5.4.5 GEOLOGIC

2016 HMP UPDATE CHANGES

- The hazard profile has been significantly enhanced to include a detailed hazard description, location, extent, previous occurrences, probability of future occurrence, and potential change in climate and its impacts on the geological hazards is discussed. The geological hazards is now located in Section 5 of the plan update. It includes landslide, land subsidence and sinkholes, all of which were profiled separately in the 2011 HMP.
- New and updated figures from federal and state agencies are incorporated. U.S. 2010 Census data was incorporated, where appropriate.
- Previous occurrences were updated with events that occurred between 2008 and 2015.
- A vulnerability assessment was conducted for the geological hazards and it now directly follows the hazard profile.

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 geological hazards in Sussex County.

5.4.5.1 PROFILE

Hazard Description

Geologic hazards are any geological or hydrological processes that pose a threat to humans and natural properties. Every year, severe natural events destroy infrastructure and cause injuries and deaths. Geologic hazards may include volcanic eruptions and other geothermal related features, earthquakes, landslides and other slope failures, mudflows, sinkhole collapses, snow avalanches, flooding, glacial surges and outburst floods, tsunamis, and shoreline movements. For the purpose of this HMP update, only landslides and land subsidence/sinkholes will be discussed in this hazard profile.

Landslides

According to the U.S. Geological Survey (USGS), the term landslide includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Although gravity acting on an over steepened slope is the primary reason for a landslide, there are other contributing factors (NJGWS 2013). Among the contributing factors are: (1) erosion by rivers, glaciers, or ocean waves which create over-steepened slopes; (2) rock and soil slopes weakened through saturation by snowmelt or heavy rains; (3) earthquakes which create stresses making weak slopes fail; and (4) excess weight from rain/snow accumulation, rock/ore stockpiling, waste piles, or man-made structures. Scientists from the USGS also monitor stream flow, noting changes in sediment load in rivers and streams that may result from landslides. All of these types of landslides are considered aggregately in USGS landslide mapping.

In New Jersey, there are four main types of landslides: slumps, debris flows, rockfalls, and rockslides. Slumps are coherent masses that move downslope by rotational slip on surfaces that underlie and penetrate the landslide deposit (Briggs et al 1975). A debris flow, also known as a mudslide, is a form of rapid mass movement in which loose soil, rock, organic matter, air, and water mobilize as slurry that flows downslope. Debris flows are often caused by intense surface water from heavy precipitation or rapid snow melt. This precipitation loosens surface matter, thus triggering the slide. Rockfalls are common on roadway cuts and steep cliffs. These landslides are abrupt movements of geological material such as rocks and boulders. Rockfalls happen when these materials become detached. Rockslides are the movement of newly detached segments of bedrock sliding on bedrock, joint, or fault surfaces (Delano and Wilshusen 2001).

Landslides can cause several types of secondary effects, such as blocking access to roads, which can isolate residents and businesses and delay commercial, public, and private transportation. This could result in economic losses for businesses. Other potential problems resulting from landslides are power and communication failures. Vegetation or poles on slopes can be knocked over, resulting in possible losses to power and communication lines. Landslides also have the potential of destabilizing the foundation of structures, which may result in monetary loss for residents. They also can damage rivers or streams, potentially harming water quality, fisheries, and spawning habitat.

Subsidence/Sinkholes

Land subsidence can be defined as the sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion, owing to the subsurface movement of earth materials (USGS 2000). Subsidence often occurs through the loss of subsurface support in karst terrain, which may result from a number of natural- and human-caused occurrences. Karst describes a distinctive topography that indicates dissolution of underlying carbonate rocks (limestone and dolomite) by surface water or groundwater over time. The dissolution process causes surface depressions and the development of sinkholes, sinking stream, enlarged bedrock fractures, caves, and underground streams (New Jersey State HMP 2014).

Sinkholes, the type of subsidence most frequently seen in New Jersey, are a natural and common geologic feature in areas with underlying limestone, carbonate rock, salt beds, or other rocks that are soluble in water. Over periods of time, measured in thousands of years, the carbonate bedrock can be dissolved through acidic rain water moving in fractures or cracks in the bedrock. This creates larger openings in the rock through which water and overlying soil materials will travel. Over time the voids will enlarge until the roof over the void is unable to support the land above at which time it will collapse, forming a sinkhole. In this example the sinkhole occurs naturally, but in other cases the root causes of a sinkhole are anthropogenic. These anthropogenic causes can include changes to the water balance of an area such as: over-withdrawal of groundwater; diverting surface water from a large area and concentrating it in a single point; artificially creating ponds of surface water; and drilling new water wells. These actions can accelerate the natural processes of creation of soil voids, which can have a direct impact on sinkhole creation (New Jersey State HMP 2014).

The State's susceptibility to subsidence is also due in part to the number of abandoned mines throughout New Jersey. The mining industry in New Jersey dates back to the early 1600s when cooper was first mined by Dutch settlers along the Delaware River in Warren County. There are approximately 450 underground mines in New Jersey, all of which are now abandoned. Although mines have closed in New Jersey, continued development in the northern part of the State has been problematic because of the extensive mining there which has caused widespread subsidence. One problem is that the mapped locations of some of the abandoned mines are not accurate. Another issue is that many of the surface openings were improperly filled in, and roads and structures have been built adjacent to or on top of these former mine sites (USGS 2006; New Jersey State HMP 2014).

Both natural and man-made sinkholes can occur without warning. Slumping or falling fence posts, trees, or foundations, sudden formation of small ponds, wilting vegetation, discolored well water, and/or structural cracks in walls and floors, are all specific signs that a sinkhole is forming. Sinkholes can range in form from steep-walled holes, to bowl, or cone-shaped depressions. When sinkholes occur in developed areas they can cause severe property damage, disruption of utilities, damage to roadways, injury, and loss of life (New Jersey State HMP 2014).

Location

Landslides

The entire U.S. experiences landslides, with 36 states having moderate to highly severe landslide hazards. Expansion of urban and recreational developments into hillside areas exposes more people to the threat of landslides each year. According to the USGS, Sussex County has low landslide potential. For a figure displaying the landslide potential of the conterminous United States, please refer to http://pubs.usgs.gov/fs/2005/3156/2005-3156.pdf (USGS 2005). Other resources, specifically the National Landslide Hazard Program (NLHP), provide a more detailed level of susceptibility analysis for the State. Based off this data and as visualized in Figure 5.4.5-1, Sussex County primarily has a low landslide potential except along parts of its north/northwestern border, where it has a high susceptibility/moderate incidence rate. The Townships of Montague, Sandyston, and Walpack are the only jurisdictions within the county to be impacted by this analysis.

Although the data from NLHP provides a starting place for the county to investigate where its land is more vulnerable to landslides, historic landslide locations also indicate potential risk areas. New Jersey has an extensive history of landslides, and they can occur for a variety of reasons. Based off historic landslide locations, the areas most susceptible to landslides are the western and southwestern portions of the county. Figure 5.4.5-2 illustrates the historic landslide locations in Sussex County. According to the figure, landslides (particularly debris flows) have occurred throughout Sussex County with a large number occurring in Vernon.

Although the two figures appear to present contradictory information, the discrepancy in potential hazard areas and previous occurrences demonstrates that landslides can occur almost anywhere in the county. Many of the landslide incidents documented under Figure 5.4.5-2 are the result of Hurricane Irene and storm damage destabilizing roads and causing debris flows. This demonstrates how landslides can be an unexpected secondary hazard during another disaster event. More information on the Hurricane Irene-related landslides can be found later in this profile or in Appendix E.

