4.3.5 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 Gloucester County.

2022 HMP Update Changes

- All subsections have been updated using best available data.
- Previous occurrences were updated with events that occurred between 2015 and 2021.
- A vulnerability assessment was conducted for the earthquake hazard using FEMA's Hazus-MH v4.2 earthquake model for the 100-year and 500-year Mean Return Period (MRP) events. An updated building stock and critical facility data set was imported in Hazus to assess damages for each jurisdiction at the aggregate Census Tract level.

4.3.5.1Profile

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 (FEMA 2001). Most earthquakes occur at the boundaries where the Earth's tectonic plates meet (faults); less than 10 percent 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 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 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 (USGS 2021), 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 Gloucester 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 4.3.8 (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. Dam failures are further discussed in Section 4.3.2 (Dam and Levee Failures) of this HMP update.

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 (US SAR Task Force n.d).

4.3.5.2 Location

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. 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 4.3.5-1, 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 4.3.5-1. 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 2021)

New Jersey Department of Transportation (NJDOT) compiled a report on seismic design consideration for bridges in New Jersey, dated March 2012 (Anil Agrawal 2012). In the report, NJDOT classifies the seismic nature of soils according to the American Association of State Highway and Transportation Officials (AASHTO) Guide Specifications for Bridge Seismic Design (SGS). For the purpose of seismic analysis and design, sites can be classified into Soil Classes A, B, C, D, E and F, ranging from hard rock to soft soil and special soils (similar to the NEHRP soil classifications with an additional class F); refer to Table 4.3.5-2.

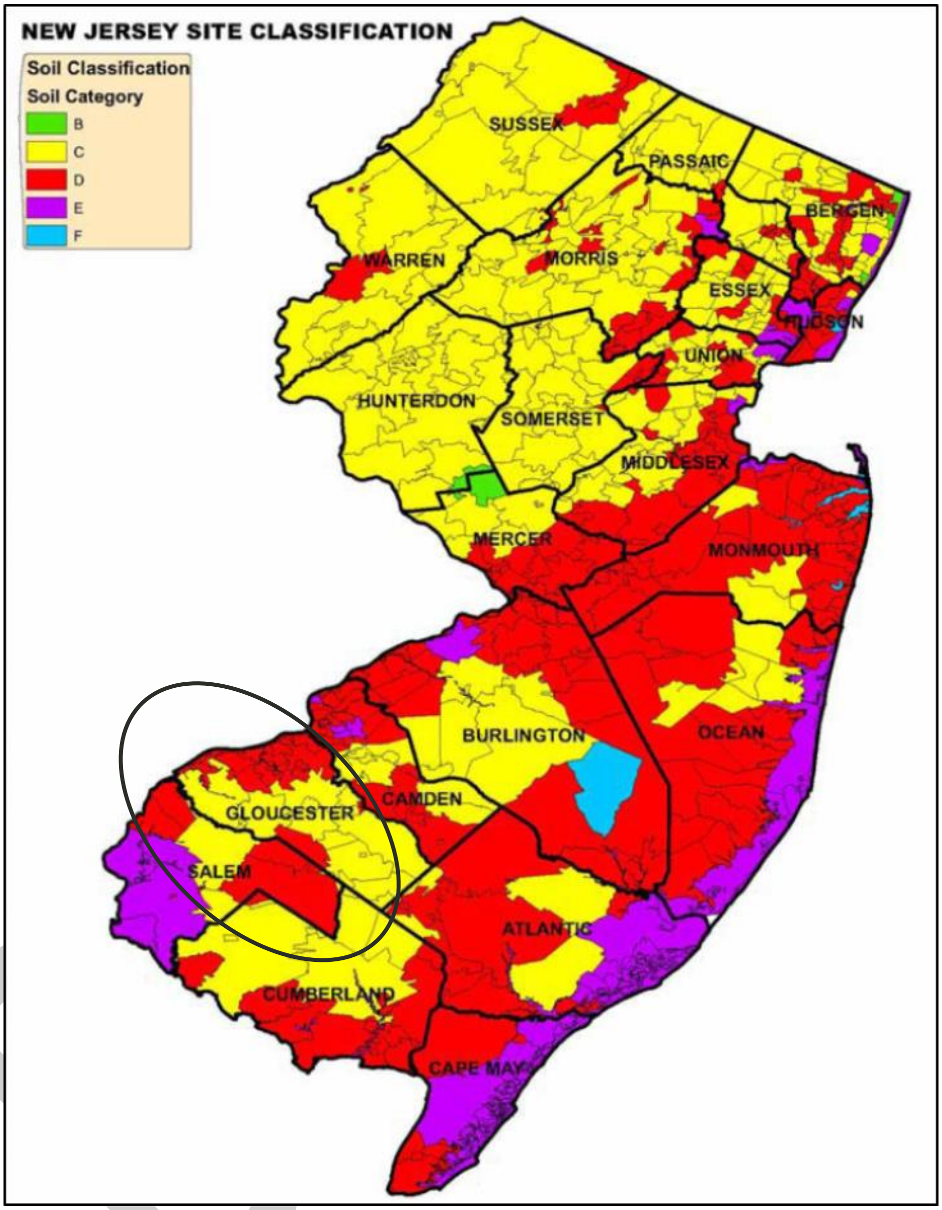
Table 4.3.5-2 NJDOT Soil Classifications

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 Gloucester County, most ZIP codes were rated as either Category C or D. Figure 4.3.5-1 provides a displays this information.

Figure 4.3.5-1. ZIP Code-Based Soil Site Class Map



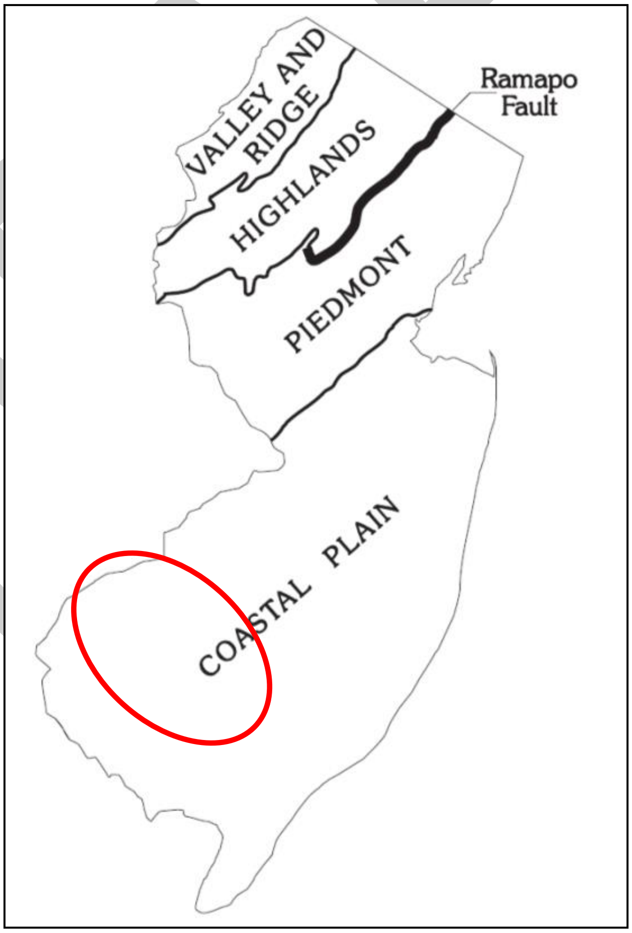
Source: NJDOT 2012
Note: Gloucester County is indicated by the black oval.

