4.3.10 Landslide

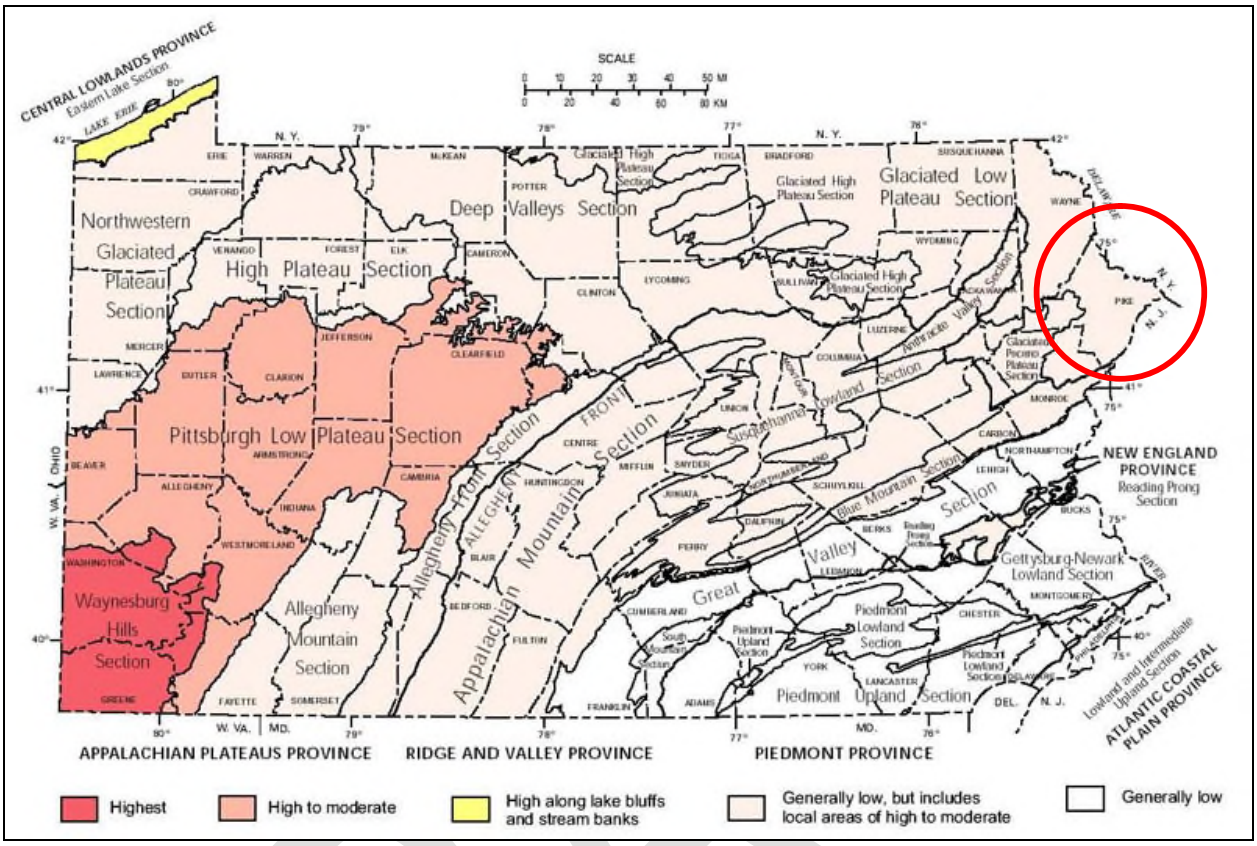
This section provides a profile and vulnerability assessment of the landslide hazard in Pike County. According to the U.S. Geological Survey (USGS), the term landslide includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows (USGS 2016). Landslides are classified by type of material involved and the type of movement. In addition, they are classified at the rate of movement and the water content of the material. Movement rates range from inches over many years to many feet per second (DCNR 2001).

Location and Extent

The entire U.S. experiences landslides, with 36 states having moderate to highly severe landslide hazards. Expansion of urban and recreational developments into hillside areas exposes more people to the threat of landslides each year. According to the USGS, Pike County has high landslide potential. For a figure displaying the landslide potential of the conterminous United States, please refer to http://pubs.usgs.gov/fs/2005/3156/2005-3156.pdf (USGS 2005).

