5.4.4 Geological Hazards

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

5.4.4.1 Hazard Profile

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

Description

Geological hazards are any geological or hydrological processes that pose a threat to human lives and natural lands. These types of hazards can include earthquakes, landslides and other slope failures, mudflows, sinkholes, and flooding. For the purpose of this HMP update, landslides, land subsidence, and mudboils will be discussed in this hazard profile. Earthquakes and flooding are addressed in separate sections of this plan, Section 5.4.2 (Earthquake) and Section 5.4.3 (Flood), respectively.

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).

Figure 5.4.4-1. Photograph of the 1993 Tully Farm Road Landslide (Largest New York State Landslide in the Past 75 Years)

Source: Jäger and Wieczorek, 2001

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

Although gravity acting on an over-steepened slope is the primary reason for a landslide, there are other contributing factors that include:

- Erosion by rivers, glaciers, or ocean waves create over-steepened slopes
- Rock and soil slopes are weakened through saturation by snowmelt or heavy rains
- Earthquakes create stresses that make weak slopes fail
- Earthquakes of magnitude 4.0 and greater have been known to trigger landslides
- Volcanic eruptions produce loose ash deposits, heavy rain, and debris flows
- Excess weight from accumulation of rain or snow or stockpiling of rock or ore, from waste piles or man-made structures may stress weak slopes to failure.(USGS 2016).

Landslides may be triggered by both natural and human-caused changes in the environment, including heavy rain, rapid snow melt, steepening of slopes caused by construction or erosion, earthquakes, and changes in groundwater levels. Areas generally prone to landslide hazards include previous landslide areas, bases of steep slopes, bases of drainage channels, developed hillsides, and areas recently burned by forest and brush fires (NYS DHSES 2014). Human activities that contribute to slope failure include altering the natural slope gradient, increasing soil water content, and removing vegetation cover. Warning signs for landslide activity include:

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavement, or sidewalk
- Soil moving away from foundations
- Ancillary structures, such as decks and patios, tilting and moving relative to the main house
- Tilting or cracking of concrete floors and foundations
- Broken water lines and other underground utilities
- Leaning telephone poles, trees, retaining walls, or fences
- Offset fence lines
- Sunken or down-dropped road beds
- Rapid increase in creek water levels, possibly accompanied by increased turbidity
- Sudden increase in creek water levels while rain is still falling or just recently ended
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb
- A faint rumbling sound that increases in volume as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together (USGS 2013).

Landslide materials may be composed of natural rock, soil, artificial fill, or a combination of these materials. They can be caused by numerous factors such as volcanic eruptions, earthquakes, fire, storms, and by human land modifications. Landslides can transpire quickly with little to no warning. Depending on the location of a landslide, they can pose significant risks to health, safety, transportation, as well as other services. Annually, landslides in the U.S. cause approximately $3.5 billion in damages and between 25 and 50 fatalities (NYS DHSES 2014).

Land Subsidence

Land subsidence can be defined as depressions, cracks, and sinkholes in the earth's surface which can threaten people and property. Land subsidence is caused by a loss of subsurface support which may result from a number of natural and human caused occurrences including subsurface mining, the pumping of oil, or ground water. Subsidence depressions, which normally occur over many days to a few years, may damage structures with low strain tolerances such as dams, factories, and utility lines. The sudden collapse of the ground surface to form sinkholes, many yards wide and deep, within the span of a few minutes to a few hours poses immediate threat to life and property (NYS DHSES 2014).

A sinkhole is a depression in the ground that has no natural external surface drainage. When it rains, all of the water stays inside the sinkhole and usually drains into the subsurface. Sinkholes are most common in areas underlain by karst terrain (limestone, carbonate rock, salt beds, and gypsum) and can occur without warning. These areas are where the types of rock below the land surface can naturally be dissolved by groundwater. When rainfall moves down through the soil, these types of rock begin to dissolve, creating underground spaces and caverns, leading to sinkholes (USGS 2019).

Land subsidence is one of the most varied forms of ground failure affecting the United States, 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 (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 United States 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).

Mudboils

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).

Figure 5.4.4-2. Mudboil/Depression Area in the Tully Valley

Source: Kappel and McPherson, 1998

Location

Landslides

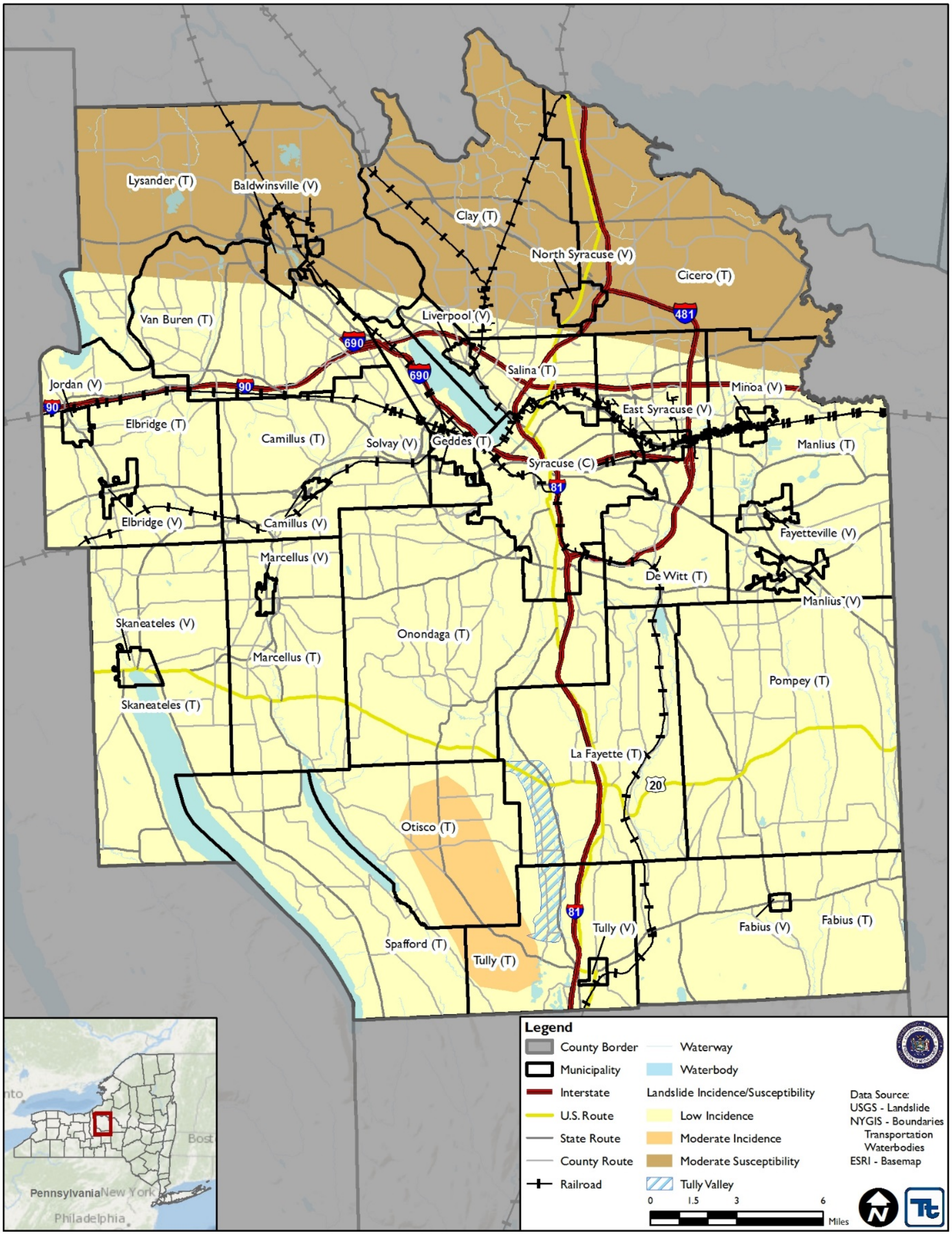
The potential for landslides exists across New York State; however, 80-percent of the state has a low susceptibility of landslides. Figure 5.4.4-3 indicates that a majority of Onondaga County has low incidence of landslides. The northern portion of the county is shown as having moderate susceptibility to landsliding and low incidence of occurrence. A small area in the center of the southern portion of the county has moderate incidence.

Areas of steep slopes are typically at greatest risk for landslide occurrences. Figure 5.4.4-4 shows areas in Onondaga County with slopes greater than 15-percent. Areas of steeper slopes increase the likelihood that landslides will occur, especially during periods of heavy rain or human activity. However, the primary cause of landslides is the influence of gravity acting on weakened materials that make up a sloping area (Conners 2018; USGS 2004). The figure shows steep slope areas throughout Onondaga County, with many steep slopes located around the lakes in southwestern Onondaga County and areas in and around Tully Valley.

Land Subsidence

Areas underlain by carbonate bedrock are the most susceptible to land subsidence and sinkhole incidents. Areas of limestone, carbonate rock, salt beds, or rocks that can naturally be dissolved by groundwater are more prone to sinkholes. As the rock dissolves, spaces and caverns develop underground, leading to sinkholes (USGS 2018). Figure 5.4.4-5 illustrates the areas of carbonate bedrock in Onondaga County. The figure shows bands of dolomite in northern and central Onondaga County, bands of limestone in central Onondaga County, and small bands of limestone in southern Onondaga County. These areas of the county may experience more sinkholes than other parts based on the rock underlaying these parts.