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 majority of Gloucester County has low to no susceptibility (NJDEP 2021).

Liquefaction occurs in saturated soils and when it occurs, the strength of the soil decreases and the ability of a soil deposit to support foundations for buildings and bridges is reduced. Shaking from earthquakes often triggers an increase in water pressure which can trigger landslides and the collapse of dams. For information regarding dam failures, refer to Section 4.3.2 (Dam and Levee Failure). Earthquakes also contribute to landslide hazards. Earthquakes create stresses that make weak slopes fail. Earthquakes of magnitude 4.0 or greater have been known to trigger landslides. For information regarding landslides, refer to Section 5.48 (Geological Hazards).

Fractures or fracture zones along with rocks on adjacent sides have broken and moved upward, downward, or horizontally are known as faults (Volkert 2015). Movement can take place at faults and cause an earthquake. Earthquake epicenters in eastern North America and the New Jersey area, however, do not typically occur on known faults. The faults in these areas are the result of tectonic activity from over 200 million years ago. One of the most well-known faults in the state is the Ramapo Fault, which separates the Piedmont and Highlands Physiographic Provinces. As indicated in Figure 4.3.5-2, Gloucester County might feel the effects of an earthquake along the Ramapo Fault; however, the fault itself is not located within County borders (Volkert 2015).

Figure 4.3.5-2. Physiographic Provinces of New Jersey and the Ramapo Fault Line



Source: NJDEP, 2021
Note: Gloucester County is indicated by the red oval

Extent

An earthquake's magnitude and intensity are used to describe the size and severity of the event (NJOEM 2019). 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 4.3.5-3. The modified Mercalli intensity scale is generally represented visually using shake maps, which show the expected ground shaking at any given location produced by an earthquake with a specified magnitude and epicenter An earthquake has only one magnitude and one epicenter, but it produces a range of ground shaking at sites throughout the region, depending on the distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the earth's crust. A USGS shake map shows the variation of ground shaking in a region immediately following significant earthquakes. Table 4.3.5-4 displays the MMI scale and its relationship to the areas peak ground acceleration (PGA).

Table 4.3.5-3. Modified Mercalli Intensity Scale

Mercalli Intensity	Description
I	Felt by very few people; barely noticeable.
II	Felt by few people, especially on upper floors.
III	Noticeable indoors, especially on upper floors, but may not be recognized as an earthquake.
IV	Felt by many indoors, few outdoors. May feel like passing truck.
V	Felt by almost everyone, some people awakened. Small objects move; trees and poles may shake.
VI	Felt by everyone; people have trouble standing. Heavy furniture can move; plaster can fall off walls. Chimneys may be slightly damaged.
VII	People have difficulty standing. Drivers feel their cars shaking. Some furniture breaks. Loose bricks fall from buildings. Damage is slight to moderate in well-built buildings; considerable in poorly built buildings.

Mercalli Intensity	Description
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 2021)

Table 4.3.5-4. Modified Mercalli Intensity and PGA Equivalents

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

Source: USGS 2021
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 4.3.5-5.

Table 4.3.5-5. Damage Levels Experienced in Earthquakes

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

Ground Motion Percentage	Explanation of Damages
20 - 50%g	May cause significant damage in some modern buildings and very high levels of damage (including collapse) in poorly designed buildings.
≥50%g	May causes higher levels of damage in many buildings, even those designed to resist seismic forces.

Source: (NJOEM 2019)
Note: %g Peak Ground Acceleration

National maps of earthquake shaking hazards provide information for creating and updating seismic design requirements for building codes, insurance rate structures, earthquake loss studies, retrofit priorities, and land use planning. After thorough review of the studies, professional organizations of engineers update the seismic-risk maps and seismic design requirements contained in building codes. The USGS updated the National Seismic Hazard Maps in 2014 (Figure 4.3.5-3 and Figure 4.3.5-4). New seismic, geologic, and geodetic information on earthquake rates and associated ground shaking were incorporated into these revised maps.

Figure 4.3.5-3 Peak Ground Acceleration (PGA) 100-Year Mean Return Period for Gloucester County