Rockfalls and other slope failures occur in areas of Pennsylvania with moderate to steep slopes; however, most of Pennsylvania has areas susceptible to landslides. The southwestern area of Pennsylvania has the highest concentration of landslides (PA HMP 2013; DCNR 2016). According to DCNR, most major and minor highways have sections cut in rock or soil that can lead to slope failure. Steep mountain slopes across Pennsylvania have experienced debris avalanches associated with extreme rainfall or rain-on-snow events. Additionally, urban and rural land development is increasing the number of landslide occurrences. Major highway construction with large excavations and fills creates potential for landslides (DCNR 2016). Figure 4.3.10-1 shows the landslide susceptible areas across the Commonwealth. Pike County is noted as having a generally low susceptibility to landslides but includes local areas of high to moderate susceptibility.

Figure 4.3.10-1. Areas of Pennsylvania Susceptible to Landslides



Source: *DCNR 2016*

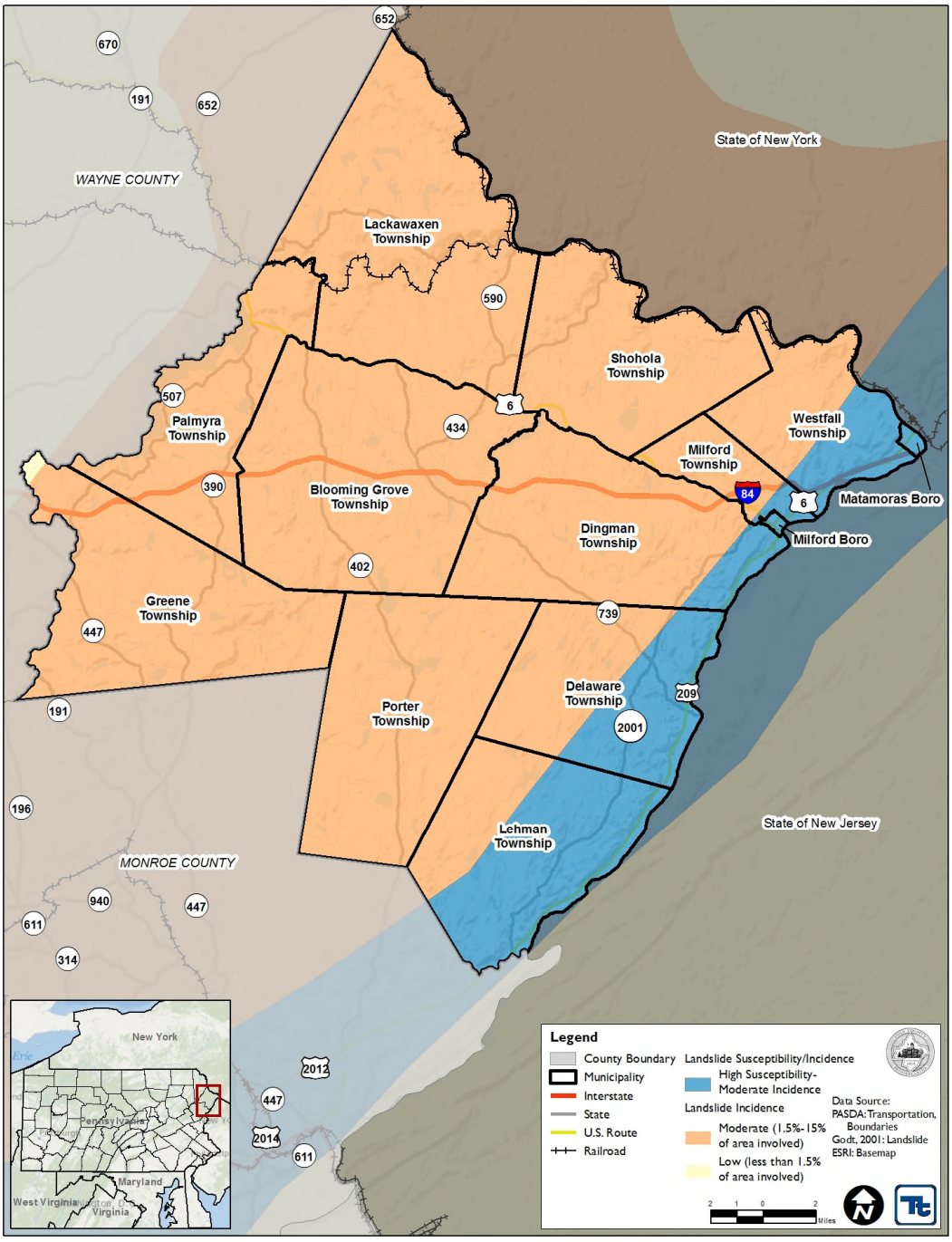
Note: *The red circle indicates the approximate location of Pike County. Pike County is shown has having a generally low susceptibility to landslides but includes local areas of high to moderate susceptibility.*

