5.4.4 GROUND FAILURE

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

HAZARD PROFILE

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

Description

According to the U.S. Geological Survey (USGS), "ground failure" is the term used to describe zones of ground cracking, fissuring, and localized horizontal and vertical permanent ground displacement that can form by a variety of mechanisms on gently sloping valley floors. Ground failure may be caused by surface rupture along faults, secondary movement on shallow faults, shaking-induced compaction of natural deposits in sedimentary basins and river valleys, and liquefaction of loose, sandy sediment (USGS, 2005).

For the purpose of this HMP, the ground failure hazard includes, but is not limited to, landslides, land subsidence, erosion, debris flows and sinkholes, which are further defined as follows:

Landslide: Landslides are a type of slope failure, resulting in a downward and outward movement of rock, debris or soil down a slope under the force of gravity (New York State Disaster Preparedness Commission [NYSDPC], 2008). They are one of the forms of erosion called mass wasting, which is broadly defined as erosion involving gravity as the agent causing movement. Because gravity constantly acts on a slope, landslides only occur when the stress produced by the force of the gravity exceeds the resistance of the material (Organization of American States [OAS], 1991).

Landslides consist of free-falling material from cliffs, broken or unbroken masses sliding down mountains or hillsides, or fluid flows. Materials can move up to 120 miles per hour (mph) or more, and slides can last a few seconds or a few minutes, or can be gradual, slower movements over several hours or days. There are several different types of landslides including:

- Rock Falls: a mass detaches from a steep slope or cliff and descends by free-fall, bounding, or rolling.
- Rock Topples: a mass tilts or rotates forward as a unit.
- Slides: a mass displaces on one or more recognizable surfaces, which may be curved or planar.
- Flows: a mass moves downslope with a fluid motion. A significant amount of water may or may not be part of the mass (OAS, 1991).

Landslides can occur naturally or be triggered by human-related activities. Naturally-occurring landslides can occur on any terrain, given the right condition of soil, moisture, and the slope's angle. They are caused from an inherent weakness or instability in the rock or soil combined with one or more triggering events, such as heavy rain, rapid snow melt, flooding, earthquakes, vibrations and other natural causes. Other natural triggers include the removal of lateral support through the erosive power of streams, glaciers, waves, and longshore and tidal currents; through weathering, and wetting, drying and freeze-thaw cycles in surficial materials; or through land subsidence or faulting that creates new slopes (International Union of Geological Sciences [IUGS], Date Unknown). Long-term climate change can influence landslide occurrences through increased precipitation, ground saturation, and a rise in groundwater level, which reduces the strength and increases the weight of the soil (City of Homer, 2004; U.S. Search and Rescue Task Force [USSARTF], 2007]; USGS, 2005).

Landslides can also be induced, accelerated or retarded by human actions. Human-related causes of landslides can include grading, terrain/slope cutting and filling, quarrying, removal of retaining walls, lowering of reservoirs, vibrations from explosions, machinery, road and air traffic and excessive development. Normally stable slopes can fail if disturbed by development activities. Often, a slope can also become unstable by earthmoving, landscaping, or vegetation clearing activities (New Jersey Office of Emergency Management [NJOEM], 2005; IUGS, Date Unknown). Changing drainage patterns, groundwater level, slope and surface water through agricultural or landscape irrigation, roof downspouts, septic-tank effluent or broken water or sewer lines can also generate landslides (City of Homer, 2004; USSARTF, 2007).

Due to the geophysical or human factors that can induce a landslide event; they can occur in developed areas, undeveloped areas, or any areas where the terrain was altered for roads, houses, utilities, buildings, and even for lawns in one's backyard. Landslides occur in all fifty states with varying frequency. More than half the states have rates sufficient to be classified as a significant natural hazard (American Planning Association, 2007). Depending on where the landslides occur, they can pose significant risks to health and safety or interruption to transportation and other services (Northern Virginia Regional Commission [NVRC], 2006; NYSDPC, 2008).

<u>Land Subsidence</u>: 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 (NYSDPC, 2008; USGS, 2007). 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 is a distinctive topography in which the landscape is largely shaped by the dissolving action of water on carbonate bedrock (usually limestone, dolomite, or marble) (NYSDPC, 2008). In Karst areas, water-soluble stones in the bedrock are gradually dissolved by the groundwater, producing cavities. If the soil layers above them collapse, subsidence on the surface is the result, often causing serious damage to buildings or roads (Federal Institute of Geosciences and Natural Resources (BGR), Date Unknown).

Subsidence is caused by either human actions, alterations to the surface and underground hydrology or natural geologic processes. Such causes include: underground mining of coal, metallic ores, limestone, salt, and sulfur; withdrawal of groundwater, petroleum, and geothermal fluids from underground reservoirs or certain types of rock (evaporate rock [salt and gypsum], or carbonate rock [limestone and dolomite]); collapse of underground mines; dewatering or drainage of organic soils; pumping of groundwater from limestone (sinkholes); wetting of dry, low-density soil (hydrocompaction); natural sediment compaction; melting of permafrost; liquefaction; and crustal deformation. Resource and land development practices, mainly underground mining, groundwater and petroleum withdrawal, and the drainage of organic soil, are key contributors to the problem of subsidence (USGS, 2006). More than 80-percent of the identified subsidence in the U.S. is a consequence of human exploitation of underground water, and the increasing development of land and water resources threatens to exacerbate existing land-subsidence problems and initiate new ones (USGS, 2007).

Another less common cause of land subsidence is a natural phenomenon known as mudboils. Mudboils are volcano-like cones of fine sand and silt that range from several inches to several feet high and from several inches to more than 30 feet in diameter. Active mudboils are dynamic ebb-and-flow features that can erupt and form a large cone in several days, then cease flowing, or they may discharge continuously for several years. Mudboils continuously discharge sediment-laden (turbid) water, pulling sediments from the subsurface, which can lead to gradual land subsidence (Kappel and McPherson, 1998; Kappel et al., 1996).

Land subsidence is one of the most varied forms of ground failure affecting the U.S., ranging from broad regional lowering of land surfaces to local collapses. Regional lowering may aggravate the flood potential or permanently inundate an area, particularly in coastal or riverine settings. Local collapse may damage or destroy buildings, roads, and utilities (Federal Emergency Management Agency [FEMA], 1997; National Research Council Commission on Engineering and Technical Systems, 1991). Other impacts of subsidence include, but are not limited to changes in elevation and slope of streams, canals, and drains; damage to bridges, roads, railroads, storm drains, sanitary sewers, canals, and levees; damage to private and public buildings; and failure of well casings from forces generated by compaction of fine-grained materials in aquifer systems. In some coastal areas, subsidence has resulted in tides moving into low-lying areas that were once above high-tide levels (Leake, 2004).

Typically, land subsidence poses a greater risk to property than to human life. The average annual damage throughout the U.S. from all types of subsidence is estimated to be at least $125 million. Damage consists primarily of direct structural damage and property loss and depreciation of land values. It also includes business and personal losses that accrue during periods of repair (FEMA, 1997).

Erosion: Erosion is the gradual breakdown and movement of land, due to both physical and chemical processes of water, wind, and general meteorological conditions. Natural (geologic) erosion has occurred since the Earth's formation and continues each year at a very slow and uniform rate. There are two types of soil erosion: wind erosion and water erosion. Wind erosion can cause significant soil loss. Winds blowing across sparsely vegetated or disturbed land can pick up soil particles and carry them through the air, causing the soil to be displaced. Water erosion can occur over land or in streams and channels. Water erosion that takes place on land can be caused by rain, shallow sheets of water flowing off the land, or shallow surface flow. Stream channel erosion may occur as the volume and velocity of water flow increases enough to cause movement of the streambed and bank soils (NVRC, 2006).