Figure 5.4.4-3. Landslide Susceptibility in Onondaga County



Note: *According to this figure, the northern portion of the county is located within the moderate susceptibility to landsliding with the remainder of the county having low landslide incidence. There is a small portion of the county with moderate landslide susceptibility in the southern portion of the county.*

Figure 5.4.4-4. Steep Slope Areas in Onondaga County

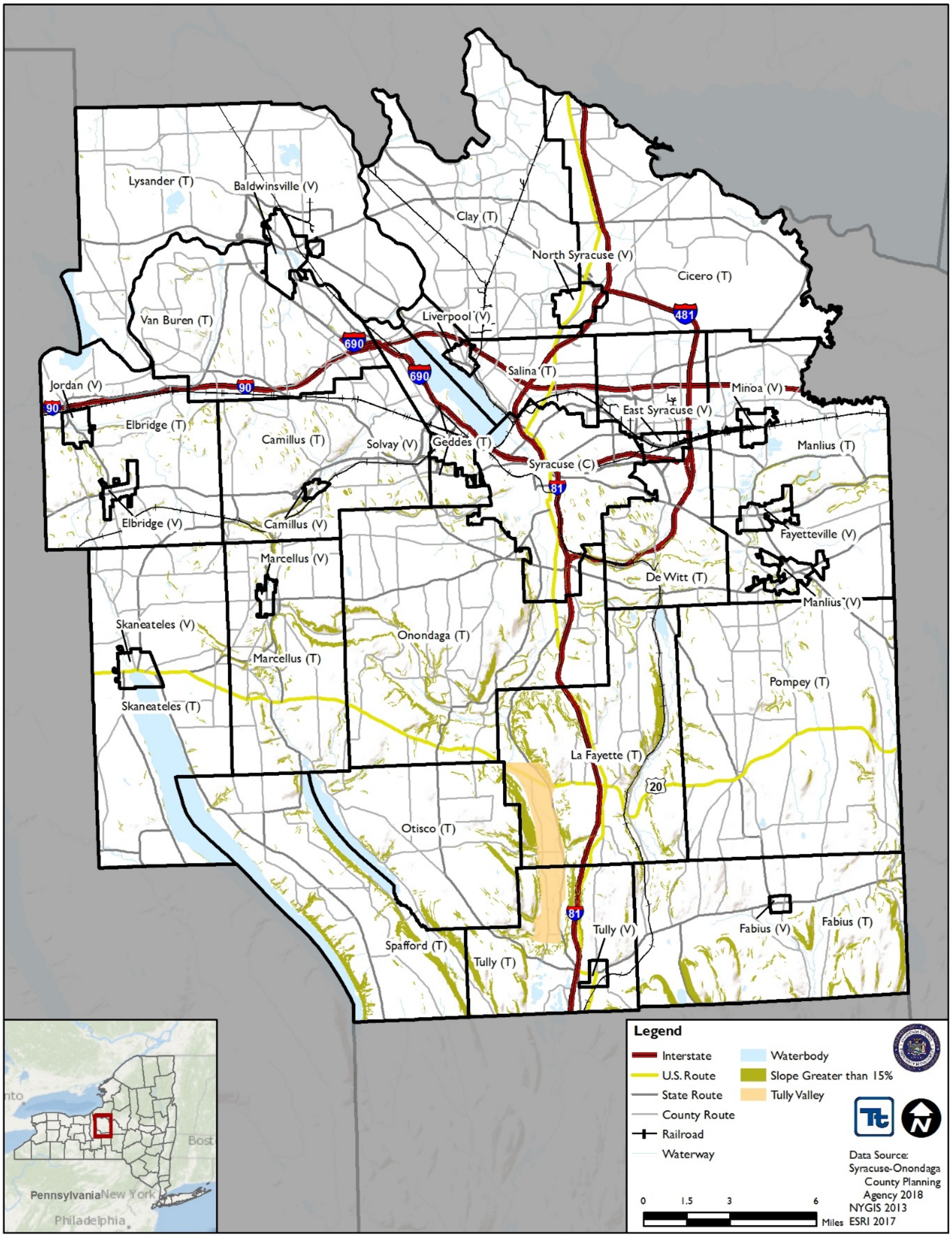
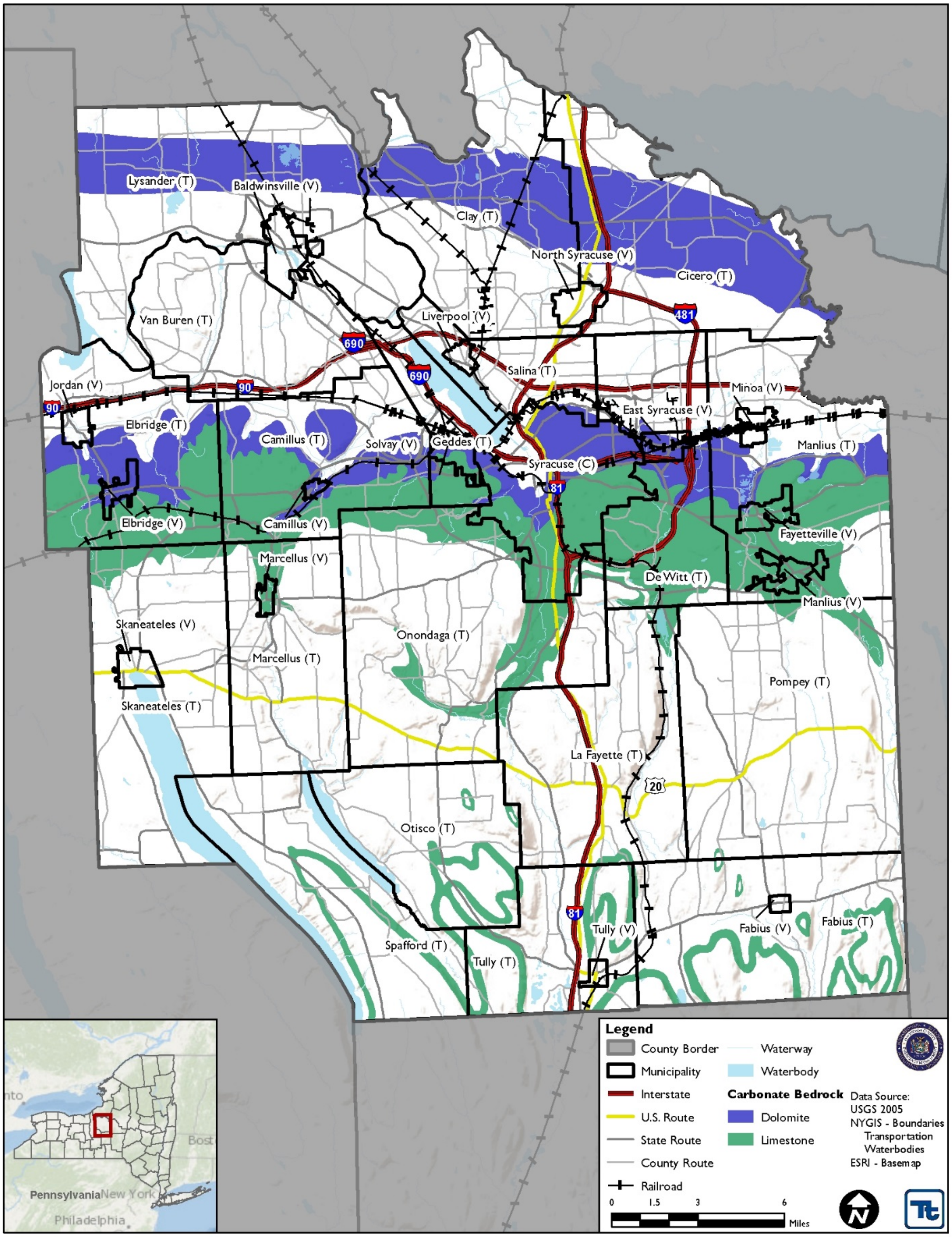
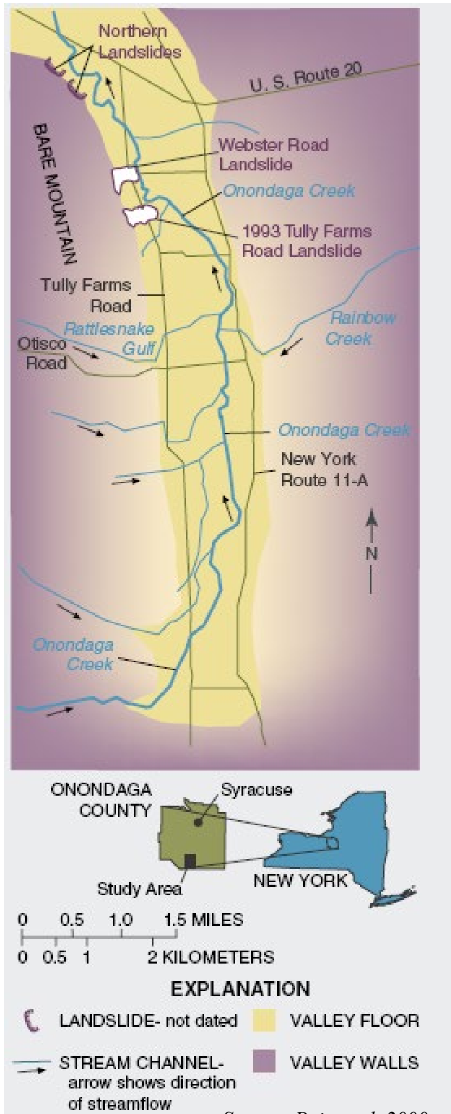


Figure 5.4.4-5. Carbonate Bedrock Areas in Onondaga County.



