4.3.6 GEOLOGIC

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.

2021 HMP Changes

- All subsections have been updated using best available data.
- Previous occurrences were updated with events that occurred between 2015 and 2020.
- Slopes greater than 15% were utilized to evaluate the potential for landslide; a higher resolution analysis compared to the Radbruch et al. Landslide Incidence and Susceptibility GIS layer from the National Atlas.

Profile

Hazard Description

For the purpose of Sussex County's HMP update, only landslides and land subsidence/sinkholes are discussed for the geological hazard.

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 2001). 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 (NJOEM 2019).

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 (NJOEM 2019).

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 588 abandoned mines in New Jersey. 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 (NJOEM 2019).

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 (NJOEM 2019).

Location

Landslides

Landslides are common in New Jersey, primarily in the northern region of the State. 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.

The Highland's Steep Stope Protection Area separates steep slopes into four classifications that are not only defined by percent of slope, but also by riparian areas, type of soils, and forestation (NJ Highlands Council 2020). In summary, any slopes above 15-percent fall into one of the four steep slope classifications. For geological hazards, slopes above 15-percent were selected using the NJDEP contour lines. As displayed in Figure 4.3.6-1, there are slopes greater than 15-percent located throughout the County.

Figure 4.3.6-2 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 and Sparta. Many of the landslide incidents documented 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 (Risk Assessment Supplement).

Subsidence/Sinkholes

New Jersey is susceptible to the effects of subsidence and sinkholes, primarily in the northwestern section of the State, which includes parts of 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 (NJOEM 2019).

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. Sussex County has bands of carbonate rock running throughout the County; the only areas not containing notable bands of carbonate rock are along the southwestern border and part of the northern section. 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 4.3.6-3). 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 4.3.6-4, 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).

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 4.3.6-5 shows the location of the mapped abandoned mines in Sussex County. 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 4.3.6-1. Landslide Susceptibility in Sussex County