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

- Landslide incidence is the number of landslides that have occurred in a given geographic area. High incidence means greater than 15% of a given area has been involved in landsliding; medium incidence means that 1.5 to 15% of an area has been involved; and low incidence means that less than 1.5% of an area has been involved (Radbruch-Hall 1982).
- 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 (Radbruch-Hall 1982).

According to the Landslide Incidence and Susceptibility GIS layer from National Atlas as shown in Figure 4.3.10-2, the eastern portion of Pike County is located in the High-Susceptibility/Moderate-Incidence zone (Godt 2001). For the purposes of this planning effort, the High-Susceptibility/Moderate-Incidence zone is considered the hazard area. The remainder of the County is located in the Moderate Incidence zone, with a small portion of Green Township in the Low Incidence zone. According to Pike County records, the most recent landslides occurred in the Townships of Shohola, Westfall, Dingman, and Delaware.

Figure 4.3.10-2. Landslide Hazard Area in Pike County



Range of Magnitude

Landslides have the potential to damage transportation routes, utilities, and buildings. They can also create travel delays and other side effects. Fortunately, deaths and injuries caused by landslides are rare in Pennsylvania, and most landslides in the Commonwealth are moderate to slow moving, damaging things rather than people. Almost all of the known deaths caused by landslides have occurred when rockfalls or other slides along highways have involved vehicles. Storm-induced debris flows are the only other type of landslide likely to cause death and injuries. As residential and recreational development increases on and near steep mountain slopes, the hazards from these events will also increase (PA HMP 2013).

According to DCNR, the Pennsylvania Department of Transportation and large municipalities incur substantial costs due to landslide damage and to extra construction costs for new roads in known landslide-prone areas. One PA DOT estimate in 1991 showed an average of $10 million per year in landslide repair contracts across the Commonwealth and a similar amount in mitigation costs for grading projects (DCNR 2014).

The impact of landslides on the environment depends on the size and specific location of the event. In general, impacts include:

- Changes to topography
- Damage or destruction of vegetation
- Potential diversion or blockage of water in the vicinity of streams, rivers, etc.
- Increased sediment runoff both during and after event (PA HMP 2013).

Pike County's worst-case scenario is for a landslide to occur during or after a heavy rain event in the area of major transportation routes (Interstate 84, US Route 209, and US Route 6). A landslide on these roads could lead to road closures and damages and cut off access to emergency response vehicles.

Past Occurrence

Outside of impacts to important transportation routes, landslide history is not documented as completely (if at all) as other hazards, primarily because landslides are not always seen, and therefore historical landslide occurrences in Pike County are not well known. Information provided by Pike County Office of Community Planning identified the following landslide events:

- 2007 – State Route 1005 in Shohola Township - $775,000 in damages
- 2009 – T397 in Shohola Township - $500,000 in damages
- August and September 2011 – Intense rain from Hurricane Irene and Tropical Storm Lee led to numerous roadway washouts leading to long-term closures throughout the Delaware Water Gap National Recreation Area. This included roadways in portions of Pike County.
- 2014 – State Route 434 in Shohola Township - $3 million in damages
- 2015 – State Route 1013 in Westfall Township - $2 million in damages
- 2015 – State Route 2002 in Delaware Township - $1.25 million in damages

Between 1954 and 2016, FEMA issued a disaster (DR) or emergency (EM) declaration for Pennsylvania for one geological hazard-related event, classified as severe storms, flooding and mudslide. This declaration did not include Pike County (FEMA 2016).