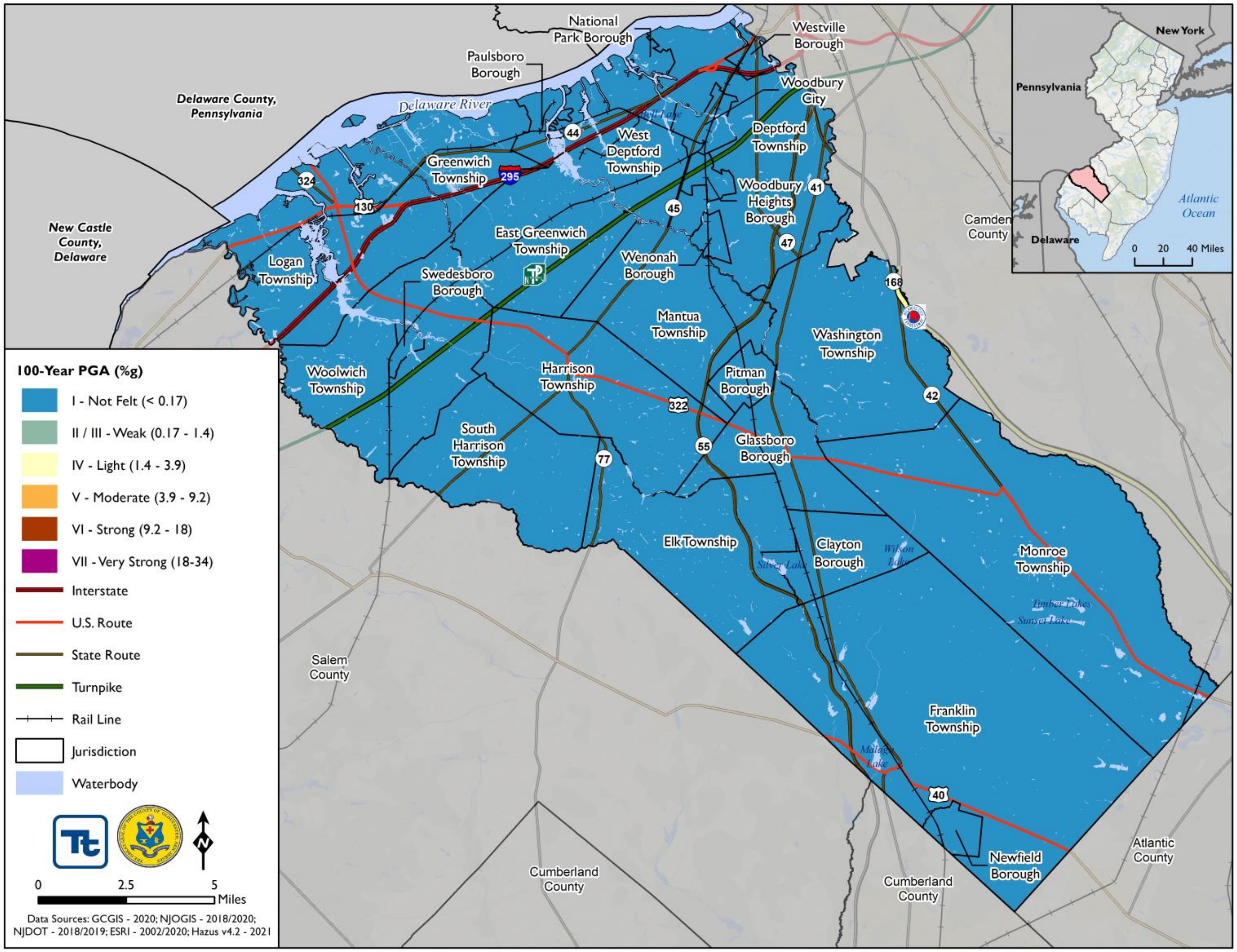
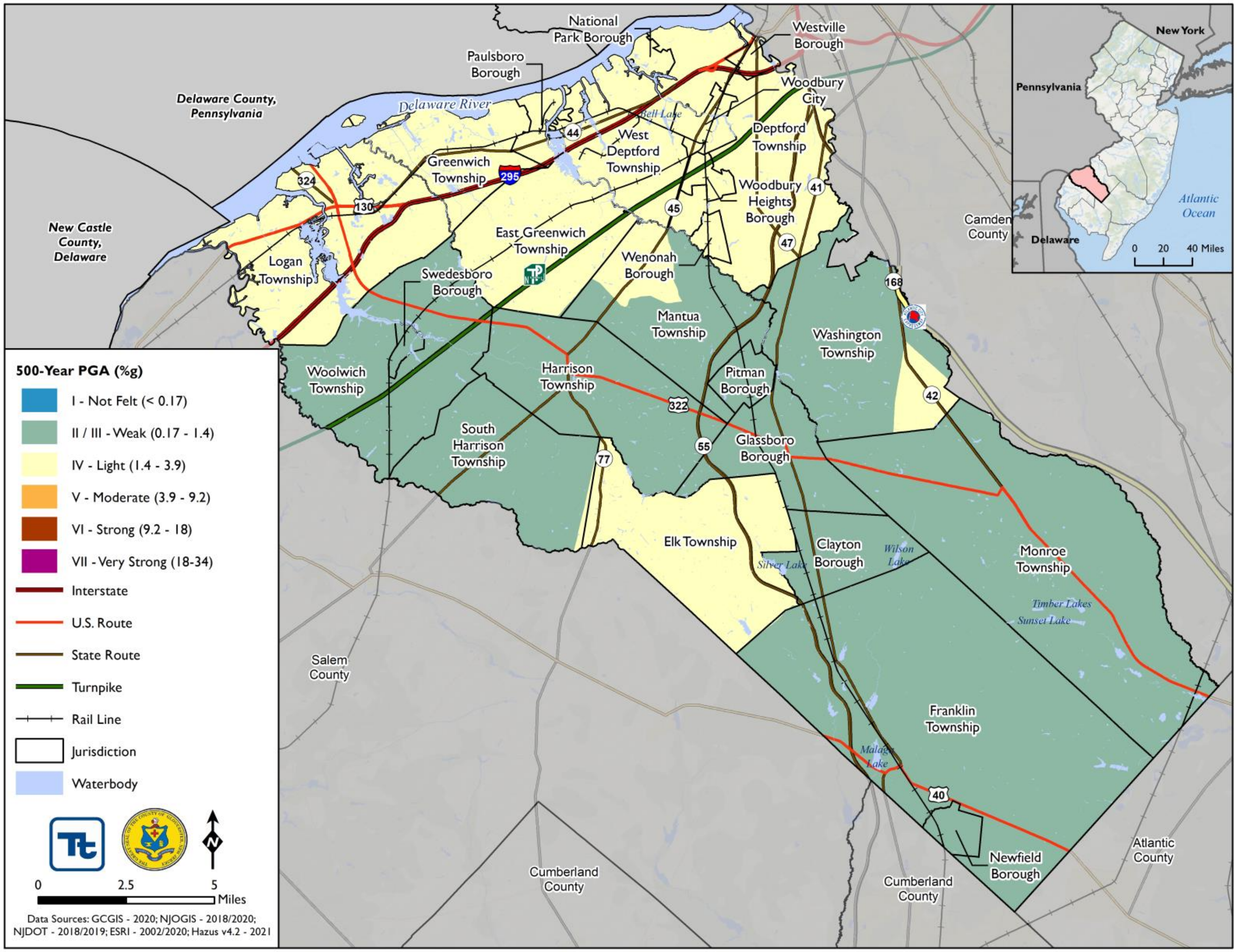


Figure 4.3.5-4 Peak Ground Acceleration (PGA) 500-Year Mean Return Period for Gloucester County



Previous Occurrences

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 1993). Figure 4.3.5-5 illustrates earthquake events with epicenters located in New Jersey. Of the 204 events in the State, 2 earthquake epicenters were located in Gloucester County. The majority of earthquakes have occurred along faults in the central and eastern Highlands, with the Ramapo Fault being the most seismically active fault in the region (Volkert 2015).

