072	$1,406,874	$20,723,715
Evesham Township	$14,666,082,424	$109,673	$7,396,226	$108,062,851
Florence Township	$2,787,263,607	$28,077	$1,835,044	$27,278,153
Hainesport Township	$3,447,208,735	$30,464	$1,980,376	$29,503,406
Lumberton Township	$5,459,557,257	$45,002	$3,006,570	$44,294,305
Mansfield Township	$4,056,501,589	$45,429	$2,832,634	$42,434,668
Maple Shade Township	$4,385,500,913	$38,743	$2,575,554	$37,409,263
Medford Borough	$1,280,050,871	$8,204	$560,296	$8,327,863
Medford Township	$12,845,907,494	$94,376	$6,370,740	$92,821,965
Moorestown Township	$10,108,801,626	$87,213	$5,750,456	$84,645,373
Mount Holly Township	$3,498,352,996	$31,498	$2,101,142	$30,582,802
Mount Laurel Township	$14,653,800,804	$112,248	$7,618,995	$111,811,091
New Hanover Township	$1,160,482,516	$14,664	$866,938	$12,963,775
New Hanover Township-Springfield Township-Wrightstown Borough	$1,711,229,964	$21,007	$1,242,763	$18,614,028
North Hanover Township	$602,320,488	$7,193	$434,673	$6,518,868
North Hanover Township-Wrightstown Borough	$2,675,960,726	$30,971	$1,973,744	$29,511,268
Palmyra Borough	$1,788,398,557	$14,997	$1,006,191	$14,723,044
Pemberton Borough	$345,869,906	$3,065	$204,133	$2,950,703
Pemberton Township	$9,786,191,797	$84,177	$5,550,565	$81,983,763
Riverside Township	$2,039,139,951	$17,705	$1,189,807	$17,536,060
Riverton Borough	$916,434,789	$7,242	$495,500	$7,278,074
Shamong Township	$2,742,281,082	$18,070	$1,220,960	$17,435,907
Southampton Township	$6,722,347,774	$57,190	$3,736,462	$54,523,655
Springfield Township	$3,806,921,605	$38,999	$2,488,701	$37,235,016
Tabernacle Township	$3,615,144,116	$25,954	$1,717,417	$24,887,104

Table 5.4.3-10. Estimated Buildings Damaged (Replacement Cost) for the 500- and 2,500-Year MRP Earthquake Events

Municipality	Total Replacement Cost Value (Structure and Contents)	Estimated Total Damages*		
		Annualized Loss	500-Year	2,500-Year
Westampton Township	$4,269,433,407	$41,964	$2,702,109	$39,798,267
Willingboro Township	$8,259,747,413	$67,514	$4,595,271	$67,289,902
Burlington County	**$165,526,729,867**	**$1,430,814**	**$94,363,339**	**$1,388,878,330**

Source: HAZUS-MH 4.0
**Total Damages is the sum of damages for all occupancy classes (residential, commercial, industrial, agricultural, educational, religious, and government).*

HAZUS-MH 4.0 estimated that there may be $94.3 million in damages to buildings in the county as a result of a 500-year earthquake event. These includes structural damage, non-structural damage and loss of contents, representing less than 1% of the total improved value for general building stock in Burlington County. For a 2,500-year MRP earthquake event, HAZUS-MH estimates greater than $1.4 billion (<1%) of the total general building stock replacement cost value. Residential and commercial buildings account for most of the damage for earthquake 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 relies 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.

Earthquakes can cause secondary hazard events such as fires. Zero fires are anticipated as a result of the 100-, 500- and 2,500-year MRP events.

Impact on Critical Facilities

All critical facilities (essential facilities, transportation systems, lifeline utility systems, high-potential loss facilities and user-defined facilities) in Burlington County are considered exposed and potentially vulnerable to the earthquake hazard. Refer to subsection "Critical Facilities" in Section 4 (County Profile) of this HMP update for a description of the critical facilities in the county.