Figure 5.4.5-1. Landslide Susceptibility in Sussex County

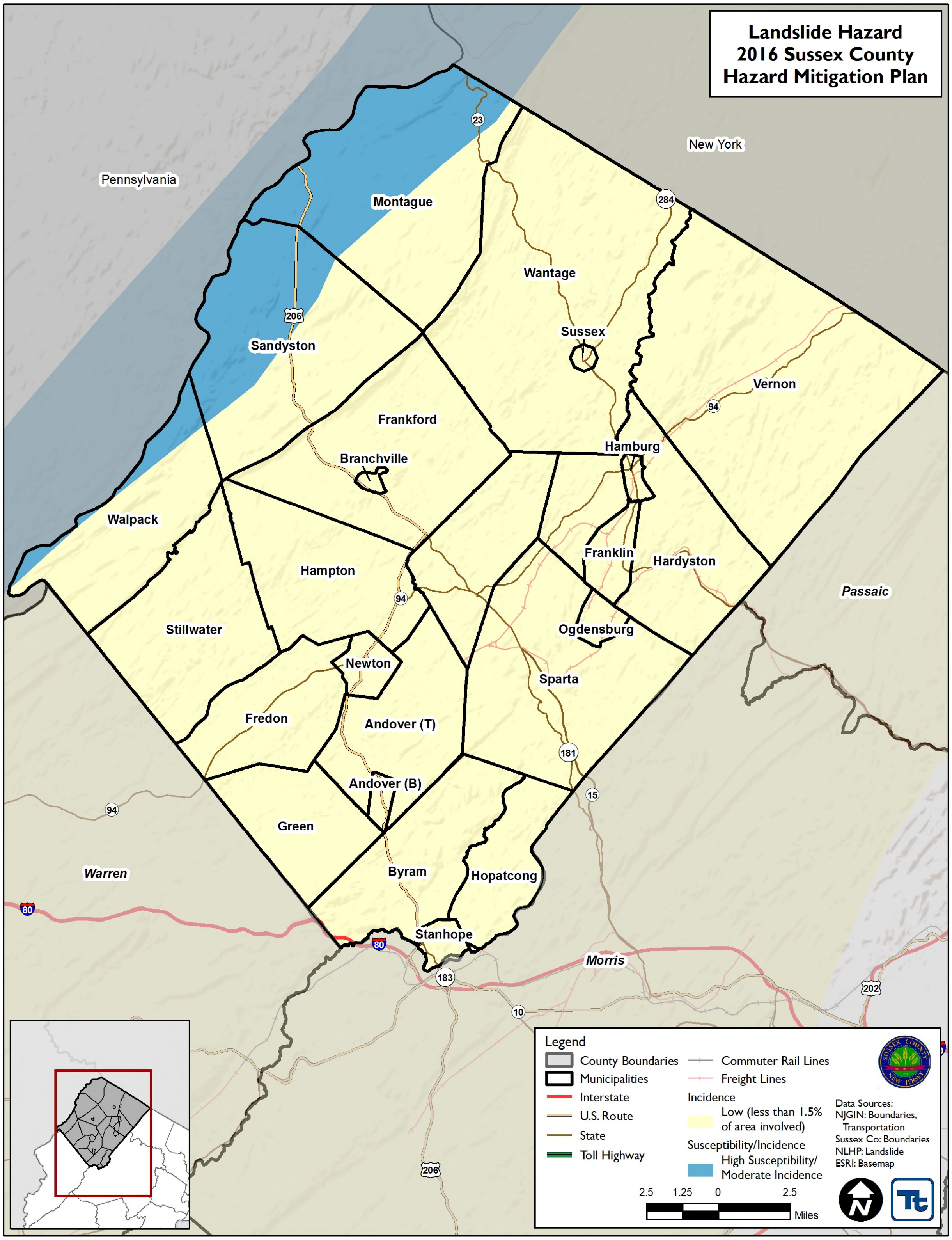
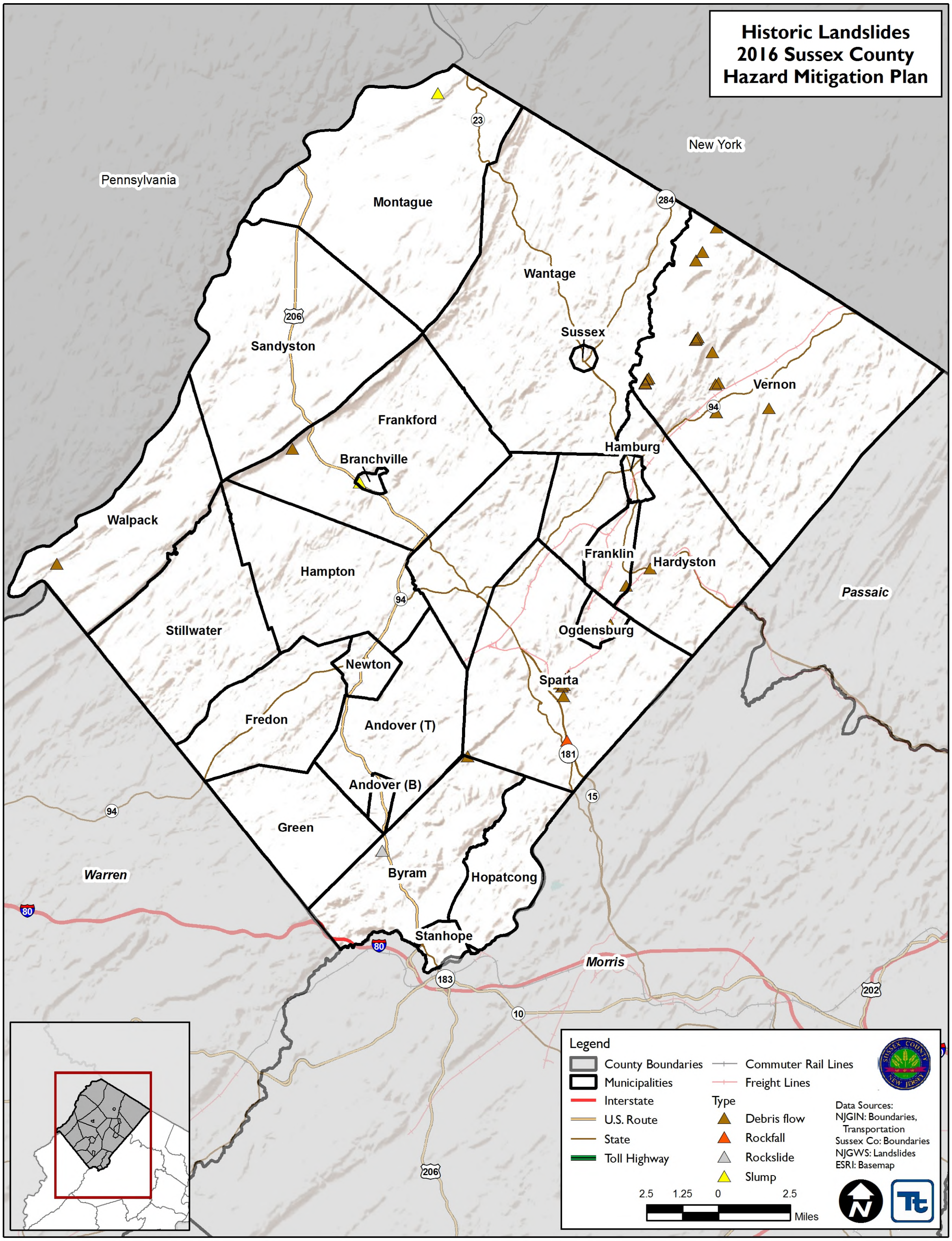