FEMA Major Disasters and Emergency Declarations

Between 2015 and 2021, no FEMA disaster declarations were made regarding earthquakes (FEMA 2021).

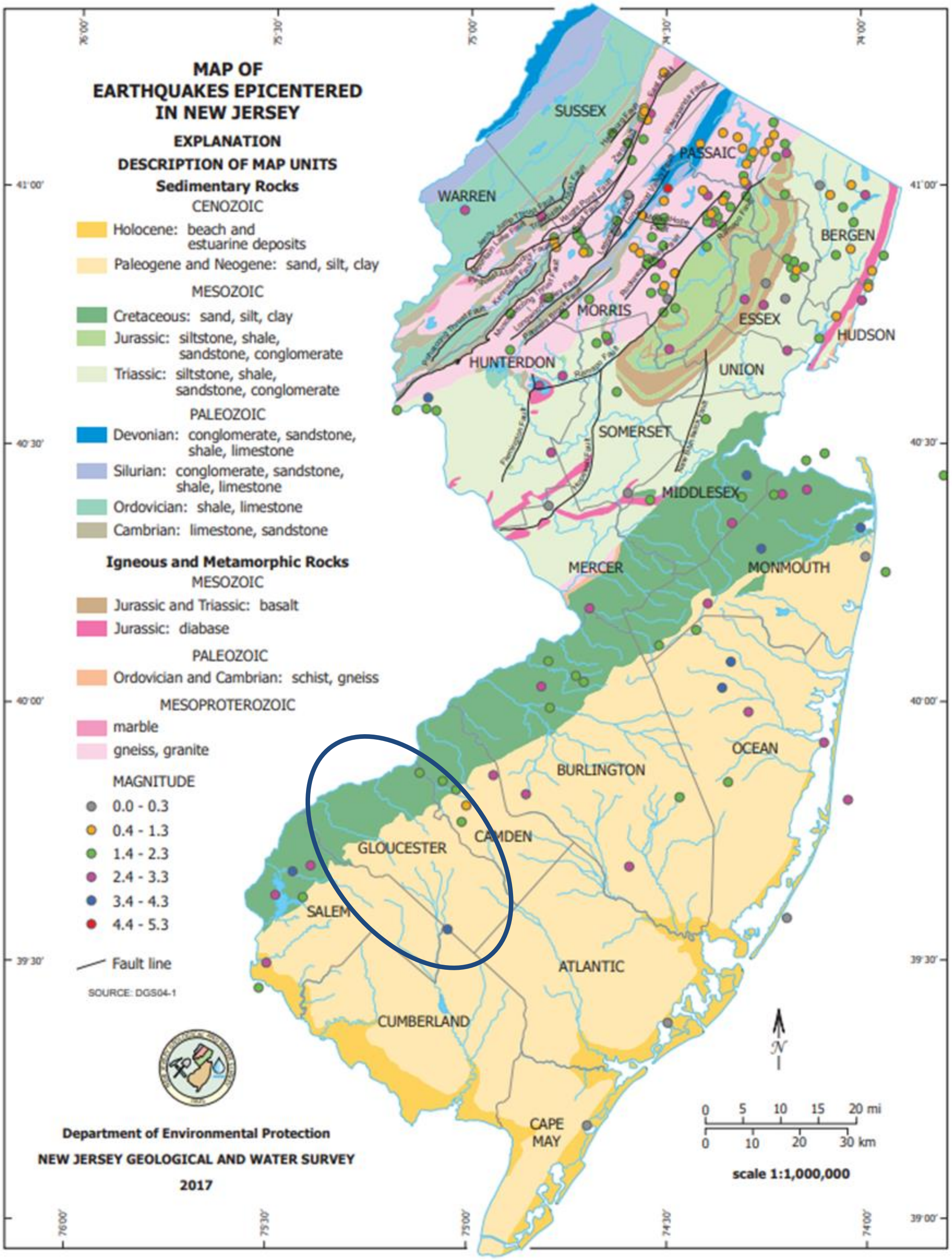
U.S. Department of Agriculture Disaster Declarations

Between 2015 and 2021, no USDA disaster declarations were made regarding earthquakes (USDA 2021).

Previous Events

For the 2022 HMP update, earthquake events that have impacted Gloucester County between 2015 and 2021 have been identified. These events have been identified and are listed in Table 4.3.5-6.

Figure 4.3.5-5 Earthquakes with Epicenters in New Jersey, 1783 to 2017



Source: NJGWS 2017

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

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Table 4.3.5-6. Earthquake Events impacting Gloucester County

Date(s) of Event	Magnitude	FEMA Declaration Number	County Designated?	Location	Description
November 30, 2017	4.1	NA	NA	Dover, DE	An earthquake centered 9 km ENE of Dover, Delaware was faintly felt in Gloucester County.
September 9, 2020	3.1	NA	NA	Marlboro, NJ	An earthquake centered 3 km WSW of Marlboro, New Jersey was faintly felt in Gloucester County.

Source: USGS 2021, Gloucester County, 2021

Probability of Future Occurrences

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

In Section 4.4 (Hazard Ranking), the identified hazards of concern for Gloucester 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 impactful earthquake events in the County is considered 'unlikely' (less than 1 percent annual chance of occurring).

Climate Change

Due to the increase in greenhouse gas concentrations since the end of the 1890s, New Jersey has experienced a 3.5° F (1.9° C) increase in the State's average temperature (ONJSC 2021) which is faster than the rest of the Northeast region (2° F [1.1° C]) (Melillo, Climate change impacts in the United States 2014) and the world (1.5° F [0.8° C]) (IPCC 2016). This warming trend is expected to continue. By 2050, temperatures in New Jersey are expected to increase by 4.1 to 5.7° F (2.3° C to 3.2° C) (R. D. Horton 2015). Thus, New Jersey can expect to experience an average annual temperature that is warmer than any to date (low emissions scenario) and future temperatures could be as much as 10° F (5.6° C) warmer (high emissions scenario) (Runkle, New Jersey State Climate Summary 2017). New Jersey can also expect that by the middle of the 21st century, 70 percent of summers will be hotter than the warmest summer experienced to date. The increase in temperatures is expected to be felt more during the winter months (December, January, and February), resulting in less intense cold waves, fewer sub-freezing days, and less snow accumulation.

