5.4.3 Earthquake

This section provides a profile and vulnerability assessment for the earthquake hazard.

5.4.3.1 Hazard Profile

This section provides profile information including description, extent, location, previous occurrences and losses and the probability of future occurrences.

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 (Stanford 2003). 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 2012a).

Extent

An earthquake's magnitude and intensity are used to describe the size and severity of the event. Magnitude describes the size at the focus of an earthquake and intensity describes the overall felt severity of shaking during the event. The earthquake's magnitude is a measure of the energy released at the source of the earthquake and is expressed by ratings on the Richter scale and/or the moment magnitude scale. The Richter Scale measures magnitude of earthquakes and has no upper limit; however, it is not used to express damage (USGS 2014). Table

5.4.3-1 presents the Richter scale magnitudes and corresponding earthquake effects. The moment magnitude scale (MMS) is used to describe the size of an earthquake. It is based on the seismic moment and is applicable to all sizes of earthquakes (USGS 2012). The Richter Scale is not commonly used anymore, as it has been replaced by the MMS which is a more accurate measure of the earthquake size (USGS 2014). The MMS is described below.

Table 5.4.3-1. Richter Magnitude Scale

Richter Magnitude	Earthquake Effects
2.5 or less	Usually not felt, but can be recorded by seismograph
2.5 to 5.4	Often felt, but causes only minor damage
5.5 to 6.0	Slight damage to buildings and other structures
6.1 to 6.9	May cause a lot of damage in very populated areas
7.0 to 7.9	Major earthquake; serious damage
8.0 or greater	Great earthquake; can totally destroy communities near the epicenter

Source: Michigan Tech University Date Unknown

The intensity of an earthquake is based on the observed effects of ground shaking on people, buildings, and natural features, and varies with location. The Modified Mercalli (MMI) scale expresses intensity of an earthquake and describes how strong a shock was felt at a particular location in values. Table 5.4.3-2 summarizes earthquake intensity as expressed by the Modified Mercalli scale. Table 5.4.3-3 displays the MMI scale and its relationship to the areas peak ground acceleration.

Table 5.4.3-2. Modified Mercalli Intensity Scale

Mercalli Intensity	Shaking	Description
I	Not Felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Source: USGS 2014

Table 5.4.3-3. Modified Mercalli Intensity and PGA Equivalents

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

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

PGA expresses the severity of an earthquake and is a measure of how hard the earth shakes, or accelerates, in a given geographic area. PGA is expressed as a percent acceleration force of gravity (%g). For example, 1.0%g PGA in an earthquake (an extremely strong ground motion) means that objects accelerate sideways at the same rate as if they had been dropped from the ceiling. 10%g PGA means that the ground acceleration is 10% that of gravity (NJOEM 2011). Damage levels experienced in an earthquake vary with the intensity of ground shaking and with the seismic capacity of structures, as noted in Table 5.4.3-4.

Table 5.4.3-4. Damage Levels Experienced in Earthquakes

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

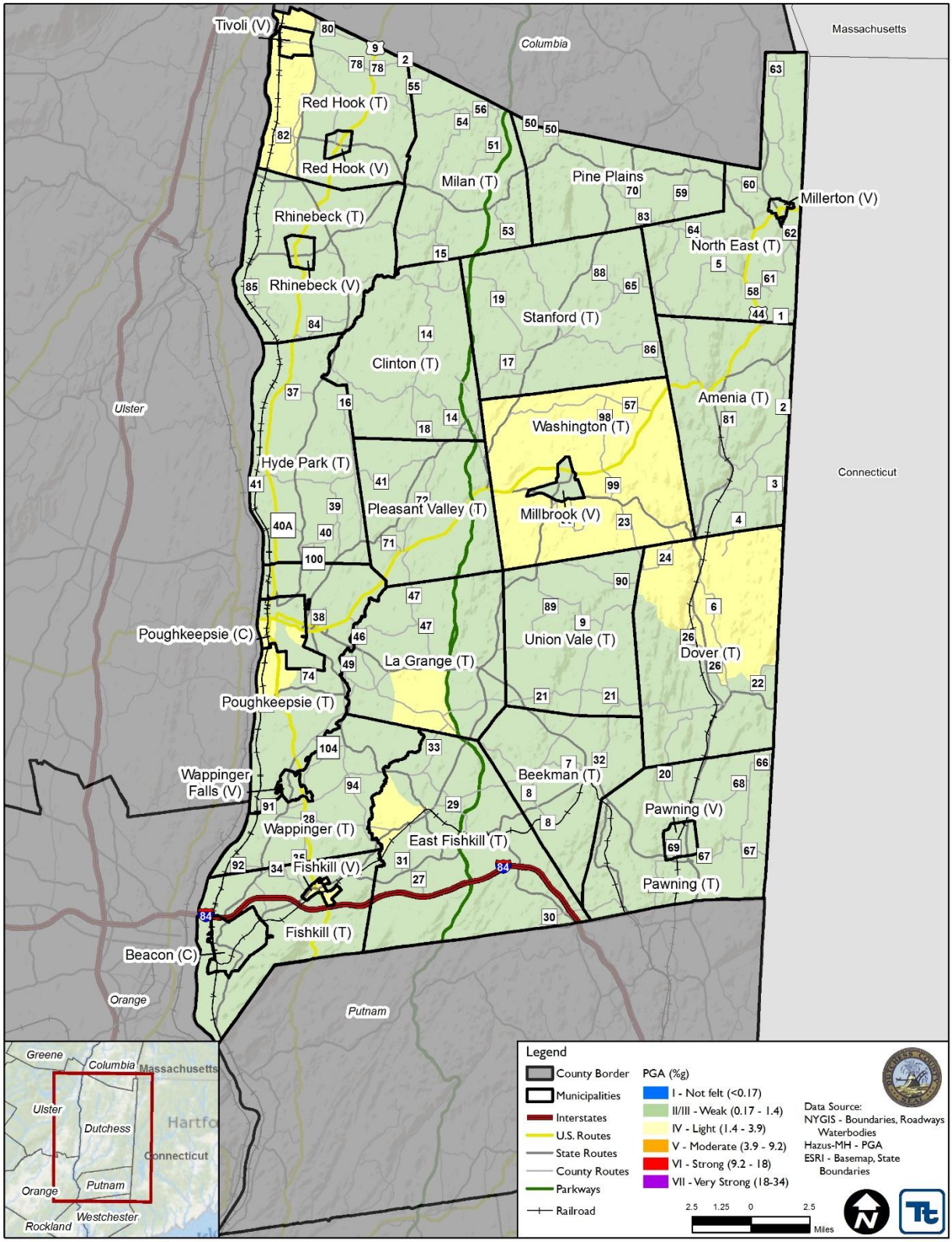
Source: NJOEM 2011
Note: %g Peak Ground Acceleration

National maps of earthquake shaking hazards 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 U.S. 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 superceded 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, Dutchess County has a PGA between 3%g and 5%g. (Petersen, et. al. 2014). The 2014 PGA map can be found at http://pubs.usgs.gov/of/2014/1091/pdf/ofr2014-1091.pdf.

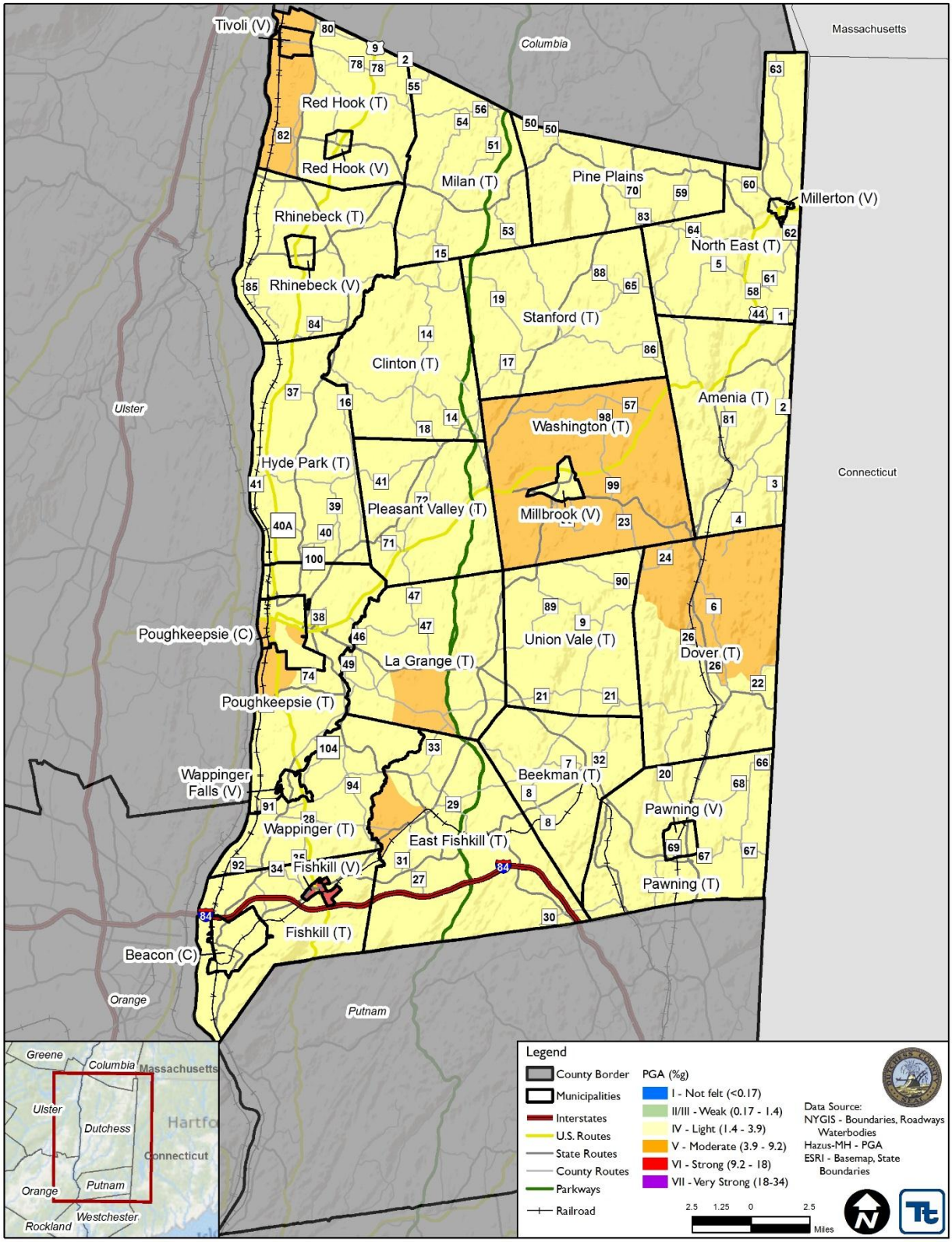
A probabilistic assessment was conducted for the 100-, 500- and 2,500-year mean return periods (MRP) in HAZUS-MH 2.2 to analyze the earthquake hazard for Dutchess County. The HAZUS analysis evaluates the statistical likelihood that a specific event will occur and what consequences will occur. Figure 5.4.3-1 through Figure 5.4.3-3 illustrates the geographic distribution of PGA (*g*) across the County or 100-, 500- and 2,500-year MRP events by Census-tract.