Debris Flows: Debris flows, sometimes referred to as mudslides, mudflows, lahars, or debris avalanches, are common types of rapidly-moving landslides. They are flowing rivers of rock, earth, and other water-saturated debris that develop when water rapidly accumulates in the ground, during heavy rainfall or rapid snowfall [Federal Emergency Management Agency (FEMA), 2006]. Debris flows generally start on steep hillsides as shallow landslides that liquefy and accelerate to speeds that are typically around 10 miles per hour, but can exceed 35 miles per hour. As they continue to flow down hills and through channels, they grow in volume with the addition of water, sand, mud, boulders, trees, and other materials (National Disaster Education Coalition, Date Unknown).

Sinkholes: Sinkholes are a natural and common geologic feature in areas with underlying limestone, carbonate rock, salt beds, or other rocks that are soluble in water. As the rock dissolves, spaces and caverns develop underground. The land usually stays intact until the underground cavities become too large. If there is not enough support for the land above these voids, a sudden collapse of overlying sediments can occur, creating a sinkhole (USGS, 2008).

There are three general types of sinkholes: collapse, solution and subsidence. Collapse sinkholes are the most common in areas where the overburden is thick with soils and heavy clay. This type can form with little warning and leave behind a deep, steep-sided hole (Cervone, 2003). Solution sinkholes form where no overburden is present and the limestone is exposed at land surface (NVRC, 2006). A bowl-shaped depression (solution sinkhole) naturally forms slowly and continuously as chemical and physical processes erode the rock. Subsidence sinkholes form gradually where the overburden is thin. The dissolving limestone is replaced by sand that falls into the depression and fills the holes. As the sediments fill the depression, water flow is restricted through the bottom hole and the hole begins to retain water. As water accumulates, a lake or pond can form (Cervone, 2003).

Sinkholes can form 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. They can form into steep-walled holes to bowl or cone shaped depressions. Sinkholes can also be triggered by human activities, 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. In urban and suburban areas, sinkholes can destroy highways and buildings (St. John's River Water Management District, 2003).

These types of ground failures, particularly landslides and land subsidence, impose many direct and indirect costs on a community. Direct costs include the actual damage sustained by buildings and property. Indirect costs are harder to measure and include business disruption, loss of tax revenues, reduced property values, loss of productivity, losses in tourism, and losses from litigation. They have a significant adverse effect on infrastructure and threaten transportation corridors, fuel and energy conduits, and communications linkages. Ground failure events have devastating economic effects on Federal, State, local, and private roads, bridges, and tunnels every year. Railroads, pipelines, electric and telecommunication lines, dams, offshore oil and gas production facilities, port facilities, and waste repositories are continually affected by land movement. Road building and construction often exacerbate the landslide problem in hilly areas by altering the landscape, slopes, and drainages and by changing runoff directions and causing channeling, thereby increasing the potential for landslides. Landslides and others forms of ground failure also have adverse environmental consequences, such as dramatically increased soil erosion, siltation of streams and reservoirs, blockage of stream drainages, and loss of valuable watershed, grazing, and timber lands (Spiker and Gori, 2000).

The historic record indicates Greene County has been impacted by ground failure, more specifically landslide and land subsidence, in the past. The County is still vulnerable to this natural hazard. For the purpose of this HMP, only these two types of ground failure will be discussed in more detail. Few incidences of other types of ground failures were found; therefore, no further assessments of erosion, mudslides and sinkholes were deemed necessary, unless they are linked with a landslide or land susceptibility incident.

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. As a result, the landslide hazard is often represented by landslide incidence and/or susceptibility, defined below:

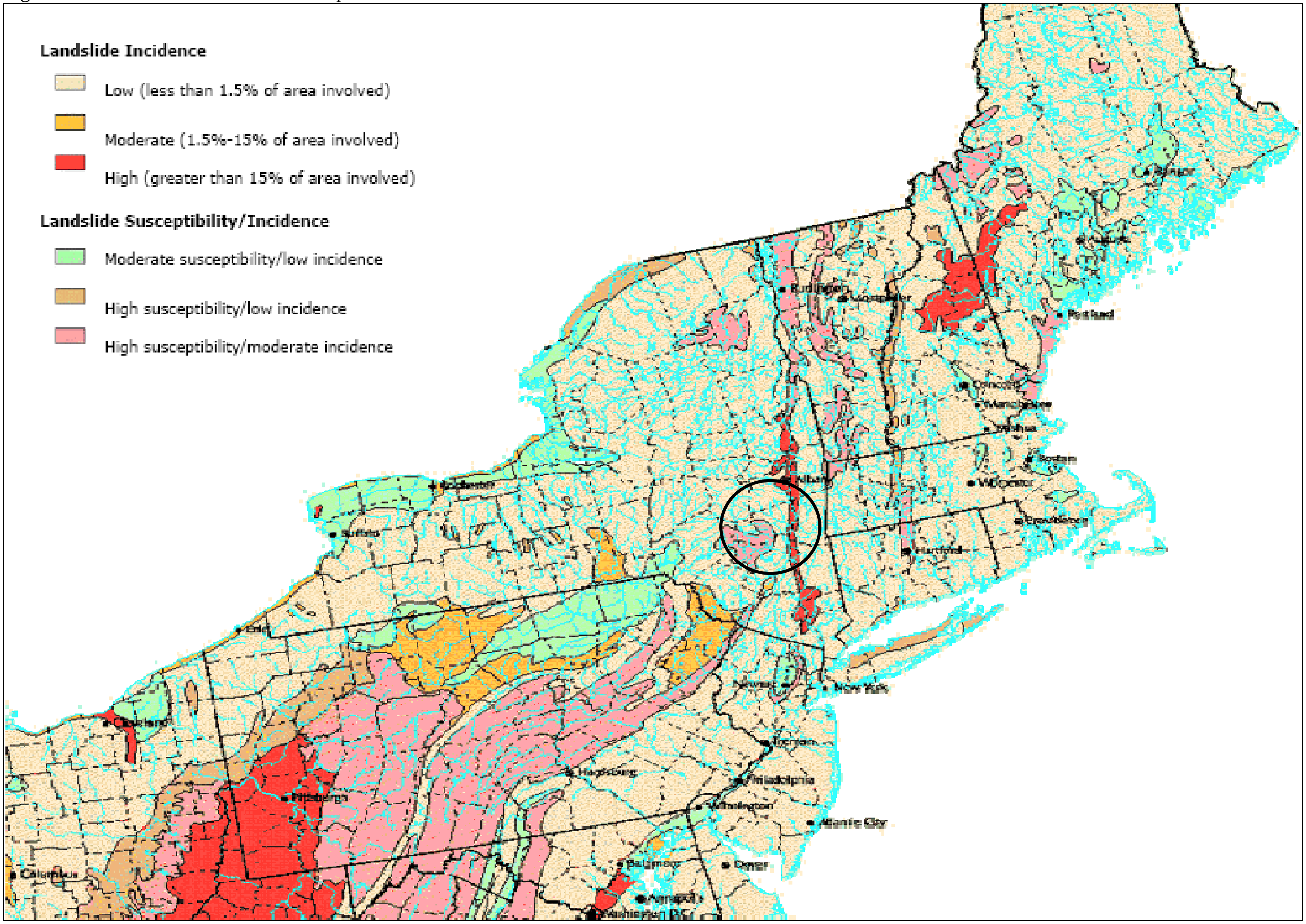
- Landslide incidence is the number of landslides that have occurred in a given geographic area. High incidence means greater than 15-percent of a given area has been involved in landsliding;

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. (Geological Hazards Program, 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 (Geological Hazards Program, Date Unknown; OAS, 1991).