Tully Valley



Source: Pair et al. 2000

Tully Valley is located in the Finger Lakes region of New York State in Onondaga County. Tully Valley is a glacially carved valley where lake sediments were deposited. It is approximately six miles long and, on average, about one mile wide along the valley floor. Onondaga Creek flows north through the valley and drains to Lake Ontario. The valley walls are forested and steep and generally consist of colluvium (weathered bedrock) and glacial till (dense soils) over bedrock. The valley floor consists of more than 400 feet of glacial lake deposits (gravel and sand grading upward to silt and clay at land surface). The valley floor terrain slopes gently (generally less than 10°) from the valley walls toward the center of the valley. At land surface the valley floor is mantled with a 60-foot-thick silt and clay unit; some of the clays within this unit are saturated and extremely soft. These materials were deposited during and after the last period of glaciation, which ended approximately 14,000 years ago. The upstream (south) end of the valley is covered by coarser sediments that form the head of the Tully (Valley Heads) Moraine. Alluvial fans emanate from the tributary valleys of Rainbow Creek and Rattlesnake Gulf, halfway up the valley and just north of Otisco Road (Kappel et al, 1996). Land use in Tully Valley is mostly agricultural and low-density residential. Brine mining (solution mining of salt) took place from 1889 to 1986 at the southern end of the valley. As a result of the former brine mining operations, the valley walls and bedrock beneath them contains fractures. Also, north of the Tully Moraine, a section of the valley floor has sunk from the salt removal that occurred beneath it (Wieczorek et al., 1998; Tamulonis, 2007; Pair et al., 2000; Onondaga Environmental Institute, Date Unknown).

Tully Valley has a landslide history dating back to 9,870 14C yr B.P. (before present). The Department of Geography at the University of Heidelberg and the USGS developed a landslide inventory ranging from 14,000 years ago to the present day based on the interpretation of aerial photographs of the Tully Valley area. This inventory indicated that 73 total landslides have occurred, of which 22-percent (16) were classified as active/recently-active (present to 200 years), 52-percent (38) fall in the category old (200 to 10,000 years), and 26-percent (19) are termed ancient (10,000 to 40,000 years) (Jäger and Wieczorek, 2001; Tamulonis, 2007).

The most recent and most documented landslide in Onondaga County and the Tully Valley area occurred on April 27, 1993 along the west wall of the Valley at the base of Bare Mountain. Debris from the landslide covered 1,500 feet of Tully Farms Road with more than 15 feet of mud. Three homes were destroyed due to this event. Most residents were away from their homes at the time, and no fatalities or serious injuries were reported (Pair et al., 2000). According to the NYSGS, this slide was the largest to have occurred in the State in more than 75 years. The location of this landslide, as well as other recent landslide events, is depicted in Figure 5.4.4-7.

The 1993 Tully Valley landslide and smaller recently-active landslides in the area, particularly along the base of Bare Mountain, have resulted in property damage, suggesting that landslides are an important hazard and potential risk within this particularly area of Onondaga County (Jäger and Wieczorek, 2001). In the aftermath of the 1993 Tully Valley landslide, residents and public officials became concerned about the potential landslide hazards in settings similar to the Tully Valley within the county. Federal and State environmental agencies and several universities conducted many studies and investigations in the Tully Valley area to identify the cause of landslides and assess the potential for future landslides (Pair, et al., 2000). Also, the USGS and the NYSGS prepared a map of 160 square miles of southern Onondaga County showing the susceptibility to landsliding categorized as low, moderate, or high. The map has been used by the towns of Tully and LaFayette and agencies of Onondaga County. Results of investigations for landslide potential, followed by mitigation efforts before land-use development, help prevent or reduce most adverse economic consequences of landslides (USGS, 1996; Kappel and McPherson, 1998).

The Bluffs (along Bluffview) in the Town of Manlius overlooking Limestone Creek have experienced geological hazard events in the past. According to an Engineering Feasibility Study conducted in 2005, four attached condominiums along Bluffview in the Town of Manlius were constructed (before 1994) close to the edge of an approximately 80-foot high bluff overlooking Limestone Creek (The Bluffs). In May 2002, an approximate 40-foot wide area of the bluff slid into Limestone Creek carrying the ground surrounding the south-side of condominium unit 8181. The earth slope failed after a heavy rain event. According to the study, a glacial till layer (fine-grained silt, sand, gravel, cobbles and boulders) supports the floors and footings of the condominiums and is susceptible to erosion by precipitation and roof runoff. The bedrock below the soil is 'thinly bedded and fractured limestone that is susceptible to surface unraveling from weathering." The study also states that deeper large scale instability in the rock cannot be ruled out, and without repair the building's structure will eventually suffer (John P. Stopen Engineering Partnership, 2005). Figure 5.4.4-6 shows an aerial photograph of Limestone Creek and the Bluffs in Manlius on October 26, 2006.

Figure 5.4.4-6. Aerial Photograph of Limestone Creek and The Bluffs in Manlius on October 26, 2006

Source: Novek, 2009

Most incidences within Onondaga County have not been well documented. This is because they either had no immediate impact or they occurred in isolated locations with few people aware of their existence. Therefore, information on actual landslide locations within the county is limited other than the information found regarding the 1993 landslide. Although most landslide events have gone unnoticed within the county, slides of varying severity over time have changed land contours, disrupted surface-water flows, altered ground-water levels, and/or modified the quality of water that ultimately flows to Onondaga Lake (OLP, 2005-2006).

These rock types and conditions have contributed to subsidence events in the Tully Valley area of Onondaga County. Documented subsidence within the Tully Valley area has been attributed to:

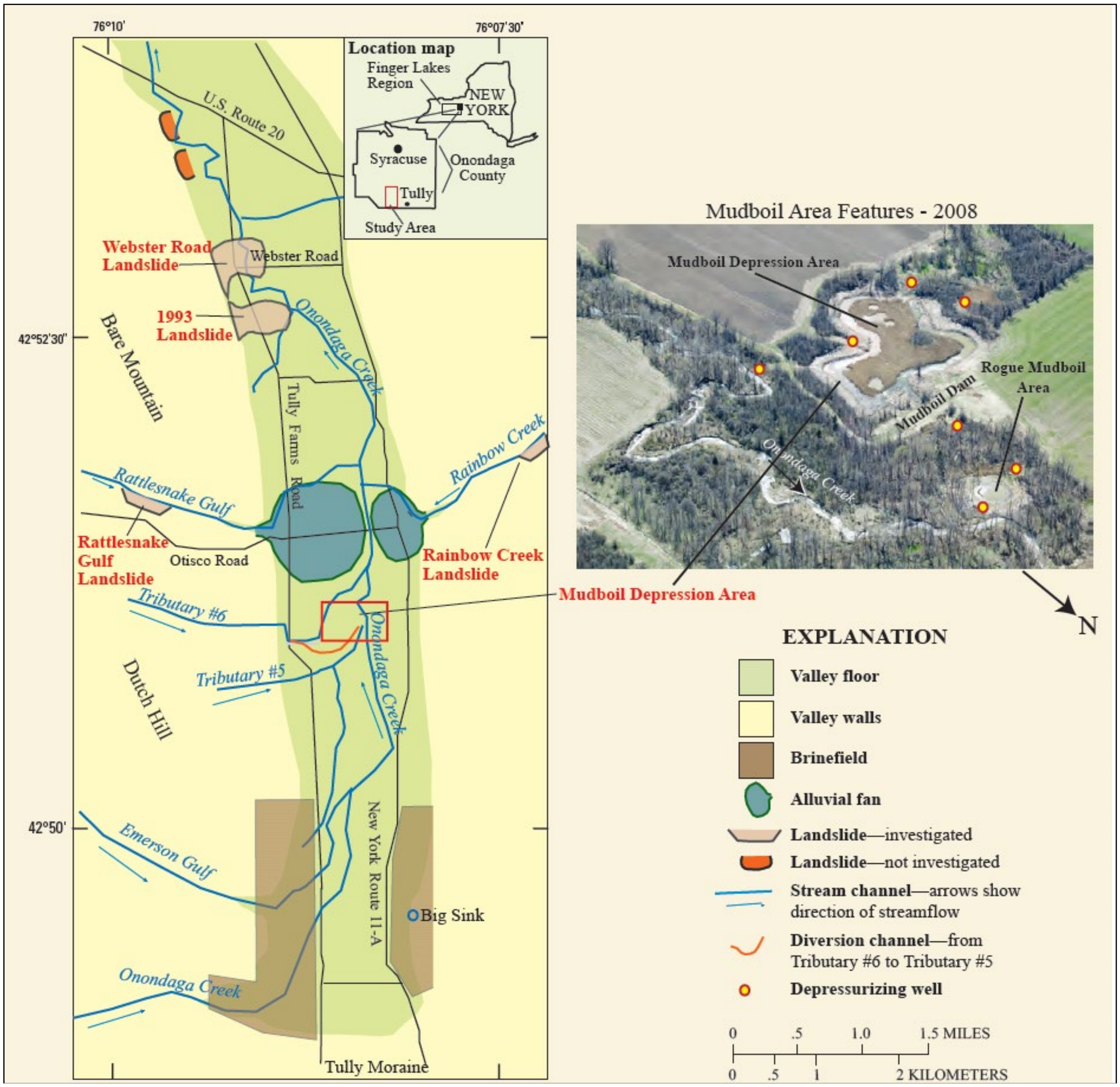
- Discharge of mudboil sediments;
- Salt-solution mining; or
- Aquifer dewatering of fine-grained deposits (Kappel, 2009).