Figure 5.4.3-1. Peak Ground Acceleration 100-Year Mean Return Period for Dutchess County



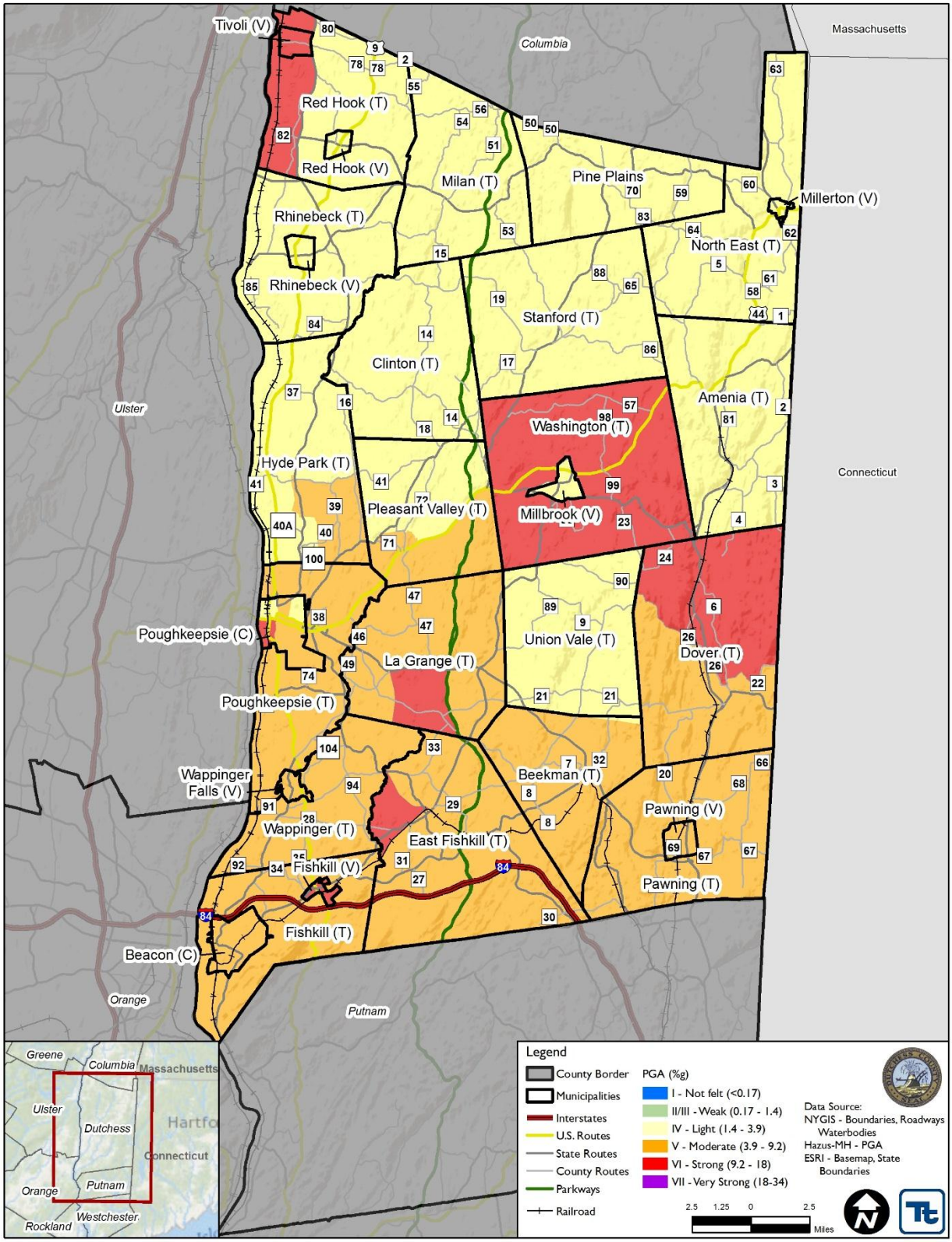
Source: HAZUS-MH 2.2

Figure 5.4.3-2. Peak Ground Acceleration 500-Year Mean Return Period for Dutchess County



Source: HAZUS-MH 2.2

Figure 5.4.3-3. Peak Ground Acceleration 2,500-Year Mean Return Period for Dutchess County



Source: HAZUS-MH 2.2

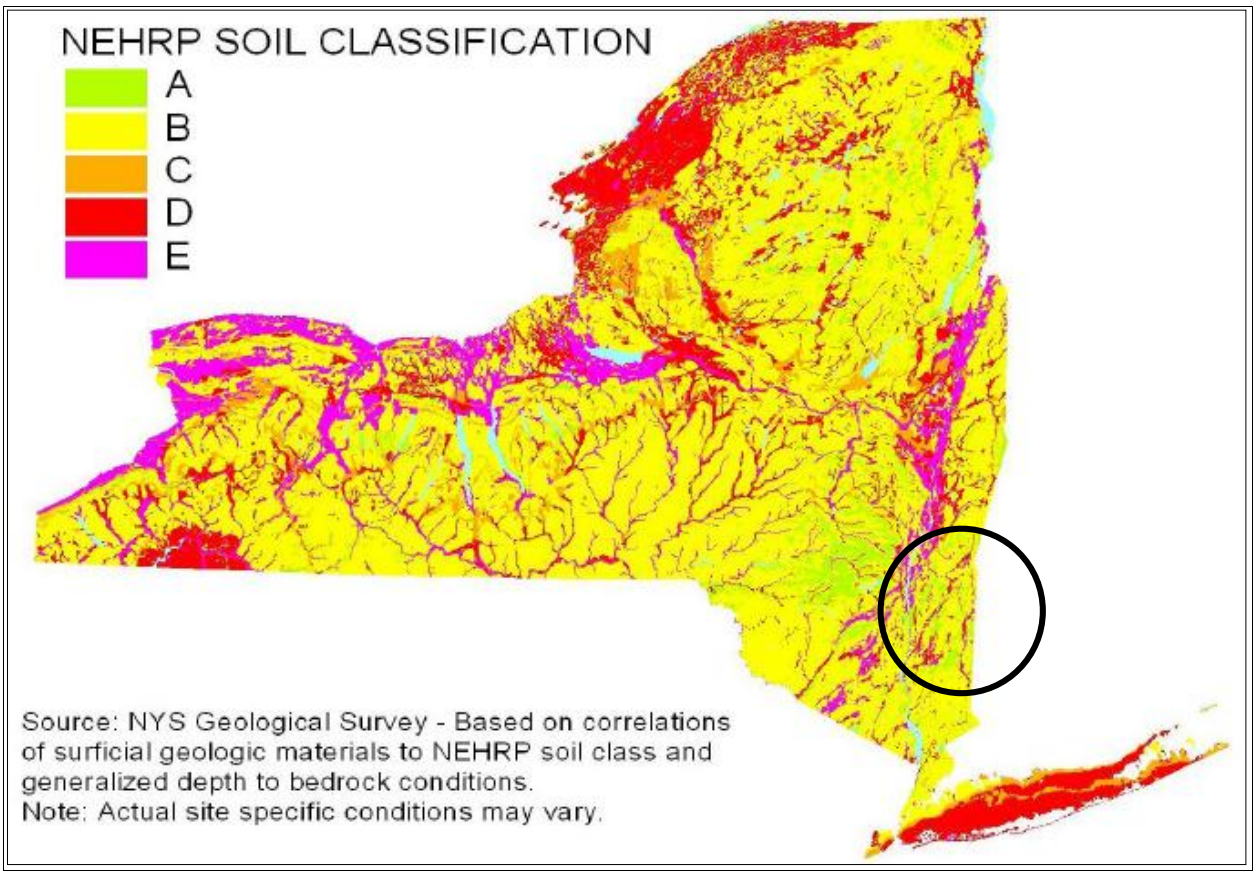
The New York State Geological Survey conducted seismic shear-wave tests of the State's surficial geology (glacial deposits). Based on these test results, the surficial geologic materials of New York State were categorized according to the National Earthquake Hazard Reduction Program's (NEHRP) Soil Site Classifications (Figure 5.4.3-4). The 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 5.4.3-5, 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. Class E soils include water-saturated mud and artificial fill. The strongest amplification of shaking due is expected for this soil type. Seismic waves travel faster through hard rock than through softer rock and sediments. As the waves pass from harder to softer rocks, the waves slow down and their amplitude increases. Shaking tends to be stronger at locations with softer surface layers where seismic waves move more slowly. Ground motion above an unconsolidated landfill or soft soils can be more than 10 times stronger than at neighboring locations on rock for small ground motions (FEMA 2014).