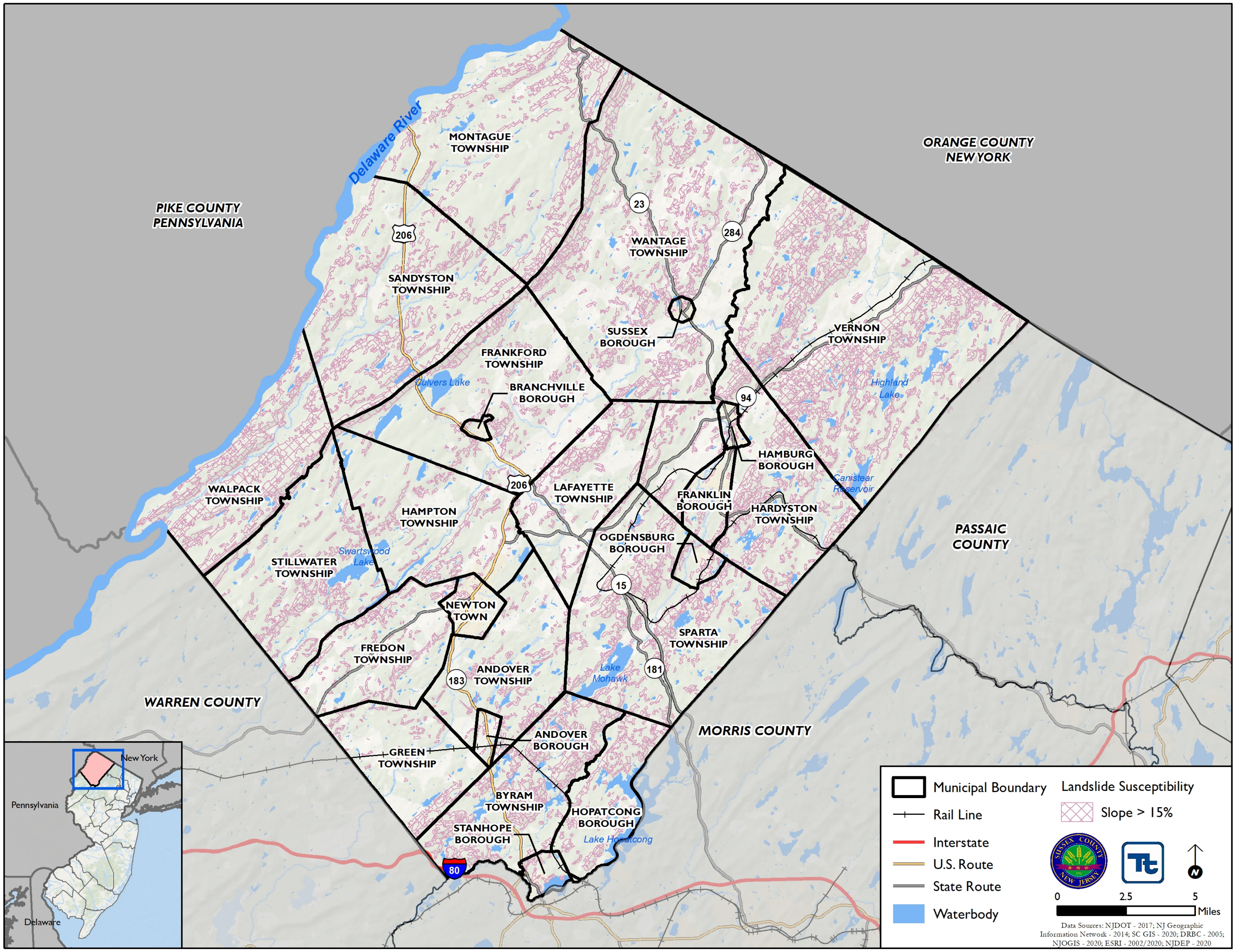


Figure 4.3.6-2. Historic Landslide Locations in Sussex County, 1869 to 2020

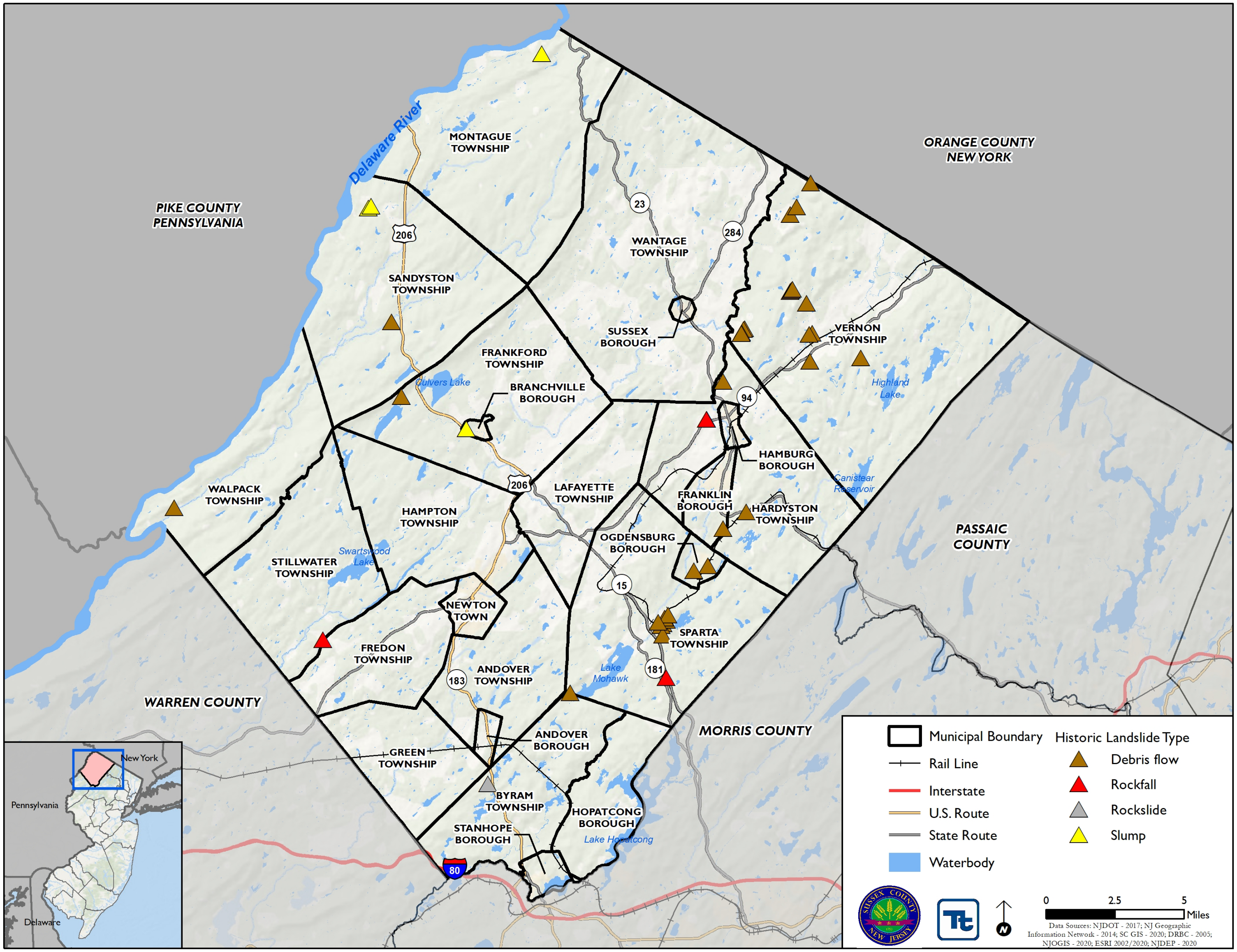
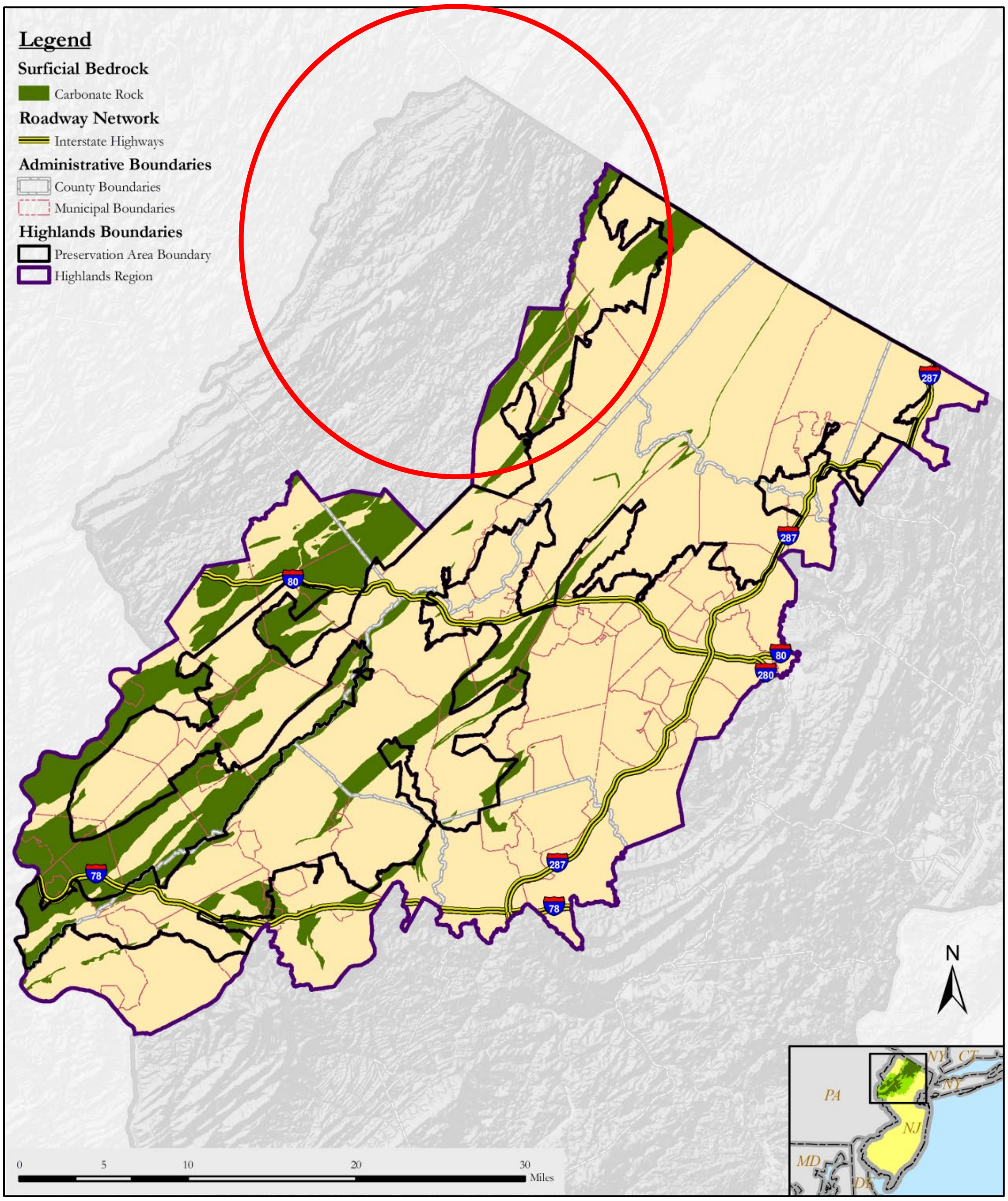


Figure 4.3.6-3. Carbonate Rock in the New Jersey Highlands



Source: New Jersey Highlands Council 2008

Note: The red circle indicates the approximate location of Sussex County.