Figure 5.4.4-1 depicts the landslide incidence and susceptibility of the northeastern U.S., identifying areas that have the potential for landslides. These areas are determined by correlating some of the principal factors that contribute to landsliding, such as steep slopes, weak geologic units that lose strength when saturated, and poorly drained rock or soil, with the past distribution of landslides. On Figure 5.4.4-1, warm colors (red, orange, and yellow) indicate unstable and marginally unstable areas and cool colors (green and beige) indicate stable areas (USGS, 2007).

Figure 5.4.4-1. Landslide Overview Map of the Northeast U.S.



Source: Godt, 2007; Hall et al., 1982. Circle indicates the approximate location of Greene County.

Land Subsidence

Several methods are available to monitor the extent and severity of land subsidence. The most basic approaches use repeated surveys with conventional or Global Positioning System (GPS) leveling. Another approach is to use permanent compaction recorders, or vertical extensometers. These devices use a pipe or a cable inside a well casing. The pipe inside the casing extends from land surface to some depth through compressible sediments. A table at land surface holds instruments that monitor change in distance between the top of the pipe and the table. If the inner pipe and casing go through the entire thickness of compressible sediments, then the device measures actual land subsidence. If both groundwater levels and compaction of sediments are measured, then the data can be analyzed to determine properties that can be used to predict future subsidence (Leake, 2004).

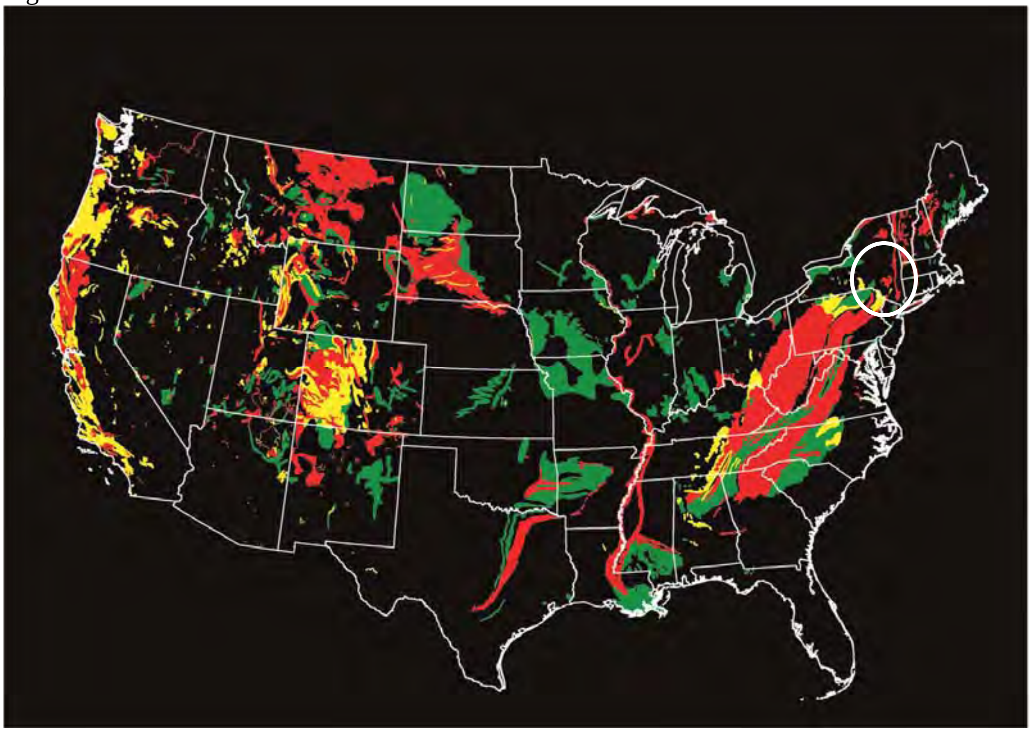
A new mapping tool called Interferometric Synthetic Aperture Radar (InSAR) is a powerful tool that uses radar signals to measure deformation of the earth's crust. This is a critical element in the assessment and mitigation of subsidence. InSAR is capable of remotely sensing small changes in land surface elevation. InSAR is being used by the USGS and others to map and monitor land subsidence caused by the compaction of aquifer systems. The new displacement maps enhance the capabilities of monitoring and managing subsidence caused by the compaction of susceptible aquifer systems (Galloway et al., 2007).

Location

Landslide

The entire U.S. experiences landslides and other ground failure hazards, with 36 states having moderate to highly severe landslide hazards (Figure 5.4.4-2).

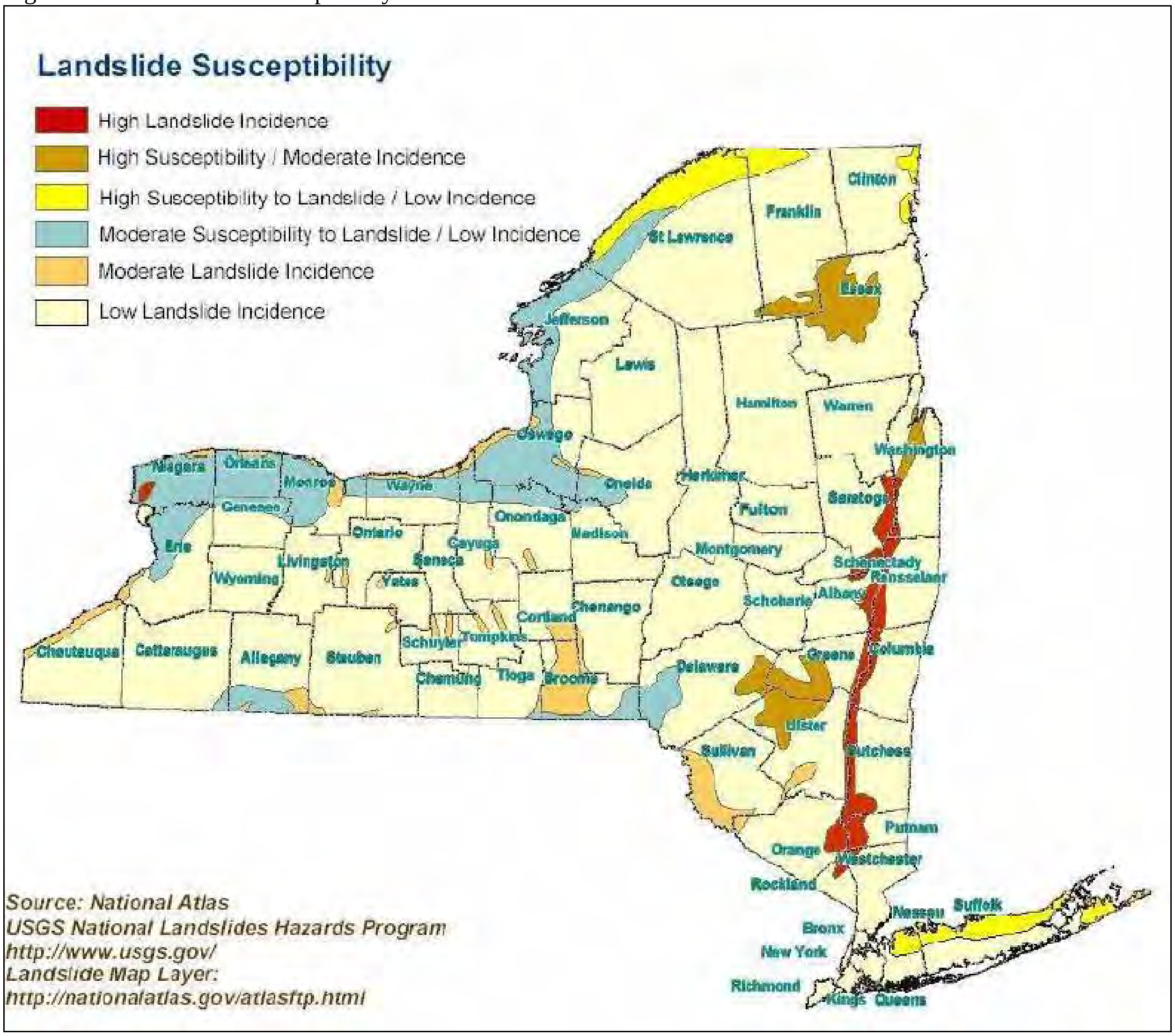
Figure 5.4.4-2. Landslide Potential of the Conterminous U.S. United States