Future Occurrence

Based upon risk factors and past occurrences, it is likely that landslides will continue to occur in Pike County in the future. However, severity of the landslides can vary depending on type and location of event. Landslide probabilities are largely a function of surface geology, but are also influenced by both weather and human activities. Mismanaged, intense development in steeply sloped areas could increase the frequency of landslide occurrence. Periods of intense rain or snowmelt can also increase the risk of landslides.

For the 2017 HMP update, the most up-to-date data was collected to calculate the probability of future occurrence of landslide events for Pike County. Information provided by Pike County was used to identify the number of landslide events that occurred between 1950 and 2015. Using these sources ensures the most accurate probability estimates possible. The table below shows these statistics, as well as the annual average number of events and the estimate percent chance of an incident occurring in a given year. Based on these statistics, there is an estimated 9.1-percent chance of a landslide event occurring in any given year in Pike County.

Table 4.3.10-1. Probability of Future Lanslide Events

Hazard Type	Number of Occurrences Between 1950 and 2015	Rate of Occurrence or Annual Number of Events (average)	Recurrence Interval (in years) (# Years/Number of Events)	Probability of Event in any given year	Percent chance of occurrence in any given year
Landslide	6	0.09	11.00	0.09	9.1%

Sources: Pike County 2016

Based on available historical data, the future occurrence of landslides can be considered *possible* as defined by the Risk Factor Methodology probability criteria (refer to Section 4.4).

Vulnerability Assessment

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

- Overview of vulnerability
- Data and methodology used for the evaluation
- Impact on (1) life; (2) health and safety; (3) general building stock; (4) critical facilities, economy; and (5) future growth and development
- Effect of climate change on vulnerability
- Additional data and next steps.

Overview of Vulnerability

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

Overall, 13.6 percent (or 76.9 square miles) of Pike County is located within the High-Susceptibility/Moderate-Incidence hazard area. Only a small area of Greene Township is located in the Low

Incidence area, with the remainder of the County located in the Moderate Incidence Area. For the purposes of this assessment, the High Susceptibility/Moderate-Incidence area is considered the hazard zone. Refer to Figure 4.3.10-2 earlier in this section. Further information regarding these hazard areas is presented below.

Data and Methodology

Unlike for flood, wind, and earthquake hazards, no standard loss estimation models have been developed for the landslide hazard. In an attempt to estimate Pike County's vulnerability, the Geology — Landslide Incidence and Susceptibility geographic information system (GIS) layer from the National Atlas was used to coarsely define the general landslide susceptible area ("approximate hazard area") (Figure 4.3.10-1). Limitations of this analysis are recognized, and results are used only to provide a general estimate. Over time, additional data will be collected to allow better analysis of this hazard. Available information and a preliminary assessment are provided below.

According to Radbruch-Hall and others, the Landslide Incidence and Susceptibility GIS layer from National Atlas:

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

To estimate exposure to the building stock, the default dasymetric building stock data from Hazards U.S. (HAZUS) – Multi-Hazard (MH) 3.1 was used for replacement cost value. Data from HAZUS-MH is at the census block level and is calculated by use of 2015 RS Means valuations. To estimate the number of structures within the hazard area, the default dasymetric building stock data from HAZUS-MH was also used.

Impact on Life, Health, and Safety

As discussed above, 13.6 percent of Pike County is located in the High-Susceptibility/Moderate-Incidence hazard area. Therefore, the County's population (U.S. Census 2010 population of 57,369) within this area is considered exposed to this hazard; however, based on the historic record, landslide events tend to be localized events. Landslide events can cause both direct and indirect (impact on buildings) damage to the County's population.

To estimate populations within the hazard area, the hazard area boundary (shown in Figure 4.3.10-1) was overlaid upon the 2010 U.S. Census population data (U.S. Census 2010). Census blocks with their centers (centroids) within the boundary of the landslide incidence hazard area were used to calculate the estimated population considered exposed to this hazard. The U.S. Census blocks do not align exactly with the hazard area, and thus these estimates should be considered for planning purposes only. Additionally, the hazard area boundary is only available at the municipal level and more detailed breakdowns are not available; this presents another reason to only use these estimates for planning purposes.