Figure 4.3.6-5. Carbonate Rock in Sussex County

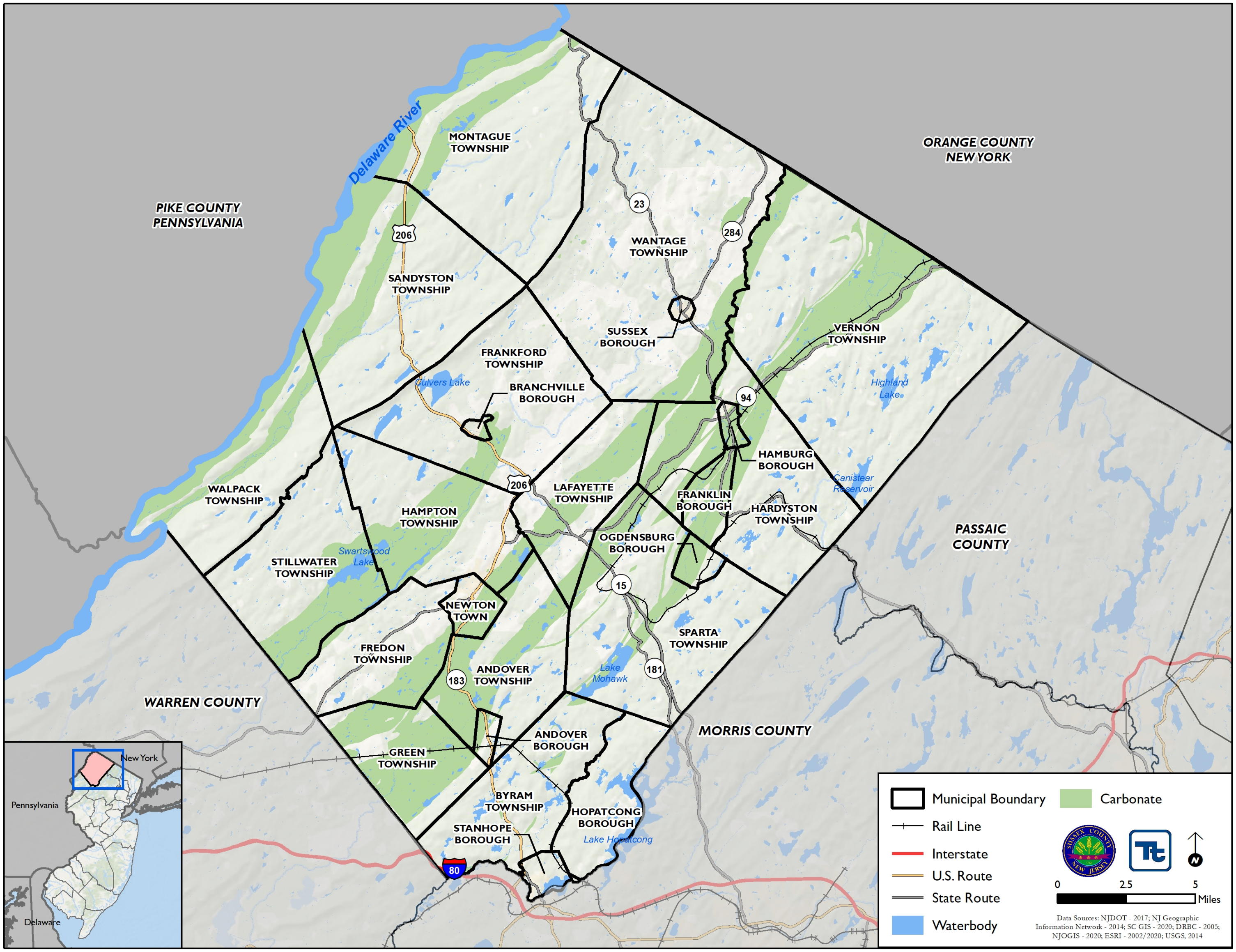
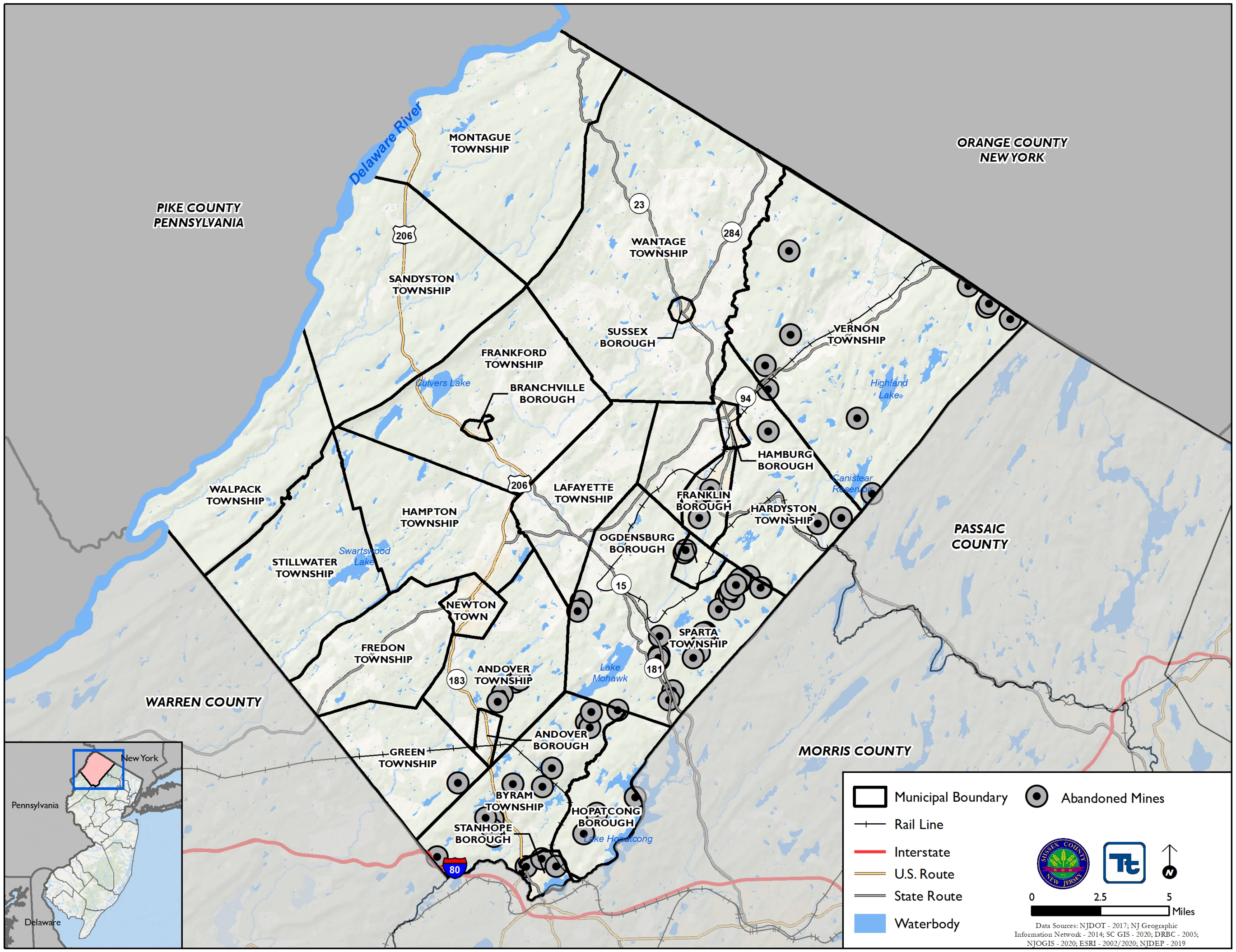


Figure 4.3.6-5. Abandoned Mines in Sussex County



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.
- 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 (NJOEM 2019).