Source: USGS, 2007
Note: Red areas have very high potential, yellow areas have high potential, and green areas have moderate potential. Landslides can and do occur in the black areas, but the potential is low. Map not to scale. Circle indicates the location of Greene County.

The potential for landslides does exist throughout the entire Northeast, including New York State. Scientific and historical landslide data indicate that some areas of northern and eastern New York State have a substantial landslide risk. However, compared to other states, New York State is not identified as a State with having a serious landslide threat. According to information provided by USGS and NYSGS it is estimated that 80-percent of New York State has a low susceptibility to landslide hazard. In general the highest potential for landslides can be found along major rivers and lake valleys that were formerly occupied by glacial lakes resulting in glacial lake deposits (glacial lake clays) and usually associated with steeper slopes. A good example of this is the Hudson and Mohawk River valley (NYSDPC, 2008). A landslide hazard susceptibility map was created by New York State Emergency Management Office (NYSEMO) based on a USGS landslide susceptibility map for New York State (Figure 5.4.4-3). Figure 5.4.4-3 was created including two primary characteristics that define landslide potential, terrain slopes and soil makeup or type.

Figure 5.4.4-3 Landslide Susceptibility in New York State



Source: NYSDPC, 2008

As illustrated in Figure 5.4.4-3 above, the central and southwest section of Greene County has a high susceptibility to landslide with a moderate incidence. These areas within the County are classified as such because of their steep slopes, resulting in bed rock topples and soil slides (also known as debris slides). The remainder of the County has a low landslide incidence. Greene County has been ranked as the 26th county in New York State most threatened by landslides and vulnerable to landslide loss (NYSDPC, 2008).

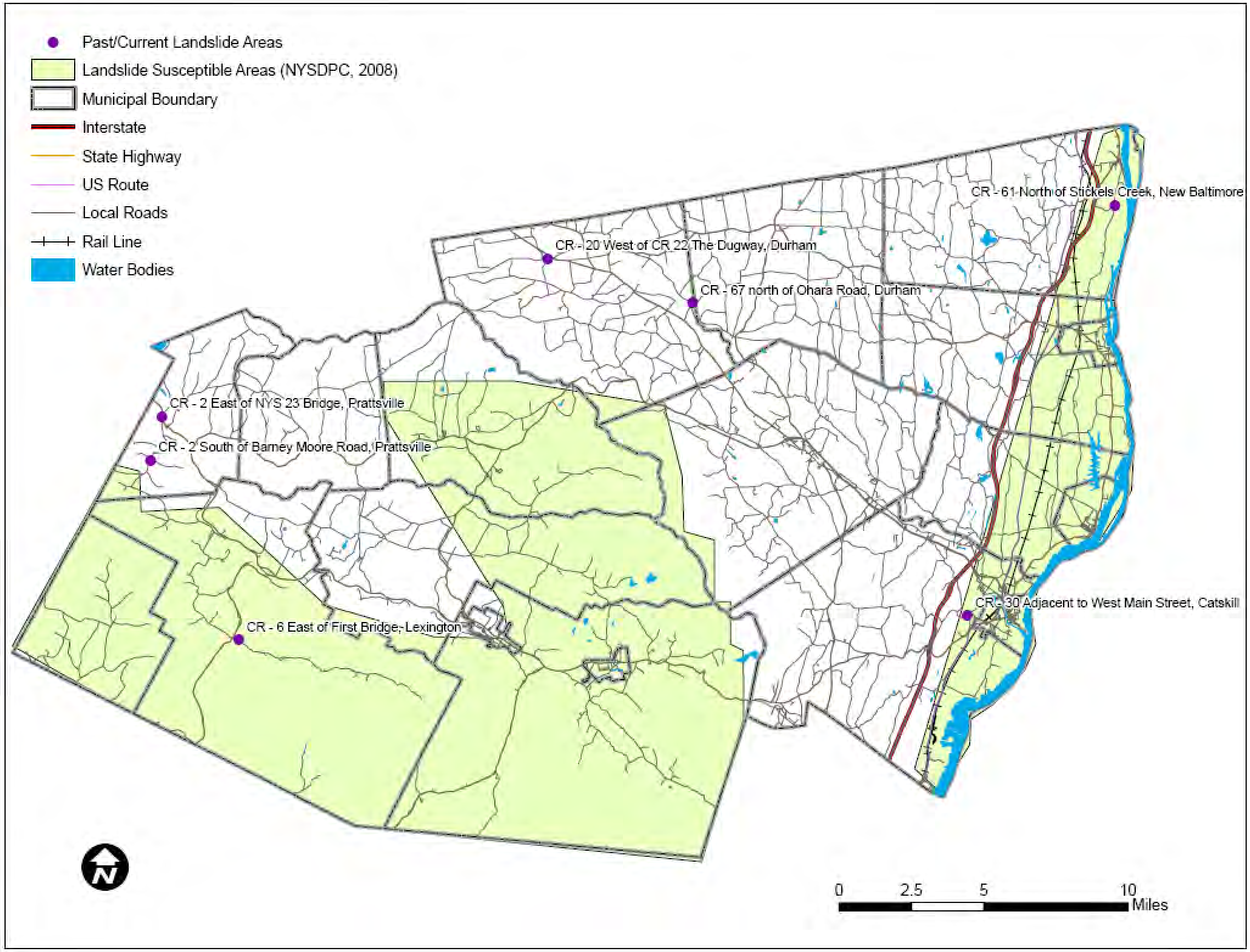
According to Greene County Highway Department ground failure or landslide conditions within the County are generally shear failure events during wet conditions when the ground becomes saturated. The majority of these events occur in the vicinity of creek beds and cause stream bank failure and road failure. Significant events include the road failure along County Route 2 which occurred in the early 1990's and the failure along the creek bed and County Route 6 in 1996-1997 in Lexington. These have both been addressed by FEMA projects. Table 5.4.4-1 summarizes past and current landslide areas on County roads in Greene County. Figure 5.4.4-4 illustrates the past and current landslide areas on County roads in Greene County.