Table 4.3.10-2 lists populations exposed by municipality (U.S. Census 2010). The population downslope of the landslide hazard areas is particularly vulnerable to this hazard. Due to the nature of U.S. Census block data, it is difficult to determine demographics of populations vulnerable to mass movements of geological material. Using this approach, 18,162 people (31.7 percent of the population) are located in the High-Susceptibility/Moderate-Incidence hazard area. Please note while reviewing the table that exposure rates do not equate to actual potential impacts. Although an entire jurisdiction may be located in a high-susceptibility area, as noted, most landslide events are localized. Therefore, while a large number of residents may have a high exposure risk to landslide events, few residents will actually be significantly impacted.

Table 4.3.10-2. Estimated Pike County Population Vulnerable to the Landslide Hazard Area

Municipalities	Total Population (2010 U.S. Census)	High-Susceptibility/Moderate-Incidence Landslide Hazard Area	
		Population Exposed	Percent Total
Blooming Grove Township	4,819	0	0.0%
Delaware Township	7,396	3,208	43.4%
Dingman Township	11,926	148	1.2%
Greene Township	3,956	0	0.0%
Lackawaxen Township	4,994	0	0.0%
Lehman Township	10,663	8,686	81.5%
Matamoras Borough	2,469	2,469	100.0%
Milford Borough	1,021	1,021	100.0%
Milford Township	1,530	592	38.7%
Palmyra Township	3,312	0	0.0%
Porter Township	485	0	0.0%
Shohola Township	2,475	0	0.0%
Westfall Township	2,323	2,038	87.7%
Pike County (Total)	**57,369**	**18,162**	**31.7%**

Sources: United States Census 2010, Godt 2001

Impact on General Building Stock

Similar to the population, the building stock data are presented by census block. For this analysis, the HAZUS-MH 3.1 dasymetric census blocks were used (refer to Section 4.1 for more information). In general, the built environment within the High-Susceptibility/Moderate-Incidence landslide incidence zone and the population, structures, and infrastructure downslope are vulnerable to this hazard. Using the default general building stock, the replacement cost values of the U.S. Census blocks with their centroids in the hazard area were totaled. Approximately $3.6 billion in replacement cost is located in the High-Susceptibility/Moderate-

Incidence hazard area (27.3 percent); or an estimated 9,747 structures. Table 4.3.10-3 lists building stock exposure per municipality.

Table 4.3.10-3. Estimated General Building Stock Exposure to the Landslide Hazard Area

Municipality	Total Number of Buildings	Total Replacement Value (Structure and Contents)	High Susceptibility/Moderate Incidence Landslide Hazard Area			
			# Buildings	Percent Total	RCV Exposed	Percent Total
Blooming Grove Township	3,998	$1,160,095,000	0	0.0%	$0	0.0%
Delaware Township	4,253	$1,496,677,000	1,901	44.7%	$665,159,000	44.4%
Dingman Township	5,480	$1,984,820,000	94	1.7%	$54,293,000	2.7%
Greene Township	3,275	$956,640,000	0	0.0%	$0	0.0%
Lackawaxen Township	4,562	$1,231,170,000	0	0.0%	$0	0.0%
Lehman Township	5,995	$1,992,003,000	4,700	78.4%	$1,532,437,000	76.9%
Matamoras Borough	972	$377,318,000	972	100.0%	$377,318,000	100.0%
Milford Borough	718	$413,430,000	718	100.0%	$413,430,000	100.0%
Milford Township	784	$670,787,000	367	46.8%	$196,594,000	29.3%
Palmyra Township	3,981	$1,244,483,000	0	0.0%	$0	0.0%
Porter Township	912	$388,599,000	0	0.0%	$0	0.0%
Shohola Township	2,311	$759,299,000	0	0.0%	$0	0.0%
Westfall Township	1,175	$383,781,000	995	84.7%	$326,285,000	85.0%
Pike County (Total)	**38,416**	**$13,059,102,000**	**9,747**	**25.4%**	**$3,565,516,000**	**27.3%**

Source: HAZUS-MH 3.1; Pike County; Godt, 2001
Notes:
% Percent
RCV Replacement cost value (structure and contents)

Critical Facilities and the Economy

To estimate exposure, the approximate hazard area was overlaid upon the essential and municipal 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, isolating neighborhoods, posing traffic problems, and causing delays of 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, rendering 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 detouring a rail line would not be as easy as detouring a local road or highway.