Figure 5.4.5-2. Historic Landslide Locations in Sussex County, 1869 to 2015



Source: NJGWS 2014
NJGWS New Jersey Geological Water Survey

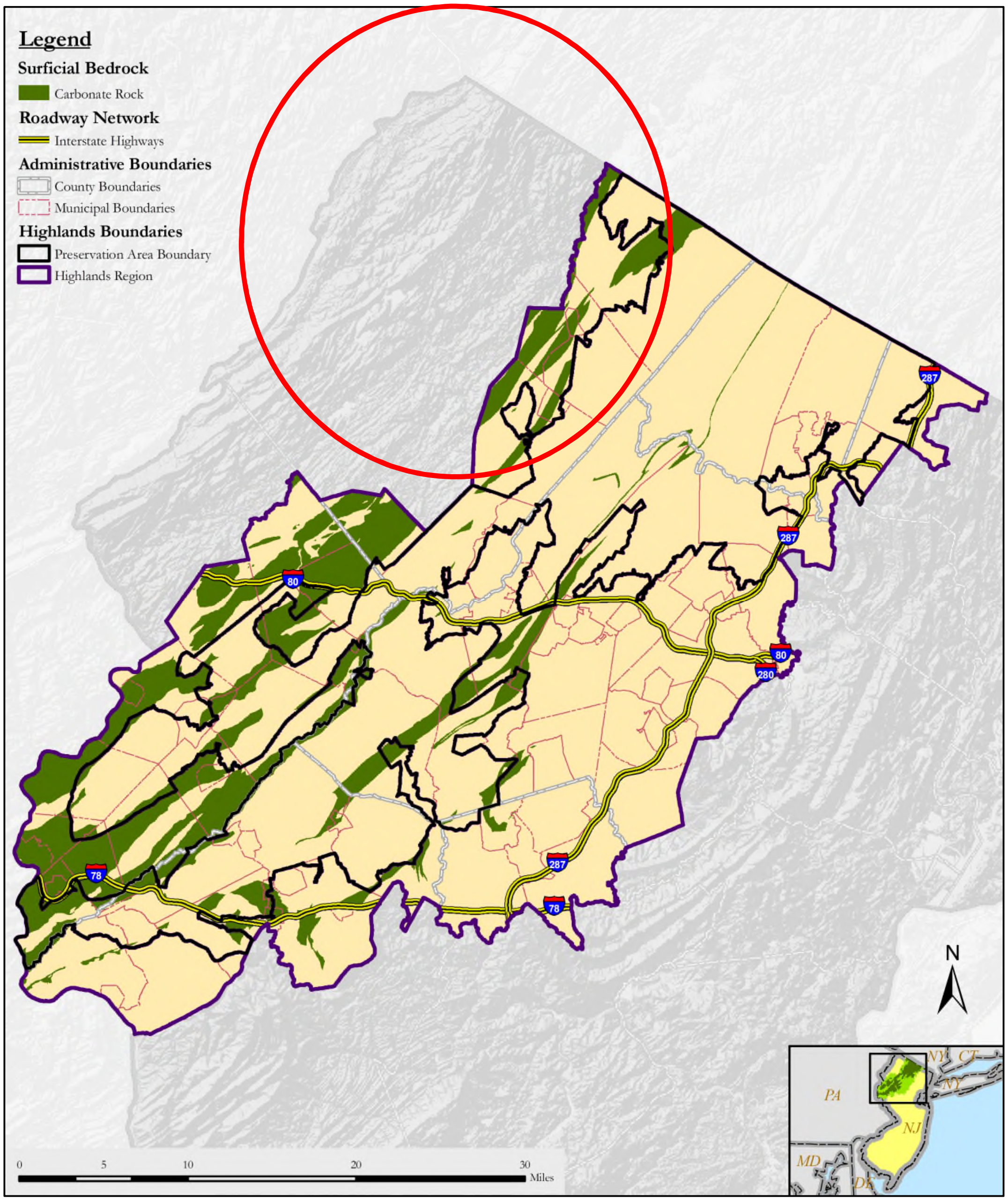
Subsidence/Sinkholes

New Jersey is susceptible to the effects of subsidence and sinkholes, primarily in the northern and northwestern section of the State, which includes Sussex County. Land subsidence and sinkholes have been known to occur as a result of natural geologic phenomenon or as a result of human alteration of surface and underground geology. The only spatial coverage for historic sinkholes in the State of New Jersey is in Sussex County; however, limiting analysis of past occurrences for other counties in the state.

Naturally occurring subsidence and sinkholes in New Jersey occur within bands of carbonate bedrock. In northern New Jersey, there are more than 225 square miles that are underlain by limestone, dolomite, and marble. In some areas, no sinkholes have appeared, while in others, sinkholes are common. In southern New Jersey, there are approximately 100 miles which are locally underlain by a lime sand with thin limestone layers. No collapse sinkholes have been identified; however, there are some features which could be either very shallow solution depressions or wind blowout features. Sussex County has numerous bands of carbonate rock running throughout most of the county; the only areas not containing notable bands of carbonate rock are along the southwestern border and part of the northern section of the county. Overall, approximately 24.9 percent (133.1 square miles) of the county has carbonate rock formation (NJGWS 2005; Godt 2001).

Substantial areas of the New Jersey Highlands are underlain by carbonate rocks, including portions of Sussex County (Figure 5.4.5-3). These rock formations, consisting primarily of limestone, dolomite, and marble, have unique characteristics that require responses to both the policy level and in specific technical guidance to municipalities. According to the NJDEP, 59 of the 88 municipalities within the Highlands region contain carbonate rocks, with eight of those municipalities located in Sussex County. As seen in Figure 5.4.5-3, the Highlands Region has several large areas of carbonate rock formations and karst features exist in some, but not all, of these areas (Highlands Regional Master Plan 2008).