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 (USGS 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 2015).

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 2015).

Previous Occurrences and Losses

FEMA Major Disasters and Emergency Declarations

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 included Sussex County (FEMA 2020). In addition, 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 such as flood-induced landslides in certain locations in the State. Sussex County experienced a debris flow along the lower end of Holland Circle a result of this incident; however, other minor events may have also occurred.

Table 4.3.6-1. FEMA DR and EM Declarations Since 2008 for Geologic Events in Sussex County

Declaration	Event Date	Declaration Date	Event Description
DR-1337	August 12, 2000 - August 21, 2000	August 17, 2000	New Jersey Severe Storms, Flooding And Mudslides
DR-4039	September 8, 2011 - October 6, 2011	October 14, 2011	New Jersey Remnants of Tropical Storm Lee

Source: FEMA 2020

U.S. Department of Agriculture Disaster Declarations

The Secretary of Agriculture from the U.S. Department of Agriculture (USDA) is authorized to designate counties as disaster areas to make emergency loans to producers suffering losses in those counties and in counties that are contiguous to a designated county. Between 2015 and 2020, Sussex County was not included in geologic related agricultural disaster declarations.

No additional geologic hazard events were identified during the research to update this section of the HMP. Please see Section 9 (Jurisdictional Annexes) for detailed information regarding impacts and losses to each municipality.

Probability of Future 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 has a roughly 50-percent chance of a landslide or other geologic event occurring in any given 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 has a roughly 25-percent chance of a landslide or other geologic event occurring in any given year. 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. Sussex 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 (Risk Assessment Supplement).

Table 4.3.6-2. Probability of Future Occurrence of Geologic Events, Calculation One

Hazard Type	Number of Occurrences Between 1950 and 2020	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	32	0.46	2.2	0.45	45.1
Rockfalls	2	0.03	35.5	0.03	2.8
Rockslide	1	0.01	71.0	0.01	1.4

Hazard Type	Number of Occurrences Between 1950 and 2020	Rate of Occurrence	Recurrence Interval (in years)	Probability of event Occurring in Any Given Year	Percent Chance of Occurring in Any Given Year
Slump	2	0.03	35.5	0.03	2.8
Sinkhole	1	0.01	71.0	0.01	1.4
Total	**38**	**0.54**	**1.9**	**0.54**	**53.5**

Source: NJDEP 2012; NOAA-NCEI 2020; NJ.Com 2015; NJ State HMP 2019

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 4.3.6-3. Probability of Future Occurrence of Geologic Events, Calculation Two

Hazard Type	Number of Occurrences Between 1950 and 2020	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	0.19	5.5	0.18	18.3
Rockfalls	2	0.03	35.5	0.03	2.8
Rockslide	1	0.01	71.0	0.01	1.4
Slump	2	0.03	35.5	0.03	2.8
Sinkhole	1	0.01	71.0	0.01	1.4
Total	**19**	**0.27**	**3.7**	**0.27**	**26.8**

Source: NJDEP 2012; NOAA-NCEI 2020; NJ.Com 2015; NJ State HMP 2019

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 4.4, 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 the geologic hazard in the county is considered 'occasional' (between 10 and 100 percent annual probability of a hazard event occurring, as presented in Table 4.4-1). The ranking of the geologic hazard for individual municipalities is presented in the jurisdictional annexes.

Climate Change Impacts

Future 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 could increase the probability of wildfire, reducing the vegetation that helps to support steep slopes. All of these factors could increase the probability for landslide occurrences.

Landslides

Both northern and southern New Jersey have become wetter over the past century. Northern New Jersey's 1971-2000 precipitation average was over five inches (12%) greater than the average from 1895-1970 (Office of New Jersey State Climatologist). Annual precipitation in New Jersey has been 8-percent above average during the last 10 years; and has experienced an upward trend of 4.1 inches in precipitation in 100-years (NJDEP 2019).

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 2020).

Vulnerability Assessment

As noted earlier, the Highland's Steep Stope Protection Area separates steep slopes into four classifications that are not only defined by percent of slope, but also by riparian areas, type of soils, and forestation (NJ Highlands Council 2020). Despite these various land attributes, any slopes above 15-percent fell into one of the four steep slope classifications. To evaluate the geological hazard, slopes above 15-percent were selected using the NJDEP contour lines. Additionally, the 2014 USGS carbonate rock layer was used to identify the geologic hazard area. The following text summarizes the potential impact of geological hazards on the County. Refer to Section 4.2 (Methodology and Tools) for additional details on the methodology used to assess geological hazard risk.

Impact on Life, Health, and Safety

Generally, a landslide or subsidence event is an isolated incidence and impacts the populations within the immediate area of the incident. Specifically, the population located downslope of the landslide hazard areas are particularly vulnerable. In addition to causing damages to residential buildings and displacing residents, landslides and subsidence events can block off or damage major roadways and inhibit travel for emergency responders or populations trying to evacuate the area.

Table 4.3.6-4 summarizes the population living on landscapes with carbonate bedrock. Table 4.3.6-5 summarizes the population living on landscapes with slopes greater than or equal to 15-percent. Overall, 40,124 persons and 18,920 persons are living on carbonate bedrock or landscapes with slopes greater than or equal to 15-percent, respectively. The Boroughs of Ogdensburg and Hamburg, and Township of Walpack have the greatest number of residents living on carbonate bedrock. The Townships of Vernon and Walpack have the greatest number of residents living on landscape slopes greater than or equal to 15-percent.

Table 4.3.6-4. Estimated Population Living on Landscape with Carbonate Rock

Jurisdiction	Total Population	Population Exposed to Carbonate Soils Hazard Area	
		Number of People	Percent of Total
Andover (B)	594	185	31.2%
Andover (Twp)	5,996	2,170	36.2%

Jurisdiction	Total Population	Population Exposed to Carbonate Soils Hazard Area	
		Number of People	Percent of Total
Branchville (B)	896	341	38.1%
Byram (Twp)	8,010	469	5.9%
Frankford (Twp)	5,361	218	4.1%
Franklin (B)	4,807	3,605	75.0%
Fredon (Twp)	3,214	257	8.0%
Green (Twp)	3,495	2,564	73.3%
Hamburg (B)	3,152	2,660	84.4%
Hampton (Twp)	4,916	1,861	37.9%
Hardyston (Twp)	7,886	4,602	58.4%
Hopatcong (B)	14,362	0	0.0%
Lafayette (Twp)	2,390	1,405	58.8%
Montague (Twp)	3,716	1,894	51.0%
Newton (T)	7,895	5,279	66.9%
Ogdensburg (B)	2,314	1,721	74.4%
Sandyston (Twp)	1,925	466	24.2%
Sparta (Twp)	18,841	3,066	16.3%
Stanhope (B)	3,377	0	0.0%
Stillwater (Twp)	3,936	2,090	53.1%
Sussex (B)	1,854	0	0.0%
Vernon (Twp)	22,369	4,885	21.8%
Walpack (Twp)	6	5	81.8%
Wantage (Twp)	10,986	382	3.5%
Sussex County (Total)	**142,298**	**40,124**	**28.2%**