The discharge of mudboil sediments and salt-solution mining have been the main causes of subsidence within the Tully Valley, and are further described below:

Mudboils

Mudboils have been documented in the Tully Valley since the late 1890s and have continuously discharged sediment-laden (turbid) water into nearby Onondaga Creek since the 1950s. This discharge causes turbidity in the Creek, which is a tributary to Onondaga Lake. Mudboil activity has caused a gradual land-surface subsidence that has led to the rerouting of a major petroleum pipeline and a buried telephone cable, and caused two road bridges to collapse. Figure 5.4.4-7 illustrates the approximate location of where mudboil activity continues to occur in southern Onondaga County (Kappel, 2009).

Figure 5.4.4-7. Geographic Features of Tully Valley



Source: Kappel, 2009

Mudboil discharge within the county is driven by artesian pressure in unconsolidated sediments that are confined by a 60-foot layer of silt and red clay. This process, once begun, has been self-propagating. Artesian pressures are about 20 feet above land surface over most of the Tully Valley floor but exceed 30 feet above land surface along Onondaga Creek where Rattlesnake Gulf and Rainbow Creek enter the Tully Valley. The source of artesian pressure is recharge from the Tully (Valley Heads) Moraine at the south end of the valley, and the alluvial fans of Rattlesnake Gulf and Rainbow Creek (Kappel et al., 2009).

Mudboils have been observed in the Tully Valley for nearly 100 years. Most of the mudboils are in two areas of the Tully Valley: (1) the Onondaga Creek mudboil "corridor," which is 1,500 feet long and 300 feet wide along Onondaga Creek, south of Otisco Road, and (2) the 5-acre area of subsidence, locally known as the mudboil/depression area (MDA), just west of the southern (upstream) end of the mudboil corridor.

The earliest known mudboil in Tully Valley, reported in the Syracuse Post-Standard on October 19, 1899, was apparently localized and short-lived. From 1899 to the 1970s, the mudboils within the Onondaga Creek mudboil corridor appeared and dissipated over a span of several weeks to a few months but had no long-term effect on the water quality of Onondaga Creek and Onondaga Lake, 20 miles downstream. Active mudboils became increasingly persistent during the mid-1970s, causing turbid discharges that degraded the quality of Onondaga Creek. Before the mid-1980s, relatively fresh groundwater was discharged from the MDA. Since then, however, the discharge has been more brackish, and land subsidence (locally as much as 15 feet) has expanded outward. In June 1991, a new mudboil appeared in Onondaga Creek just upstream of the Otisco Road Bridge, and within two months the bridge collapsed. Subsidence around the 150-foot radius of this collapse area ranges from several inches at the perimeter to more than five feet at the bridge (NYSDPC, 2008). Currently, the MDA contains most of the active mudboils and contributes most of the sediment that is discharged to Onondaga Creek from this part of the valley; it also has the greatest amount of mudboil-induced land subsidence in the valley (Kappel et al., 2009).

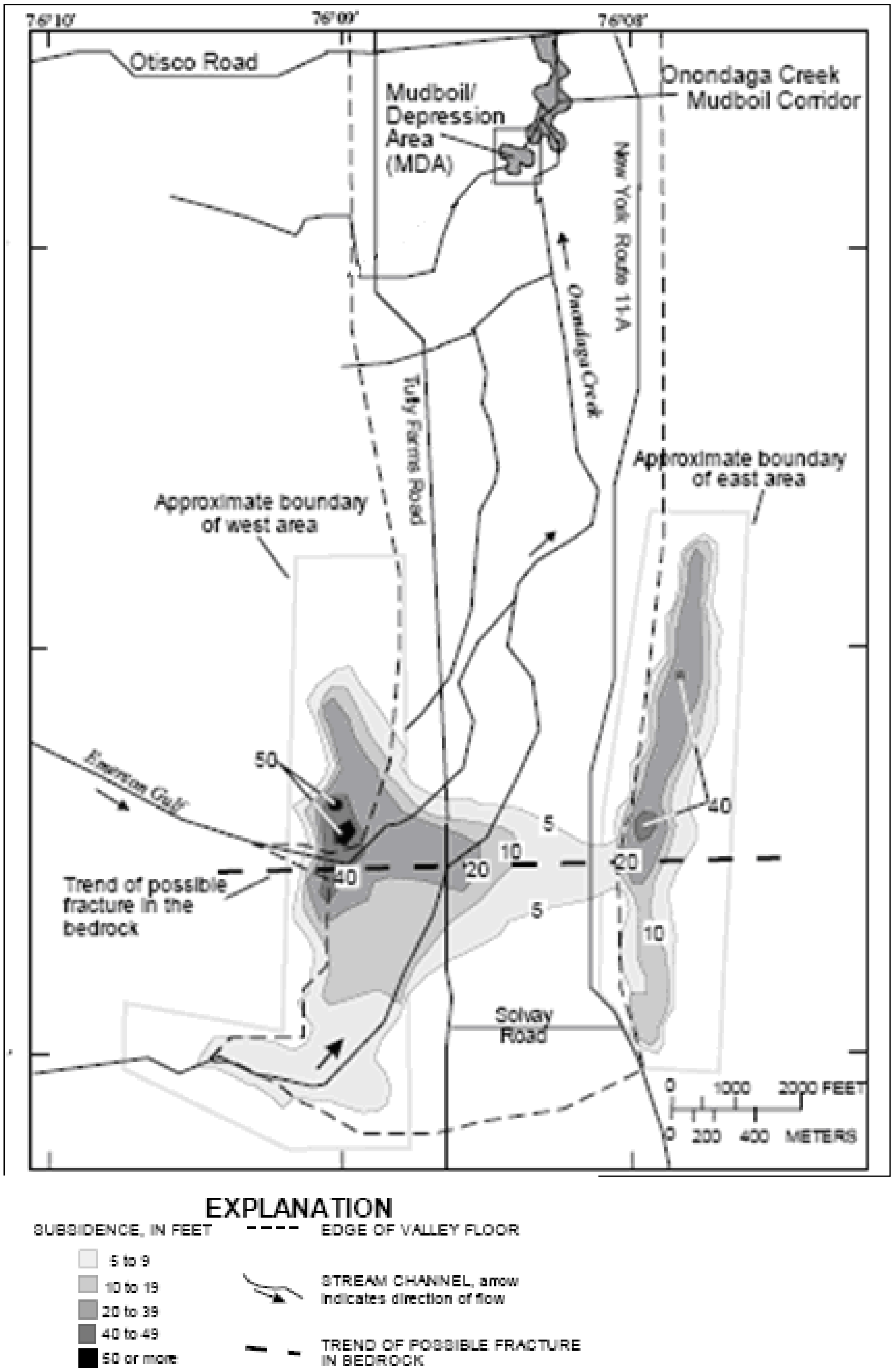
Salt-Solution Mining

Salt-solution mining areas exist in the east and west valley walls at the south end of the Tully Valley (Figure 5.4.4-8). The east area (also known as the east brinefield area) was developed in 1889 after the discovery of a 45-foot layer of salt 1,216 feet below land surface; production continued there through the late 1950s. The west brinefield area developed in 1895 and remained in production through the late 1980s. The solution-mining operation entailed drilling wells into the salt beds and injecting freshwater from the Tully Lakes, south of the Tully Moraine, to dissolve the salt and produce saturated brine. Tully Lakes are 500 feet higher than the brine wellheads, and the elevation difference was sufficient to lift the dense, saturated brine from the wells. The brine was then discharged to a pipeline that flowed north to Syracuse, where it was used in the production of soda ash. At peak production, approximately one billion gallons of brine per year was piped to Syracuse. In 1986 the west brine field ceased most operations, and a few wells were sold to another manufacturer, who ceased all brining operations two years later. The nearly 100 years of salt-solution mining removed about 100 million tons, or 31,000 acre-feet of salt within the Tully Valley (Kappel et al., 2009).

Initial solution mining in the east brinefield area resulted in the removal of most of the 35- to 45-foot-thick salt layer at 31 wells. Early and frequent caving within the solution-mined cavities was documented, but no general surface subsidence was noted. Surface subsidence measurements did not begin in either brinefield area until the late 1950s. From 1895 through 1900, 21 solution wells were drilled in the western brinefield area and resulted in similar caving. As more wells were drilled into the deeper salt beds, other well development and pumping strategies were tried in an attempt to decrease the caving and increase brine production. By 1950, a total of 99 wells had been drilled in the eastern and western areas, 86 of which were abandoned as a result of caving, shearing of well casings, and the collapse of the overlying bedrock into solution-mined salt cavities (Kappel et al., 2009).

As early as 1943, general land subsidence and development of rock fissures along the eastern side of the east brinefield area were noted. In the late 1950s, subsequent development of several chimney-collapse areas (or rock-filled cylinders) prompted land-subsidence surveys in both brine field areas. The extent of land subsidence due to the removal of salt since 1957, when the initial survey was made, is depicted in Figure 5.4.4-8. This map indicates subsidence of 5 feet to more than 50 feet in the two brine field areas. Although subsidence outside the brinefield has not been documented, local landowners have noted bedrock fracturing upslope of the east brinefield area (Kappel et al., 2009).

Figure 5.4.4-8. Extent and Depth of Brinefield Subsidence (1957-1993) in East and West Areas and Along a Possible Bedrock Fracture in Southern Part of Tully Valley.



Source: Kappel et al., 1996

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).

Subsidence

To determine the extent of the subsidence hazard, the affected areas need to be identified and the probability of the subsidence occurring within some time period needs to be assessed. Natural variables that contribute to the overall extent of potential subsidence activity in any particular area include soil properties, and underlaying geologic feature. Predicting subsidence is difficult, even under ideal conditions. As a result, the subsidence hazard is often represented by presence of evaporite or carbonate rock.