Table 5.4.4-1. Past and Current Landslide Areas in Greene County

Location	Town	Status of Mitigation Project
CR 2 – East of NYS 23 Bridge	Prattsville	Fixed
CR 2 – South of Barney Moore Road	Prattsville	On-going (FEMA funded)
CR 6 – East of First Bridge	Lexington	Fixed (FEMA funded)
CR 20 – West of CR 22 (also known as 'The Dugway')	Durham	On-going (FEMA funded)
CR 30 – Adjacent to West Main Street	Catskill	On-going
CR 61 – North of Stickels Creek	New Baltimore	On-going (FEMA funded)
CR 67 – North of O'Hara Road	Durham	Fixed (Bond funded)

Source: Greene County Highway Department
Note: CR = County Route

Figure 5.4.4-4. Past and Current Landslide Areas in Greene County



Source: Greene County Highway Department

The West Kill tributary to Schoharie Creek has contributed historically to land failure in the Town of Lexington and Village of Hunter. The highest flows are generally associated with the hurricane season in the fall, followed by winter and spring snowmelt or rain-on-snow events. Recent events in April 1987, 1996 and 1999 really impacted the stream corridor, resulting in damages primarily in the form of collapsed bridges and extreme stream bank failure which damaged the adjacent roadways. Long sections of the stream corridor were found to be highly unstable (New York State Floodplain and Stormwater Managers Association, 2002). Flood hazard mitigation projects have been initiated or completed in the West Kill since the Flood of 1996, including the Melodywood Condominium Project in the Village of Hunter, which was completed at a cost of $727,000 in 1997 (GCSWCD, 2005; GCSWCD, Date Unknown).

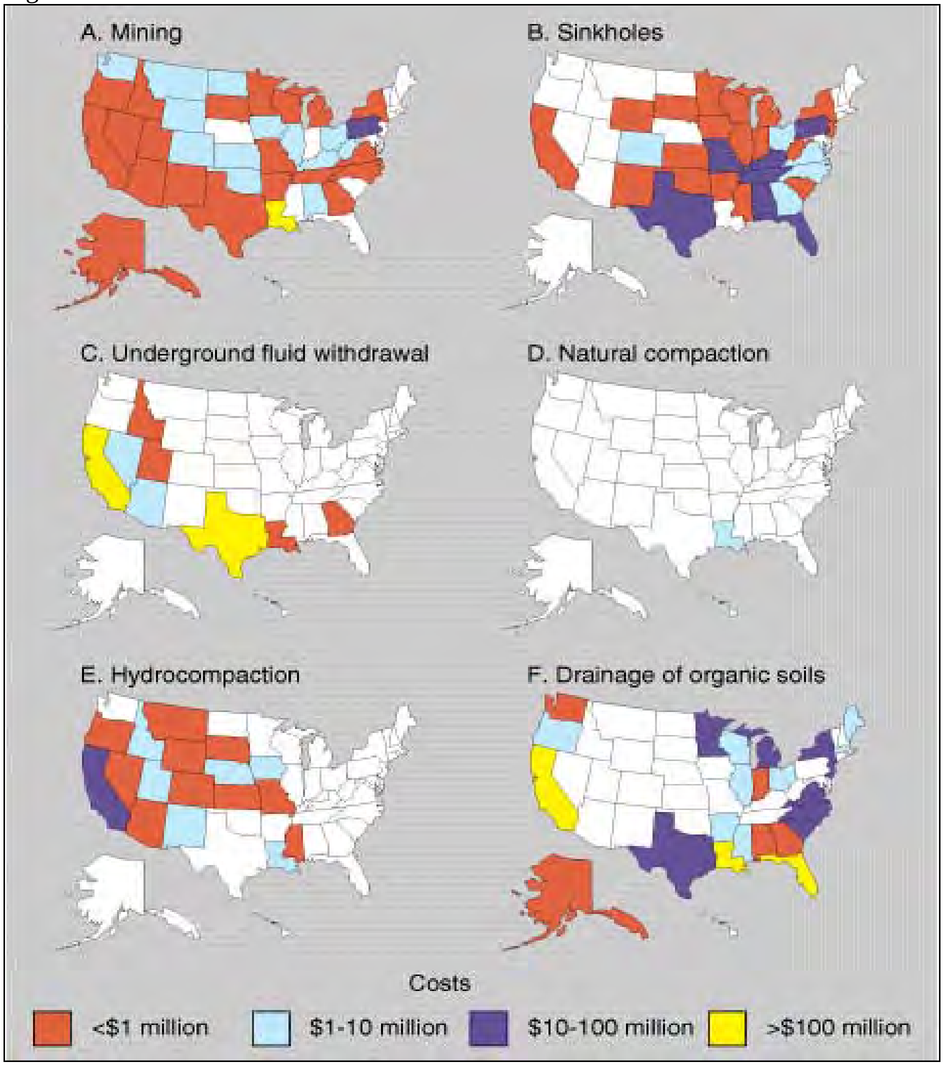
Smaller events included:

- Minor road failure along County Route 67 in the Town of Greenville in 2004-2005 resulting in road settlement of approximately one foot,
- Road failure of approximately one foot on County Route 61 in New Baltimore in 2004-2005,
- Bank failure along County Route 23B in the Village of Catskill in about 1999, and
- Ongoing monitoring of failures along Route 30 in Catskill and Route 20 in Durham.

Land Subsidence

In the U.S., more than 17,000 square miles in 45 states have been directly affected by many types of land subsidence (Galloway et al., 2007). Figure 5.4.4-5 shows the distribution, major types and losses of subsidence affecting the U.S. The costs displayed on this figure are a loss estimate over an unspecified period of time and have only relative magnitudes for each state (Leake, 2004). The potential for land subsidence to occur across New York State is particularly a result of underground mining, sinkholes and drainage of organic soils (Leake, 2004).