Source: American Community Survey 2018 5-Year Estimates; USGS – 2014
Note: B – Borough; T – Town; Twp – Township; % - Percent

Table 4.3.6-5. Estimated Population Living on Landscape with 15-Percent or Greater Slopes

Jurisdiction	Total Population	Population Exposed to Steep Slope (Greater Than 15-Percent) Hazard Area	
		Number of People	Percent of Total
Andover (B)	594	28	4.7%
Andover (Twp)	5,996	526	8.8%
Branchville (B)	896	37	4.1%
Byram (Twp)	8,010	1,398	17.5%
Frankford (Twp)	5,361	331	6.2%
Franklin (B)	4,807	420	8.7%
Fredon (Twp)	3,214	315	9.8%

Jurisdiction	Total Population	Population Exposed to Steep Slope (Greater Than 15-Percent) Hazard Area	
		Number of People	Percent of Total
Green (Twp)	3,495	322	9.2%
Hamburg (B)	3,152	334	10.6%
Hampton (Twp)	4,916	224	4.6%
Hardyston (Twp)	7,886	636	8.1%
Hopatcong (B)	14,362	1,408	9.8%
Lafayette (Twp)	2,390	202	8.5%
Montague (Twp)	3,716	167	4.5%
Newton (T)	7,895	387	4.9%
Ogdensburg (B)	2,314	199	8.6%
Sandyston (Twp)	1,925	385	20.0%
Sparta (Twp)	18,841	3,173	16.8%
Stanhope (B)	3,377	613	18.2%
Stillwater (Twp)	3,936	310	7.9%
Sussex (B)	1,854	131	7.1%
Vernon (Twp)	22,369	5,657	25.3%
Walpack (Twp)	6	2	27.3%
Wantage (Twp)	10,986	1,713	15.6%
Sussex County (Total)	**142,298**	**18,920**	**13.3%**

Source: American Community Survey 2018 5-Year Estimates; USGS 1999
Note: B – Borough; T - Town; Twp – Township; % - Percent

Research has also shown that some populations, while they may not have more hazard exposure, may experience exacerbated impacts and prolonged recovery if/when impacted. For example, persons over the age of 65 and people below the poverty level are most vulnerable to geologic hazards because of the potential limited access to mobilization or medical resources if a landslide or subsidence event occurs. According to the 2018 American Community Survey 5-Year Population Estimate, there are 22,889 persons over 65 years old and 7,191 persons living below the poverty level out of the total 142,298 persons that live in Sussex County. Higher concentrations of persons over 65 years in age reside in the Township of Walpack (i.e., 100-percent of total population) and higher concentrations of persons living below the poverty level reside in the Borough of Sussex (i.e., 16-percent of total population).

Impact on General Building Stock

In general, the built environment is vulnerable to the geologic hazard if built on soils/geology susceptible to landsliding or sink holes such as carbonate bedrock or slopes that are greater than 15-percent. Geologic hazard areas may destabilize the foundation of structures resulting in monetary losses to businesses and residents. There are 20,410 buildings with a replacement cost value of approximately $21 billion built on lands with carbonate bedrock. Furthermore, there are 9,101 buildings with a replacement cost value of approximately $4.3 billion built on lands with slopes greater than 15-percent. The Township of Vernon has the greatest number of buildings built on carbonate bedrock; 2,853 buildings (23.7-percent of its total building stock) with an estimated replacement cost of $2.1 billion. The Township of Vernon also has the greatest number of buildings built on landscapes with slopes greater than 15-percent; 2,925 buildings (24.3-percent of its total building stock) with an estimated replacement cost of $1.0 billion. Table 4.3.6-6 summarizes the number of buildings built on each geologic hazard area and the total replacement cost of these buildings by municipality.

Table 4.3.6-6. Number and Value of Buildings Built on Lands with Carbonate Bedrock and Steep Slope (>15-percent) by Municipality

Jurisdiction	Total Number of Buildings	Total Replacement Cost Value (RCV)	Carbonate Rock Hazard Area				Landslide - Steep Slope (Greater Than 15-Percent) Hazard Area			
			Number of Buildings	Percent of Total	Replacement Cost Value ($)	Percent of Total	Number of Buildings	Percent of Total	Replacement Cost Value ($)	Percent of Total
Andover (B)	328	628,463,030	113	34.5%	280,691,477	44.7%	14	4.3%	6,700,947	1.1%
Andover (Twp)	2,584	3,609,679,724	977	37.8%	944,612,676	26.2%	194	7.5%	89,880,361	2.5%
Branchville (B)	426	532,377,368	151	35.4%	164,220,678	30.8%	17	4.0%	70,514,303	13.2%
Byram (Twp)	3,676	2,746,550,446	241	6.6%	134,049,838	4.9%	603	16.4%	270,948,636	9.9%
Frankford (Twp)	3,537	3,129,888,305	173	4.9%	277,940,682	8.9%	221	6.2%	291,532,196	9.3%
Franklin (B)	2,061	1,921,211,856	1,574	76.4%	1,548,691,319	80.6%	166	8.1%	75,207,126	3.9%
Fredon (Twp)	1,615	1,372,050,934	128	7.9%	116,945,626	8.5%	151	9.3%	113,552,287	8.3%
Green (Twp)	1,698	1,598,635,804	1,265	74.5%	1,336,468,311	83.6%	146	8.6%	83,464,927	5.2%
Hamburg (B)	1,594	1,588,049,291	1,336	83.8%	1,301,386,122	81.9%	165	10.4%	121,533,854	7.7%
Hampton (Twp)	2,763	2,196,131,598	1,033	37.4%	682,894,556	31.1%	127	4.6%	79,371,471	3.6%
Hardyston (Twp)	4,403	3,183,033,542	2,577	58.5%	2,129,949,178	66.9%	350	7.9%	192,368,391	6.0%
Hopatcong (B)	8,040	2,888,571,676	0	0.0%	0	0.0%	794	9.9%	256,352,950	8.9%
Lafayette (Twp)	1,462	1,958,174,065	793	54.2%	829,384,510	42.4%	130	8.9%	133,486,764	6.8%
Montague (Twp)	2,175	1,459,611,020	1,113	51.2%	757,855,613	51.9%	93	4.3%	36,781,164	2.5%
Newton (T)	2,679	5,093,275,807	1,701	63.5%	1,949,256,805	38.3%	115	4.3%	81,410,916	1.6%
Ogdensburg (B)	992	819,879,629	755	76.1%	724,843,800	88.4%	89	9.0%	50,845,572	6.2%
Sandyston (Twp)	1,528	1,212,626,664	444	29.1%	419,749,258	34.6%	243	15.9%	120,669,734	10.0%
Sparta (Twp)	8,132	9,070,094,285	1,585	19.5%	3,887,789,926	42.9%	1,269	15.6%	583,093,689	6.4%
Stanhope (B)	1,557	1,051,183,581	0	0.0%	0	0.0%	267	17.1%	96,888,673	9.2%
Stillwater (Twp)	2,493	1,417,579,398	1,275	51.1%	751,289,915	53.0%	204	8.2%	110,706,157	7.8%
Sussex (B)	678	1,945,578,916	0	0.0%	0	0.0%	42	6.2%	38,283,996	2.0%