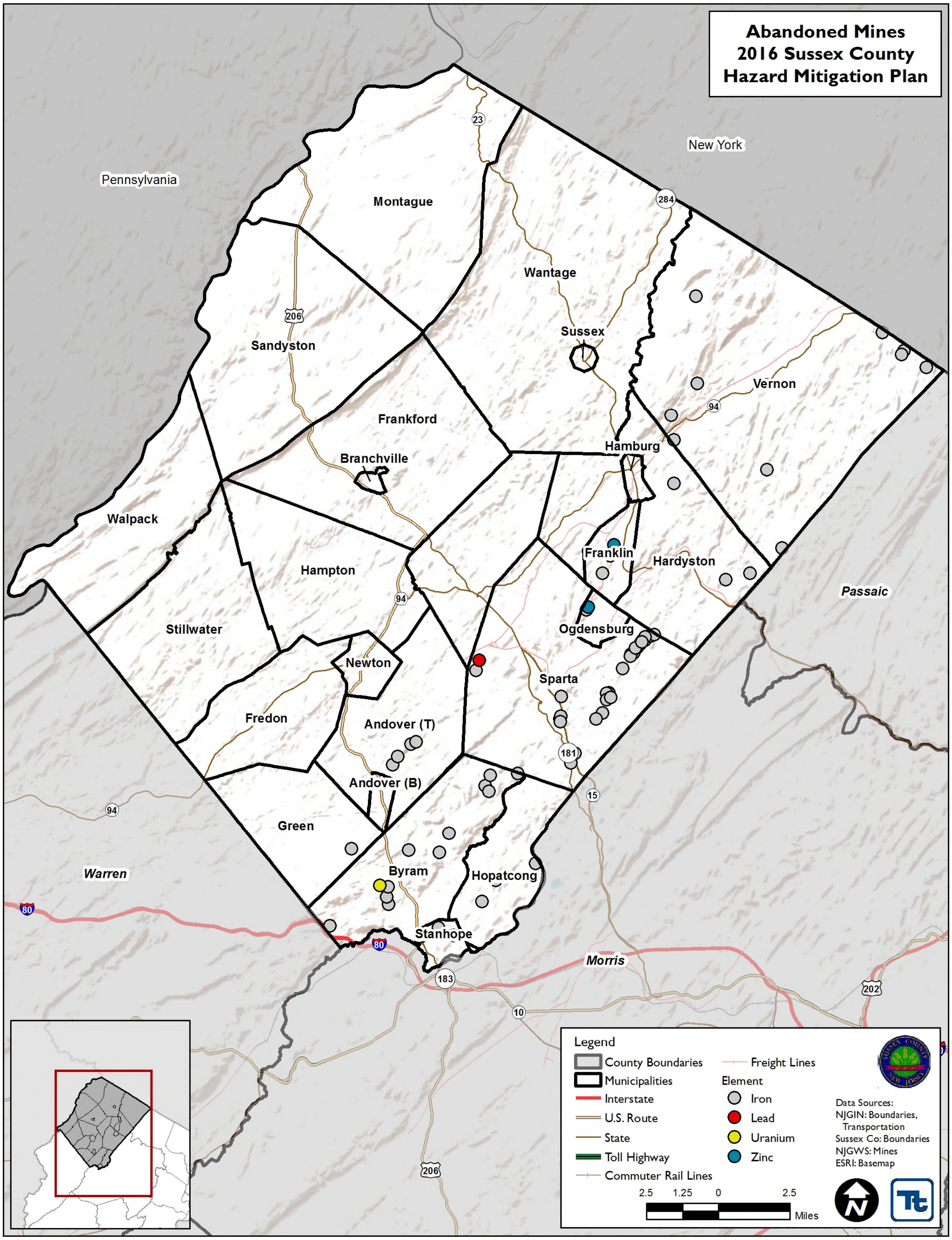
Figure 5.4.5-3. Carbonate Rock in the New Jersey Highlands



Source: New Jersey Highlands Council 2007
Note: The red circle indicates the approximate location of Sussex County.

As previously stated, abandoned mines are a source for sinkholes and subsidence in New Jersey. Mines create voids under the earth's surface, making areas above mines more susceptible to land subsidence. Sinkholes and subsidence occur from the collapse of the mine roof into a mine opening. Areas most vulnerable to sinkholes are those where mining occurred 20 to 30 feet below the surface. Figure 5.4.5-4 shows the location of the mapped abandoned mines in New Jersey. The data from NJGWS and the figure indicate that Sussex County has 75 abandoned mines, mainly iron mines with a few lead, zinc, and uranium mines. These mines are principally located in the eastern and southern portions of the county (NJGWS 2006).

Figure 5.4.5-4. Abandoned Mines in Sussex County



Source: NJGWS 2006

Extent

Landslide

To determine the extent of a landslide hazard, the affected areas need to be identified and the probability of the landslide occurring within some time period needs to be assessed. Natural variables that contribute to the overall extent of potential landslide activity in any particular area include soil properties, topographic position and slope, and historical incidence. Predicting a landslide is difficult, even under ideal conditions and with reliable information. As a result, the landslide hazard is often represented by landslide incidence and/or susceptibility, as defined below:

- Landslide incidence is the number of landslides that have occurred in a given geographic area. High incidence means greater than 15 percent of a given area has been involved in landsliding; medium incidence means that 1.5 to 15 percent of an area has been involved; and low incidence means that less than 1.5 percent of an area has been involved (State of Alabama Date Unknown).
- Landslide susceptibility is defined as the probable degree of response of geologic formations to natural or artificial cutting, to loading of slopes, or to unusually high precipitation. It can be assumed that unusually high precipitation or changes in existing conditions can initiate landslide movement in areas where rocks and soils have experienced numerous landslides in the past. Landslide susceptibility depends on slope angle and the geologic material underlying the slope. Landslide susceptibility only identifies areas potentially affected and does not imply a time frame when a landslide might occur. High, medium, and low susceptibility are delimited by the same percentages used for classifying the incidence of landsliding (State of Alabama Date Unknown).

Subsidence/Sinkhole

Landslide subsidence occurs slowly and continuously over time or abruptly for various reasons. Subsidence and sinkholes can occur due to either natural processes (karst sinkholes in areas underlain by soluble bedrock) or as a result of human activities. Subsidence in the U.S. has directly affected more than 17,000 square miles in 45 states, and associated annual costs are estimated to be approximately $125 million. The principal causes of subsidence are aquifer-system compaction, drainage of organic soils, underground mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost (Galloway et al. 2000). There are several methods used to measure land subsidence. Global Positioning System (GPS) is a method used to monitor subsidence on a regional scale. Benchmarks (geodetic stations) are commonly space around four miles apart (State of California 2009).

Another method which is becoming increasingly popular is Interferometric Synthetic Aperture Radar (InSAR). InSAR is a remote sensing technique that uses radar signals to interpolate land surface elevation changes. It is a cost-effective solution for measuring land surface deformation for a region while offering a high degree of spatial detail and resolution (State of California 2009).

Previous Occurrences and Losses

Numerous sources provided historical information regarding previous occurrences and losses associated with geological hazard events throughout Sussex County. According to the NJDEP, Sussex County has experienced 36 landslide events between 1782 and 2015; however, sinkhole/subsidence history could not be determined due to limited historical records. Many sources were reviewed for the purpose of this HMP and loss and impact information could vary depending on the source. Therefore, the accuracy of monetary figures, if any, is based only on the available information identified during research for this HMP.

Between 1954 and 2015, FEMA issued a disaster (DR) or emergency (EM) declaration for the State of New Jersey for one geological hazard-related event, classified as severe storms, flooding and mudslide. This declaration did include Sussex County (FEMA 2015). Sussex County is included in the FEMA disaster declaration for the remnants of Tropical Storm Lee in 2011. Although this disaster is due to severe storms and flooding, it resulted in secondary geological hazard impacts in certain locations in the State. Sussex County did not specifically note geologic incidents tied to this storm event; however, multiple landslides (debris flows) were recorded in late August 2011. Table 5.4.5-1 lists FEMA DR and EM declarations since 2008 for this HMP update.

Table 5.4.5-1. FEMA DR and EM Declarations Since 2008 for Geologic Events in Sussex County

FEMA Declaration Number	Date(s) of Event	Event Type	Location
DR-4039	September 28, 2011 - October 6, 2011	Remnants of Tropical Storm Lee	Six Counties in New Jersey including Sussex County

Source: FEMA 2015

The New Jersey State HMP also documents notable geologic incidents, including both landslides and sinkholes/subsidence. None of these narrative events occurred in Sussex County, although neighboring counties experienced several events.