Figure 5.4.4-5. Distribution of land subsidence in the U.S

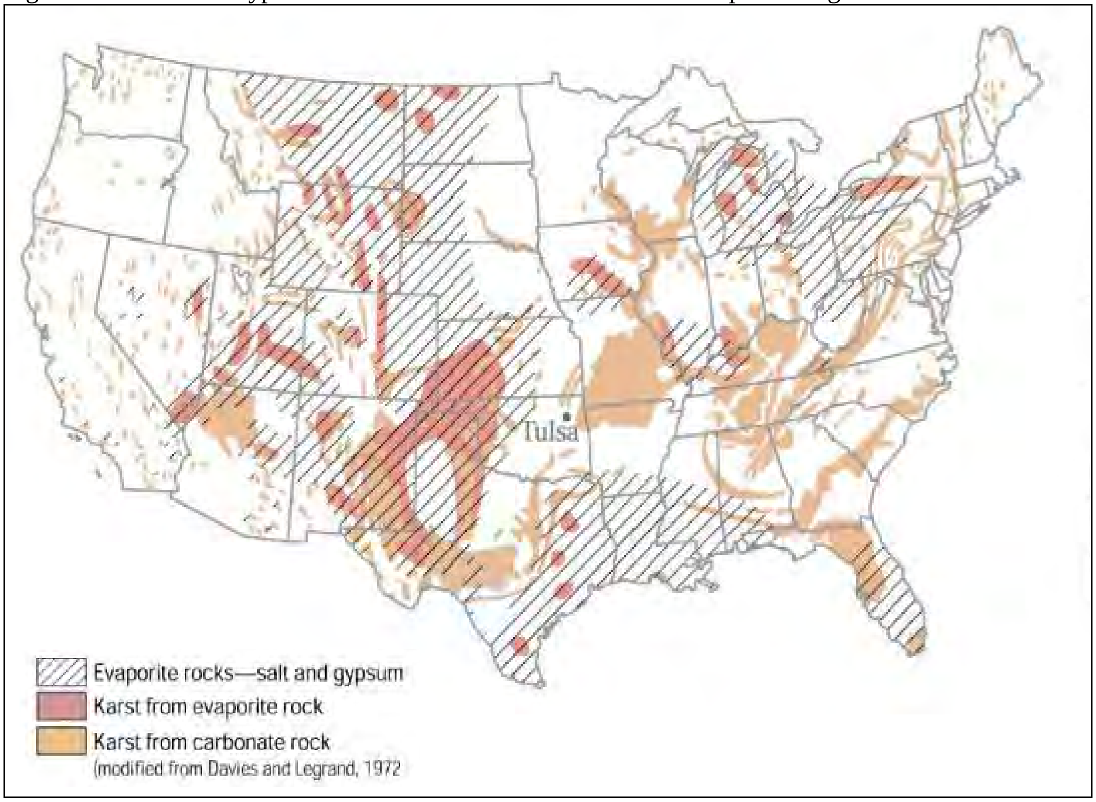


Source: Leake, 2004

The collapse of surficial materials into underground voids (underground mines or cavities) is the most dramatic kind of subsidence. In the U.S., Karst landscapes, which are largely shaped by the dissolving action of water on carbonate bedrock (limestone and dolomite) and evaporites (salt, gypsum, and anhydrite), are often associated with land subsidence (Figure 5.4.4-6). Evaporite rocks underlie about 35 to 40-percent of the U.S., though in many areas they are buried at great depths. These soluble rocks form of cavities beneath the earth's surface. Salt and gypsum are the rock types most often associated with catastrophic sinkhole formation. Their high solubilities permit cavities to form in days to years, whereas cavity formation in carbonate bedrock is a very slow process that generally occurs over centuries to millennia (NYSDPC, 2008; Galloway et al., 2007).

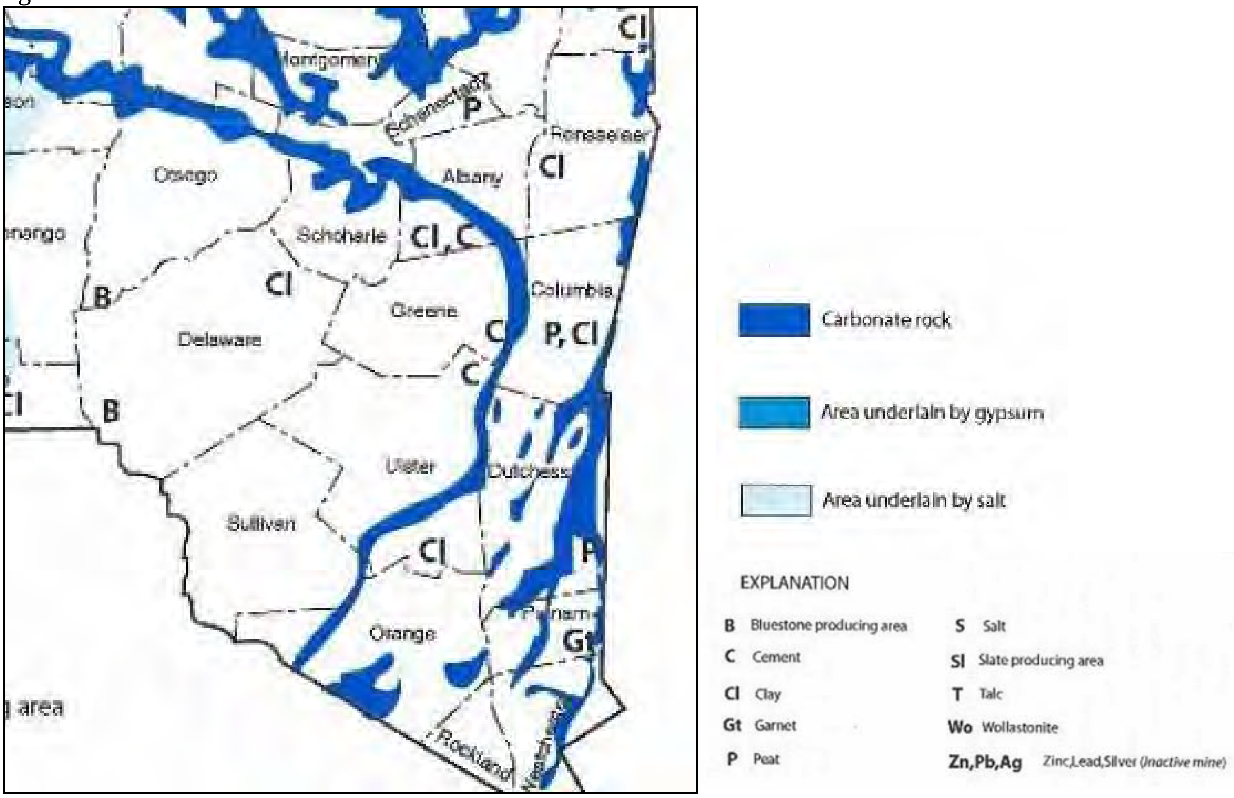
Human activities can expedite cavity formation and collapse in these susceptible materials or even trigger the collapse of pre-existing subsurface cavities. Though the collapsed features tend to be highly localized, their impacts can extend beyond the collapse zone via the potential introduction of contaminants to the groundwater system (NYSDPC, 2008; Galloway et al., 2007). Figure 5.4.4-6 indicates that most of western and central New York State consists of subsurface Karst landscapes from evaporative rock types, increasing the potential risk of land subsidence to occur in this region of the State. Within the eastern section of the State, Karst landscapes exist from carbonate rock, including areas located within the northeastern section of Greene County (Figure 5.4.4-6 and Figure 5.4.4-7).

Figure 5.4.4-6. Rock Types Associated with Land Subsidence Collapse throughout the U.S.



Source: Galloway et al., 2007

Figure 5.4.4-7. Mineral Resources in Southeastern New York State



Source: NYSDPC, 2008 Note: Information provided by the New York State Museum in 2003

Previous Occurrences and Losses

Many sources provided historical information regarding ground failures events in Greene County.

Major ground failure events or periods that have impacted Greene County are summarized in Table 5.4.4-2. Monetary losses associated with each incident are scarce.