HAZUS-MH 4.0 estimates the probability that critical facilities may sustain damage as a result of 100-, 500- and 2,500-year MRP earthquake events. The model was used to assign a probability of each damage state to every critical facility in the planning area, which was then averaged across the facility category. Additionally, HAZUS-MH estimates percent functionality for each facility days after the event. Results are presented as probability of being functional at specified time increments. For example, Hazus may estimate that a facility has 5 percent chance of being fully functional at Day 3, and a 95-percent chance of being fully functional at Day 90. As a result of a 100-Year MRP event, HAZUS-MH 4.0 estimates that emergency facilities (police, fire, EMS and medical facilities), schools, utilities and specific facilities identified by Burlington County as critical will be nearly 100% functional with negligible damages. Therefore, the impact to critical facilities is not significant for the 100-year event. Results for the 500- and 2,500-year events are summarized in Table 5.4.3-11 and Table 5.4.3-12.

Table 5.4.3-11. Estimated Damage and Loss of Functionality for Critical Facilities in Burlington 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
Fire	91-98	2-6	0.5-3	<1	0	91-97	97-99	100	100
Police	91-97	2-6	0.6-3	<1	0	91-97	97-99	100	100
EOC	96-98	2-3	<1	<1	0	96-97	99	100	100
Medical	91	3-6	1-3	<1	0	91-97	97-99	100	100
School	91-98	2-6	0.5-3	<1	0	91-97	97-99	100	100
Senior	96-97	2-3	<1	<1	0	96-97	99	100	100
Shelter	96-98	2-3	0.5-1	<1	0	96-97	99	100	100
Municipal Hall	96-98	2-3	<1	<1	0	96-97	99	100	100

Source: HAZUS-MH 4.0

Table 5.4.3-12. Estimated Damage and Loss of Functionality for Critical Facilities in Burlington County for the 2,500-Year MRP Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Fire	68-85	10-17	4-11	0.7-3	<1	68-85	85-95	96-99	98-100
Police	68-84	10-17	5-11	1-3	<1	68-84	85-94	93-99	98-100
EOC	76-85	10-15	4-8	0.7-2	<1	76-85	90-95	98-99	99-100
Medical	66-68	13-17	6-11	1-3	<1	66-80	84-92	96-99	98-99
School	68-85	10-17	4-11	0.7-3	<1	68-85	85-95	96-99	98-100
Senior	76-81	12-15	6-8	1-2	<1	76-81	91-93	98-99	100
Shelter	76-85	10-15	4-8	0.7-2	<1	76-85	90-95	98-99	100
Municipal Hall	76-85	10-15	4-8	0.7-2	<1	76-85	91-95	98-99	100

Source: HAZUS-MH 4.0

Impact on Economy

The risk of a damaging earthquake, in combination with the density of value of buildings in New Jersey, place the State 10th among all states for potential economic loss from earthquakes (Stanford 2003).

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. Direct building losses are the estimated costs to repair or replace the damage caused to the building ("Impact on General Building Stock"). Lifeline-related losses include the direct repair cost to transportation and utility systems and are reported in terms of the probability of reaching or exceeding a specified level of damage when subjected to a given level of ground motion. HAZUS-MH 4.0 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 4.0 are summarized in Table 5.4.3-13; no economic losses were estimated for the 100-year MRP event.

Table 5.4.3-13. Building-Related Economic Losses from the 500 and 2,500-Year MRP Earthquake Event

Level of Severity	Mean Return Period	
	500-year	2,500-year
Income Losses		
Wage	$1,970,000	$17,430,000
Capital Related	$700,000	$6,610,000
Rental	$2,790,000	$25,250,000
Relocation	$7,890,000	$74,610,000
Subtotal	**$13,350,000**	**$123,900,000**
Capital Stock Losses		
Structural	$26,380,000	$233,730,000
Non-Structural	$51,830,000	$783,130,000
Content	$16,150,000	$372,030,000
Inventory	$250,000	$5,240,000
Subtotal	**$94,610,000**	**$1,394,120,000**

Source: HAZUS-MH 4.0.