Known geological hazard events that have impacted Sussex County between 2008 and 2015 are identified in Appendix E. Refer to the 2011 HMP for geological hazard events prior to 2008. With geological hazard documentation being so extensive, not all sources have been identified or researched. Therefore, Appendix E may not include all events that have occurred in Sussex County.

Probability of Future Occurrences

Based upon risk factors and past occurrences, it is likely that geological hazards will occur in Sussex County in the future. Landslide probabilities are largely a function of surface geology, but are also influenced by both weather and human activities. Because of the large number of landslides precipitated by Hurricane Irene in August 2011, landslide probability for Sussex County can be calculated in two ways. If each individual landslide during Hurricane Irene is considered a unique event, then based on NJGWS historic data, Sussex County can expect to experience 0.47 landslide events per year. In contrast, if all of the Hurricane Irene-related landslides are treated as a single event due to having the same cause, then Sussex County can expect to experience 0.2 landslide events per year. With these factors taken into consideration (and with treating landslides from Hurricane Irene as a single event), the county has experienced one landslide event every 1-2 years. Additionally, the county experiences sinkhole and subsidence events every 5-10 years. Specific analyses on the probability of future geologic hazard calculations can be seen in the following two tables, where the first table treats the landslides during Hurricane Irene each as unique events and the second table treats these landslides as one combined event.

There are presumably other smaller landslides and sinkholes that have occurred in the county that have not been reported to the NJGWS and are not included in these calculations. The county will continue to experience the direct and indirect impacts of geological hazards and its impacts on occasion, with the secondary effects causing potential disruption or damage to communities. The table below shows the probability of future geologic events impacting the county, as based on data from the previous occurrences table in Appendix E.

Table 5.4.5-2. Probability of Future Occurrence of Geologic Events, Calculation One

Hazard Type	Number of Occurrences Between 1950 and 2015	Rate of Occurrence	Recurrence Interval (in years)	Probability of event Occurring in Any Given Year	Percent Chance of Occurring in Any Given Year
Debris Flows	31	0.48	2.13	0.47	47.0%
Rockfalls	2	0.03	33.00	0.03	3.0%
Rockslide	1	0.02	66.00	0.02	1.5%
Slump	2	0.03	33.00	0.03	3.0%
Sinkhole	1	0.02	66.00	0.02	1.5%

Source: NJDEP 2012; NOAA-NCDC 2015; NJ.Com 2015; NJ State HMP 2011

Note: The calculations in this table are based off each landslide during Hurricane Irene being treated as unique events. The most notable differences in calculations for this table are for the debris flows.

Table 5.4.5-3. Probability of Future Occurrence of Geologic Events, Calculation Two

Hazard Type	Number of Occurrences Between 1950 and 2015	Rate of Occurrence	Recurrence Interval (in years)	Probability of event Occurring in Any Given Year	Percent Chance of Occurring in Any Given Year
Debris Flows	13	0.20	5.07	0.20	19.7%
Rockfalls	2	0.03	33.00	0.03	3.03%
Rockslide	1	0.02	66.00	0.02	1.52%
Slump	2	0.03	33.00	0.03	3.03%
Sinkhole	1	0.02	66.00	0.02	1.52%

Source: NJDEP 2012; NOAA-NCDC 2015; NJ.Com 2015; NJ State HMP 2011

Note: The calculations in this table are based off all the landslides during Hurricane Irene being treated as a single event. The most notable differences in calculations for this table are for the debris flows.

In Section 5.3, the identified hazards of concern for Sussex County were ranked. The probability of occurrence, or likelihood of the event, is one parameter used for hazard rankings. Based on historical records and input from the Planning Committee, the probability of occurrence for geological hazards in the county is considered 'frequent' (likely to occur within 25 years, as presented in Table 5.3-3).

Climate Change Impacts

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

Temperatures in the Northeast United States have increased 1.5 degrees Fahrenheit (°F) on average since 1900. Most of this warming has occurred since 1970. The State of New Jersey, for example, has observed an increase in average annual temperatures of 1.2°F between the period of 1971-2000 and the most recent decade of 2001-2010 (ONJSC, 2011). Winter temperatures across the Northeast have seen an increase in average temperature of 4°F since 1970 (Northeast Climate Impacts Assessment [NECIA] 2007). By the 2020s, the average annual temperature in New Jersey is projected to increase by 1.5°F to 3°F above the statewide baseline (1971 to 2000), which was 52.7°F. By 2050, the temperature is projected to increase 3°F to 5°F (Sustainable Jersey Climate Change Adaptation Task Force 2013). Both northern and southern New Jersey have become wetter over the past century. Northern New Jersey's 1971-2000 precipitation average was over 5" (12 percent) greater than the average from 1895-1970. Southern New Jersey became 2" (5 percent) wetter late in the 20th century (Office of New Jersey State Climatologist).

Landslides

Climate change may impact storm patterns, increasing the probability of more frequent, intense storms with varying duration. Increase in global temperature could affect the snowpack and its ability to hold and store water. Warming temperatures also could increase the occurrence and duration of droughts, which would increase the probability of wildfire, reducing the vegetation that helps to support steep slopes. All of these factors would increase the probability for landslide occurrences.

Subsidence/Sinkholes

Similar to landslides, climate change will affect subsidence and sinkholes in New Jersey. As discussed throughout this profile, one of the triggers for subsidence and sinkholes is an abundance of moisture which has the potential to permeate the bedrock causing an event. Climatologists expect an increase in annual precipitation amounts. This increase will coincide with an increased risk in subsidence and sinkholes in vulnerable areas.

More recently, sinkholes have been correlated to land use practices, especially from groundwater pumping and from construction and development practices. Sinkholes may also form when the land surface is changed, such as when industrial and runoff-storage ponds are created. The substantial weight of the new material can trigger an underground collapse of supporting material, thus causing a sinkhole. Additionally, the overburden sediments that cover buried cavities in the aquifer systems are delicately balanced by groundwater fluid pressure. Groundwater is helping keep the surface soil in place. Pumping groundwater for urban water supply and for irrigation can produce new sinkholes in sinkhole-prone areas. If pumping results in a lowering of groundwater levels, then underground structural failure, sinkholes may occur as well (USGS 2014).

5.4.5.2 VULNERABILITY ASSESSMENT

To understand risk, a community must evaluate what assets are exposed or vulnerable to the identified hazard. For geologic hazards, the known landslide and subsidence/sinkhole vulnerable areas as identified by the New Jersey Geologic and Water Survey have been identified as the hazard area. The following text evaluates and estimates the potential impact of geologic hazards on the county including:

- 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 environment, and (5) future growth and development
- Effect of climate change on vulnerability
- Change of vulnerability as compared to that presented in the 2011 Sussex County HMP
- Further data collections that will assist understanding this hazard over time

Overview of Vulnerability

Vulnerability to ground failure hazards is a function of location, soil type, geology, type of human activity, use, and frequency of events. The effects of ground failure on people and structures can be lessened by total avoidance of hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Local governments can reduce ground failure effects by educating themselves on past hazard history of the site and by making inquiries to planning and engineering departments of local governments (National Atlas, 2007).