Table 5.4.3-5. NEHRP Soil Classifications

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

Source: FEMA 2013

Figure 5.4.3-4. NEHRP Soils in New York

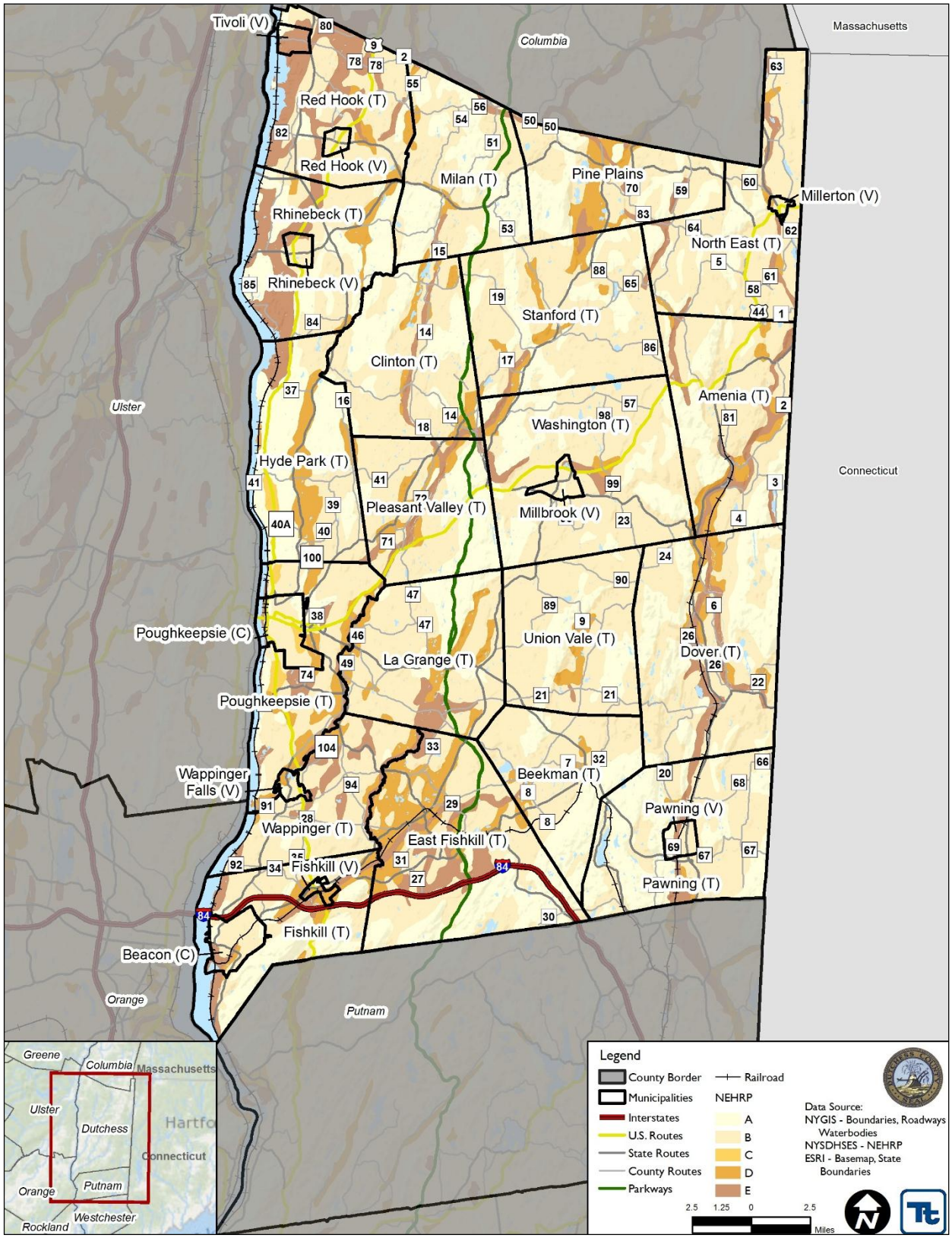


Source: NYS DHSES, 2014

Note: The black oval indicates the approximate location of Dutchess County. The figure shows that the County's NEHRP soil classifications include A, B, and D soils.

Figure 5.4.3-5 illustrates the NEHRP soils located throughout Dutchess County. The data was available from the NYS DHSES. The available NEHRP soils information is incorporated into the HAZUS-MH earthquake model for the risk assessment (discussed in further detail later in this section). According to this figure, Dutchess County is predominately underlain by Class A and B soils with bands of C, D, and E running throughout the County. In the southwestern portion of the County, in the Towns of East Fishkill, Fishkill, and Wappingers, there are larger areas underlain by Class D and E soils.

Figure 5.4.3-5. NEHRP Soils in Dutchess County



Source: HAZUS-MH 2.2

Location

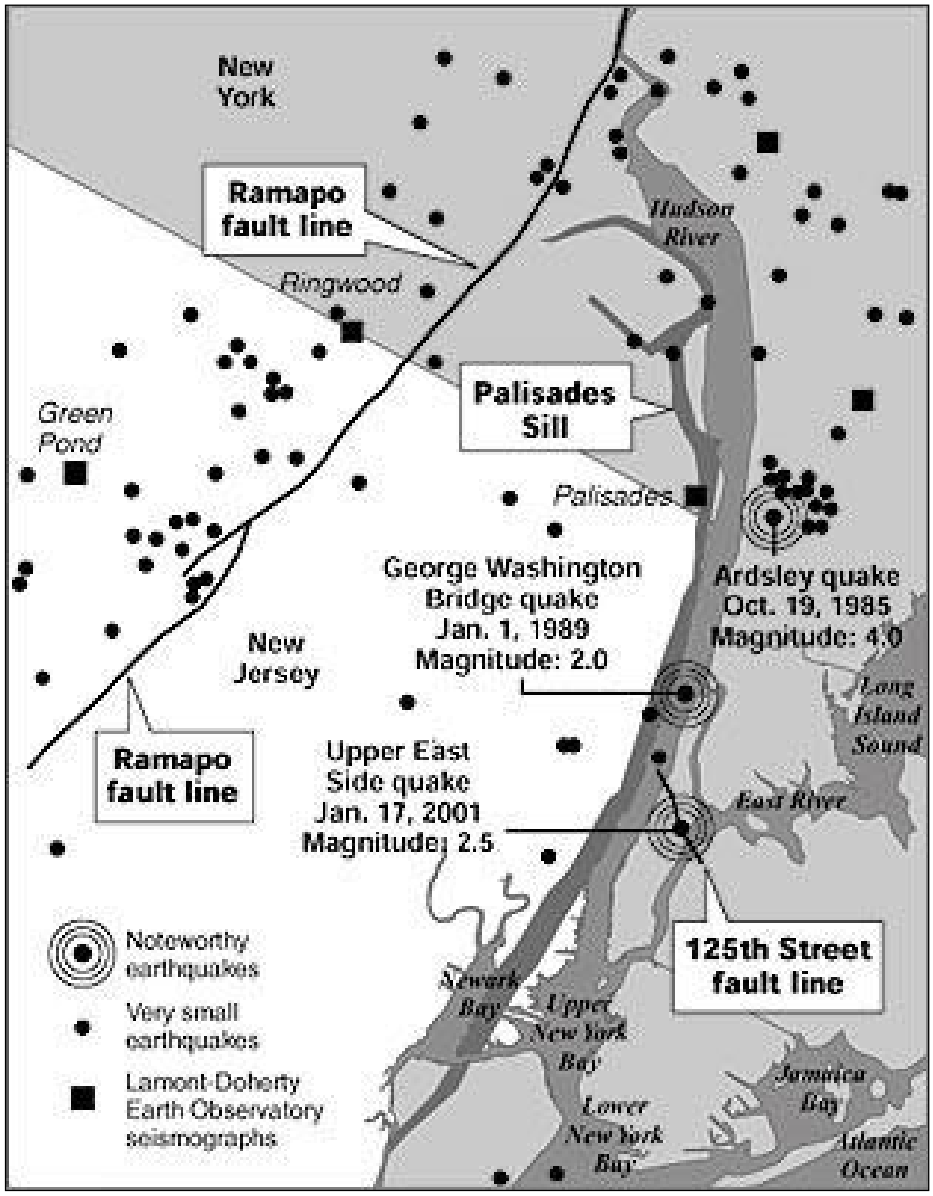
As noted in the NYS HMP, the importance of the earthquake hazard in New York State is often underestimated because other natural hazards (for example, hurricanes and floods) occur more frequently and because major floods and hurricanes have occurred more recently than a major earthquake event (NYS DHSES 2011). However, the potential for earthquakes exists across all of New York State and the entire northeastern U.S. The New York City Area Consortium for Earthquake Loss Mitigation (NYCEM) ranks New York State as having the third highest earthquake activity level east of the Mississippi River (Tantala et al., 2003).

There are three general regions in New York State that have a higher seismic risk compared to other parts of the State. These regions are: 1) the north and northeast third of the State, which includes the North Country/Adirondack region and a portion of the greater Albany-Saratoga region; 2) the southeast corner, which includes the greater New York City area and western Long Island; and 3) the northwest corner, which includes Buffalo and its surrounding area. Overall, these three regions are the most seismically active areas of the State, with the north-northeast portion having the higher seismic risk and the northwest corner of the State has the lower seismic risk (NYS DHSES 2014).

Fractures or fracture zones along with rocks on adjacent sides have broken and moved upward, downward, or horizontally are known as faults (Volkert and Witte 2015). Movement can take place at faults and cause an earthquake. There are numerous faults throughout New York State. Figure 5.4.3-7 illustrates the faults relative to Dutchess County (New York State Museum, 2012). According to this figure, there are numerous fault lines that run throughout and surrounding the County.