No two subsidence areas or sinkholes are exactly alike. Variations in size and shape, time period under which they occur (i.e. gradually or abruptly), and their proximity to development ultimately determines the magnitude of damage incurred. Based on the geologic formations underlying parts of Onondaga County, subsidence and sinkhole events may occur gradually or abruptly. Events could result in minor elevation changes or deep, gaping holes in the ground surface. Subsidence and sinkhole events can cause severe damage in urban environments, although gradual events can be addressed before significant damage occurs. Primarily, problems related to subsidence include the disruption of utility services and damages to private and public property including buildings, roads, and underground infrastructure. If long-term subsidence or sinkhole formation is not recognized and mitigation measures are not implemented, fractures or complete collapse of building foundations and roadways may result.

The worst-case scenario for subsidence and sinkholes in Onondaga County would be for a sinkhole to form in an urban area. A sinkhole in a city, either in a highly trafficked pedestrian area or under one of the many high traffic roadways or bridges, could potentially cause significant property damage and/or loss of life. Refer to the Vulnerability Assessment for further details on the population, general building stock, and critical facilities and infrastructure vulnerable to this hazard.

Previous Occurrences and Losses

While numerous sources were researched during this plan update, information regarding occurrences and losses associated with geological hazard events in Onondaga County was limited. According to the 2014 New York State HMP, Onondaga County has not experienced any recent landslide or land subsidence events.

Between 1954 and 2018, FEMA issued a major disaster (DR) or emergency (EM) declaration for New York State for one geological hazard-related event. Generally, these disasters cover a wide region of the State; therefore, it may have impacted many counties. Onondaga County was included in the declaration.

Table 5.4.4-1. FEMA DR and EM Declarations for Geological Hazard Events in Onondaga County

FEMA Declaration Number	Date(s) of Event	Declaration Date	Event Type	Details
DR-487	October 2, 1975	October 2, 1975	Flood	Storms, Rain, Landslides & Flooding

Source: FEMA 2019

For this plan update, landslide events that occurred in the county between 2011 and 2018 were researched. However, specific information regarding any landslide or land subsidence events was not identified. Appendix E (Supplementary Data) provides information on events that occurred prior to 2011.

Climate Change Projections

Projecting future climate change within a specific region is challenging. Shorter-term projections are more closely tied to existing trends, rendering longer-term projections even more challenging. The further into the future a prediction extends, the more it is subject to change.

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.

Probability of Future Events

As indicated in the 2014 New York State HMP, and given the history of landslides in the state, future landslides certainly will occur, but severity of these landslides cannot be determined. Therefore, probability of future landslides in the state is considered high; however, because documentation on landslides in Onondaga County is sparse, predicting the extent of future landslides in the county is difficult.

According to the New York State Geological Survey (NYSGS) Landslide Inventory Study to estimate probability of future landslides (based on documented historical occurrences), New York state can expect on average approximately two major landslides each year; a greater number of smaller but still significant slides, slumps, or flows each year; and at least one landslide causing a fatality once every 12 years.

Additionally, the New York State HMP notes that the nature of all forms of land subsidence and expansive soils in New York makes it difficult to determine probability of future events (frequency). As moderate to low land subsidence susceptibility does exist in Onondaga County and land subsidence has occurred in the state in the past, the state HMP suggests that, although very infrequent, land subsidence is likely to occur at some point.

Since landslides can occur as a result of many factors within Onondaga County, including past landslides and their distribution; bedrock; slope steepness or inclination, hydrologic factor and human-initiated effects; it is extremely difficult to predict landslide hazards in absolute terms (OAS, 1991). However, a sufficient understanding of landslide processes within the county does exist through various studies and mapping sources to be able to make an estimation of landslide hazard potential. The potential increase in the risk posed by the landslide hazard can be curbed through a continued understanding and mapping of the hazards and improved capabilities to mitigate and respond to the landslide hazard (Spiker and Gori, 2000).

Regarding mudboil activity in the Tully Valley, the OLP indicates that there is no way to predict future activity of the mudboils, although it is surmised that they won't go away within the near future (OLP, Date Unknown). Since 1992, the Onondaga Lake Management Conference began remediation efforts to decrease mudboil discharge. Remediation projects have been designed to reduce artesian pressure that drives mudboil activity and decrease the discharge of sediment. Remedial efforts near the Tully Valley mudboils include:

- Diverting flow from the tributary that feeds the MDA to an adjacent tributary. The diversion of water and the impoundment of water and sediment at the MDA outflow decreased mudboil-sediment discharge to Onondaga Creek by about 80-percent.
- Installing depressurizing wells at several locations around the MDA and along Onondaga Creek to decrease the artesian pressure. Depressurizing wells installed near the collapsed Otisco Road bridge seems to have reduced sediment discharge and may have stabilized the area around the bridge; alternately, mudboil activity may have migrated away from the Tully Valley area.
- Constructing a dam and sediment-settling impoundment to detain mudboil sediment that would normally discharge to Onondaga Creek (Kappel and McPherson, 1998).

These projects are expected to slow, but not stop, mudboil activity. As a result, turbidity in Onondaga Creek will decline, as will the rate of land subsidence in the Tully Valley. Although these remedial activities may have reduced mudboil activity and land subsidence, mudboils will persist in the Tully Valley as long as the two confined aquifers have artesian pressure that will 'push' water above land surface. Further work is needed at the MDA and along Onondaga Creek to lower artesian heads and reduce the discharge of fine-grained sediments. Left unchecked, mudboil activity will persist along the creek, but most of the mudboil activity and land subsidence will be in the MDA as subsidence moves toward the Rattlesnake alluvial fan—one of the sources of artesian pressure in this area. Mudboil activity is greatest during the spring and late fall, when artesian pressures increase rapidly from seasonal recharge to the confined freshwater and brackish-water aquifers. The gradual increase in brackish-water discharge at the MDA may continue as the hydraulic connection between the lower to the upper aquifer develops over time (Kappel et al., 1996; Kappel and McPherson, 1998).

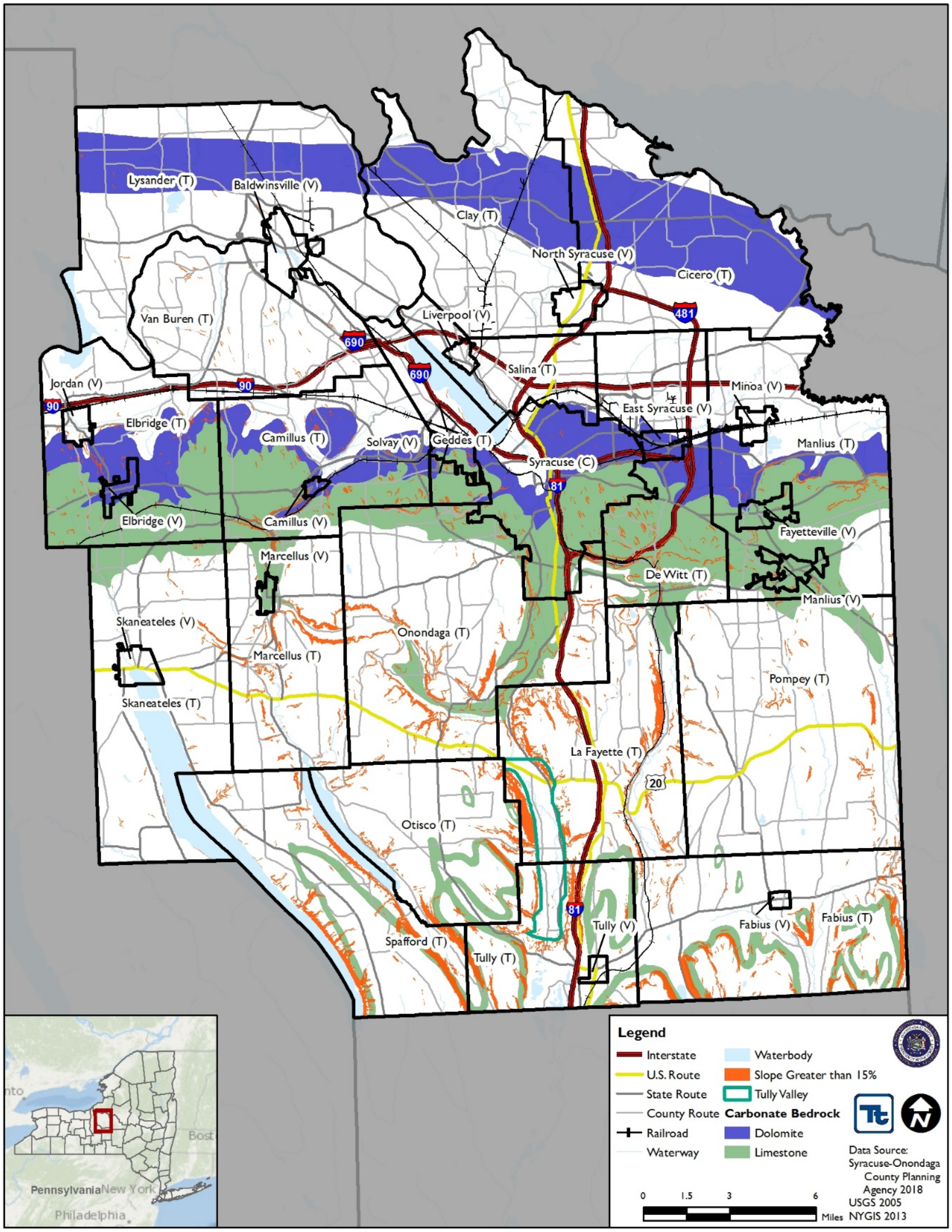
In Section 5.3, identified hazards of concern for Onondaga County were ranked according to various parameters. Probability of occurrence, or likelihood of the event, is one parameter used for hazard rankings. Based on historical records and input from the Planning Partnership, probability of occurrence of landslides and subsidence in Onondaga County is considered *occasional* (between 10 and 100% annual probability of a hazard event occurring).