To determine vulnerability, a spatial analysis was conducted in GIS using the landslide susceptibility and geological hazard datasets discussed below. When the analysis determined the hazard area may potentially impact the area in a jurisdiction, or the location of critical facilities, these locations were deemed vulnerable to the hazard.

Data and Methodology

According to Radbruch-Hall et al., the Landslide Incidence and Susceptibility GIS layer from National Atlas "…was prepared by evaluating formations or groups of formations shown on the geologic map of the United States (King and Beikman 1974) and classifying them as having high, medium, or low landslide incidence (number of landslides) and being of high, medium, or low susceptibility to landsliding. Thus, those map units or parts of units with more than 15 percent of their area involved in landsliding were classified as having high incidence; those with 1.5 to 15 percent of their area involved in landsliding, as having medium incidence; and those with less than 1.5 percent of their area involved, as having low incidence. This classification scheme was modified where particular lithofacies are known to have variable landslide incidence or susceptibility. In continental glaciated areas, additional data were used to identify surficial deposits that are susceptible to slope movement. Susceptibility to landsliding was defined as the probable degree of response of the areal rocks and soils to natural or artificial cutting or loading of slopes or to anomalously high precipitation. High, medium, and low susceptibility are delimited by the same percentages used in classifying the incidence of landsliding. For example, it was estimated that a rock or soil unit characterized by high landslide susceptibility would respond to widespread artificial cutting by some movement in 15 percent or more of the affected area. We did not evaluate the effect of earthquakes on slope stability, although many catastrophic landslides have been generated by ground shaking during earthquakes. Areas susceptible to landslides under static conditions would probably also be susceptible to failure during earthquakes" (Radbruch-Hall 1982).

The NJGWS' Carbonate Formations GIS layer differentiates areas of carbonate and non-carbonate geological formations for New Jersey. According to the NJGS, the areas of carbonate have a potential for natural subsidence (also known as karst areas).

In an attempt to estimate Sussex County's vulnerability to landslides and subsidence and sinkholes, these layers were used to coarsely define the general hazard area. The layers were overlaid upon the Sussex County 2010 U.S. Census population data, updated building inventory, and Sussex County's critical facility inventory to estimate exposure.

The limitations of this analysis are recognized and are only used to provide a general estimate of exposure and vulnerability. Over time additional data will be collected to allow better analysis for this hazard. Available information and a preliminary assessment are provided below.

Impact on Life, Health and Safety

To estimate the population located within the geologic hazard areas, the hazard area boundaries were overlaid upon the 2010 U.S. Census population data (U.S. Census, 2010). The Census blocks with their center (centroid) within the landslide and carbonate area boundaries were used to calculate the estimated population considered exposed to the hazard. Please note the Census blocks do not align exactly with the hazard areas and, therefore, these estimates should be considered for planning purposes only.

Table 5.4.5-4 summarizes the population within each identified hazard area by municipality (U.S. Census 2010). The remainder of the county is not located in the high susceptibility/moderate incidence landslide area; it is located within the low incidence landslide area.

Specifically, the population located downslope of the landslide hazard areas are particularly vulnerable to this hazard. Due to the nature of Census block data and uncertain area impacted downslope of a landslide event, it is difficult to determine demographics of populations vulnerable to mass movements of geological material.

Table 5.4.5-4. Estimated Population Located in the Geologic Hazard Areas

Municipalities	Total Population (2010 U.S. Census)	NJGWS-Karst Area		High Susceptibility/Moderate Incidence Landslide Area	
		Population Exposed	Percent Total	Population Exposed	Percent Total
Borough of Andover	606	288	47.5%	0	0.0%
Township of Andover	6,319	2,889	45.7%	0	0.0%
Borough of Branchville	841	297	35.3%	0	0.0%
Township of Byram	8,350	531	6.4%	0	0.0%
Township of Frankford	5,565	268	4.8%	0	0.0%
Borough of Franklin	5,045	3,970	78.7%	0	0.0%
Township of Fredon	3,437	459	13.4%	0	0.0%
Township of Green	3,601	2,499	69.4%	0	0.0%
Borough of Hamburg	3,277	2,787	85.0%	0	0.0%
Township of Hampton	5,196	1,362	26.2%	0	0.0%
Township of Hardyston	8,213	4,151	50.5%	0	0.0%
Borough of Hopatcong	15,147	0	0.0%	0	0.0%

Municipalities	Total Population (2010 U.S. Census)	NJGWS-Karst Area		High Susceptibility/Moderate Incidence Landslide Area	
		Population Exposed	Percent Total	Population Exposed	Percent Total
Township of Lafayette	2,538	1,068	42.1%	0	0.0%
Township of Montague	3,847	2,292	59.6%	3,810	99.0%
Town of Newton	7,997	4,244	53.1%	0	0.0%
Borough of Ogdensburg	2,410	1,867	77.5%	0	0.0%
Township of Sandyston	1,998	620	31.0%	1,250	62.6%
Township of Sparta	19,722	3,109	15.8%	0	0.0%
Borough of Stanhope	3,610	0	0.0%	0	0.0%
Township of Stillwater	4,099	2,164	52.8%	0	0.0%
Borough of Sussex	2,130	0	0.0%	0	0.0%
Township of Vernon	23,943	4,715	19.7%	0	0.0%
Township of Walpack	16	9	56.3%	6	37.5%
Township of Wantage	11,358	445	3.9%	**0**	0.0%
Sussex County Total	**149,265**	**40,034**	**26.8%**	**5,066**	**3.4%**

Source: United States Census 2010; NJGWS

Impact on General Building Stock

In general, the built environment located in the high susceptibility/moderate incidence zones and the population, structures and infrastructure located downslope are vulnerable to this hazard. In an attempt to estimate the general building stock vulnerable to this hazard, the building replacement cost values (buildings and contents) were determined for the buildings with their centroids within the approximate geologic hazard areas. Table 5.4.5-5 summarizes the exposed building stock in the landslide susceptibility and subsidence hazard areas by municipality. As stated above, the remainder of the county is not located in the high susceptibility/moderate incidence area; it is in the low incidence area. Municipalities with areas defined as low landslide incidence include Montague, Sandyston and Walpack; refer to Figure 5.4.5-1 presented earlier in this section.