Jurisdiction	Total Number of Buildings	Total Replacement Cost Value (RCV)	Carbonate Rock Hazard Area				Landslide - Steep Slope (Greater Than 15-Percent) Hazard Area			
			Number of Buildings	Percent of Total	Replacement Cost Value ($)	Percent of Total	Number of Buildings	Percent of Total	Replacement Cost Value ($)	Percent of Total
Vernon (Twp)	12,039	5,658,971,163	2,853	23.7%	2,059,570,999	36.4%	2,925	24.3%	1,033,072,351	18.3%
Walpack (Twp)	51	63,691,550	42	82.4%	48,293,650	75.8%	18	35.3%	8,861,768	13.9%
Wantage (Twp)	5,510	4,877,543,885	281	5.1%	685,129,146	14.0%	758	13.8%	400,957,731	8.2%
Sussex County (Total)	**72,021**	**60,022,853,539**	**20,410**	**28.3%**	**21,031,014,086**	**35.0%**	**9,101**	**12.6%**	**4,346,485,965**	**7.2%**

Source: Sussex County GIS 2020; RS Means 2020; USGS 2014; NJDEP 1999
Note: B – Borough; T - Town; Twp – Township; % - Percent

Impact on Critical Facilities and Lifelines

To estimate potential risk to critical facilities, the critical facility and lifeline inventory was overlaid upon the geologic hazard areas. There are 223 critical facilities built on lands with carbonate bedrock and 19 critical facilities built on landscapes with slopes greater than 15-percent. All of these critical facilities are considered lifelines. Refer to Table 4.3.6-7 which summarizes the number of critical facilities and lifelines exposed to the geologic hazard areas by municipality. Additionally, Table 4.3.6-8 and Table 4.5.6-9 summarize the distribution of critical facilities and lifelines exposed to the geologic hazard area by type. Overall, dams are the most common facility type exposed to both geologic hazards areas. Refer to Table 4.3.6-10 and Table 4.3.6-11 for the assets exposed to the geologic hazard areas categorized by the FEMA lifeline categories. Based on the exposure analysis, safety and security community lifelines are most at risk to impacts from the geologic hazards.

Table 4.3.6-7. Number of Critical Facilities and Lifelines Built on Land with Carbonate Bedrock and Steep Slopes (> 15-percent)

Jurisdiction	Total Critical Facilities and Lifelines Located in Jurisdiction	Carbonate Rock Hazard Area		Landslide Hazard Area - Steep Slope (Greater Than 15-Percent)	
		Critical Facilities and Lifelines	Percent of Total Critical Facilities and Lifelines	Critical Facilities and Lifelines	Percent of Total Critical Facilities and Lifelines
Andover (B)	12	3	25.0%	0	0.0%
Andover (Twp)	37	22	59.5%	1	2.7%
Branchville (B)	4	0	0.0%	0	0.0%
Byram (Twp)	37	4	10.8%	0	0.0%
Frankford (Twp)	23	6	26.1%	1	4.3%
Franklin (B)	10	9	90.0%	0	0.0%
Fredon (Twp)	17	0	0.0%	0	0.0%
Green (Twp)	21	20	95.2%	0	0.0%
Hamburg (B)	19	18	94.7%	3	15.8%
Hampton (Twp)	20	10	50.0%	1	5.0%
Hardyston (Twp)	27	8	29.6%	1	3.7%
Hopatcong (B)	22	0	0.0%	4	18.2%
Lafayette (Twp)	14	7	50.0%	0	0.0%
Montague (Twp)	32	18	56.3%	0	0.0%
Newton (T)	39	14	35.9%	1	2.6%
Ogdensburg (B)	7	5	71.4%	0	0.0%
Sandyston (Twp)	28	11	39.3%	0	0.0%
Sparta (Twp)	74	30	40.5%	0	0.0%
Stanhope (B)	7	0	0.0%	0	0.0%
Stillwater (Twp)	24	12	50.0%	0	0.0%
Sussex (B)	8	0	0.0%	0	0.0%
Vernon (Twp)	74	20	27.0%	3	4.1%

Jurisdiction	Total Critical Facilities and Lifelines Located in Jurisdiction	Carbonate Rock Hazard Area		Landslide Hazard Area - Steep Slope (Greater Than 15-Percent)	
		Critical Facilities and Lifelines	Percent of Total Critical Facilities and Lifelines	Critical Facilities and Lifelines	Percent of Total Critical Facilities and Lifelines
Walpack (Twp)	11	4	36.4%	1	9.1%
Wantage (Twp)	29	2	6.9%	3	10.3%
Sussex County (Total)	**596**	**223**	**37.4%**	**19**	**3.2%**

Source: Sussex County GIS 2020; FEMA 2020; USGS 2014; NJDEP 1999
Note: B – Borough; T - Town; Twp – Township; % - Percent

Table 4.3.6-8. Distribution of Critical Facilities by Type Built on Land with Carbonate Bedrock

Jurisdiction	Facility Types																						
	Airport	Communication Facility	Dam	DPW	Electrical Substation	EMS	EOC	Fire Station	Food Pantry	Fuel	Government Building	Hazardous Material	Police Station	Post Office	Potable Pump Station	Potable Water Treatment	Primary Education	Religious Center	Secondary Education	Senior Center	Shelter	Wastewater Pump	Well
Andover (B)	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Andover (Twp)	1	3	7	1	0	1	1	3	0	0	0	0	1	0	0	0	1	0	0	2	1	0	0
Branchville (B)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Byram (Twp)	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Frankford (Twp)	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0
Franklin (B)	0	0	1	0	0	1	0	1	0	0	1	1	1	0	0	0	2	0	0	0	1	0	0
Fredon (Twp)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green (Twp)	0	0	3	1	0	1	1	1	0	0	1	2	0	2	0	0	4	2	1	0	1	0	0
Hamburg (B)	0	0	2	1	1	1	0	1	0	0	2	4	1	0	0	0	1	0	0	0	1	2	1
Hampton (Twp)	0	0	5	0	0	0	0	1	0	0	1	0	0	0	0	0	2	0	0	1	0	0	0
Hardyston (Twp)	0	0	0	1	0	1	0	1	0	0	1	1	1	0	0	0	2	0	0	0	0	0	0
Hopatcong (B)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lafayette (Twp)	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	2	0	0
Montague (Twp)	0	0	4	1	0	1	0	2	1	0	1	0	0	0	1	0	0	0	0	0	2	0	5
Newton (T)	0	0	0	1	1	1	0	1	0	0	0	1	0	0	1	0	4	0	0	0	0	4	0
Ogdensburg (B)	0	0	0	0	0	1	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0
Sandyston (Twp)	0	0	6	1	0	0	0	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Sparta (Twp)	0	0	7	2	1	1	1	0	1	0	1	4	1	0	2	0	4	0	0	0	1	3	1
Stanhope (B)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stillwater (Twp)	0	0	4	1	0	1	0	2	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0
Sussex (B)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vernon (Twp)	0	0	7	1	0	0	0	1	0	0	1	2	1	0	0	0	5	0	0	0	2	0	0
Walpack (Twp)	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Wantage (Twp)	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0