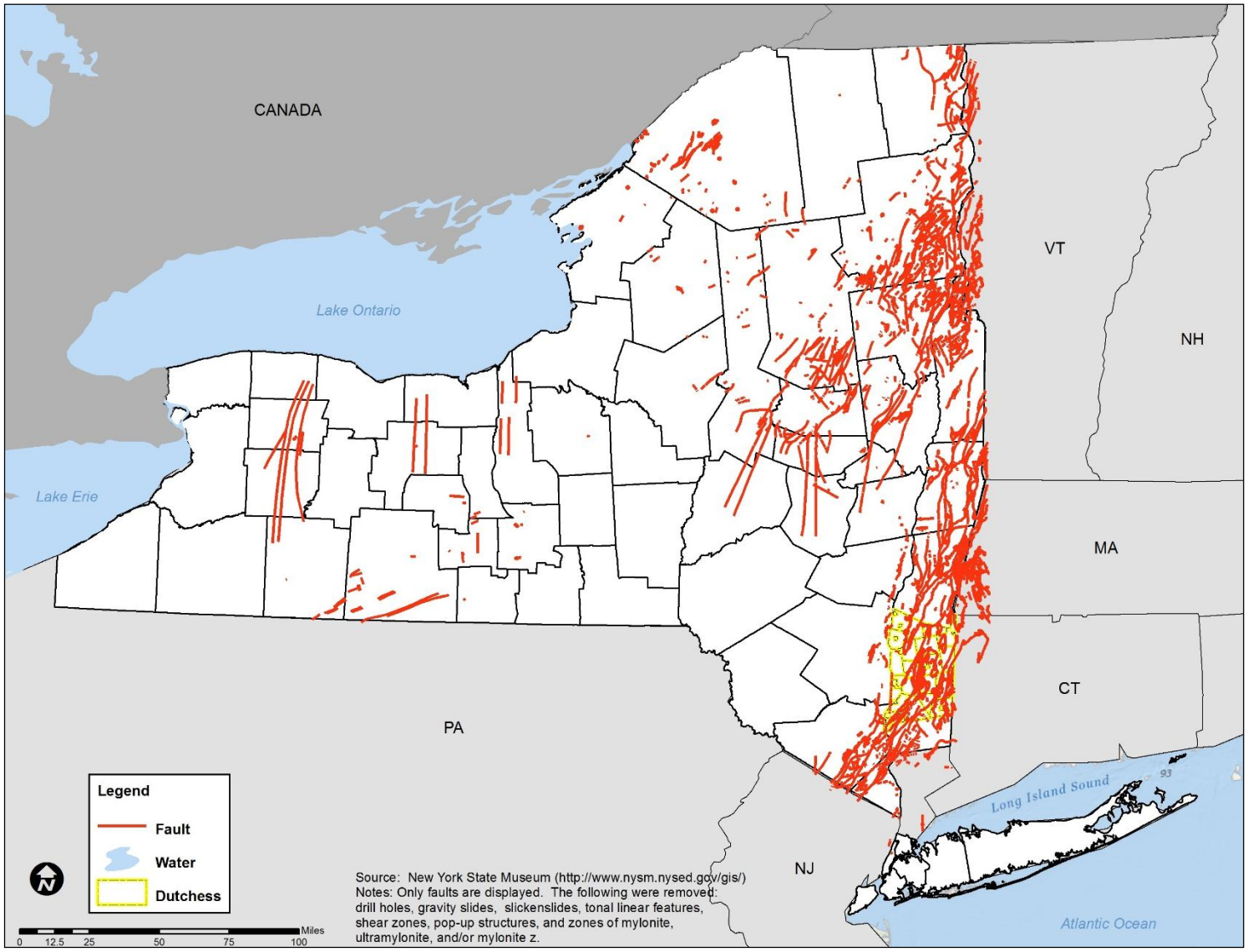
The Ramapo Seismic Zone is one of the major known fault features that runs from eastern Pennsylvania to the mid-Hudson Valley. Researchers from the Lamont-Doherty Earth Observatory found that this system contains numerous smaller faults that include the 125th Street Fault in Manhattan, the Dyckman Street Fault, the Mosholu Parkway fault, and the Dobbs Ferry fault. According to a study conducted by the Lamont-Doherty Earth Observatory, research has found evidence of an active seismic zone running at least 25 miles from Stamford, Connecticut to the Hudson Valley's Town of Peekskill (Westchester County), known as the Stamford-Peekskill line. Small clusters of earthquake events are found along the length of the line and to its immediate southwest. Just north of the line, there are no recorded earthquakes. The Stamford-Peekskill line runs parallel to the other faults beginning at 125th Street and researchers believe this fault is in the same family capable of producing at least a magnitude 6.0 earthquake. This fault also intersects the Ramapo seismic zone (Sykes et al., 2008). Figure 5.4.3-6 shows the location of the Ramapo and 125th Street fault lines and earthquakes that have occurred in the area.

Figure 5.4.3-6. Fault Lines in the New York City Area



Source: Groves 2001

Figure 5.4.3-7. Faults in Dutchess County

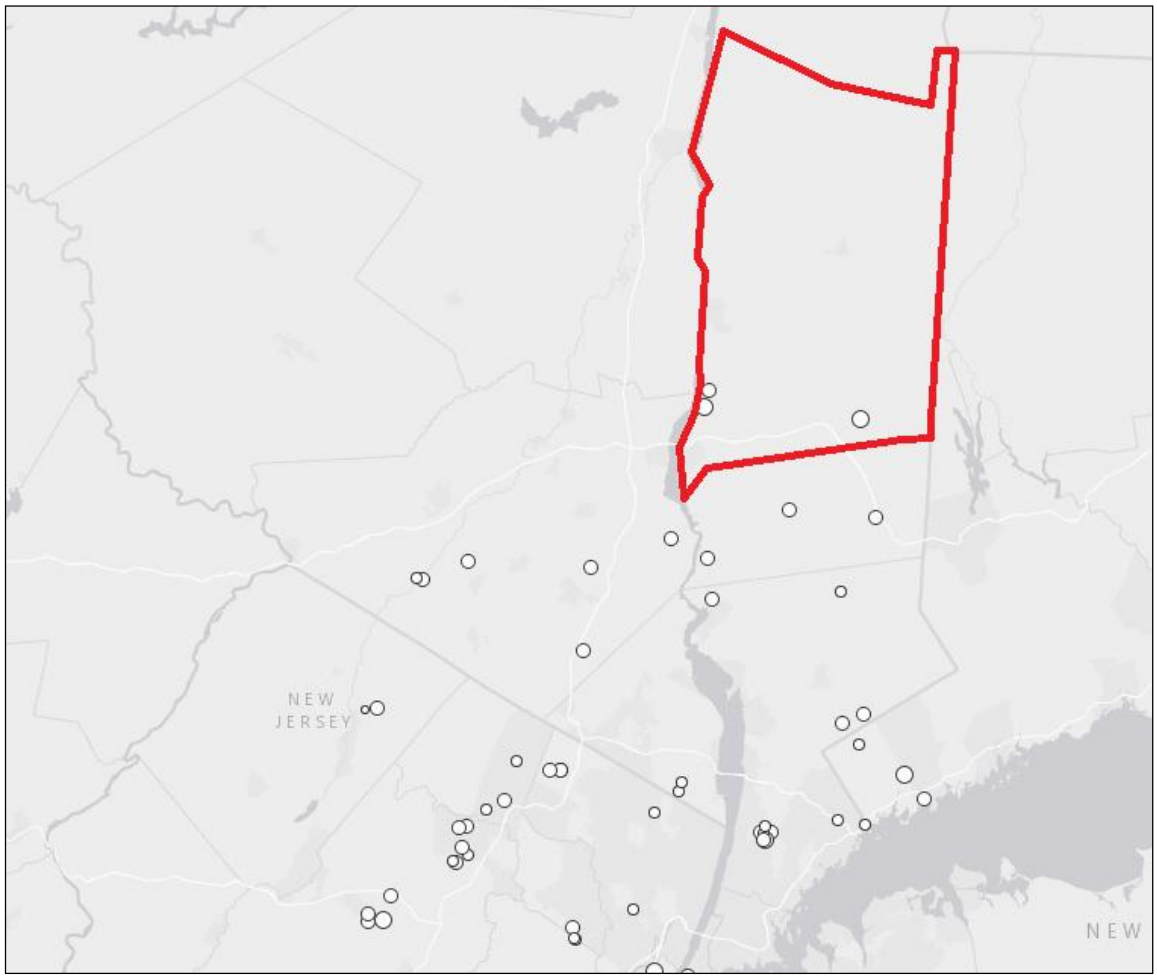


Source: New York State Museum 2012
Note: Dutchess County is outlined in yellow

The Lamont-Doherty Cooperative Seismographic Network (LCSN) monitors earthquakes that occur primarily in the northeastern United States. The goal of the project is to compile a complete earthquake catalog for this region, to assess the earthquake hazards, and to study the causes of the earthquakes in the region. The LCSN operates 52 seismographic stations in the following seven states: Connecticut, Delaware, Maryland, New Jersey, New York, Pennsylvania, and Vermont. There are no seismic stations in Dutchess County; however, there are several within the vicinity of the County (LCSN 2014). In addition to the Lamont-Doherty Seismic Stations, the USGS operates a global network of seismic stations to monitor seismic activity. While no seismic stations are located in New York State, nearby stations are positioned in State College, Pennsylvania and Oak Ridge, Massachusetts.

Figure 5.4.3-8 illustrates historic earthquake epicenters across the southeast New York State and northern New Jersey between 1950 and 2015. According to this figure, there are have been three earthquakes epicentered in Dutchess County (June 1974, October 1975, and February 1983). In addition to these earthquakes in Dutchess County, there have been numerous events originating outside of New York State that have been felt within the State. According to the NYS HMP, such events are considered significant for hazard mitigation planning because they could produce damage within the State in certain situations (NYS DHSES 2014). For details regarding these events, please refer to Table 5.4.3-6.

Figure 5.4.3-8. Earthquake Epicenters in Dutchess County and the Surrounding Area, 1950 – 2015



Source: USGS 2015
Note: Dutchess County is outlined in red.

Previous Occurrences and Losses

Many sources provided historical information regarding previous occurrences and losses associated with earthquakes throughout New York State. Therefore, with so many sources reviewed for the purpose of this HMP, loss and impact information for many events could vary depending on the sources. According to the New York State 2014 HMP, between 1973 and 2012, 189 earthquakes were epicentered in New York State. Of those 189 earthquakes, six were reported in Dutchess County.

Between 1954 and 2015, New York State was included in one earthquake-related major disaster (DR) or emergency (EM) declaration. Generally, these disasters cover a wide region of the State; therefore, they may have impacted many counties. However, not all counties were included in the disaster declaration. Dutchess County was not included in any DRs or EMs (FEMA, 2014).

For this HMP, known earthquakes events that have impacted New York State and Dutchess County between 1990 and 2015 are identified in Table 5.4.3-6. Many sources were researched for historical information regarding earthquake events in Dutchess County; therefore, Table 5.4.3-6 may not include all earthquake events that have impacted the County.

Table 5.4.3-6. Earthquake Events Impacting Dutchess County, 1990 to 2015

Dates of Event	Event Type	Location	FEMA Declaration Number	County Designated?	Losses / Impacts
April 12, 1991	Earthquake 2.0-2.7	2.2 miles from North Castle, NY	N/A	N/A	Last just five seconds and caused no damage
January 15, 1992	Earthquake 2.5	0.64 miles from Tuxedo, NY	N/A	N/A	No reference and/or no damage reported.
August 22, 2000	Earthquake 2.5	Carmel, NY	N/A	N/A	The epicenter was located approximately 2.5 miles northeast of the Town of Carmel in Putnam County. This event was felt in the Town of Pawling in Dutchess County.
April 20, 2002	Earthquake 5.2	Au Sable Forks, NY	DR-1415	No	Some roads, bridges, chimneys and water lines damaged in Clinton and Essex Counties. Many buildings in the area had cracked walls and foundations, broken windows and small items knocked from shelves. Maximum intensity (VII) at Au Sable Forks. Felt from New Brunswick and Maine to Ohio and Michigan and from Ontario and Quebec to Maryland.
October 14, 2004	Earthquake 2.7	1.5 miles from Highlands, NY	N/A	N/A	No reference and/or no damage reported.
June 24, 2010	Earthquake	Ottawa, Canada	N/A	N/A	An earthquake centered north of Ottawa, Canada was felt in the Hudson Valley and elsewhere in New York State and across a wide swath of the northeast United States. In Dutchess County, people in the Town of Rhinebeck reported feeling the quake and the Town of East Fishkill police department responded to a report of a building that was evacuated.
August 23, 2011	Earthquake 5.8	Mineral, Virginia	DR-4044 (Washington D.C.) DR-4022 (Virginia)	No	A 5.8 earthquake occurred during the afternoon of August 23rd when a fault near Mineral, VA ruptured. It damaged older buildings, shut down much of Washington D.C. and impacted people from New England to the Carolinas. Many buildings in Virginia and Washington D.C. were damaged as a result of this event. Tremors from this earthquake were felt throughout Dutchess County, causing little damage and only minor impacts on residents.
June 23, 2013	Earthquake 2.1	Greater New York Area	N/A	N/A	No reference and/or no damage reported.
May 12, 2014	Earthquake 1.7	Heritage Hills, NY	N/A	N/A	No reference and/or no damage reported.
July 5, 2014	Earthquake 2.5	5.2 miles south of Peekskill	N/A	N/A	No reference and/or no damage reported.