Table 5.4.5-5. Estimated Building Exposure in the Geologic Hazard Areas

Municipality	Total Number of Buildings	Total Replacement Cost Value (structure and contents)	NJGWS-Karst Area				High Susceptibility/Moderate Incidence Landslide Area			
			# Buildings	% Total	Exposed Replacement Value	% Total	# Buildings	% Total	Exposed Replacement Value	% Total
Borough of Andover	257	$182,562,894	88	34.2%	$57,441,735	31.5%	0	0.0%	$0	0.0%
Township of Andover	2,248	$1,259,872,091	832	37.0%	$389,977,595	31.0%	0	0.0%	$0	0.0%
Borough of Branchville	353	$174,318,470	111	31.4%	$48,198,523	27.6%	0	0.0%	$0	0.0%
Township of Byram	3,401	$1,543,404,464	218	6.4%	$99,500,701	6.4%	0	0.0%	$0	0.0%
Township of Frankford	2,716	$1,653,244,645	102	3.8%	$84,219,174	5.1%	0	0.0%	$0	0.0%
Borough of Franklin	1,630	$881,717,214	1,368	83.9%	$710,251,061	80.6%	0	0.0%	$0	0.0%
Township of Fredon	1,236	$842,171,127	113	9.1%	$67,425,407	8.0%	0	0.0%	$0	0.0%
Township of Green	1,280	$962,383,257	915	71.5%	$743,457,272	77.3%	0	0.0%	$0	0.0%
Borough of Hamburg	1,464	$747,007,403	1,210	82.7%	$625,285,229	83.7%	0	0.0%	$0	0.0%
Township of Hampton	2,143	$1,398,457,332	815	38.0%	$620,791,042	44.4%	0	0.0%	$0	0.0%
Township of Hardyston	3,731	$1,652,499,901	2,312	62.0%	$1,042,265,110	63.1%	0	0.0%	$0	0.0%
Borough of Hopatcong	6,378	$2,224,090,408	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Township of Lafayette	1,020	$802,389,890	531	52.1%	$388,321,883	48.4%	0	0.0%	$0	0.0%
Township of Montague	1,972	$858,431,631	1,133	57.5%	$481,080,865	56.0%	1,929	97.8%	$843,493,589	98.3%
Town of Newton	2,320	$1,504,040,803	1,455	62.7%	$808,978,405	53.8%	0	0.0%	$0	0.0%
Borough of Ogdensburg	915	$390,034,452	701	76.6%	$302,371,341	77.5%	0	0.0%	$0	0.0%
Township of Sandyston	1,136	$588,862,570	334	29.4%	$230,730,635	39.2%	585	51.5%	$371,282,636	63.1%
Township of Sparta	7,447	$4,731,600,744	1,286	17.3%	$809,670,046	17.1%	0	0.0%	$0	0.0%
Borough of Stanhope	1,468	$859,784,777	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Township of Stillwater	1,871	$931,811,957	965	51.6%	$511,409,996	54.9%	0	0.0%	$0	0.0%
Borough of Sussex	579	$424,677,833	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Township of Vernon	11,280	$4,759,388,701	2,675	23.7%	$1,429,071,427	30.0%	0	0.0%	$0	0.0%
Township of Walpack	25	$16,093,258	12	48.0%	$7,039,461	43.7%	7	28.0%	$3,576,249	22.2%
Township of Wantage	4,156	$2,250,158,879	166	4.0%	$118,027,239	5.2%	0	0.0%	$0	0.0%
Sussex County Total	**61,026**	**$31,639,004,702**	**17,342**	**28.4%**	**$9,575,514,146**	**30.3%**	**2,521**	**4.1%**	**$1,218,352,473**	**3.9%**

Source: Sussex County, NJ Department of the Treasury, 2015, NJGWS

Impact on Critical Facilities

To estimate exposure, the approximate hazard areas were overlaid upon the essential and municipal facilities. As stated earlier, a majority of the Sussex County, with the exception of portions of Montague, Sandyston and Walpack, is located in the high susceptibility/moderate incidence area. Critical facilities located in this defined hazard area are potentially exposed to the landslide hazard; refer to Table 5.4.5-6. Table 5.4.5-7 summarizes the number of critical facilities located in the carbonate formation hazard area.

In addition to critical facilities, a significant amount of infrastructure can be exposed to mass movements of geological material:

- *Roads*—Access to major roads is crucial to life-safety after a disaster event and to response and recovery operations. Landslides can block egress and ingress on roads, causing isolation for neighborhoods, traffic problems, and delays for public and private transportation. This can result in economic losses for businesses.
- *Bridges*—Landslides can significantly impact road bridges. Mass movements can knock out bridge abutments or significantly weaken the soil supporting them, making them hazardous for use.
- *Power Lines*—Power lines are generally elevated above steep slopes; but the towers supporting them can be subject to landslides. A landslide could trigger failure of the soil underneath a tower, causing it to collapse and ripping down the lines. Power and communication failures due to landslides can create problems for vulnerable populations and businesses.
- *Rail Lines* – Similar to roads, rail lines are important for response and recovery operations after a disaster. Landslides can block travel along the rail lines, which would become especially troublesome, because it would not be as easy to detour a rail line as it is on a local road or highway. Many residents rely on public transport to get to work around the county and into New York City, and a landslide event could prevent travel to and from work.

Several other types of infrastructure may also be exposed to landslides, including water and sewer infrastructure. At this time all critical facilities, infrastructure, and transportation corridors located within the hazard areas are considered vulnerable until more information becomes available.

Table 5.4.5-6. Critical Facilities in the High Susceptibility/Moderate Incidence Landslide Hazard Area

Municipality	Facility Types							
	DPW	EMS	Fire	Municipal Hall	Potable Pump	School	Shelter	Substation
Borough of Andover	0	0	0	0	0	0	0	0
Township of Andover	0	0	0	0	0	0	0	0
Borough of Branchville	0	0	0	0	0	0	0	0
Township of Byram	0	0	0	0	0	0	0	0
Township of Frankford	0	0	0	0	0	0	0	0
Borough of Franklin	0	0	0	0	0	0	0	0
Township of Fredon	0	0	0	0	0	0	0	0
Township of Green	0	0	0	0	0	0	0	0
Borough of Hamburg	0	0	0	0	0	0	0	0
Township of Hampton	0	0	0	0	0	0	0	0
Township of Hardyston	0	0	0	0	0	0	0	0
Borough of Hopatcong	0	0	0	0	0	0	0	0
Township of Lafayette	0	0	0	0	0	0	0	0
Township of Montague	1	1	1	1	1	1	1	1
Town of Newton	0	0	0	0	0	0	0	0
Borough of Ogdensburg	0	0	0	0	0	0	0	0
Township of Sandyston	0	0	2	1	0	1	0	0
Township of Sparta	0	0	0	0	0	0	0	0
Borough of Stanhope	0	0	0	0	0	0	0	0
Township of Stillwater	0	0	0	0	0	0	0	0
Borough of Sussex	0	0	0	0	0	0	0	0
Township of Vernon	0	0	0	0	0	0	0	0
Township of Walpack	0	0	0	0	0	0	0	0
Township of Wantage	0	0	0	0	0	0	0	0
Sussex County Total	**1**	**1**	**3**	**2**	**1**	**2**	**1**	**1**

Source: Sussex County, NJGWS
Note: DPW – Department of Public Works
EMS – Emergency Medical Services

Table 5.4.5-7. Critical Facilities in the Carbonate Formation Hazard Area

Municipality	Facility Types														
	Air	Communication	DPW	EMS	EOC	Fire	Municipal Building	Police	Potable Pump	School	Senior	Shelter	Substation	Wastewater Pump	Well
Borough of Andover	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0
Township of Andover	2	3	1	1	1	3	0	1	0	1	2	1	0	0	0
Borough of Branchville	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Township of Byram	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Township of Frankford	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Borough of Franklin	0	0	0	1	0	1	1	1	0	2	0	1	0	0	0
Township of Fredon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Township of Green	1	0	0	1	1	1	1	0	0	4	0	1	0	0	0
Borough of Hamburg	0	0	1	0	0	2	1	1	1	1	0	1	1	2	1
Township of Hampton	0	0	0	0	0	1	1	0	0	2	1	0	0	0	0
Township of Hardyston	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0
Borough of Hopatcong	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Township of Lafayette	0	0	1	0	0	1	1	0	0	1	0	2	0	0	0
Township of Montague	0	0	1	1	0	1	1	0	1	1	0	1	1	0	0
Town of Newton	0	0	0	1	0	2	0	0	0	4	0	0	0	0	0
Borough of Ogdensburg	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0
Township of Sandyston	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
Township of Sparta	0	0	0	1	1	0	1	1	1	4	0	1	1	0	0
Borough of Stanhope	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Township of Stillwater	0	0	1	0	0	2	0	0	0	1	0	2	0	0	0
Borough of Sussex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Township of Vernon	0	0	1	0	0	1	1	1	0	5	0	2	0	0	0
Township of Walpack	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Township of Wantage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sussex County Total	**3**	**3**	**7**	**9**	**4**	**21**	**12**	**7**	**3**	**29**	**3**	**14**	**3**	**3**	**1**