Jurisdiction	Facility Types																						
	Airport	Communication Facility	Dam	DPW	Electrical Substation	EMS	EOC	Fire Station	Food Pantry	Fuel	Government Building	Hazardous Material	Police Station	Post Office	Potable Pump Station	Potable Water Treatment	Primary Education	Religious Center	Secondary Education	Senior Center	Shelter	Wastewater Pump	Well
Sussex County (Total)	**1**	**3**	**51**	**13**	**3**	**11**	**5**	**20**	**3**	**1**	**13**	**17**	**7**	**3**	**4**	**1**	**29**	**2**	**1**	**3**	**15**	**10**	**7**

Source: Sussex County GIS 2020; USGS 2014
Notes: B = Borough, C = City, Twp = Township, T = Town, % - Percent

Table 4.3.6-9. Distribution of Critical Facilities by Type Built on Land with Steep Slopes (Greater Than 15-Percent)

Jurisdiction	Facility Types									
	Communication Facility	Correctional Facility	Dam	DPW	Potable Pump Station	Primary Education	Senior Center	Shelter	Wastewater Pump	Well
Andover (B)	0	0	0	0	0	0	0	0	0	0
Andover (Twp)	0	0	1	0	0	0	0	0	0	0
Branchville (B)	0	0	0	0	0	0	0	0	0	0
Byram (Twp)	0	0	0	0	0	0	0	0	0	0
Frankford (Twp)	0	0	0	1	0	0	0	0	0	0
Franklin (B)	0	0	0	0	0	0	0	0	0	0
Fredon (Twp)	0	0	0	0	0	0	0	0	0	0
Green (Twp)	0	0	0	0	0	0	0	0	0	0
Hamburg (B)	0	0	0	0	1	0	0	0	1	1
Hampton (Twp)	0	0	1	0	0	0	0	0	0	0
Hardyston (Twp)	0	0	1	0	0	0	0	0	0	0
Hopatcong (B)	0	0	1	0	0	1	1	1	0	0
Lafayette (Twp)	0	0	0	0	0	0	0	0	0	0
Montague (Twp)	0	0	0	0	0	0	0	0	0	0
Newton (T)	0	1	0	0	0	0	0	0	0	0

Jurisdiction	Facility Types									
	Communication Facility	Correctional Facility	Dam	DPW	Potable Pump Station	Primary Education	Senior Center	Shelter	Wastewater Pump	Well
Ogdensburg (B)	0	0	0	0	0	0	0	0	0	0
Sandyston (Twp)	0	0	0	0	0	0	0	0	0	0
Sparta (Twp)	0	0	0	0	0	0	0	0	0	0
Stanhope (B)	0	0	0	0	0	0	0	0	0	0
Stillwater (Twp)	0	0	0	0	0	0	0	0	0	0
Sussex (B)	0	0	0	0	0	0	0	0	0	0
Vernon (Twp)	0	0	3	0	0	0	0	0	0	0
Walpack (Twp)	0	0	1	0	0	0	0	0	0	0
Wantage (Twp)	1	0	2	0	0	0	0	0	0	0
Sussex County (Total)	**1**	**1**	**10**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Source: Sussex County GIS 2020; NJDEP 1999
Notes: B = Borough, C = City, Twp = Township, T = Town, % = Percent
Note: Asset types that are not listed in the tables were not exposed to the flood hazard.

Table 4.3.6-10. Number of Lifelines Located on Carbonate Rock

FEMA Lifeline Category	Number of Lifelines	Number of Lifelines Exposed to the Carbonate Rock Hazard Area
Communications	9	3
Energy	12	4
Food, Water, Shelter	75	39
Hazardous Materials	20	17
Health and Medical	15	4
Safety and Security	463	155
Transportation	2	1
Sussex County (Total)	**596**	**223**

Source: Sussex County GIS 2020; FEMA 2020; USGS 2014

Table 4.3.6-11. Number of Lifelines Built on Steep Slopes (>15-percent)

FEMA Lifeline Category	Number of Lifelines	Number of Lifelines Exposed to the Landslide - Steep Slope (Greater Than 15-Percent) Hazard Area
Communications	9	1
Energy	12	0
Food, Water, Shelter	75	4
Hazardous Materials	20	0
Health and Medical	15	1
Safety and Security	463	13
Transportation	2	0
Sussex County (Total)	**596**	**19**

Source: Sussex County GIS 2020; FEMA 2020; USGS 2014

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 the geologic hazards, including water and sewer infrastructure. The miles of roads exposed to landslide and carbonate hazard areas are summarized in Table 4.3.6-12. Out of the 1,771 miles of roads in the County, 389 miles are built on steep slopes (>15%) and 862 miles are located on carbonate rock.

Table 4.3.6-12. Major Transportation Routes Exposed to Steep Slope and Carbonate Hazard Areas

Road Type	Total Miles for County	Landslide - Steep Slope (Greater Than 15-Percent) Hazard Area		Carbonate Rock Hazard Area	
		Miles	Percent of Total	Miles	Percent of Total
Local and Private Roads	1,337	228	17.1%	471	35.2%
County Roads	313	154	49.2%	353	112.8%
State Routes	86	6	6.5%	28	32.9%
US Highways	34	1	3.5%	9	26.8%
Interstate	1	<1	<.1%	<1	<0.1%
County Total	**1,771**	**389**	**22.0%**	**862**	**48.7%**

Source: Sussex County GIS 2020; USGS 2014; NJDEP 1999; NJDOT 2017
Note: % - Percent

Impact on the Economy

Geologic hazards can impose direct and indirect impacts on society. Direct costs include the actual damage sustained by buildings, property, and infrastructure due to ground failure, which also threatens transportation corridors, fuel and energy conduits, and communication lines (USGS 2020). Indirect costs, such as clean-up costs, business interruption, loss of tax revenues, reduced property values, and loss of productivity may also occur, but are difficult to measure. Buildings susceptible to landslide events were summarized earlier in this section. Losses to these structures will impact the local tax base and economy.

Impact on the Environment

Steep slopes within the Highlands Region play an important ecological, recreational, scenic, and functional role. They provide specialized habitats for rare plant and animal species. Areas of steep slope provide recreational opportunities and contribute to the rural character of the Highlands Region and Sussex County. Disturbance of areas containing steep slopes can trigger erosion and sedimentation, resulting in the loss of topsoil. Silting of wetlands, lakes, ponds, and streams damages and degrades wetland and aquatic habitats that are found throughout the region and receive the State's highest water quality protections. Steep slope disturbance can also result in the loss of habitat quality, degradation of surface water quality, silting of wetlands, and alteration of drainage patterns (NJ Highlands Council 2012).