Source(s): *NYS DHSES, 2014; USGS, 2014; FEMA 2015*
DR *Major Disaster Declaration (FEMA)*
FEMA *Federal Emergency Management Agency*
N/A *Not Applicable*
NY *New York*
USGS *U.S. Geological Survey*

Probability of Future Events

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), Dutchess County had a PGA of 3-5%g for earthquakes with a 10-percent probability of occurring within 50 years.

The NYSDPC indicates that the earthquake hazard in New York State is often understated because other natural hazards occur more frequently (for example: hurricanes, tornadoes and flooding) and are much more visible. However, the potential for earthquakes does exist across the entire northeastern U.S., and New York State is no exception (NYS DHSES 2014).

Earlier in this section, the identified hazards of concern for Dutchess County were ranked. NYS DHSES conducts a similar ranking process for hazards that affect the State. 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' (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 ignite fires and cause utility failure.

Impact of Climate Change

The impacts of global climate change on earthquake probability are unknown. Some scientists say 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. NASA and USGS scientists found that retreating glaciers in southern Alaska may be opening the way for future earthquakes (NASA 2004).

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

5.4.3.2 Vulnerability Assessment

To understand risk, a community must evaluate what assets are exposed or vulnerable in the identified hazard area. For the earthquake hazard, the entire County has been identified as exposed. Therefore, all assets in Dutchess County (population, structures, critical facilities and lifelines), as described in the County Profile (Section 4), are potentially vulnerable. The following section includes an evaluation and estimation of the potential impact of the earthquake hazard on Dutchess County including the following:

- Overview of vulnerability
- Data and methodology used for the evaluation
- Impact on: (1) life, health and safety of residents, (2) general building stock, (3) critical facilities, (4) economy, and (5) future growth and development
- Change of vulnerability as compared to that presented in the 2006 Dutchess County Hazard Mitigation Plan and 2010 Eastern Dutchess All-Hazard Mitigation Plan
- Effect of climate change on vulnerability
- Further data collections that will assist understanding this hazard over time

Overview of Vulnerability

Earthquakes usually occur without warning and can impact areas a great distance from their point of origin. The extent of damage depends on the density of population and building and infrastructure construction in the area shaken by the quake. Some areas may be more vulnerable than others based on soil type, the age of the buildings and building codes in place. Compounding the potential for damage – historically, Building Officials Code Administration (BOCA) used in the Northeast were developed to address local concerns including heavy snow loads and wind; seismic requirements for design criteria are not as stringent compared to the west coast's reliance on the more seismically-focused Uniform Building Code). As such, a smaller earthquake in the Northeast can cause more structural damage than if it occurred out west.

The entire population and general building stock inventory of the County is at risk of being damaged or experiencing losses due to impacts of an earthquake. Potential losses associated with the earth shaking were calculated for Dutchess County for three probabilistic earthquake events, the 100-year, 500- and 2,500-year mean return periods (MRP). The impacts on population, existing structures, critical facilities and the economy within Dutchess County are presented below, following a summary of the data and methodology used.

Data and Methodology

A probabilistic assessment was conducted for Dutchess County for the 100-, 500- and 2,500-year MRPs through a Level 2 analysis in HAZUS-MH 2.2 to analyze the earthquake hazard and provide a range of loss estimates for Dutchess County. The probabilistic method uses information from historic earthquakes and inferred faults, locations and magnitudes, and computes the probable ground shaking levels that may be experienced during a recurrence period by Census tract. According to the New York City Area Consortium for Earthquake Loss Mitigation (NYCEM), probabilistic estimates are best for urban planning, land use, zoning and seismic building code regulations (NYCEM, 2003). The default assumption is a magnitude 7 earthquake for all return periods. In addition, an annualized loss run was also conducted in HAZUS-MH 2.2 to estimate the annualized general building stock dollar losses for Dutchess County.

Ground shaking is the primary cause of earthquake damage to man-made structures and soft soils amplify ground shaking. One contributor to the site amplification is the velocity at which the rock or soil transmits shear waves (S-waves). The 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, 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.

As illustrated in Figure 5.4.3-5 earlier in this section, Dutchess County is made up primarily of very hard rock (A) and rock or firm ground (B; areas of dense soil/soft rock (C), stiff/soft soils (D), and soft soils (E) are located throughout the County and along the Hudson River. When unchanged, HAZUS-MH default soil types are class "D". However, for this analysis HAZUS-MH was updated with the specific NEHRP soil types for Dutchess County as provided by NYS DHSES.

In addition to the probabilistic scenarios mentioned, an annualized loss run was conducted in HAZUS 2.1 to estimate the annualized general building stock dollar losses for the County. The annualized loss methodology combines the estimated losses associated with ground shaking for eight return periods: 100, 250, 500, 750, 1000, 1500, 2000, 2500-year, which are based on values from the USGS seismic probabilistic curves. Annualized losses are useful for mitigation planning because they provide a baseline upon which to 1) compare the risk of one hazard across multiple jurisdictions and 2) compare the degree of risk of all hazards for each participating jurisdiction.

As noted in the HAZUS-MH Earthquake User Manual '*Uncertainties are inherent in any loss estimation methodology. They arise in part from incomplete scientific knowledge concerning earthquakes and their effects upon buildings and facilities. They also result from the approximations and simplifications that are necessary for comprehensive analyses. Incomplete or inaccurate inventories of the built environment, demographics and economic parameters add to the uncertainty. These factors can result in a range of uncertainly in loss estimates produced by the HAZUS Earthquake Model, possibly at best a factor of two or more*.' However, HAZUS' potential loss estimates are acceptable for the purposes of this HMP.

The occupancy classes available in HAZUS-MH 2.2 were condensed into the following categories (residential, commercial, industrial, agricultural, religious, government, and educational) to facilitate the analysis and the presentation of results. Residential loss estimates address both multi-family and single family dwellings. Impacts to critical facilities and utilities were also evaluated.

Data used to assess this hazard include data available in the HAZUS-MH 2.2 earthquake model, USGS data, data provided by NYS DHSES, professional knowledge, and information provided by the County's Planning Committee.

Impact on Life, Health and Safety

Overall, the entire population of Dutchess County is exposed to the earthquake hazard 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 Dutchess 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.

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 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 Dutchess County.

An exposure analysis was performed using the NEHRP soils data and the 2010 Census population data. The sum of the population by Census Block within the NEHRP class "D" and "E" soil types were calculated and

summarized in Table 5.4.3-7 below. Overall, approximately 22.4-percent of the County's population is located on NEHRP class "D" and "E" soils.

Table 5.4.3-7. Approximate Population within NEHRP 'D" and 'E' Soils

Municipality	Total Population (2010 Census)	Population NEHRP Class "D" and "E" Soils	
		Number	%
Amenia (T)	4,436	942	21.2%
Beacon (C)	15,541	1,400	9.0%
Beekman (T)	14,621	355	2.4%
Clinton (T)	4,312	779	18.1%
Dover (T)	8,699	3,558	40.9%
East Fishkill (T)	29,029	11,239	38.7%
Fishkill (T)	19,936	6,998	35.1%
Fishkill (V)	2,171	1,734	79.9%
Hyde Park (T)	21,571	4,924	22.8%
LaGrange (T)	15,730	2,154	13.7%
Milan (T)	2,370	77	3.2%
Millbrook (V)	1,452	10	<1%
Millerton (V)	958	31	3.2%
Northeast (T)	2,073	203	9.8%
Pawling (T)	6,116	402	6.6%
Pawling (V)	2,347	558	23.8%
Pine Plains (T)	2,473	1,219	49.3%
Pleasant Valley (T)	9,672	3,028	31.3%
Poughkeepsie (C)	32,736	2,742	8.4%
Poughkeepsie (T)	42,399	13,203	31.1%
Red Hook (T)	8,240	2,190	26.6%
Red Hook (V)	1,961	0	0.0%
Rhinebeck (T)	4,891	1,459	29.8%
Rhinebeck (V)	2,657	454	17.1%
Stanford (T)	3,823	257	6.7%
Tivoli (V)	1,118	1,052	94.1%
Union Vale (T)	4,877	16	<1%
Wappinger (T)	22,468	3,831	17.1%
Wappinger Falls (V)	5,522	1,489	27.0%
Washington (T)	3,289	334	10.2%
Dutchess County (TOTAL)	**297,488**	**66,638**	**22.4%**

Sources: NYS DHSES 2008; U.S. Census 2010

Residents may be displaced or require temporary to long-term sheltering due to an earthquake event. The number of people requiring shelter is generally less than the number displaced as some displaced persons use hotels or

stay with family or friends following a disaster event. Table 5.4.3-8 summarizes the households HAZUS-MH 2.2 estimates will be displaced and population that may require short-term sheltering as a result of the 100-, 500- and 2,500-year MRP earthquake events.

Table 5.4.3-8. Summary of Estimated Sheltering Needs for Dutchess County

Scenario	Displaced Households	Persons Seeking Short-Term Shelter
100-Year Earthquake	1	0
500-Year Earthquake	20	12
2,500-Year Earthquake	197	121

Source: HAZUS-MH 2.2

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 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 5.4.3-9 and Table 5.4.3-10 summarize the County-wide injuries and casualties estimated for the 500- and 2,500-year MRP earthquake event.