As temperatures increase, Earth's atmosphere can hold more water vapor which leads to a greater potential for precipitation. Currently, New Jersey receives an average of 46 inches of precipitation each year (ONJSC 2021). Since the end of the twentieth century, New Jersey has experienced slight increases in the amount of precipitation it receives each year, and over the last 10 years there has been a 7.9 percent increase. By 2050, annual precipitation in New Jersey could increase by 4 percent to 11 percent (R. D. Horton 2015). By the end of this century, heavy precipitation events are projected to occur two to five times more often (Walsh 2014) and with more intensity (Huang 2017) than in the last century. New Jersey will experience more intense rain events, less snow, and more rainfalls (Fan 2014). Also, small decreases in the amount of precipitation may occur in the summer months, resulting in greater potential for more frequent and prolonged droughts (Trenberth 2011).

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. The 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).

4.3.5.3 Vulnerability Assessment

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

Impact on Life, Health, and Safety

The entire County may experience an earthquake. However, the degree of impact is dependent on many factors including the age and type of construction people live in, the soil types their homes are located on, and the intensity of the earthquake. Whether directly or indirectly impacted, residents could be faced with business closures, road closures that could isolate populations, and loss of function of critical facilities and utilities.

According to the 2015-2019 ACS 5-year population estimate, Gloucester County had a population of 291,165 people. Overall, risk to public safety and loss of life from an earthquake in the County is minimal for low magnitude events. However, there is a higher risk to public safety for those inside buildings due to structural damage or people walking below building ornamentations and chimneys that may be shaken loose and fall because of an earthquake.

As noted earlier, NEHRP soil classes D and E can amplify ground shaking to damaging levels even during a moderate earthquake, and thus increase risk to the population. Populations within municipalities located on class D and E soils were estimated and are listed in Table 4.3.5-7 below. Overall, approximately 107,065 residents (36.8-percent of the County's population) reside on class D. Out of the 24 municipalities in the County, 7 are estimated to have 100-percent of their population living on Class D soils.

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Table 4.3.5-7. Approximate Population Located Within Soil Class D Hazard Areas

Jurisdiction	Total Population (American Community Survey 2015-2019)	Estimated Population Located in the Class D NEHRP Soil Hazard Area	
		Number of People	Percent of Total
Clayton (B)	8,626	0	0.0%
Deptford (Twp)	30,448	28,467	93.5%
East Greenwich (Twp)	10,488	10,488	100.0%
Elk (Twp)	4,135	2,394	57.9%
Franklin (Twp)	16,440	898	5.5%
Glassboro (B)	19,826	0	0.0%
Greenwich (Twp)	4,831	4,818	99.7%
Harrison (Twp)	12,995	54	0.4%
Logan (Twp)	5,924	632	10.7%
Mantua (Twp)	14,941	8,079	54.1%
Monroe (Twp)	36,789	0	0.0%
National Park (B)	2,959	2,959	100.0%
Newfield (B)	1,521	0	0.0%
Paulsboro (B)	5,904	5,904	100.0%
Pitman (B)	8,805	0	0.0%
South Harrison (Twp)	3,148	0	0.0%
Swedesboro (B)	2,579	0	0.0%
Washington (Twp)	47,833	1,954	4.1%
Wenonah (B)	2,259	2,259	100.0%
West Deptford (Twp)	21,149	21,149	100.0%
Westville (B)	4,169	4,164	99.9%
Woodbury (C)	9,861	9,861	100.0%
Woodbury Heights (B)	2,986	2,986	100.0%
Woolwich (Twp)	12,549	0	0.0%
Gloucester County (Total)	**291,165**	**107,065**	**36.8%**

Source: ACS 5-year Estimates 2015-2019; NJDOT 2012
Notes: B = Borough, C = City, Twp = Township, % = Percent, < = Less Than

Populations considered most vulnerable are those located in/near the built environment, particularly those near unreinforced masonry construction. Of these most vulnerable populations, socially vulnerable populations, including the elderly (persons over age 65) and individuals living below the poverty threshold, are most susceptible. Factors leadings to this higher susceptibility include decreased mobility and financial ability to react or respond during a hazard, and the location and construction quality of their housing. According to the 2015 – 2019 5-year ACS estimates, there are 21,340 total persons living below the poverty level and 44,794 persons over the age of 65 years in Gloucester County.

As a result of a significant earthquake event, residents may be displaced or require temporary to long-term sheltering. The number of people requiring shelter is generally less than the number displaced as some displaced persons use hotels or stay with family or friends following a disaster event. Hazus estimates that there will be zero displaced households and zero persons seeking short-term sheltering caused by the 100-year MRP event. Further, Hazus estimates that there will be 11 households displaced and seven persons seeking short-term sheltering caused by the 500-year MRP event (Table 4.3.5-8).

Table 4.3.5-8. Estimated Displaced Households and Persons Seeking Shelter Caused by the 500-Year Mean Return Period (MRP) Earthquake Event

Jurisdiction	500-Year MRP Displaced Households	500-Year MRP People Requiring Short-Term Shelter
Clayton (B)	0	0
Deptford (Twp)	5	3
East Greenwich (Twp)	0	0
Elk (Twp)	0	0
Franklin (Twp)	0	0
Glassboro (B)	0	0
Greenwich (Twp)	0	0
Harrison (Twp)	0	0
Logan (Twp)	0	0
Mantua (Twp)	0	0
Monroe (Twp)	0	0
National Park (B)	0	0
Newfield (B)	0	0
Paulsboro (B)	0	0
Pitman (B)	0	0
South Harrison (Twp)	0	0
Swedesboro (B)	0	0
Washington (Twp)	0	0
Wenonah (B)	0	0
West Deptford (Twp)	0	0
Westville (B)	1	1
Woodbury (C)	3	2
Woodbury Heights (B)	0	0
Woolwich (Twp)	0	0
Gloucester County (Total)	**11**	**7**

Source: Hazus v4.2
Notes: B = Borough, C = City, Twp = Township, MRP = Mean Return Period

According to the 1999-2003 NYCEM Summary Report (*Earthquake Risks and Mitigation in the New York / New Jersey / Connecticut Region*), a strong correlation exists between structural building damage and number of injuries and casualties from an earthquake event. Further, the time of day also exposes different sectors of the community to the hazard. For example, Hazus considers the residential occupancy at its maximum at 2:00 a.m., where the educational, commercial, and industrial sectors are at their maximum at 2:00 p.m., with peak commute time at 5:00 p.m. Whether directly impacted or indirectly impact, the entire population will have to deal with the consequences of earthquakes to some degree. Business interruption could prevent people from working, road closures could isolate populations, and loss of functions of utilities could impact populations that suffered no direct damage from an event itself. Overall, Hazus estimates that there are no injuries or casualties caused by the 100-year MRP event; 16 injuries caused by the 500-year MRP event (4 during the 2:00 am commute, 8 during the 2:00 pm commute, and 4 during the 5:00 pm commute); and one hospitalization caused by the 500-year MRP event.