5.4.4.2 VULNERABILITY ASSESSMENT

To understand risk, a community must evaluate what assets are exposed or vulnerable to the identified hazard. For this analysis, the hazard area is defined as areas of slopes greater than 15 percent, carbonate bedrock (limestone and dolomite), and Tully Valley. This approximate hazard area encompasses landslide susceptible areas, vulnerable bedrock types, historic ground failure sites, and more localized hazard areas including the mudboil depression area, Onondaga Creek mudboil corridor and extent of brinefield subsidence in Tully Valley.

Figure 5.4.4-9 depicts the geological hazard areas in Onondaga County. The following text provides an analysis of potential impacts of geological hazards on Onondaga County.

Figure 5.4.4-9. Geological Hazard Areas in Onondaga County



Impact on Life, Health and Safety

Overall, a landslide or other geologic hazard event would be an isolated incidence and impact the populations within the immediate area of the incident. Specifically, the population located downslope of the landslide hazard areas are particularly vulnerable to this hazard. 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. Mudboils in Onondaga Creek and its tributaries increase the turbidity of the waterways and can impact usage of these waterways for communities downstream within and outside Tully Valley that use them for recreation, fishing, etc.

Table 5.4.4-2 displays the populations located on steep slopes and in Tully Valley by municipality. Countywide, there are 6,039 people located on areas of steep slopes, and 210 people residing in Tully Valley. The City of Syracuse has the greatest total number of people located on areas of steep slopes (1,582), while the Village of Camillus has the greatest percentage of its population located on areas of steep slopes (23.2 percent). The City of Syracuse also has the greatest total number of people located on areas underlain by carbonate bedrock (137,317), while several communities have 100 percent exposure of their populations; these communities are the Villages of Camillus, Elbridge, Fayetteville, Manlius, and Marcellus. Tully Valley is located in the Towns of LaFayette and Tully, so only populations in these towns will be directly impacted by the geological hazard events in the valley. The Town of LaFayette has a greater total number of people and percentage of people located in Tully Valley than the Town of Tully.

Table 5.4.4-2. Estimated Population Exposed to Geologic Hazards in Onondaga County

Municipality	Total Population (U.S. Census 2010)	Steep Slopes		Carbonate Bedrock		Tully Valley	
		Population Exposed	% of Total	Population Exposed	% of Total	Population Exposed	% of Total
Baldwinsville (V)	7,378	0	0.0%	-	-	-	-
Camillus (T)	22,954	1,166	5.1%	20,401	88.9%	-	-
Camillus (V)	1,213	282	23.2%	1,213	100.0%	-	-
Cicero (T)	29,641	0	0.0%	17,743	59.9%	-	-
Clay (T)	53,397	0	0.0%	9,239	17.3%	-	-
DeWitt (T)	22,754	456	2.0%	16,040	70.5%	-	-
East Syracuse (V)	3,084	0	0.0%	2,765	89.7%	-	-
Elbridge (T)	3,496	20	0.6%	2,584	73.9%	-	-
Elbridge (V)	1,058	0	0.0%	1,058	100.0%	-	-
Fabius (T)	1,612	81	5.0%	176	10.9%	-	-
Fabius (V)	352	0	0.0%	-	-	-	-
Fayetteville (V)	4,373	0	0.0%	4,373	100.0%	-	-
Geddes (T)	10,534	121	1.1%	7,405	70.3%	-	-
Jordon (V)	1,368	84	6.1%	0	0.0%	-	-
LaFayette (T)	4,952	341	6.9%	154	3.1%	188	3.8%
Liverpool (V)	2,347	0	0.0%	-	-	-	-
Lysander (T)	17,175	9	0.1%	4,909	28.6%	-	-
Manlius (T)	19,844	258	1.3%	15,392	77.6%	-	-
Manlius (V)	4,704	0	0.0%	4,704	100.0%	-	-
Marcellus (T)	4,397	116	2.6%	996	22.7%	-	-
Marcellus (V)	1,813	0	0.0%	1,813	100.0%	-	-

Municipality	Total Population (U.S. Census 2010)	Steep Slopes		Carbonate Bedrock		Tully Valley	
		Population Exposed	% of Total	Population Exposed	% of Total	Population Exposed	% of Total
Minoa (V)	3,449	0	0.0%	0	0.0%	-	-
North Syracuse (V)	6,800	0	0.0%	-	-	-	-
Onondaga (T)	23,101	941	4.1%	7,815	33.8%	-	-
Onondaga Nation Territory	468	0	0.0%	249	53.2%	-	-
Otisco (T)	2,541	84	3.3%	421	16.6%	-	-
Pompey (T)	7,080	84	1.2%	786	11.1%	-	-
Salina (T)	31,363	0	0.0%	2,099	6.7%	-	-
Skaneateles (T)	4,669	2	0.0%	584	12.5%	-	-
Skaneateles (V)	2,540	0	0.0%	-	-	-	-
Solvay (V)	6,584	136	2.1%	6,554	99.5%	-	-
Spafford (T)	1,686	133	7.9%	171	10.1%	-	-
Syracuse (C)	145,170	1,582	1.1%	137,317	94.6%	-	-
Tully (T)	1,865	7	0.4%	450	24.1%	22	1.2%
Tully (V)	873	0	0.0%	-	-	-	-
Van Buren (T)	10,391	136	1.3%	-	-	-	-
Onondaga County	**467,026**	**6,039**	**1.3%**	**267,411**	**57.3%**	**210**	**0.0%**

Source: United States Census 2010; Syracuse-Onondaga County Planning Agency, 2018
Note: The hazard area boundaries were overlaid on the U.S. Census block; the blocks with their centroids within hazard areas were totaled for each municipality.

Socially vulnerable populations (e.g., the elderly and low-income populations) are particularly vulnerable to a hazard event. Within the steep slopes hazard area, there are approximately 721 people over the age of 65 and 864 people considered low income populations. There are approximately 36,251 people over the age of 65 and 59,590 people considered low income populations located in areas underlain by carbonate bedrock. As for populations within Tully Valley, there are approximately 22 people over the age 65 and 17 people considered low income populations; all 17 people considered low income populations reside in the Town of LaFayette.

Impact on General Building Stock

Landslides and other geologic hazards have the potential to destabilize the foundation of structures, which may result in monetary losses to businesses and residents. As seen along Limestone Creek and the Bluffs in Manlius, geological hazard events can expose the underlying bedrock adjacent to structures, which can erode and threaten the structural integrity and safety of the structure above. Table 5.4.4-3 summarizes the exposed building stock to the steep slope hazard areas by municipality, Table 5.4.4-4 summarizes the exposed building stock on carbonate bedrock by municipality, and Table 5.4.4-5 summarizes the exposed building stock located in Tully Valley. There are 977 buildings located on areas of steep slopes countywide. The Town of Spafford has the greatest number of buildings and greatest percentage of buildings located on areas of steep slopes (216 – 9.6 percent). The Town of LaFayette has over five times as many buildings located in Tully Valley than the Town of Tully: 376 buildings and 71 buildings, respectively.

Table 5.4.4-3. Estimated Number of Buildings and Replacement Cost Values Located on Steep Slopes

Municipality	Total Number of Buildings	Total Replacement Cost Value (Structure and Contents)	Number of Buildings		Replacement Cost Value	
			Number Exposed	% of Total	Value Exposed	% of Total
Baldwinsville (V)	3,321	$1,504,827,309	0	0.0%	$0	0.0%
Camillus (T)	11,611	$4,945,293,987	83	0.7%	$22,345,937	0.5%
Camillus (V)	490	$182,330,235	23	4.7%	$5,268,144	2.9%
Cicero (T)	15,558	$7,104,912,499	0	0.0%	$0	0.0%
Clay (T)	22,004	$13,377,871,396	0	0.0%	$0	0.0%
DeWitt (T)	11,191	$11,163,898,629	117	1.0%	$57,222,067	0.5%
East Syracuse (V)	1,662	$901,239,284	0	0.0%	$0	0.0%
Elbridge (T)	3,020	$1,214,372,973	9	0.3%	$2,871,765	0.2%
Elbridge (V)	654	$243,606,959	0	0.0%	$0	0.0%
Fabius (T)	1,717	$873,582,692	21	1.2%	$4,879,171	0.6%
Fabius (V)	245	$100,916,840	0	0.0%	$0	0.0%
Fayetteville (V)	1,999	$1,065,416,400	6	0.3%	$1,785,290	0.2%
Geddes (T)	6,048	$3,940,020,462	11	0.2%	$5,285,303	0.1%
Jordon (V)	754	$324,416,761	4	0.5%	$444,328	0.1%
LaFayette (T)	3,742	$1,385,373,038	42	1.1%	$10,381,063	0.7%
Liverpool (V)	1,379	$585,988,259	0	0.0%	$0	0.0%
Lysander (T)	9,513	$5,511,947,365	0	0.0%	$0	0.0%
Manlius (T)	10,101	$5,931,420,911	54	0.5%	$27,094,458	0.5%
Manlius (V)	1,724	$1,225,609,003	20	1.2%	$10,917,591	0.9%
Marcellus (T)	3,442	$1,592,818,810	25	0.7%	$21,041,710	1.3%
Marcellus (V)	790	$446,005,634	1	0.1%	$975,958	0.2%
Minoa (V)	1,579	$677,670,815	0	0.0%	$0	0.0%
North Syracuse (V)	3,297	$1,347,498,685	0	0.0%	$0	0.0%
Onondaga (T)	11,826	$5,889,094,715	66	0.6%	$22,266,738	0.4%
Onondaga Nation Territory	638	$182,143,705	12	1.9%	$1,833,035	1.0%
Otisco (T)	2,567	$1,070,059,196	38	1.5%	$12,843,437	1.2%
Pompey (T)	5,096	$2,547,562,317	19	0.4%	$10,455,724	0.4%
Salina (T)	14,486	$8,140,248,129	0	0.0%	$0	0.0%
Skaneateles (T)	4,439	$2,334,223,245	53	1.2%	$16,156,332	0.7%
Skaneateles (V)	1,583	$871,003,682	0	0.0%	$0	0.0%
Solvay (V)	3,003	$1,402,099,960	31	1.0%	$7,623,149	0.5%
Spafford (T)	2,302	$826,800,666	216	9.4%	$54,622,855	6.6%
Syracuse (C)	51,837	$25,010,023,305	101	0.2%	$420,100,260	1.7%
Tully (T)	1,585	$882,534,759	15	0.9%	$4,257,258	0.5%
Tully (V)	511	$314,789,328	0	0.0%	$0	0.0%
Van Buren (T)	5,971	$3,347,767,581	10	0.2%	$1,611,843	0.0%
Onondaga County	**221,685**	**$118,465,389,533**	**977**	**0.4%**	**$722,283,415**	**0.6%**