Table 5.4.3-9. Estimated Number of Injuries and Casualties from the 500-Year MRP Earthquake Event.

Level of Severity	Time of Day		
	2:00 AM	2:00 PM	5:00 PM
Injuries	6	7	6
Hospitalization	1	1	1
Casualties	0	0	0

Source: HAZUS-MH 2.2

Table 5.4.3-10. Estimated Number of Injuries and Casualties from the 2,500-Year MRP Earthquake Event

Level of Severity	Time of Day		
	2:00 AM	2:00 PM	5:00 PM
Injuries	46	65	47
Hospitalization	8	11	9
Casualties	1	2	2

Source: HAZUS-MH 2.2

Impact on General Building Stock

After considering the population vulnerable to the earthquake hazard, the value of general building stock exposed to and damaged by 100-, 500- and 2,500-year MRP earthquake events was evaluated. In addition, annualized losses were calculated using HAZUS-MH 2.2. The entire County's general building stock is considered at risk and exposed to this hazard.

As stated earlier, soft soils (NEHRP soil classed D and E) can amplify ground shaking to damaging levels even in a moderate earthquake (NYCEM, 2003). Therefore, buildings located on NEHRP soil classes D and E have an increased risk of damages from an earthquake. Table 5.4.3-11 summarizes the number and value of buildings in Dutchess County on the approximately located NEHRP soils classed D and E.

Table 5.4.3-11. Number and Improvement Value of Buildings within NEHRP 'D' and 'E' Soils

Municipality	Total Number of Buildings	Total Improvement (Structure and Contents)	Buildings NEHRP Class "D" and "E" Soils		
			Number	Improvement	% of Total Improvement
Amenia (T)	2,691	$1,943,434,588	863	$478,138,730	24.6%
Beacon (C)	4,395	$3,343,631,632	486	$456,561,234	13.7%
Beekman (T)	5,075	$3,824,624,378	474	$268,912,289	7.0%
Clinton (T)	3,110	$2,069,522,881	590	$400,036,702	19.3%
Dover (T)	4,612	$2,781,316,617	1,702	$1,067,007,348	38.4%
East Fishkill (T)	11,772	$10,141,818,207	4,429	$4,079,590,380	40.2%
Fishkill (T)	5,654	$6,611,883,715	1,590	$2,652,227,944	40.1%
Fishkill (V)	590	$684,424,401	432	$548,051,773	80.1%
Hyde Park (T)	8,593	$6,063,728,469	2,840	$1,826,920,017	30.1%
LaGrange (T)	6,802	$5,916,908,642	1,268	$1,280,257,372	21.6%
Milan (T)	2,086	$1,230,195,126	175	$98,326,272	8.0%
Millbrook (V)	752	$729,406,405	8	$5,563,315	<1%
Millerton (V)	510	$331,725,332	48	$51,699,296	15.6%
Northeast (T)	1,863	$1,427,398,702	300	$146,667,190	10.3%
Pawling (T)	3,403	$2,567,191,358	168	$208,871,863	8.1%
Pawling (V)	882	$776,997,342	296	$205,708,459	26.5%
Pine Plains (T)	1,935	$1,278,056,930	991	$690,203,491	54.0%
Pleasant Valley (T)	4,718	$3,111,800,909	1,469	$885,675,659	28.5%
Poughkeepsie (C)	7,829	$6,538,699,835	141	$222,670,942	3.4%
Poughkeepsie (T)	14,092	$15,283,939,811	4,730	$4,878,046,586	31.9%
Red Hook (T)	3,996	$3,159,628,647	1,065	$904,379,392	28.6%
Red Hook (V)	930	$774,900,418	0	$0	0.0%
Rhinebeck (T)	3,217	$2,464,483,474	1,111	$851,252,566	34.5%
Rhinebeck (V)	1,303	$1,157,909,263	152	$293,373,318	25.3%
Stanford (T)	3,192	$2,113,883,643	356	$248,675,938	11.8%
Tivoli (V)	488	$340,051,328	445	$297,007,352	87.3%

Table 5.4.3-11. Number and Improvement Value of Buildings within NEHRP 'D' and 'E' Soils

Municipality	Total Number of Buildings	Total Improvement (Structure and Contents)	Buildings NEHRP Class "D" and "E" Soils		
			Number	Improvement	% of Total Improvement
Union Vale (T)	2,509	$2,093,773,650	46	$34,763,171	1.7%
Wappinger (T)	7,899	$5,787,089,913	1,408	$995,757,771	17.2%
Wappinger Falls (V)	1,395	$1,153,456,878	389	$374,810,887	32.5%
Washington (T)	2,812	$2,223,473,555	295	$245,388,977	11.0%
Dutchess County (TOTAL)	**119,105**	**$97,925,356,049**	**28,267**	**$24,696,546,238**	**25.2%**

Sources: NYS DHSES 2008, Dutchess County
Note: RCV is the estimated replacement cost value of both structure and contents.

According to NYCEM, where earthquake risks and mitigation were evaluated in the New York, New Jersey and Connecticut region, most damage and loss caused by an earthquake is directly or indirectly the result of ground shaking (NYCEM, 2003). NYCEM indicates there is a strong correlation between PGA and the damage a building might experience. The HAZUS-MH model is based on the best available earthquake science and aligns with these statements. HAZUS-MH 2.2 methodology and model were used to analyze the earthquake hazard for the general building stock for Dutchess County. See Figure 5.4.3-1 through Figure 5.4.3-3 earlier in this profile which illustrate the geographic distribution of PGA (g) across the County for 100-, 500- and 2,500-year MRP events at the Census-Tract level.

In addition, according to NYCEM, 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 2.2 across the following damage categories (none, slight, moderate, extensive and complete). Table 5.4.3-12 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 5.4.3-12. 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-MH Technical Manual

Table 5.4.3-13 shows the estimated buildings damaged by occupancy class for both the 100- and 500-year MRP earthquake events. Table 5.4.3-13 shows the estimated buildings damaged by occupancy class for the 2,500-year MRP earthquake event.

Table 5.4.3-15 and Table 5.4.3-16 summarize the damage estimated for the 100-, 500- and 2,500-year MRP earthquake events by Census Tract. Damage loss estimates include structural and non-structural damage to the building and loss of contents.

Table 5.4.3-13. Estimated Buildings Damaged by General Occupancy for 500-year and 2,500-year MRP Earthquake Events

Category	Average Damage State									
	100-Year MRP					500-Year MRP				
	None	Slight	Moderate	Extensive	Complete	None	Slight	Moderate	Extensive	Complete
Residential	106,508 (89.4%)	49 (<1%)	12 (<1%)	1 (<1%)	0 (0%)	105,244 (88.4%)	1,028 (<1%)	269 (<1%)	28 (<1%)	2 (<1%)
Commercial	6,373 (5.4%)	6 (<1%)	1 (<1%)	0 (0%)	0 (0%)	6,242 (5.2%)	99 (<1%)	32 (<1%)	4 (<1%)	0 (0%)
Industrial	1,018 (<1%)	1 (<1%)	0 (0%)	0 (0%)	0 (0%)	1,001 (1%)	13 (<1%)	4 (<1%)	0 (0%)	0 (0%)
Agriculture, Education, Government, Religion	5,123 (4.3%)	9 (<1%)	2 (<1%)	0 (0%)	0 (0%)	4,996 (4.2%)	105 (<1%)	32 (<1%)	4 (<1%)	0 (0%)

Source: HAZUS-MH 2.2

Table 5.4.3-14. Estimated Buildings Damaged by General Occupancy for 2,500-year MRP Earthquake Events

Category	Average Damage State				
	2,500-Year MRP				
	None	Slight	Moderate	Extensive	Complete
Residential	99,193 (83.3%)	5,389 (4.5%)	1,662 (1.4%)	290 (<1%)	38 (<1%)
Commercial	5,703 (4.8%)	398 (<1%)	217 (<1%)	51 (<1%)	7 (<1%)
Industrial	924 (<1%)	57 (<1%)	30 (<1%)	7 (<1%)	1 (<1%)
Agriculture, Education, Government, Religion	4,469 (3.8%)	387 (<1%)	215 (<1%)	55 (<1%)	9 (<1%)

Source: HAZUS-MH 2.2

Table 5.4.3-15. Estimated Value (Building and Contents) Damaged by the 100-, 500- and 2,500-Year MRP Earthquake Events

Municipality	Total Improvement (Structure and Contents)	Estimated Total Damages*				Percent of Total Building and Contents **			
		Annualized Loss	100-Year	500-Year	2,500-Year	Annualized Loss	100-Year	500-Year	2,500-Year
Amenia (T)	$1,938,712,077	$3,420	$0	$299,973	$3,641,799	<1%	0.0%	<1%	<1%
Beacon (C)	$3,126,284,913	$8,786	$0	$548,558	$9,676,174	<1%	0.0%	<1%	<1%
Beacon (C) - Fishkill (T)	$290,847,953	$783	$0	$48,898	$861,564	<1%	0.0%	<1%	<1%
Beekman (T)	$3,789,188,263	$8,895	$0	$626,970	$9,259,122	<1%	0.0%	<1%	<1%
Clinton (T)	$2,069,631,650	$3,640	$0	$317,692	$3,891,971	<1%	0.0%	<1%	<1%
Dover (T)	$2,776,724,976	$54,097	$228,154	$4,174,329	$39,020,695	<1%	<1%	<1%	1.41%
East Fishkill (T)	$10,135,465,873	$32,971	$0	$2,303,227	$34,390,715	<1%	0.0%	<1%	<1%
Fishkill (T)	$6,552,225,114	$16,145	$0	$1,009,672	$18,488,924	<1%	0.0%	<1%	<1%
Fishkill (V)	$680,784,082	$34,383	$105,916	$2,327,547	$25,179,691	<1%	<1%	<1%	3.70%
Hyde Park (T)	$6,069,736,771	$9,367	$0	$776,370	$10,232,882	<1%	0.0%	<1%	<1%
LaGrange (T)	$5,917,967,673	$38,802	$121,437	$3,110,554	$32,773,487	<1%	<1%	<1%	<1%
Milan (T)	$1,229,588,532	$2,030	$0	$188,138	$2,128,185	<1%	0.0%	<1%	<1%
Millbrook (V)	$724,739,657	$1,366	$0	$118,607	$1,465,348	<1%	0.0%	<1%	<1%
North East (T) - Millerton (V)	$1,758,581,131	$2,247	$0	$204,887	$2,362,784	<1%	0.0%	<1%	<1%
Pawling (T)	$2,565,986,679	$6,095	$0	$428,365	$6,371,403	<1%	0.0%	<1%	<1%
Pawling (V)	$779,227,564	$1,964	$0	$133,969	$2,080,739	<1%	0.0%	<1%	<1%
Pine Plains (T)	$1,278,056,930	$2,155	$0	$197,961	$2,260,785	<1%	0.0%	<1%	<1%
Pleasant Valley (T)	$3,106,404,238	$5,585	$0	$465,247	$6,070,946	<1%	0.0%	<1%	<1%
Poughkeepsie (C)	$6,540,841,340	$48,243	$113,044	$3,404,496	$38,363,066	<1%	<1%	<1%	<1%
Poughkeepsie (T)	$15,277,830,620	$42,562	$0	$3,164,546	$43,866,906	<1%	0.0%	<1%	<1%
Red Hook (T)	$2,520,449,166	$4,216	$0	$391,251	$4,409,713	<1%	0.0%	<1%	<1%
Red Hook (T) - Tivoli (V)	$959,944,586	$30,751	$163,388	$2,473,931	$20,072,096	<1%	<1%	<1%	2.09%
Red Hook (V)	$795,887,628	$1,377	$0	$126,975	$1,448,936	<1%	0.0%	<1%	<1%
Rhinebeck (T)	$2,456,364,047	$3,112	$0	$272,722	$3,333,031	<1%	0.0%	<1%	<1%
Rhinebeck (V)	$1,165,958,887	$2,004	$0	$177,691	$2,135,851	<1%	0.0%	<1%	<1%