Impact on General Building Stock

The entire County's general building stock is considered at risk and exposed to this hazard. Soft soils (classes D and E) can amplify ground shaking to damaging levels even during a moderate earthquake. Therefore, buildings located on classes D and E soils are at increased risk of damage from an earthquake. Table 4.3.5-9 summarizes the number and replacement cost value of buildings in Gloucester County located on soil Class D hazard areas. Overall, 39-percent of the County's total general building stock replacement cost value is located on the Class D soil types.

Table 4.3.5-9. Estimated Number of Buildings Located in the NEHRP Class D Soil Hazard Area

Jurisdiction	Total Number of Buildings	Total Replacement Cost Value (RCV)	Estimated Building Stock Located in the Class D NEHRP Soil Hazard Area			
			Number of Buildings	Percent of Total	Replacement Cost Value (RCV)	Percent of Total
Clayton (B)	3,295	$1,933,299,905	0	0.0%	$0	0.0%
Deptford (Twp)	11,284	$10,081,159,584	10,486	92.9%	$8,794,741,181	87.2%
East Greenwich (Twp)	4,346	$2,927,045,409	4,346	100.0%	$2,927,045,409	100.0%
Elk (Twp)	2,339	$1,784,179,937	1,474	63.0%	$1,352,855,414	75.8%
Franklin (Twp)	8,432	$5,637,186,975	446	5.3%	$241,591,669	4.3%
Glassboro (B)	5,959	$5,816,332,907	0	0.0%	$0	0.0%
Greenwich (Twp)	2,807	$2,734,741,222	2,801	99.8%	$2,732,819,188	99.9%
Harrison (Twp)	4,817	$4,828,239,008	18	0.4%	$6,774,534	0.1%
Logan (Twp)	2,805	$6,591,573,691	290	10.3%	$204,957,068	3.1%
Mantua (Twp)	6,569	$4,738,271,524	3,439	52.4%	$2,083,188,719	44.0%
Monroe (Twp)	12,553	$8,458,118,166	0	0.0%	$0	0.0%
National Park (B)	1,483	$781,021,288	1,483	100.0%	$781,021,288	100.0%
Newfield (B)	891	$622,948,021	0	0.0%	$0	0.0%
Paulsboro (B)	2,615	$2,076,864,026	2,615	100.0%	$2,076,864,026	100.0%
Pitman (B)	3,521	$2,916,470,733	0	0.0%	$0	0.0%
South Harrison (Twp)	1,726	$1,494,748,661	0	0.0%	$0	0.0%
Swedesboro (B)	1,040	$936,236,069	0	0.0%	$0	0.0%
Washington (Twp)	17,413	$13,732,374,547	735	4.2%	$678,328,272	4.9%
Wenonah (B)	930	$778,702,966	930	100.0%	$778,702,966	100.0%
West Deptford (Twp)	7,561	$9,201,121,261	7,561	100.0%	$9,201,121,261	100.0%
Westville (B)	1,733	$1,529,846,612	1,731	99.9%	$1,528,849,303	99.9%
Woodbury (C)	3,605	$4,139,381,075	3,605	100.0%	$4,139,381,075	100.0%
Woodbury Heights (B)	1,295	$1,265,332,236	1,295	100.0%	$1,265,332,236	100.0%
Woolwich (Twp)	4,074	$4,551,585,778	0	0.0%	$0	0.0%
Gloucester County (Total)	**113,093**	**$99,556,781,602**	**43,255**	**38.2%**	**$38,793,573,609**	**39.0%**

Source: NJDOT 2012
Notes: B = Borough, C = City, Twp = Township, RCV = Replacement Cost Value

There is a strong correlation between PGA and damage a building might undergo (New Jersey 2019). The Hazus model is based on best available earthquake science and aligns with these statements. The

Hazus probabilistic earthquake model was applied to analyze effects from the earthquake hazard on general building stock in Gloucester County. Refer to Figure 4.3.5-3 and **Error! Reference source not found.** earlier in this profile which illustrates the geographic distribution of PGA (%g) across the County for 100-year and 500-year MRP events at the Census-tract level.

A building's construction determines how well it can withstand the force of an earthquake. The New Jersey 2019 HMP 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 considers building construction and age of building as part of the analysis. Because a custom general building stock was used for this Hazus analysis, the building ages and building types from the inventory were incorporated into the Hazus model.

Potential building damage was evaluated by Hazus across the following damage categories: none, slight, moderate, extensive, and complete. Table 4.3.5-10 provides definitions of these five categories of damage for a light wood-framed building. Definitions for other building types are included in the Hazus technical manual documentation. The results of potential damage states for buildings in Gloucester County categorized by general occupancy classes (i.e., residential, commercial, industrial, etc.) from Hazus are summarized in Table 4.3.5-11 for the 500-year MRP event. Hazus estimates that there are zero damages to structures caused by the 100-year MRP event.

Table 4.3.5-10. Example of Structural Damage State Definitions for a Light Wood-Framed Building

Damage Category	Description
Slight	Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.
Moderate	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
Extensive	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of room-over-garage or other soft-story configurations.
Complete	Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple-wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks.

Source: Hazus Technical Manual

Table 4.3.5-11. Estimated Buildings Damaged by General Occupancy for the 500-Year Mean Return Period (MRP) Earthquake Event

Occupancy Class	Total Number of Buildings in Occupancy	Severity of Expected Damage	Earthquake 500-Year	
			Building Count	Percent Buildings in Occupancy Class
	101,804	None	100,845	99.1%

Occupancy Class	Total Number of Buildings in Occupancy	Severity of Expected Damage	Earthquake 500-Year	
			Building Count	Percent Buildings in Occupancy Class
Residential Exposure (Single and Multi-Family Dwellings)		Minor	788	0.8%
		Moderate	156	0.2%
		Extensive	13	0.0%
		Complete Destruction	1	0.0%
Commercial Buildings	6,750	None	6,645	98.4%
		Minor	86	1.3%
		Moderate	18	0.3%
		Extensive	1	0.0%
		Complete Destruction	0	0.0%
Industrial Buildings	951	None	893	93.9%
		Minor	40	4.2%
		Moderate	16	1.6%
		Extensive	2	0.2%
		Complete Destruction	0	0.0%
Government, Religion, Agricultural, and Education Buildings	3,588	None	3,537	98.6%
		Minor	43	1.2%
		Moderate	8	0.2%
		Extensive	1	0.0%
		Complete Destruction	0	0.0%

Source: Gloucester County GIS 2021; MODIV 2020; Hazus v4.2
Notes: % = Percent, < = Less Than

Building damage as a result of the 100-year and 500-year MRP earthquakes were estimated for each municipality using Hazus. Hazus estimates that zero damages will occur to buildings or contents during the 100-year MRP event. Table 4.3.5-12 summarizes estimated total building and content losses caused by the 500-year MRP event by jurisdiction. This table also summarizes losses for structures categorized as residential, commercial, and all other occupancy classes. Less than 0.1-percent of the County's structures are impacted by the 500-year MRP event (i.e., approximately $30 million in replacement cost value). Majority of the losses are estimated to occur in the Township of West Deptford.