Future Changes That May Impact Vulnerability

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

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

Projected Development

Any areas of growth could be potentially impacted by the geologic hazard if located within the identified hazard areas or downslope. In general, development of slopes is not recommended due to the increased risk of erosion, stormwater runoff and flooding potential. The additional runoff results in sedimentation of down slope surface waters, which damages habitat and has the potential to damage property. The Highlands Council has template ordinances available to define Steep Slope Protection Areas and protect from their disturbance. In addition, there are recommendations for site design for permitted disturbances to minimize impacts.

A spatial analysis was conducted to determine the intersection of potential new development with steep slopes and carbonate soil. The exposure analysis shows that six new developments will be built in steep slope hazard area and 27 new developments will be built in the carbonate soil hazard area: refer to Figure 4.3.6-7 and Figure 4.3.6-7

Projected Changes in Population

Sussex County has experienced population decline since 2010. According to the U.S. Census Bureau, the County's population has decreased 4.7-percent between 2010 and 2018 (U.S. Census Bureau 2020). The population is expected to continue to decrease as residents move away from the suburbs and towards urban centers (Stirling 2018). Even though the population has decreased over the past decade, any changes in the density of population can impact the number of persons exposed to geologic hazard areas. Changes in density can not only create issues for local residents during evacuation of a landslide or ground failure event, but can also have an effect on commuters that travel into and out of the County for work, particularly during a geologic event that breaches major transportation corridors, which are also major commuter roads.

Climate Change

A direct impact of climate change on landslides is difficult to determine. Multiple secondary effects of climate change have the potential to increase the likelihood of landslides. Warming temperatures resulting in wildfires would reduce vegetative cover along steep slopes and destabilize the soils due to destruction of the root system; increased intensity of rainfall events would increase saturation of soils on steep slopes. Under these future conditions, the County's assets located on or at the base of these steep slopes will have an increased risk to landslides. Roadways and other transportation infrastructure located in these areas will also be at an increased risk of closure, which would impact the County's risk as described above.

Higher temperatures and the possibility of more intense, less frequent summer rainfall may lead to changes in water resource availability. Increase in average temperatures may lead to an increase in the frequency of droughts. Sinkhole activity intensifies in some karst areas during periods of drought. With an increase in drought periods, the number of sinkholes could increase. Additionally, changes to the water balance of an area including 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 will cause sinkholes. These actions can also serve to accelerate the natural processes of bedrock degradation, which can have a direct impact on sinkhole creation.

Vulnerability Changes Since the 2016 HMP

This updated HMP has utilized updated building stock and critical asset inventories to assess the County's risk to the geologic hazard areas. The building inventory was updated using RS Means 2020 values, which is more current and reflects replacement cost versus the building stock improvement values reported in the 2016 HMP. Further, the 2018 5-year population estimates from the American Community Survey were used to evaluate the population exposed to the dam inundation areas. Additionally, the 2014 carbonate rock layer from USGS and the 1999 digitized contours from NJDEP were referenced to assess the County's assets to the geologic hazard. Overall, signification increase in vulnerability would be attributed to changes in population density, impacts from storm events, and new development.

Figure 4.3.6-6 Carbonate Rock and New Development in Sussex County

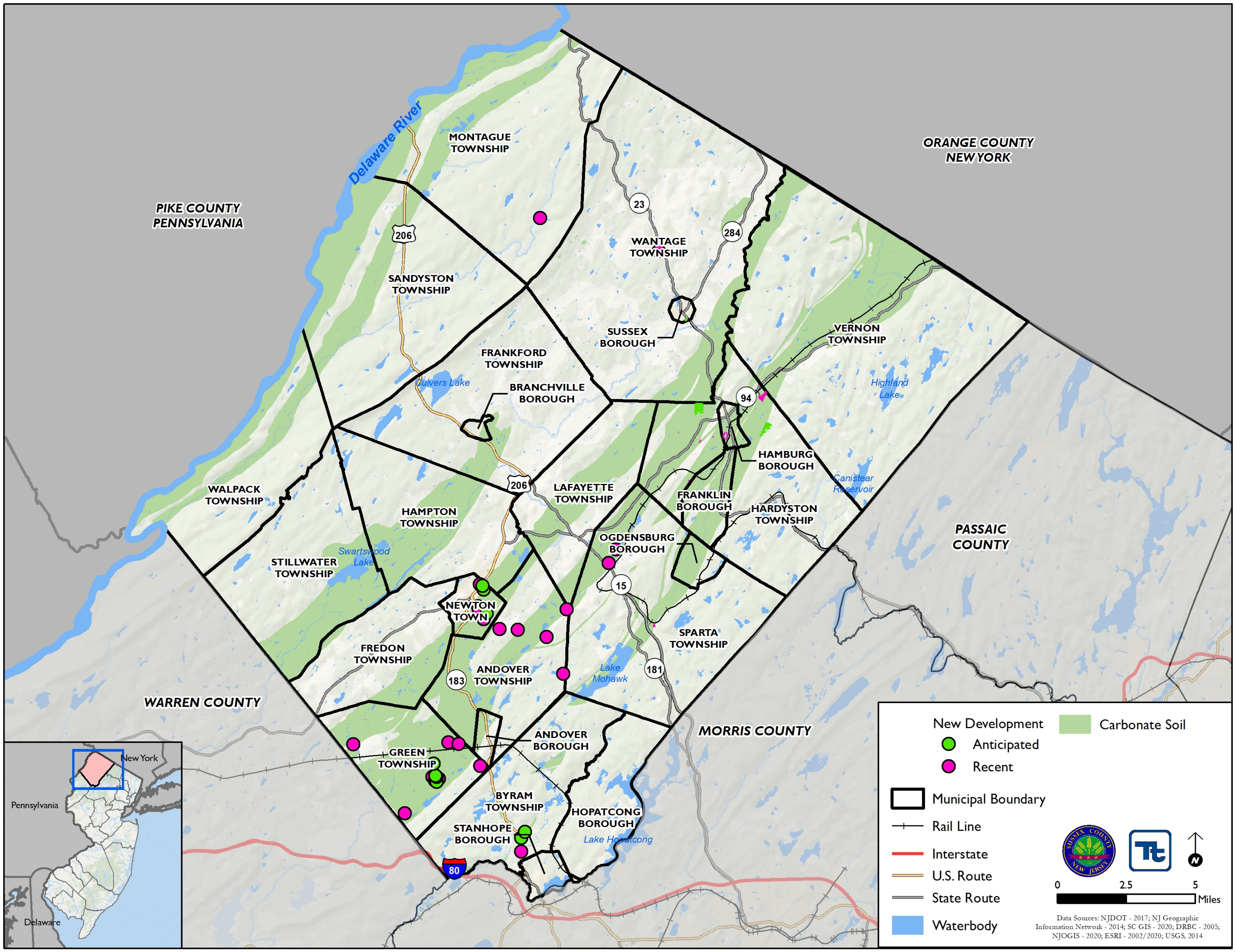


Figure 4.3.6-7 Steep Slope and New Development in Sussex County