Source: Syracuse-Onondaga County Planning Agency, 2018

Table 5.4.4-4. Estimated Number of Buildings and Replacement Cost Values Located on Carbonate Bedrock

Municipality	Total Number of Buildings	Total Replacement Cost Value (Structure and Contents)	Number of Buildings		Replacement Cost Value	
			Number Exposed	% of Total	Value Exposed	% of Total
Baldwinsville (V)	3,321	$1,504,827,309	-	-	-	-
Camillus (T)	11,611	$4,945,293,987	9,626	82.9%	$4,240,114,083	85.7%
Camillus (V)	490	$182,330,235	490	100.0%	$182,330,235	100.0%
Cicero (T)	15,558	$7,104,912,499	8,343	53.6%	$3,592,944,422	50.6%
Clay (T)	22,004	$13,377,871,396	4,419	20.1%	$2,458,151,596	18.4%
DeWitt (T)	11,191	$11,163,898,629	7,141	63.8%	$5,047,475,498	45.2%
East Syracuse (V)	1,662	$901,239,284	1,553	93.4%	$861,884,033	95.6%
Elbridge (T)	3,020	$1,214,372,973	1,884	62.4%	$836,791,105	68.9%
Elbridge (V)	654	$243,606,959	654	100.0%	$243,606,959	100.0%
Fabius (T)	1,717	$873,582,692	64	3.7%	$21,163,533	2.4%
Fabius (V)	245	$100,916,840	-	-	-	-
Fayetteville (V)	1,999	$1,065,416,400	1,999	100.0%	$1,065,416,400	100.0%
Geddes (T)	6,048	$3,940,020,462	3,908	64.6%	$1,634,343,774	41.5%
Jordon (V)	754	$324,416,761	36	4.8%	$16,425,048	5.1%
LaFayette (T)	3,742	$1,385,373,038	294	7.9%	$107,056,428	7.7%
Liverpool (V)	1,379	$585,988,259	-	-	-	-
Lysander (T)	9,513	$5,511,947,365	2,086	21.9%	$947,776,742	17.2%
Manlius (T)	10,101	$5,931,420,911	7,062	69.9%	$4,505,835,693	76.0%
Manlius (V)	1,724	$1,225,609,003	1,724	100.0%	$1,225,609,003	100.0%
Marcellus (T)	3,442	$1,592,818,810	642	18.7%	$281,016,425	17.6%
Marcellus (V)	790	$446,005,634	725	91.8%	$421,369,774	94.5%
Minoa (V)	1,579	$677,670,815	0	0.0%	$0	0.0%
North Syracuse (V)	3,297	$1,347,498,685	-	-	-	-
Onondaga (T)	11,826	$5,889,094,715	3,677	31.1%	$1,828,848,086	31.1%
Onondaga Nation Territory	638	$182,143,705	327	51.3%	$103,159,023	56.6%
Otisco (T)	2,567	$1,070,059,196	292	11.4%	$112,021,736	10.5%
Pompey (T)	5,096	$2,547,562,317	590	11.6%	$316,959,045	12.4%
Salina (T)	14,486	$8,140,248,129	1,297	9.0%	$453,785,278	5.6%
Skaneateles (T)	4,439	$2,334,223,245	486	10.9%	$219,872,649	9.4%
Skaneateles (V)	1,583	$871,003,682	-	-	-	-
Solvay (V)	3,003	$1,402,099,960	2,992	99.6%	$1,398,007,506	99.7%
Spafford (T)	2,302	$826,800,666	144	6.3%	$47,411,824	5.7%
Syracuse (C)	51,837	$25,010,023,305	49,432	95.4%	$21,177,063,222	84.7%
Tully (T)	1,585	$882,534,759	304	19.2%	$119,909,583	13.6%
Tully (V)	511	$314,789,328	-	-	-	-
Van Buren (T)	5,971	$3,347,767,581	-	-	-	-
Onondaga County:	**221,685**	**$118,465,389,533**	**112,191**	**50.6%**	**$53,466,348,702**	**45.1%**

Source: Syracuse-Onondaga County Planning Agency, 2018

Table 5.4.4-5. Estimated Number of Buildings and Replacement Cost Values Located in Tully Valley

Municipality	Total Number of Buildings	Total Replacement Cost Value (Structure and Contents)	Number of Buildings		Replacement Cost Value	
			Number Exposed	% of Total	Value Exposed	% of Total
LaFayette (T)	3,670	$1,385,373,038	376	10.0%	$120,910,777	8.7%
Tully (T)	1,553	$882,534,759	71	4.5%	$40,295,130	4.6%
Onondaga County:	**221,685**	**$118,465,389,533**	**447**	**0.2%**	**$161,205,907**	**0.1%**

Source: Syracuse-Onondaga County Planning Agency, 2018

Impact on Critical Facilities

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 Philadelphia and New York City, and a landslide event could prevent travel to and from work.

Several other types of infrastructure may also be exposed to landslides and other geologic hazards, including water and sewer infrastructure. At this time all critical facilities, infrastructure, and transportation corridors located within the hazard areas are considered vulnerable until more information becomes available. Figure 5.4.4-10 displays the critical facilities located on areas of steep slopes. Overall there are 14 critical facilities located on areas of steep slopes, with chemical storage facilities being the most exposed with four. Figure 5.4.4-11 displays the critical facilities located on areas underlain by carbonate rock. There are 1,482 critical facilities exposed to the carbonate hazard area; chemical storage facilities have the most facilities exposed with 521, followed by day care facilities with 277 exposed. There are three critical facilities located in Tully Valley; all the facilities are in the Town of LaFayette. Two of these facilities are wells and the other facility is a fire station.