Table 4.3.5-12. Estimated Building Damages (Structure and Contents) from the 500-year Mean Return Period (MRP) Earthquake Event

Jurisdiction	Replacement Cost Value (RCV)	500-Year MRP				
		Estimated Total Damage	Percent of Total Building and Contents Replacement Cost Value	Estimated Residential Damage	Estimated Commercial Damage	Estimated Damages for All Other Occupancies
Clayton (B)	$1,933,299,905	$442,581	<0.1%	$321,380	$44,975	$76,226
Deptford (Twp)	$10,081,159,584	$4,174,429	<0.1%	$2,342,556	$1,057,832	$774,041
East Greenwich (Twp)	$2,927,045,409	$1,165,690	<0.1%	$826,961	$204,642	$134,087
Elk (Twp)	$1,784,179,937	$463,922	<0.1%	$309,057	$33,322	$121,542
Franklin (Twp)	$5,637,186,975	$1,068,783	<0.1%	$618,050	$132,804	$317,930
Glassboro (B)	$5,816,332,907	$1,348,529	<0.1%	$587,935	$244,637	$515,957
Greenwich (Twp)	$2,734,741,222	$2,104,059	0.1%	$1,022,477	$152,334	$929,248
Harrison (Twp)	$4,828,239,008	$762,837	<0.1%	$545,205	$96,562	$121,070
Logan (Twp)	$6,591,573,691	$1,667,998	<0.1%	$294,413	$896,572	$477,013
Mantua (Twp)	$4,738,271,524	$1,168,626	<0.1%	$780,202	$267,516	$120,907
Monroe (Twp)	$8,458,118,166	$1,580,200	<0.1%	$926,645	$337,300	$316,255
National Park (B)	$781,021,288	$297,554	<0.1%	$198,646	$55,184	$43,723
Newfield (B)	$622,948,021	$108,337	<0.1%	$53,615	$19,196	$35,525
Paulsboro (B)	$2,076,864,026	$1,131,807	0.1%	$505,214	$200,256	$426,337
Pitman (B)	$2,916,470,733	$854,254	<0.1%	$580,362	$120,744	$153,148
South Harrison (Twp)	$1,494,748,661	$214,116	<0.1%	$156,104	$15,495	$42,516
Swedesboro (B)	$936,236,069	$199,724	<0.1%	$86,318	$69,003	$44,403
Washington (Twp)	$13,732,374,547	$2,410,451	<0.1%	$1,344,470	$583,086	$482,896
Wenonah (B)	$778,702,966	$362,653	<0.1%	$313,393	$17,319	$31,942
West Deptford (Twp)	$9,201,121,261	$4,273,695	<0.1%	$1,533,533	$1,946,123	$794,039
Westville (B)	$1,529,846,612	$809,257	0.1%	$485,236	$255,500	$68,522
Woodbury (C)	$4,139,381,075	$2,099,600	0.1%	$1,115,275	$699,034	$285,291
Woodbury Heights (B)	$1,265,332,236	$537,840	<0.1%	$278,481	$157,809	$101,550
Woolwich (Twp)	$4,551,585,778	$744,645	<0.1%	$516,963	$113,292	$114,390
Gloucester County (Total)	**$99,556,781,602**	**$29,991,586**	**<0.1%**	**$15,742,492**	**$7,720,537**	**$6,528,557**

Source: Hazus 4.2; Gloucester County GIS 2021; MODIV 2020; RS Means 2021
Notes: B = Borough, C = City, Twp = Township, % = Percent, < = Less Than

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 and Lifelines

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

The Hazus earthquake model was used to assign the range or average probability of each damage state category to the critical facilities and lifelines in Gloucester County for the 100-year and 500-year MRP events. In addition, Hazus estimates the time to restore critical facilities to fully functional use. Results are presented as a probability of being functional at specified time increments (days after the event). For example, Hazus might estimate that a facility has 5 percent chance of being fully functional at Day 3, and a 95 percent chance of being fully functional at Day 90. For percent probability of sustaining damage, the minimum and maximum damage estimated value for that facility type is presented.

As a result of a 100-year MRP event, Hazus estimates that critical facilities will be nearly 100-percent functional with negligible damages. Therefore, the impact to critical facilities is not significant for the 100-year event. Whereas, for the 500-year MRP events, functionality can approximately decrease as low as 4.3-percent. Table 4.3.5-13 summarizes the damage state probabilities for critical facilities during the 500-year MRP event.

Table 4.3.5-13. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities in Gloucester County for the 500-Year Mean Return Period (MRP) Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Essential Facilities									
EOC	99.2% - 99.6%	0.4% - 0.7%	<0.1%	0.0%	0.0%	99.1% - 99.6%	99.9%	99.9%	99.9%
Medical Facilities	99.1% - 99.6%	0.4% - 0.8%	<0.1%	0.0%	0.0%	99.1% - 99.5%	99.9%	99.9%	99.9%
Police Stations	97.6% - 98.8%	0.7% - 1.4%	0.4% - 0.8%	<0.1% - 0.1%	0.0%	97.5% - 98.7%	98.9% - 99.5%	99.8% - 99.9%	99.9%
Fire Stations/EMS	97.6% - 98.8%	0.7% - 1.4%	0.4% - 0.8%	<0.1% - 0.1%	0.0%	97.5% - 98.8%	98.9% - 99.5%	99.8% - 99.9%	99.9%
Schools	98.4% - 99.2%	0.6% - 1.1%	0.2% - 0.4%	<0.1%	0.0%	98.3% - 99.2%	99.4% - 99.7%	99.9%	99.9%
Utilities									
Potable Water	95.7% - 99.6%	0.4% - 2.9%	<0.1% - 1.3%	0.0% - 0.1%	0.0%	96.9% - 99.8%	99.7% - 99.9%	99.8% - 99.9%	99.9%
Wastewater	97.6% - 98.7%	0.8% - 1.4%	0.4% - 0.8%	<0.1% - 0.1%	0.0%	98.1% - 99.0%	99.7% - 99.8%	99.8% - 99.9%	99.9%
Electric Power	97.6%	1.4%	0.8%	0.1%	0.0%	98.4%	99.9%	99.9%	99.9%
Transportation									
Bus Facilities	99.1%	0.8%	<0.1%	0.0%	0.0%	99.9%	99.9%	99.9%	99.9%
Port Facilities	99.1% - 99.6%	0.4% - 0.9%	<0.1%	0.0%	0.0%	99.9%	99.9%	99.9%	99.9%