5.4.4-2. Ground Failure Events in Greene County

Event Date / Period	Location	Losses / Impact	Source(s)
Early 1990's	Town of Lexington	Road failure on County Route 2	Greene County Highway Department
1996 – 1997	Town of Lexington	Creek bed failure and road failure on County Route 6	Greene County Highway Department
1999	Village of Catskill	Bank failure along County Route 23B	Greene County Highway Department
Landslide March 19, 2003	Not specified	Closed driving lane of NYS Thruway (I87) for one day.	NYSDPC
2004 - 2005	Town of Greenville	Minor road failure along County Route 67 resulting in road settlement of approximately one foot.	Greene County Highway Department
2004-2005	Town of New Baltimore	Road failure of approximately one foot on County Route 61.	Greene County Highway Department
Landslide /	Palenville,	In 2006, the segment of NY 23A from Palenville to	NYSDOT

Event Date / Period	Location	Losses / Impact	Source(s)
Mudslide June/July 2006	Haines Falls	Haines Falls through Kaaterskill Clove was closed to traffic for several months by the New York State Department of Transportation due to landslides/mudslides caused by heavy rains in downstate New York. The road, closed in mid-June was repaired at a cost of roughly $5 million and reopened in late November in time for the Thanksgiving holiday period.	
Landslide Date Unknown	Towns of Catskill and Durham	Ongoing monitoring of failures along Route 30 in Catskill and Route 20 in Durham	Greene County Highway Department
Landslide Date Unknown	Town of Prattsville	CR 2 – East of NYS 23 Bridge	Greene County Highway Department
Landslide Date Unknown	Town of Prattsville	CR 2 – South of Barney Moore Road	Greene County Highway Department
Landslide Date Unknown	Town of Lexington	CR 6 – East of First Bridge	Greene County Highway Department
Landslide Date Unknown	Town of Durham	CR 20 – West of CR 22 (also known as 'The Dugway')	Greene County Highway Department
Landslide Date Unknown	Town of Catskill	CR 30 – Adjacent to West Main Street	Greene County Highway Department
Landslide Date Unknown	Town of New Baltimore	CR 61 – North of Stickels Creek	Greene County Highway Department
Landslide Date Unknown	Town of Durham	CR 67 – North of O'Hara Road	Greene County Highway Department

NYSDPC New York State Disaster Preparedness Commission
USGS U.S. Geological Survey

Probability of Future Events

Landslides

As indicated in the NYS HMP, given the history of landslide occurrences in New York State, it is certain that future landslides will occur. Therefore, the probability of future landslides in New York State is considered 'frequent' (hazard event is likely to occur within 25 years). However, the severity of landslides cannot be determined. Using documented historical occurrences from the NYSGS Landslide Inventory Study to estimate the probability of future landslides, New York State can expect on average approximately two major landslides each year, a greater number of smaller but still significant slides/slumps/flows each year and at least one landslide causing a fatality, is expected once every 12 years. Although historical data indicates a high frequency of landslide occurrence, the NYSGS estimates that 80-percent of the State has a low susceptibility to landslides. The frequency of damaging landslides within and adjacent to New York State has been and can be classified, relative to other higher risk states, as low. However, the fact that high landslide susceptibility exists and landslides have occurred in the past suggests that the states infrastructure and many people are at risk from damaging landslide hazards in New York State.

Land Subsidence

Earlier in this section, the identified hazards of concern for Greene County were ranked. The NYS HMP conducts a similar ranking process for hazards that affect the State. The probability of occurrence, or likelihood of the event, is one parameter used for ranking hazards. Based on historical records and input from the Planning Committee, it is estimated that Greene County will experience 'frequent' ground failure, which may, depending on its severity and where it occurs, affect the general building stock, local economy and may induce secondary hazards such as utility failures, damaged roadways and buildings and transportation delays/accidents/inconveniences and public health concerns.

VULNERABILITY ASSESSMENT

To understand risk, a community must evaluate what assets are exposed or vulnerable in the identified hazard area. The following section discusses the potential impact of the ground failure hazard on Greene County including:

- Overview of vulnerability
- Data and methodology used for the evaluation
- Impact, including: (1) impact on life, safety and health of County residents, (2) general building stock, (3) critical facilities, (4) economy and (5) future growth and development
- Further data collections that will assist understanding of this hazard over time
- Overall vulnerability conclusion

Overview of Vulnerability

Vulnerability to landslide hazards is a function of location, type of human activity, use, and frequency of landslide events. The effects of landslides on people and structures can be lessened by total avoidance of landslide hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Local governments can reduce landslide effects through land use policies and regulations. Individuals can reduce their exposure to hazards by educating themselves on past hazard history of the site and by making inquries to planning and engineering departments of local governments (National Atlas, 2007).

As described earlier in this profile, a landslide hazard susceptibility map was created by NYSEMO based on a USGS landslide susceptibility map for New York State (Figure 5.4.4-3). According to this map, the central and southwest section of Greene County has a high susceptibility to landslide with a moderate incidence. These areas within the County are classified as such because of their steep slopes, resulting in bed rock topples and soil slides (also known as debris slides). The area along the Hudson River in the eastern portion of the County is characterized as a high landslide incidence area and the remainder of the County has a low landslide incidence. Greene County has been ranked as the 26th county in New York State most threatened by landslides and vulnerable to landslide loss. In total, 287.33 square miles or 43% of the County is susceptible to landslides (NYSDPC, 2008).

Data and Methodology

To estimate the population and general building stock vulnerability to this hazard of concern, a GIS layer was created to capture the general landslide susceptible area (hazard area) in Greene County using Figure 5.4.4-3. The areas noted as “high landslide incidence” and “high susceptibility/moderate incidence” were used to generate the hazard area. This GIS layer was then overlaid upon the population and general building stock data available in HAZUS-MH MR3. The Census blocks with their center within the hazard area were used to estimate the population and building stock exposed to this hazard. As noted in the NYS HMP, the limitations of this analysis are recognized and are only used to provide a general estimate. 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 exposed to this hazard, the Census 2000 population was determined for the Census blocks located within the hazard area using the method described above. Approximately 31% of the population is vulnerable. Table 5.4.4-3 lists the population in each jurisdiction vulnerable to this hazard of concern.

Table 5.4.4-3. Population Exposed and Vulnerable to Landslides in Greene County

Jurisdiction	Total Population	Population Exposed	Percentage of Total Population
Town of Ashland	752	0	0
Town of Athens	2,296	1,276	55.6
Town of Cairo	6,355	10	0.2
Town of Catskill	7,457	1,910	25.6
Town of Coxsackie	5,989	4,102	68.5
Town of Durham	2,592	35	1.4
Town of Greenville	3,316	0	0
Town of Halcott	193	193	100
Town of Hunter	1,783	1,729	97.0
Town of Jewett	970	339	34.9
Town of Lexington	830	621	74.8
Town of New Baltimore	3,417	1,007	29.5
Town of Prattsville	665	17	2.6
Town of Windham	1,660	1,575	94.9
Village of Athens	1,695	1,695	100
Village of Catskill	4,392	4,392	100
Village of Coxsackie	2,895	2,895	100
Village of Hunter	490	57	11.6
Village of Tannersville	448	448	100
Sleepy Hollow Lake*	979	979	100
Greene County	**48,195**	**14,968**	**31.1**

Sources: HAZUS-MH MR3, 2007

*The Sleepy Hollow Lake community (SHL) is located within the Town of Coxsackie, Town of Athens and Village of Athens. The population exposed is based on the approximate area (polygon) generated in GIS of the community (2,474 acres). The Town of Coxsackie, Town of Athens and Village of Athens total population includes the population of SHL.

Impact on General Building Stock

As discussed above, to estimate the general building stock vulnerable to this hazard, the associated building replacement values (buildings and contents) were determined for the identified Census blocks within the hazard area. Nearly 39% of the general building stock is vulnerable. Table 5.4.4-4 lists the replacement value (structure and contents) of general building stock exposed to this hazard.