Figure 5.4.4-10. Estimated Number of Critical Facilities Located on Steep Slopes

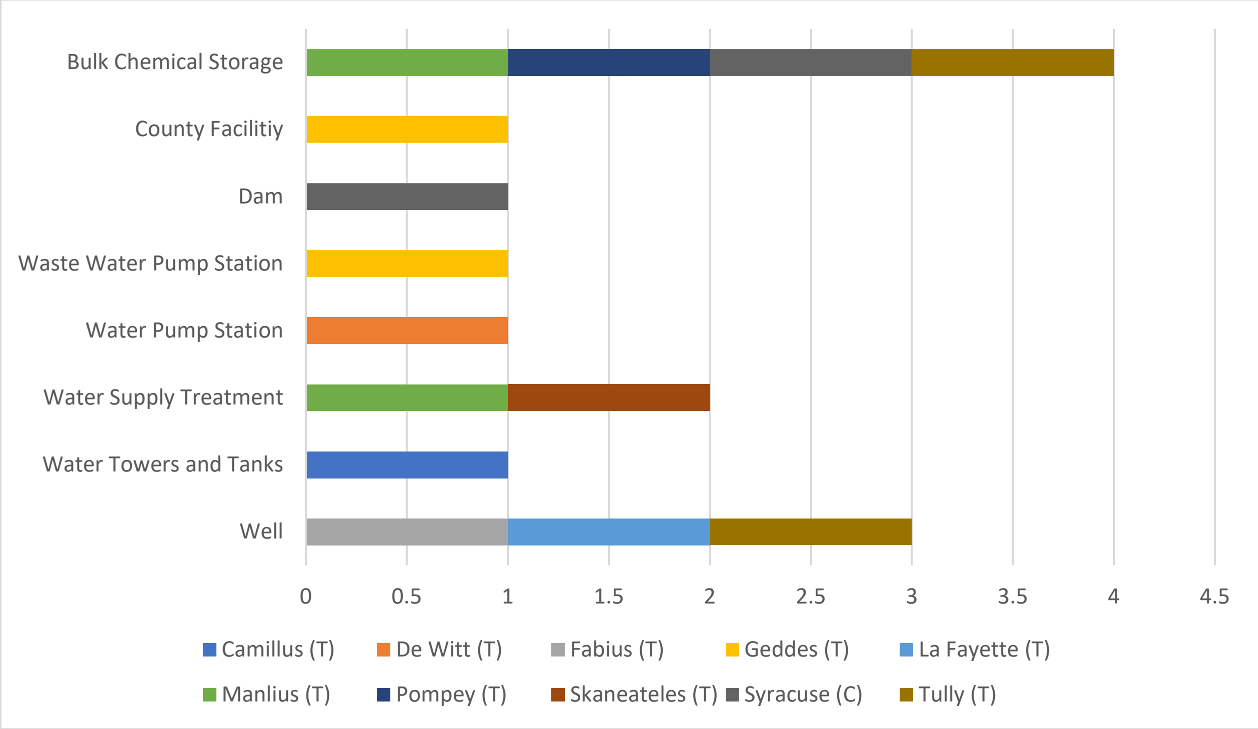
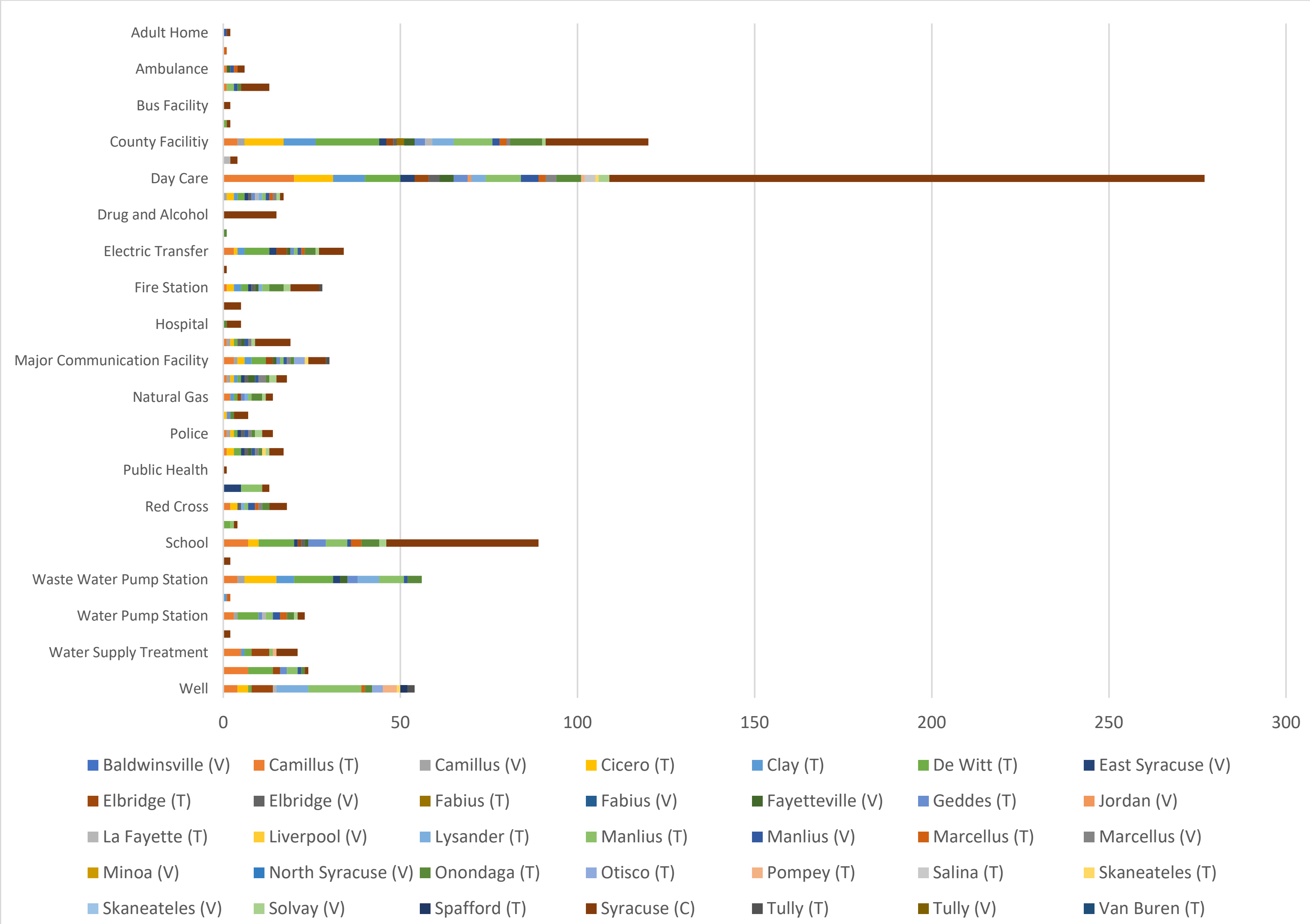


Figure 5.4.4-11. Estimated Number of Critical Facilities Located on Carbonate Bedrock



Impact on the Economy

The impact of geologic hazards on the economy and estimated dollar losses are difficult to measure. As stated earlier, landslides and other geological hazards can impose direct and indirect impacts on society. Direct costs include the actual damage sustained by buildings, property and infrastructure. Indirect costs, such as clean-up costs, business interruption, loss of tax revenues, reduced property values, and loss of productivity are difficult to measure. Additionally, geological hazards threaten 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. They also can damage rivers or streams, potentially harming water quality, fisheries, and spawning habitat.

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 nearly $32 billion. This estimate represents 47% 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 Onondaga County's tax base and the local economy.

Landslides and other geologic hazards 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. I-81, I-481, I-690, NY-5, NY-41, NY-80, NY-91, NY-92, NY-173, NY-174, NY-175, NY-257, NY-290, NY-370, NY-635, NY-695, NY-11A, NY-931F, US-11, and US-20 intersect areas of steep slopes around the county. I-81, I-481, I-690, NY-5, NY-31, NY-41, NY-48, NY-80, NY-91, NY-92, NY-173, NY-174, NY-175, NY-257, NY-290, NY-297, NY-298, NY-317, NY-321, NY-370, NY-481, NY-598, NY-635, NY-695, NY-11A, NY-930P, NY-931F, and US-11 traverse areas underlain by carbonate bedrock. NY-11A traverses Tully Valley from north to south along the eastern border, running along the east brinefield in southern Tully Valley; US-20 traverses Tully Valley from east to west through the northern region of the valley. Refer to Figure 5.4.4-9 for locations of major roadways in the county within hazard areas.

Future Changes that May Impact Vulnerability

Understanding future changes that affect 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

Several communities have ordinances and land use laws protecting against development on steep slopes, so future growth and development will not have a direct impact on the county's vulnerability to landslides. However, any developments at or near the base of steep slopes may be at risk to losses from a landslide. Although areas of steep slopes are most at risk for landslides, landslides are still possible on lesser slopes, and future developments are not completely free of risk.

Any areas of growth could be affected by geologic hazards if the growth areas are within identified hazard areas. Each municipality identified areas of recent development and proposed development in their community. Developments that could be located using an address or Parcel ID were geocoded and overlain with the geologic hazard areas to determine vulnerability. There is one recent development in the Town of Manlius located on steep slopes, and one proposed development located on steep slopes in the Town of Skaneateles. There are 27 recent and proposed developments located on areas underlain by carbonate bedrock. Of these 27 developments, 22 are recent developments and 5 are proposed developments. The Village of Fayetteville has the most developments exposed with 3 recent and 2 proposed developments located in areas underlain by carbonate bedrock. The Specific areas of development are indicated in tabular form in the jurisdictional annexes in Volume II, Section 9 of this plan update.

Projected Changes in Population

According to population projections from the Cornell Program on Applied Demographics, Onondaga County will experience a slight population decrease through 2040 (less than 10,000 people in total by 2040). Population change is not expected to have a measurable effect on the overall vulnerability of the county's population over time. As discussed in *Long Range Transportation Plan 2050: Moving Towards a Greater Syracuse*, the population of Syracuse has decreased as the other municipalities in the county have seen an increase, which has led to an increased reliance on motor vehicles to travel around the county (Syracuse Metropolitan Transportation Council, 2015). If this trend continues, the population that remains in the county will move into areas reliant on the county's major highways, many of which are vulnerable to landslide and other geological hazard events.

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 geological hazard events. 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. The projection in the increase of average temperatures may lead to an increase in the frequency of droughts. In some karst areas, sinkhole activity intensifies and increases during periods of drought. With an increase in drought periods, the number of sinkholes can increase (Linares et al. 2016). Additionally, sinkholes can result from 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. These actions can also serve to accelerate the natural processes of bedrock degradation, which can have a direct impact on sinkhole creation.

Change of Vulnerability

Due to differences in the hazard data used to assess the County's vulnerability, a direct comparison between plan vulnerability assessment results could not be conducted to determine whether there has been a change over time. This plan update looked to use specific and localized areas of concern. Steep slopes around the county were used to delineate the landslide hazard area, rather than the more generalized USGS landslide incidence/susceptibility spatial layer. Tully Valley was identified as the primary area at risk for additional geologic hazards in the county and was used as a hazard area for the analysis. Areas underlain by carbonate bedrock were used to assess the County's vulnerability to subsidence and sinkhole events.

Overall, the vulnerability assessment presented provides a more accurate assessment of Onondaga County's risk to geologic hazards. Onondaga County and its municipalities continue to be vulnerable. Mitigation measures undertaken by each jurisdiction are described in the jurisdictional annexes in Section 9 of this HMP.

Identified Issues

Identified issues associated with geological hazards in Onondaga County include the following:

- Mapping and assessment of landslide and land subsidence hazards are constantly evolving. As new data and science become available, assessments of geological hazard risk should be reevaluated.
- The impact of climate change on geological hazards is uncertain. If climate change impacts atmospheric conditions, then exposure to landslides and land subsidence risks are likely to increase.
- Landslides may cause negative environmental consequences, including water quality degradation.