Source: Gloucester County Planning Partnership 2021; Gloucester County GIS 2021; Hazus v4.
Notes: EOC = Emergency Operations Center, EMS = Emergency Medical Services, < = Less Than, % = Percent

Impact on Economy

Earthquakes also have impacts on the economy, including loss of business function, damage to inventory, relocation costs, wage loss, and rental loss due to the repair/replacement of buildings. Hazus estimates building-related economic losses, including income losses (wage, rental, relocation, and capital-related losses) and capital stock losses (structural, non-structural, content, and inventory losses). Economic losses estimated by Hazus are summarized in Table 4.3.5-14. Hazus estimates that there are zero economic losses caused by the 100-year earthquake event.

Table 4.3.5-14. Economic Losses for the 500-Year Mean Return Period (MRP) Earthquake Event

Level of Severity	Mean Return Period 500-year
Income Losses	
Wage	$1,184,800
Capital Related	$628,000
Rental	$1,405,400
Relocation Loss	$3,836,900
Subtotal	**$7,055,100**
Capital Stock Losses	
Building and Content Losses	$29,990,900
Inventory	$124,800
Subtotal	**$30,115,700**

Source: Hazus v4.2

Although the Hazus analysis did not compute damage estimates for individual roadway segments and railroad tracks, assumedly these features would undergo damage due to ground failure, resulting in interruptions of regional transportation and of distribution of materials. Losses to the community that would result from damage to lifelines could exceed costs of repair (FEMA 2019).

Earthquake events can also significantly affect road bridges, many of which provide the only access to certain neighborhoods. Because softer soils generally follow floodplain boundaries, bridges that cross watercourses should be considered vulnerable. Another key factor in degree of vulnerability is age of facilities and infrastructure, which correlates with standards in place at times of construction.

Hazus also estimates the volume of debris that may be generated as a result of an earthquake event to enable the study region to prepare and rapidly and efficiently manage debris removal and disposal. Debris estimates are divided into two categories: (1) reinforced concrete and steel that require special equipment to break it up before it can be transported, and (2) brick, wood, and other debris that can be loaded directly onto trucks with bulldozers (Hazus Earthquake User's Manual 2019).

For the 100-year MRP event, Hazus estimates that zero tons of debris will be generated. For the 500-year MRP event, Hazus estimates a total of 13,706 tons of debris will be generated county-wide. Table 4.3.5-15 summarizes the estimated debris generated as a result of these events by municipality.

Table 4.3.5-15. Estimated Debris Generated by the 500-Year Mean Return Period (MRP) Earthquake Event

Jurisdiction	500-Year	
	Brick/Wood (tons)	Concrete/Steel (tons)
Clayton (B)	241	46
Deptford (Twp)	1,162	438
East Greenwich (Twp)	377	82
Elk (Twp)	108	28
Franklin (Twp)	417	91
Glassboro (B)	596	136
Greenwich (Twp)	1,804	375
Harrison (Twp)	147	32
Logan (Twp)	651	167
Mantua (Twp)	313	94
Monroe (Twp)	488	129
National Park (B)	34	21
Newfield (B)	63	14
Paulsboro (B)	588	177
Pitman (B)	503	115
South Harrison (Twp)	32	6
Swedesboro (B)	50	30
Washington (Twp)	532	101
Wenonah (B)	162	37
West Deptford (Twp)	1,038	424
Westville (B)	334	110
Woodbury (C)	713	300
Woodbury Heights (B)	137	71
Woolwich (Twp)	159	31
Gloucester County (Total)	**10,649**	**3,057**

Source: Hazus 4.2
Notes: Twp = Township, B = Borough, T = Town, C = City

Impact on the Environment

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

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

Future Growth and Development

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

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

Projected Development

As discussed and illustrated in Section 3 (County Profile), areas targeted for future growth and development have been identified across the County. The New Jersey Highlands Council has identified areas of potential growth (Sewer Service Areas) that may provide insight as to where potential new development may occur in Gloucester County. Further, the New Jersey Pinelands Commission has identified Pinelands Management Area Boundaries, including regional growth areas and rural development areas that may also provide insight to where development and growth may occur in the County. In addition, each community was requested to provide recent and anticipated new development and infrastructure projects; summarized in Section 9 (Jurisdictional Annexes). According to the Gloucester County Planning Partnership, there are 38 recent or anticipated new development sites in Gloucester County.

Development built in areas with softer NEHRP soil classes, liquefaction, and landslide-susceptible areas may experience shifting or cracking in the foundation during earthquakes because of the loose soil characteristics of these soil classes. However, current building codes require seismic provisions that should render new construction less vulnerable to seismic impacts than older, existing construction that may have been built to lower construction standards. Refer to Section 4.3.8 for more information about the new development sites located in the geologic hazard areas.

Projected Changes in Population

Gloucester County has experienced an increase in its population since 2010. According to the U.S. Census Bureau, the County's population increased by approximately 1-percent between 2010 and 2019 (U.S. Census Bureau 2020). Persons that move into older buildings may increase their overall vulnerability to earthquakes. As noted earlier, if moving into new construction, current building codes require seismic provisions that should render new construction less vulnerable to seismic impacts.

Climate Change

Because the impacts of climate change on earthquakes are not well understood, a change in the County’s vulnerability as the climate continues to change is difficult to determine. However, climate change has the potential to magnify secondary impacts of earthquakes. As a result of the climate change projections discussed above, the County's assets located on areas of saturated soils and on or at the base of steep slopes, are at a higher risk of landslides/mudslides because of seismic activity. Refer to Section 4.3.8 for additional discussion of the geological hazard.

Vulnerability Change Since the 2016 HMP

Overall, the entire County continues to be vulnerable to earthquakes. For the 2021 HMP, the building inventory was updated using RS Means 2021 values, which is more current and reflects replacement cost versus the building stock improvement values reported in the 2016 HMP. Additional building stock updates include updates to the critical facility inventory provided by Gloucester County. Updated hazard areas were used as well; since the 2016 HMP, an updated version of Hazus-MH was released (v4.2). This updated model includes longer historical records to pull from to generate probabilistic events.