Several other types of infrastructure may also be exposed to landslides, including water and sewer infrastructure. At this time, all critical facilities, infrastructure, and transportation corridors within the hazard areas are considered vulnerable until more information becomes available. Table 4.3.10-4 lists critical facilities located in the High-Susceptibility/Moderate-Incidence hazard area.

Table 4.3.10-4. Critical Facilities in the High-Susceptibility/Moderate-Incidence Landslide Hazard Area

Municipality	Facility Types											
	Cell Tower	County Building	Daycare	Emergency Operation Center	Fire Station	Medical Facility	Municipal Building	Nursing Home	Police Station	School	Shelter	Wastewater Facility
Blooming Grove Township	0	0	0	0	0	0	0	0	0	0	0	0
Delaware Township	1	0	2	0	2	0	1	0	0	0	1	0
Dingman Township	0	0	0	0	0	0	0	0	0	0	0	0
Greene Township	0	0	0	0	0	0	0	0	0	0	0	0
Lackawaxen Township	0	0	0	0	0	0	0	0	0	0	0	0
Lehman Township	1	0	2	0	1	0	1	0	0	0	2	1
Matamoras Borough	0	0	2	0	1	0	1	0	1	1	1	1
Milford Borough	0	2	3	1	1	1	1	1	2	0	1	0
Milford Township	1	0	2	0	0	0	1	0	0	0	1	0
Palmyra Township	0	0	0	0	0	0	0	0	0	0	0	0
Porter Township	0	0	0	0	0	0	0	0	0	0	0	0
Shohola Township	0	0	0	0	0	0	0	0	0	0	0	0
Westfall Township	1	0	0	0	1	0	1	2	0	4	3	0
Pike County (Total)	**4**	**2**	**12**	**1**	**6**	**1**	**6**	**3**	**3**	**5**	**9**	**2**

Sources: Pike County, Godt 2001

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

A landslide event alters the landscape. In addition to changes in topography, vegetation and wildlife habitats may be damaged or destroyed, and soil and sediment runoff will accumulate downslope, potentially blocking waterways and roadways and impacting quality of streams and other water bodies. Additional environmental impacts include loss of forest productivity. Considering both landslide hazard areas, the entire building stock is potentially exposed to a landslide event. These dollar value losses to Pike County's total building inventory would impact Pike County's tax base and the local economy.

All major roadways and transportation routes located in, and downslope of, the High-Susceptibility/Moderate-Incidence zone may be vulnerable to a landslide event.

Future Growth and Development

Areas targeted for potential future growth and development within the next five years have been identified across Pike County. Refer to Section 2.4 of this HMP for further details. New development within the High-Susceptibility/Moderate-Incidence landslide hazard areas are considered exposed to these risks.

Effect of Climate Change on Vulnerability

Climate is defined not just as average temperature and precipitation but also by type, frequency, and intensity of weather events. Both globally and at the local scale, climate change could alter prevalence and severity of extremes such as severe storms, including those that may bring intense or prolonged precipitation (U.S. Environmental Protection Agency [EPA] 2006). An increase in rainfall intensity and duration will saturate the soil, potentially erode the local landscape, and impair slope stability, leading to an increase of landslide events in Pike County.

While predicting changes in these types of events under a changing climate is difficult, understanding vulnerabilities to potential changes is a critical part of estimating future climate change impacts on human health, society, and the environment (EPA 2006). Potential effects of climate change on Pike County's vulnerability to landslide events must be considered as understanding of impacts of regional climate change increases.

Additional Data and Next Steps

More detailed landslide susceptibility zones can be generated so that communities can more accurately identify high hazard areas. A pilot study conducted for Schenectady County, New York, (described in the 2011 Draft New York State Hazard Mitigation Plan) developed higher-resolution landslide susceptibility zones. The methodology included use of the Natural Resource Conservation Services (NRCS) Digital Soil Survey soil units and their associated properties, including the American Association of State Highway and Transportation Officials (AASHTO) rating, liquid limit, hydrologic group, percentage of silt and clay, erosion potential, and slope, derived from high-resolution digital elevation models. Identifying historical damages to buildings and infrastructure incurred from landslides will also help with loss estimates and future modeling efforts, given a margin of uncertainty. Furthermore, research on rainfall thresholds for forecasting landslide potential may also be an option for Pike County.