Table 5.4.3-15. Estimated Value (Building and Contents) Damaged by the 100-, 500- and 2,500-Year MRP Earthquake Events

Municipality	Total Improvement (Structure and Contents)	Estimated Total Damages*				Percent of Total Building and Contents **			
		Annualized Loss	100-Year	500-Year	2,500-Year	Annualized Loss	100-Year	500-Year	2,500-Year
Stanford (T)	$2,115,093,577	$2,627	$0	$232,135	$2,800,189	<1%	0.0%	<1%	<1%
Union Vale (T)	$2,127,321,202	$3,330	$0	$250,440	$3,757,008	<1%	0.0%	<1%	<1%
Wappinger (T)	$5,821,139,630	$14,138	$0	$973,318	$15,062,098	<1%	0.0%	<1%	<1%
Wappinger Falls (V)	$1,114,875,997	$2,812	$0	$188,883	$3,002,141	<1%	0.0%	<1%	<1%
Washington (T)	$2,243,175,472	$67,296	$344,235	$5,691,362	$48,048,430	<1%	<1%	<1%	2.14%
Dutchess County (TOTAL)	**$97,925,356,049**	**$455,197**	**$1,076,173**	**$34,628,712**	**$396,456,675**	**<1%**	**<1%**	**<1%**	**<1%**

Source: HAZUS-MH 2.2

**Total Damages is sum of damages for all occupancy classes (residential, commercial, industrial, agricultural, educational, religious, and government).*

Table 5.4.3-16. Estimated Value (Building and Contents) Damaged by the 100-, 500-, and 2,500-Year MRP Earthquake Events (Continued)

Municipality	Total Improvement (Building and Contents)	Estimated Residential Damage			Estimated Commercial Damage		
		100-Year	500-Year	2,500-Year	100-Year	500-Year	2,500-Year
Amenia (T)	$1,938,712,077	$0	$193,121	$2,230,457	$0	$52,337	$720,916
Beacon (C)	$3,126,284,913	$0	$384,923	$6,331,446	$0	$87,253	$1,760,777
Beacon (C) - Fishkill (T)	$290,847,953	$0	$38,426	$626,578	$0	$0	$0
Beekman (T)	$3,789,188,263	$0	$537,119	$7,689,300	$0	$40,200	$701,417
Clinton (T)	$2,069,631,650	$0	$282,780	$3,434,912	$0	$9,819	$133,546
Dover (T)	$2,776,724,976	$143,854	$2,487,719	$21,922,548	$43,077	$896,394	$9,238,656
East Fishkill (T)	$10,135,465,873	$0	$1,905,050	$26,833,401	$0	$159,570	$2,388,807
Fishkill (T)	$6,552,225,114	$0	$605,826	$10,358,154	$0	$342,795	$6,816,656
Fishkill (V)	$680,784,082	$51,706	$1,104,982	$11,451,760	$45,491	$1,019,625	$11,502,228
Hyde Park (T)	$6,069,736,771	$0	$568,286	$7,416,303	$0	$84,381	$1,214,138
LaGrange (T)	$5,917,967,673	$95,697	$2,419,616	$24,858,853	$6,982	$255,265	$3,170,280
Milan (T)	$1,229,588,532	$0	$160,607	$1,797,314	$0	$5,804	$73,109
Millbrook (V)	$724,739,657	$0	$61,806	$765,624	$0	$16,520	$210,320

Table 5.4.3-16. Estimated Value (Building and Contents) Damaged by the 100-, 500-, and 2,500-Year MRP Earthquake Events (Continued)

Municipality	Total Improvement (Building and Contents)	Estimated Residential Damage			Estimated Commercial Damage		
		100-Year	500-Year	2,500-Year	100-Year	500-Year	2,500-Year
North East (T) - Millerton (V)	$1,758,581,131	$0	$127,251	$1,459,082	$0	$20,278	$235,169
Pawling (T)	$2,565,986,679	$0	$350,737	$5,079,797	$0	$46,363	$773,960
Pawling (V)	$779,227,564	$0	$78,000	$1,146,871	$0	$12,771	$202,137
Pine Plains (T)	$1,278,056,930	$0	$149,934	$1,675,307	$0	$24,255	$301,636
Pleasant Valley (T)	$3,106,404,238	$0	$379,400	$4,910,476	$0	$50,811	$692,173
Poughkeepsie (C)	$6,540,841,340	$37,969	$1,513,389	$17,148,194	$66,197	$1,500,603	$16,591,298
Poughkeepsie (T)	$15,277,830,620	$0	$1,647,717	$22,434,973	$0	$708,227	$9,910,161
Red Hook (T)	$2,520,449,166	$0	$313,456	$3,498,956	$0	$26,353	$314,272
Red Hook (T) - Tivoli (V)	$959,944,586	$89,253	$1,341,864	$9,828,846	$3,292	$56,155	$514,000
Red Hook (V)	$795,887,628	$0	$71,847	$813,937	$0	$22,653	$264,305
Rhinebeck (T)	$2,456,364,047	$0	$215,007	$2,603,941	$0	$30,096	$384,344
Rhinebeck (V)	$1,165,958,887	$0	$111,579	$1,290,652	$0	$49,231	$651,311
Stanford (T)	$2,115,093,577	$0	$194,984	$2,353,235	$0	$5,372	$66,241
Union Vale (T)	$2,127,321,202	$0	$187,684	$2,781,245	$0	$14,670	$256,868
Wappinger (T)	$5,821,139,630	$0	$764,624	$11,555,178	$0	$147,881	$2,423,772
Wappinger Falls (V)	$1,114,875,997	$0	$115,774	$1,720,119	$0	$46,821	$749,105
Washington (T)	$2,243,175,472	$244,927	$3,964,873	$31,252,743	$22,918	$410,893	$3,909,331
Dutchess County (TOTAL)	**$97,925,356,049**	**$663,406**	**$22,278,380**	**$247,270,200**	**$187,956**	**$6,143,394**	**$76,170,930**

Source: HAZUS-MH 2.2

HAZUS-MH estimated over $834 thousand in damages to the building stock as a result of the 100-year earthquake event. It is also estimated that there would be over $56 million in damages to buildings in the County as a result of a 500-year earthquake event. This includes structural damage, non-structural damage and loss of contents, representing less than one-percent of the total replacement value for general building stock in Dutchess County. For a 2,500-year MRP earthquake event, HAZUS-MH estimates over $729 million, nearly one-percent of the total general building stock replacement value. Residential and commercial buildings account for most of the damage for earthquake events.

Earthquakes can cause secondary hazard events such as fires. HAZUS-MH estimates there will be no ignitions anticipated as a result of the 100-, 500-, and 2,500-year MRP events.

Impact on Critical Facilities

After considering the general building stock exposed to, and damaged by, 100-, 500- and 2,500-year MRP earthquake events, critical facilities were evaluated. All critical facilities (essential facilities, transportation systems, lifeline utility systems, high-potential loss facilities and user-defined facilities) in Dutchess County are considered exposed and potentially vulnerable to the earthquake hazard. Refer to subsection "Critical Facilities" in Section 4 (County Profile) of this Plan for a complete inventory of critical facilities in the County.

To estimate critical facility exposure to the potential impacts of an earthquake an exposure analysis was performed using the NEHRP soils data to determine the critical facility's location in relation to these areas. The critical facilities and utilities in the areas were calculated and summarized in Table 5.4.3-17 below.

Table 5.4.3-17. Number of Critical Facilities Located in the NEHRP Soil Class D and E

Municipality	Facility Types																				
	Accommodation	Air	Dam	DPW	EOC	Fire/EMS	Gas Station	Government	Library	Medical	Police	Post Office	Potable Pump	Rail Facility	School	Senior	Potable Storage	Town Hall	Well	Wastewater Pump	Wastewater Treatment
Amenia (T)	0	1	1	2	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Beacon (C)	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Beekman (T)	2	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Clinton (T)	0	0	3	2	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0
Dover (T)	1	0	1	0	0	2	5	0	1	0	1	2	1	2	3	1	1	0	0	2	2
East Fishkill (T)	2	2	3	1	0	1	9	0	1	0	1	1	1	0	4	1	1	1	6	0	0
Fishkill (T)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Fishkill (V)	6	0	1	1	0	1	5	0	0	0	1	0	2	1	3	0	0	1	6	0	0
Hyde Park (T)	6	1	0	0	0	1	2	0	1	0	1	1	0	0	0	0	0	1	0	0	1
LaGrange (T)	1	0	0	1	0	5	2	1	1	0	1	1	3	0	4	0	1	0	0	0	0
Milan (T)	2	0	1	1	0	0	4	0	0	0	1	1	2	0	4	0	1	1	0	1	1
Millbrook (V)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Millerton (V)	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Northeast (T)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pawling (T)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Pawling (V)	0	0	0	0	0	0	1	0	1	0	1	1	0	1	0	1	0	2	0	2	0
Pine Plains (T)	1	0	1	1	0	1	1	0	1	0	1	1	1	0	3	0	0	0	1	0	0
Pleasant Valley (T)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Poughkeepsie (C)	1	0	2	0	0	2	3	0	0	0	0	1	0	0	2	0	0	1	0	0	0
Poughkeepsie (T)	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0