Table 5.4.4-4. General Building Stock Exposed and Vulnerable to Landslides in Greene County

Jurisdiction	Total GBS RV	GBS (RV) Exposed	Percentage of Total GBS RV Exposed
Town of Ashland	$120,010,000	$0	0
Town of Athens	$281,294,000	$155,963,000	55.4
Town of Cairo	$690,593,000	$1,593,000	0.2
Town of Catskill	$1,032,330,000	$356,756,000	34.5
Town of Coxsackie	$397,940,000	$225,424,000	56.6

Jurisdiction	Total GBS RV	GBS (RV) Exposed	Percentage of Total GBS RV Exposed
Town of Durham	$366,723,000	$5,708,000	1.6
Town of Greenville	$404,803,000	$0	0
Town of Halcott	$40,774,000	$40,912,000	100
Town of Hunter	$418,007,000	$375,697,000	97.8
Town of Jewett	$323,021,000	$121,764,000	37.6
Town of Lexington	$136,315,000	$105,028,000	76.8
Town of New Baltimore	$356,974,000	$110,448,000	30.9
Town of Prattsville	$81,346,000	$1,911,000	2.4
Town of Windham	$461,227,000	$444,095,000	96.3
Village of Athens	$224,451,000	$224,451,000	100
Village of Catskill	$586,776,000	$586,776,000	100
Village of Coxsackie	$400,478,000	$400,478,000	100
Village of Hunter	$86,425,000	$23,162,000	19.3
Village of Tannersville	$83,663,000	$83,663,000	100
Sleepy Hollow Lake*	$82,219,000	$82,219,000	100
Greene County	**$6,493,150,000**	**$2,518,385,000**	**38.8**

Source: HAZUS-MH MR3
Notes: RV = Replacement Value.
The total building count and total replacement values are the sum of all seven general occupancy classifications (residential, commercial, industrial, agricultural, religious, government and educational) for that jurisdiction.
The valuation of general building stock and loss estimates determined in Greene County were based on the default general building stock database provided in HAZUS-MH MR3. The general building stock valuations provided in HAZUS-MH MR3 are Replacement Cost Value from R.S. Means as of 2006.
*The Sleepy Hollow Lake community (SHL) is located within the Town of Coxsackie, Town of Athens and Village of Athens. The building stock exposed/vulnerable in SHL was calculated based on the community's approximate area (polygon) generated in GIS (2,474 acres). The Town of Coxsackie, Town of Athens and Village of Athens general building stock exposure includes the inventory for SHL.

Due to a lack of data regarding past losses specific to Greene County or its municipalities, it is not possible at this time to estimate potential future losses to ground failure events.

Impact on Critical Facilities

Table 5.4.4-5 lists the emergency critical facilities (i.e., police, fire, EOCs and hospitals) located within the landslide hazard area.

Table 5.4.4-5. Emergency Critical Facilities Susceptible to Landslides in Greene County

Jurisdiction	Facility Type	Facility Name
Athens (T)	Fire/EMS	West-Athens Limestreet Station #2
Athens (T)	User Defined	Edward J. Arthur Elementary School
Athens (V)	Police	Village of Athens Police Department
Athens (V)	School	Edward J. Arthur ES
Athens (V)	Fire/EMS	Athens Fire Dept
Athens (V)	User Defined	Senior Living Facility
Athens (V)	User Defined	Rivertown Apartments

Jurisdiction	Facility Type	Facility Name
Athens (V)	User Defined	Home for Developmentally Disabled Adults
Athens (V)	User Defined	Athens Fire Department
Athens (V)	User Defined	Athens Community Center
Cairo (T)	School	Cairo-Durham HS
Catskill	User Defined	Catskill United Methodist Church
Catskill (T)	User Defined	Catskill Masonic Lodge 468
Catskill (V)	Police	Village of Catskill Police Department
Catskill (V)	Police	Greene County Sheriff Department Headquarters
Catskill (V)	School	Catskill MS
Catskill (V)	School	Grapeville Baptist School
Catskill (V)	Fire/EMS	Catskill East Side Station
Catskill (V)	Fire/EMS	Catskill Fire Company
Catskill (V)	User Defined	Catskill DPW
Catskill (V)	User Defined	Catskill Correctional Facility
Catskill (V)	User Defined	EMS/Shelter Facilities
Catskill (V)	User Defined	CATSKILL CSD
Catskill (V)	User Defined	Catskill High School
Catskill (V)	User Defined	Catskill Middle School
Catskill (V)	User Defined	Catskill Elementary School
Coxsackie (T)	Police	NYS Police Town of Coxsackie Satellite Station
Coxsackie (T)	User Defined	Coxsackie Correctional Facility
Coxsackie (T)	User Defined	Greene Correctional Facility
Coxsackie (V)	Police	Village of Coxsackie Police Department
Coxsackie (V)	School	Coxsackie-Athens MS
Coxsackie (V)	School	Coxsackie ES
Coxsackie (V)	Fire/EMS	D.M. Hamilton Steamer #2
Coxsackie (V)	Fire/EMS	Coxsackie Hose #3
Coxsackie (V)	User Defined	Coxsackie Athens CSD
Coxsackie (V)	User Defined	Coxsackie Campus
Durham (T)	School	Durham ES
Greenville (T)	School	Scott M. Ellis ES
Greenville (T)	School	Greenville MS
Greenville (T)	School	Greenville HS
Hunter (T)	Police	Town of Hunter Police Department
Hunter (T)	Police	NYS Police Town of Hunter Satellite Station
Hunter (T)	Fire/EMS	H.D. Lane Volunteer Fire Co.
Hunter (T)	Fire/EMS	Haines Falls Volunteer Fire Co.
Hunter (T)	User Defined	Catskill Bruderhof
Jewett (T)	Fire/EMS	East Jewett Fire Dept.
Lexington (T)	Fire/EMS	Town of Lexington Fire co.
Lexington (T)	Fire/EMS	Town of Lexington Fire Station #2

Jurisdiction	Facility Type	Facility Name
Lexington (T)	User Defined	Town Hall
Lexington (T)	User Defined	Town Highway
New Baltimore (T)	Fire/EMS	Cornell H&L Fire Co.
Tannersville (V)	Fire/EMS	Tannersville Fire Dept.
Tannersville (V)	User Defined	Village Hall/Court
Tannersville (V)	User Defined	Village Garage
Tannersville (V)	User Defined	Hunter Tannersville CSD
Tannersville (V)	User Defined	Hunter-Tannersville Middle and High School
Tannersville (V)	User Defined	Tannersville Fire and Rescue
Windham (T)	Police	Town of Windham Police Department
Windham (T)	Fire/EMS	Hensonville Hose Co.
Windham (T)	Fire/EMS	Windham Hose Co. #1
Windham (T)	Fire/EMS	Windham Ambulance
Windham (T)	User Defined	Windham Ashland Jewett CSD
Windham (T)	User Defined	Windham-Ashland-Jewett Central School
Windham (T)	User Defined	School Bus Garage
Windham (T)	User Defined	Town Hall
Windham (T)	User Defined	Main Car Fuel Storage Center

Source: HAZUS-MH MR3, 2007 and Planning Committee

Impact on the Economy

Ground failure's impact on the economy and estimated dollar losses are difficult to measure. As stated earlier, landslides and other ground failure 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.

Direct building losses are the estimated costs to repair or replace the damage caused to the building. The estimated replacement value of general building stock located in landslide susceptible areas is $2,518,385,000. This estimate represents nearly 39% of the total building stock value inventory in the County. These dollar value losses to the County's total building inventory replacement value would impact Greene's tax base and the local economy.

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 the County. It is anticipated that new development within the high landslide incidence and high susceptibility/moderate incidence areas identified by USGS will be exposed to such risks.

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.

Overall Vulnerability Assessment

Ground failure can significantly impact the County's population health and safety, general building stock and economy. The overall hazard ranking determined for the ground failure hazard is 'Medium' (see Tables 5.3-3 through 5.3-6).