Utility damage results are not considered to be significant as a result of the 100-year and 500-year events. For the 500-year event, there is a 96-percent or greater probability that utilities will not experience any damage; and up to a four-percent probability 'slight' damage could be experienced. Therefore, utility loss estimates as a result of the 100- and 500-year events are not discussed further in this assessment for this HMP. Table 5.4.3-14 summarizes the estimated losses to utilities as a result of the 2,500-year event.

Table 5.4.3-14. Estimated Utility Impacts in Burlington County from 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
Communication	39-83	11-42	6-17	0.3-2	<1	90-96	98-100	99-100	100
Electric	81-85	9-11	5-7	<1	<1	87-95	96-97	99-100	100
Potable Water	43-87	8-41	4-15	0.2-2	<1	72-96	96-99	99-100	99-100
Wastewater	42-85	9-41	5-15	0.2-2	<1	57-89	86-97	97-100	98-100

Source: HAZUS-MH 4.0

Earthquake events can significantly impact road bridges. These are important because they often provide the only access to certain neighborhoods. Since softer soils can generally follow floodplain boundaries, bridges that cross watercourses should be considered vulnerable. A key factor in the degree of vulnerability will be the age of the facility or infrastructure, which will help indicate to which standards the facility was built. HAZUS-MH estimates the long-term economic impacts to the county for 15-years after the 2,500-year earthquake event. In terms of the transportation infrastructure, HAZUS-MH 4.0 estimates $14.7 million in direct repair costs to bridges, highway, railways, bus, and airport facilities. There are no losses computed by HAZUS-MH for business interruption due to transportation or utility lifeline losses.

It is estimated that the airports in Burlington County will be 96-percent functional on day one of the 2,500-year event and an estimated 10-percent probability they will experience slight damage.

HAZUS-MH 4.0 also estimated 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 of these 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 4.0 estimated that no debris would result from the 100-year event. HAZUS-MH 4.0 estimated generation of more than 2,500 tons of debris during the 500-year MRP event, and nearly 14,000 tons of debris during the 2,500-year MRP event. Table 5.4.3-15 below lists estimated County-wide debris amounts by Mean Return Period during 500- and 2,500-year events.

Table 5.4.3-15. Estimated Debris Generated by the 500- and 2,500-year MRP Earthquake Events

Mean Return Period	Brick/Wood (tons)	Concrete/Steel (tons)
500-Year	20,750	6,710
2,500-Year	125,781	78,385

Source: HAZUS-MH 4.0

Future Growth and Development

As discussed in Section 4, areas targeted for future growth and development have been identified across the county. It is anticipated that the human exposure and vulnerability to earthquake impacts in newly developed areas will be similar to those that currently exist within the county. Current building codes require seismic provisions that should render new construction less vulnerable to seismic impacts than older, existing construction that may have been built to lower construction standards. Overall, any new developments in the County will be impacted by earthquakes. Refer to the jurisdictional annexes in Volume II of this HMP for a list of new developments in each municipality.

Effect of Climate Change on Vulnerability

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

Secondary impacts of earthquakes could be magnified by future climate change. Increased rainfall will lead to changes in soil saturation and increase the risk to liquefaction from seismic activity on more saturated soils. In areas of saturated soils and steep slopes, the County's assets on or at the base of these slopes are at a higher to landslides/mudslides as a result of seismic activity. Seismic activity can also impact the structural integrity of a dam storing increased volumes of water because of changes in flow rates. Failure of the dam would result in flooding of the County's assets located in the inundation area.

Change of Vulnerability Since the 2014 HMP

Burlington County continues to be vulnerable to the earthquake hazard. However, there are differences between the potential loss estimates between this plan update to the results in the 2014 HMP. For the 2019 HMP update, probabilistic scenarios were evaluated using an updated version of HAZUS-MH. In addition, a more current and accurate building stock inventory and critical facility inventory was used for this HMP update.