Table 5.4.3-17. Number of Critical Facilities Located in the NEHRP Soil Class D and E

Municipality	Facility Types																				
	Accommodation	Air	Dam	DPW	EOC	Fire/EMS	Gas Station	Government	Library	Medical	Police	Post Office	Potable Pump	Rail Facility	School	Senior	Potable Storage	Town Hall	Well	Wastewater Pump	Wastewater Treatment
Red Hook (T)	2	1	3	0	1	2	10	0	0	0	1	2	0	1	8	2	2	0	1	0	2
Red Hook (V)	0	0	4	0	0	0	0	0	0	0	0	1	3	0	1	1	0	0	1	0	1
Rhinebeck (T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhinebeck (V)	3	0	6	1	0	2	2	0	1	0	1	1	1	1	0	2	0	0	0	0	1
Stanford (T)	0	0	4	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	1	1
Tivoli (V)	0	0	2	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
Union Vale (T)	2	0	1	0	0	1	0	0	1	0	0	1	3	0	0	0	1	1	0	0	1
Wappinger (T)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wappinger Falls (V)	0	1	2	0	0	1	1	1	0	0	1	0	0	0	1	1	0	0	2	1	2
Washington (T)	0	0	1	0	0	1	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0
Dutchess County (TOTAL)	0	0	3	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Source: NYS DHSES, 2008, Dutchess County, NYSGIS
Note: DPW = Department of Public Works
EMS = Emergency Medical Services

HAZUS-MH 2.2 estimates the probability that critical facilities may sustain damage as a result of 100-, 500- and 2,500-year MRP earthquake events. Additionally, HAZUS-MH estimates percent functionality for each facility days after the event. Table 5.4.3-18 through Table 5.4.3-20 list the percent probability of critical facilities sustaining the damage category as defined by the column heading and percent functionality after the event for the 100-, 500- and 2,500-year MRP earthquake events.

Table 5.4.3-18. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities in for the 100-Year MRP Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Critical Facilities									
Medical	99-100	<1	0-1	<1	0	99-100	100	100	100
Police	96-100	<1	0-1	<1	0	96-100	99-100	100	100
Fire	99-100	0-1	<1	0	0	99-100	100	100	100
EOC	99.7	<1	<1	0	0	100	100	100	100
School	99-100	0-1	<1	0	0	99-100	100	100	100
Utilities									
Potable Water	99.7-100	<1	0	0	0	100	100	100	100
Wastewater	99.7-100	<1	0	0	0	100	100	100	100

Source: HAZUS-MH 2.2

Table 5.4.3-19. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities for the 500-Year MRP Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Critical Facilities									
Medical	89-99	1-7	0.3-3	<1	0	89-99	97-100	100	100
Police	81-99	0.7-12	0.2-6	0-1	<1	81-99	92-100	99-100	99-100
Fire	88-99	0.7-8	0.2-3	<1	0	88-99	96-100	99-100	100
EOC	95	3.7	1.2	<1	0	95	99	100	100
School	88-99	0.7-8	0.2-3	<1	0	88-9	96-100	99-100	100
Utilities									
Potable Water	94-100	0.2-5	0-2	0	0	97-100	100	100	100
Wastewater	94-100	0.2-5	0-2	0	0	95-100	100	100	100

Source: HAZUS-MH 2.2

Table 5.4.3-20. Estimated Damage and Loss of Functionality for Critical Facilities and Utilities for the 2,500-Year MRP Earthquake Event

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Critical Facilities									
Medical	65-92	6-19	2-12	0.3-3	<1	65-92	84-97	97-100	98-100
Police	54-93	5-23	2-17	0.2-6	0-2	54-93	75-98	93-100	96-100
Fire	56-93	5-23	2-16	0.2-5	<1	56-93	78-98	95-100	97-100
EOC	77.3	14	7.1	1.4	<1	77	91	98	99
School	54-93	5-23	2-17	0.2-5	<1	54-93	76-98	94-100	96-100

Name	Percent Probability of Sustaining Damage					Percent Functionality			
	None	Slight	Moderate	Extensive	Complete	Day 1	Day 7	Day 30	Day 90
Utilities									
Potable Water	46-98	2-20	0.4-27	0-5	0-1	66-99	93-100	97-100	99-100
Wastewater	46-98	2-20	0.4-27	0-5	0-1	57-99	91-100	95-100	99-100

Source: HAZUS-MH 2.2

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. A Level 2 HAZUS-MH analysis estimates the total economic loss associated with each earthquake scenario, which includes building- and lifeline-related losses (transportation and utility losses) based on the available inventory (facility [or GIS point] data only). Direct building losses are the estimated costs to repair or replace the damage caused to the building. This is reported in the "Impact on General Building Stock" subsection discussed earlier in this section. 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. Additionally, economic loss includes business interruption losses associated with the inability to operate a business due to the damage sustained during the earthquake as well as temporary living expenses for those displaced. These losses are discussed below.

For the 100-year event, HAZUS-MH 2.2 estimates $290 thousand in income loss (wage, rental, relocation and capital-related losses) and $1.1 million in capital stock losses (structural, non-structural, content and inventory losses. It is significant to note that for the 500-year event, HAZUS-MH 2.2 estimates the County will incur nearly $6.8 million in income losses (wage, rental, relocation and capital-related losses) in addition to the 500–year event structural, non-structural, content and inventory losses ($35 million).

For the 2,500-year event, HAZUS-MH 2.2 estimates the County will incur approximately $55.3 million in income losses, mainly to the residential and commercial occupancy classes associated with wage, rental, relocation and capital-related losses. In addition, the 2,500-year event structural, non-structural, content and inventory losses equate to greater than an estimated $399 million.

Roadway segments and railroad tracks may experience damage due to ground failure and regional transportation and distribution of these materials will be interrupted as a result of an earthquake event. Losses to the community that result from damages to lifelines can be much greater than the cost of repair (HAZUS-MH 2.2 Earthquake User Manual, 2012).

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 earthquake event. In terms of the transportation infrastructure, HAZUS-MH estimates $700 thousand in direct repair costs to highway bridges as a result of the 500- and $15 million in direct costs as a result of the 2,500-year event; HAZUS-MH estimates no long-term economic impacts as a result of the 100-year event.

HAZUS-MH 2.2 also estimates the volume of debris that may be generated as a result of an earthquake event to enable the study region to prepare and rapidly and efficiently manage debris removal and disposal. Debris estimates are divided into two categories: (1) reinforced concrete and steel that require special equipment to

break it up before it can be transported, and (2) brick, wood and other debris that can be loaded directly onto trucks with bulldozers (HAZUS-MH Earthquake User's Manual).

For the 100-year MRP event, HAZUS-MH 2.2 estimates less than 500 tons of brick and wood debris and less than 150 tons of concrete and steel debris will be generated. For the 500-year MRP event, HAZUS-MH 2.2 estimates greater than 12 thousand tons of debris will be generated. For the 2,500-year MRP event, HAZUS-MH 2.2 estimates approximately 90 thousand tons of debris will be generated.

Table 5.4.3-21. Estimated Debris Generated by the 500- and 2,500-year MRP Earthquake Events

Municipality	500-Year		2,500-Year	
	Brick/Wood (tons)	Concrete/Steel (tons)	Brick/Wood (tons)	Concrete/Steel (tons)
Amenia (T)	138	35	748	278
Beacon (C)	237	56	1,404	504
Beacon (C) - Fishkill (T)	18	4	107	38
Beekman (T)	233	50	1,351	420
Clinton (T)	127	26	701	204
Dover (T)	959	398	5,523	5,144
East Fishkill (T)	792	196	4,645	1,769
Fishkill (T)	433	114	2,762	1,072
Fishkill (V)	500	275	3,060	4,393
Hyde Park (T)	359	81	2,134	677
LaGrange (T)	740	211	3,898	2,188
Milan (T)	78	16	422	122
Millbrook (V)	57	14	305	111
North East (T) - Millerton (V)	96	26	541	204
Pawling (T)	159	34	917	289
Pawling (V)	62	16	355	137
Pine Plains (T)	85	19	461	152
Pleasant Valley (T)	203	44	1,163	356
Poughkeepsie (C)	783	320	4,371	4,036
Poughkeepsie (T)	1,184	364	6,628	3,132
Red Hook (T)	163	35	885	271
Red Hook (T) - Tivoli (V)	466	204	1,989	2,282
Red Hook (V)	60	15	321	116
Rhinebeck (T)	122	28	709	228
Rhinebeck (V)	82	20	444	158
Stanford (T)	101	21	581	167
Union Vale (T)	108	25	689	229
Wappinger (T)	424	91	2,508	788
Wappinger Falls (V)	91	22	518	192
Washington (T)	1,007	434	4,560	4,912
Dutchess County (TOTAL)	**9,864**	**3,192**	**54,700**	**34,570**

Source: HAZUS-MH 2.2

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.

New development located in areas with softer NEHRP soil classes may be more vulnerable to the earthquake hazard. Refer to Section 4, and Volume II Section 9 for potential new development and approximate NEHRP soil class areas in Dutchess County.

Change of Vulnerability

Dutchess County continues to be vulnerable to the earthquake hazard. The HAZUS-MH model was not used to estimate potential losses for the 2006 HMP and 2010 Eastern Dutchess AHMP. The best available data were used for the 2015 HMP update; probabilistic scenarios were evaluated using HAZUS-MH and updated building stock and critical facility inventories were developed and utilized.

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. 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.

Additional Data and Next Steps

A Level 2 HAZUS-MH earthquake analysis was conducted for Dutchess County using the default model data, with the exception of the updated building and critical facility inventories which included user-defined data, and NEHRP soil data. Additional data needed to further refine the County's vulnerability assessment include: (1) updated demographic data to update the default data in HAZUS-MH; and (2) soil liquefaction data. Additionally, the County can identify un-reinforced masonry critical facilities and privately-owned buildings (i.e., residences) using local knowledge and/or pictometry/orthophotos. These buildings may not withstand earthquakes of certain magnitudes and plans to provide emergency response/recovery efforts for these properties can be set in place. Further mitigation actions include training of County and municipal personnel to provide post-hazard event rapid visual damage assessments, increase of County and local debris management and logistic capabilities, and revised regulations to prevent additional construction of non-reinforced masonry buildings.