Source: Sussex County, NJGWS
Note: DPW – Department of Public Works
EMS – Emergency Medical Services

Impact on the Economy and Environment

Geologic hazards can impose direct and indirect impacts on society. Direct costs include the actual damage sustained by buildings, property and infrastructure. Indirect costs, such as clean-up costs, business interruption, loss of tax revenues, reduced property values, and loss of productivity are difficult to measure. Additionally, ground failure threatens transportation corridors, fuel and energy conduits, and communication lines (USGS 2003). Estimated potential damages to general building stock can be quantified as discussed above. For the purposes of this analysis, general building stock damages are discussed further.

A landslide or sinkhole/subsidence event will alter the landscape. In addition to changes in topography, vegetation and wildlife habitats may be damaged or destroyed, and soil and sediment runoff will accumulate downslope potentially blocking waterways and roadways and impacting quality of streams and other water bodies. Additional environmental impacts include loss of forest productivity.

Landslides, sinkhole and subsidence events can cause major damage to buildings if they occur on the property. There are 17,342 buildings located within karst areas and account for $9.6 billion, or 30.3 percent of the county's total building assessed value (structure and estimated contents). Additionally, there are 2,521 buildings that account for $1.2 billion (3.9 percent) of the county's total building assessed value located in other sinkhole/subsidence susceptible areas. These dollar value losses to Sussex County's total building inventory would impact Sussex County's tax base and the local economy.

Many of the major transportation routes in the county could be affected by a landslide or sinkhole/subsidence event in the designated susceptible areas. These include US-206 and NJ-94, NJ-23, and NJ-284.

Future Growth and Development

As discussed in Section 4 and Volume II, Section 9, areas targeted for future growth and development have been identified across Sussex County. It is anticipated that new development within the identified hazard area will be exposed to such risks. Figure 5.4.5-5 illustrates the identified areas of potential new development in relation to the geologic hazard boundaries.

Change of Vulnerability

Sussex County and all plan participants continue to be vulnerable to the geologic hazard. The original 2011 HMP detailed past landslide events in the county, but did not provide a quantitative vulnerability assessment for the hazard. For the 2016 HMP update, updated population data, an updated general building stock based upon 2015 RS Means valuations and structural data provided by Sussex County and MODIV tax assessment data, and an updated critical facility inventory were used to assess the county's risk to the hazard areas.

Effect of Climate Change on Vulnerability

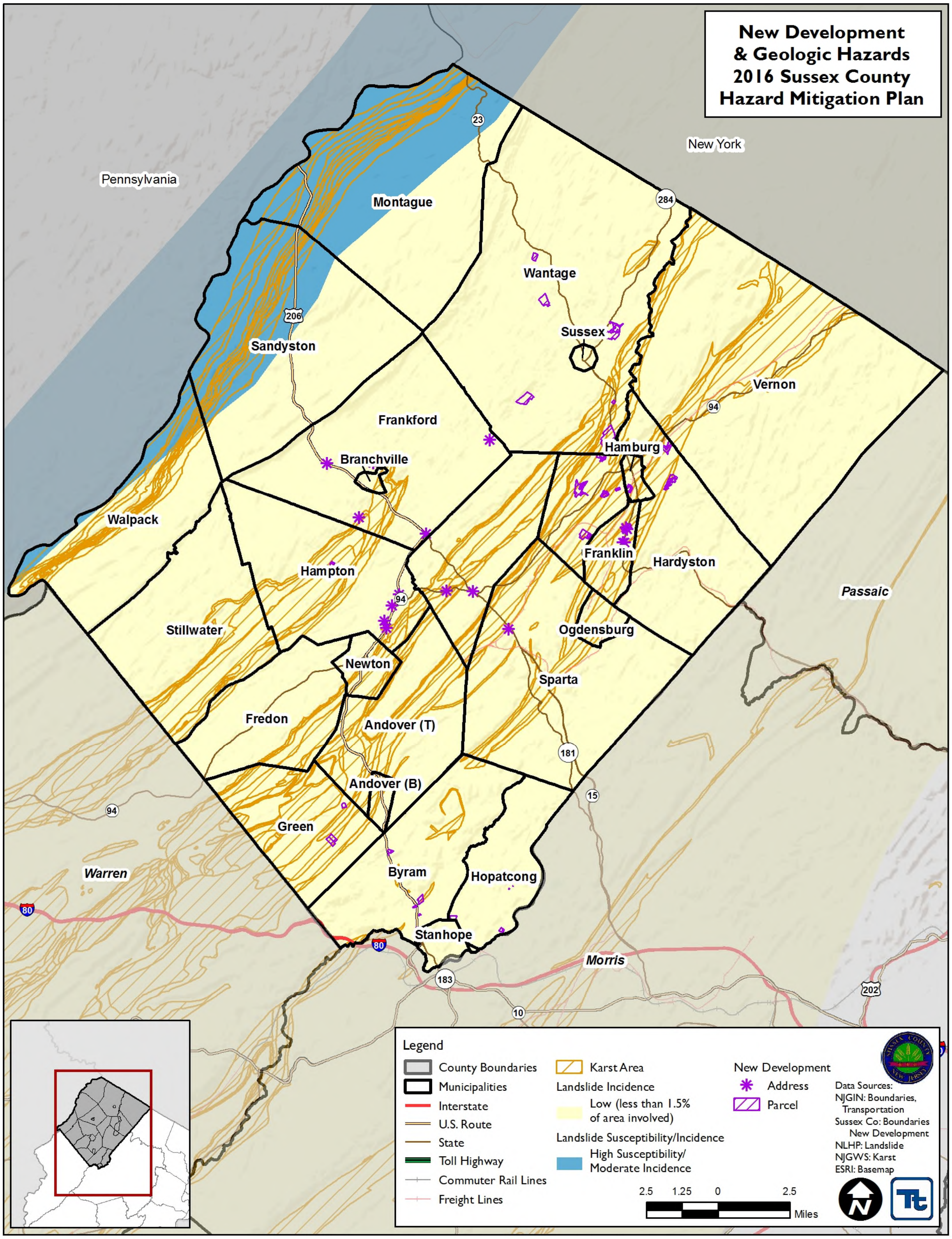
Providing projections of future climate change for a specific region is challenging. Some scientists feel that melting glaciers could induce tectonic activity. As ice melts and water runs off, tremendous amounts of weight are shifted on the Earth's crust. As newly freed crust returns to its original, 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

Obtaining historic damages to buildings and infrastructure incurred due to ground failure will help with loss estimates and future modeling efforts, given a margin of uncertainty. More detailed landslide susceptibility zones can be generated so that communities can more specifically identify high hazard areas. Further, research on rainfall thresholds for forecasting landslide potential may also be an option for Sussex County.

Figure 5.4.5-5. Potential New Development and Geologic Hazard Areas



Source: NJGWS, NLHP, Sussex County