4.3.9 Subsidence and Sinkholes

This section provides a profile and vulnerability assessment for the subsidence and sinkhole hazard for Fulton County. Subsidence and sinkholes may be natural or related to underground mining activities. The predominant cause of subsidence and sinkholes in Fulton County is its underlying carbonite bedrock composition, which can include limestone and dolomite. Although underground mining is not considered the primary cause of sinkholes or subsidence in the County, instances of subsidence and sinkholes may occur in the future because of mining activity. Thus, information in this section will be presented to highlight the cause and its potential impacts of the hazard. Although underground mining is not considered a geologic hazard, it will be treated as such in this document because of its relationship with the potential for subsidence events.

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 (U.S. Geological Survey [USGS] 2017). Subsidence often occurs through the loss of subsurface support due to mining or 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).

Karst features are defined as pockets of limestone or dolomite bedrock located within more stable geological formations that could cause subsidence or sinkholes. The density of karst features ranges from 0 to 600 features per square mile, with wide variations in size. Fewer karst features have been mapped in existing urban areas; however, this is likely a result of development activities that disguise, cover, or fill existing features rather than an absence of the features themselves (Pennsylvania Emergency Management Agency [PEMA] 2018).

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. Over periods of time measured in thousands of years, the carbonate bedrock can be dissolved through acidic rainwater moving through fractures or cracks in the bedrock. This creates larger openings in the rock through which water and overlying soil materials travel. Over time, the deposited soils compromise the strength of the bedrock until it is unable to support the land surface above, causing a collapse or sinkhole. In this example, the sinkhole occurs naturally; however, in other cases, the root causes of a sinkhole are anthropogenic, especially those that involve 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 directly impact sinkhole creation.

Both natural and manmade sinkholes can occur without warning. Specific signs that a sinkhole is forming include 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. Sinkholes can form into steep-walled holes or into bowl- or cone-shaped depressions. When sinkholes occur in developed areas, they can cause severe property damage, injury, loss of life, disruption of utilities, and damage to roadways. In urban and suburban areas, sinkholes can destroy highways and buildings.

Two common causes of subsidence in Pennsylvania are (1) dissolution of carbonate rock, such as limestone or dolomite; and (2) mining activity. Water passing through naturally occurring fractures and bedding planes dissolves bedrock, leaving voids below the surface. Eventually, overburden on top of the voids collapses, leaving surface depressions resulting in karst topography. Characteristic features associated with karst topography include sinkholes, linear depressions, and caves. Often, subsurface solution of limestone will not result in the immediate formation of karst features. Collapse sometimes occurs only after a large amount of activity, or when a heavy burden is placed on the overlying material (PEMA 2018).

The following sections discuss the location and extent, range of magnitude, previous occurrence, future occurrence, and vulnerability assessment associated with the subsidence/sinkhole hazard for Fulton County.

4.3.9.1 Location and Extent

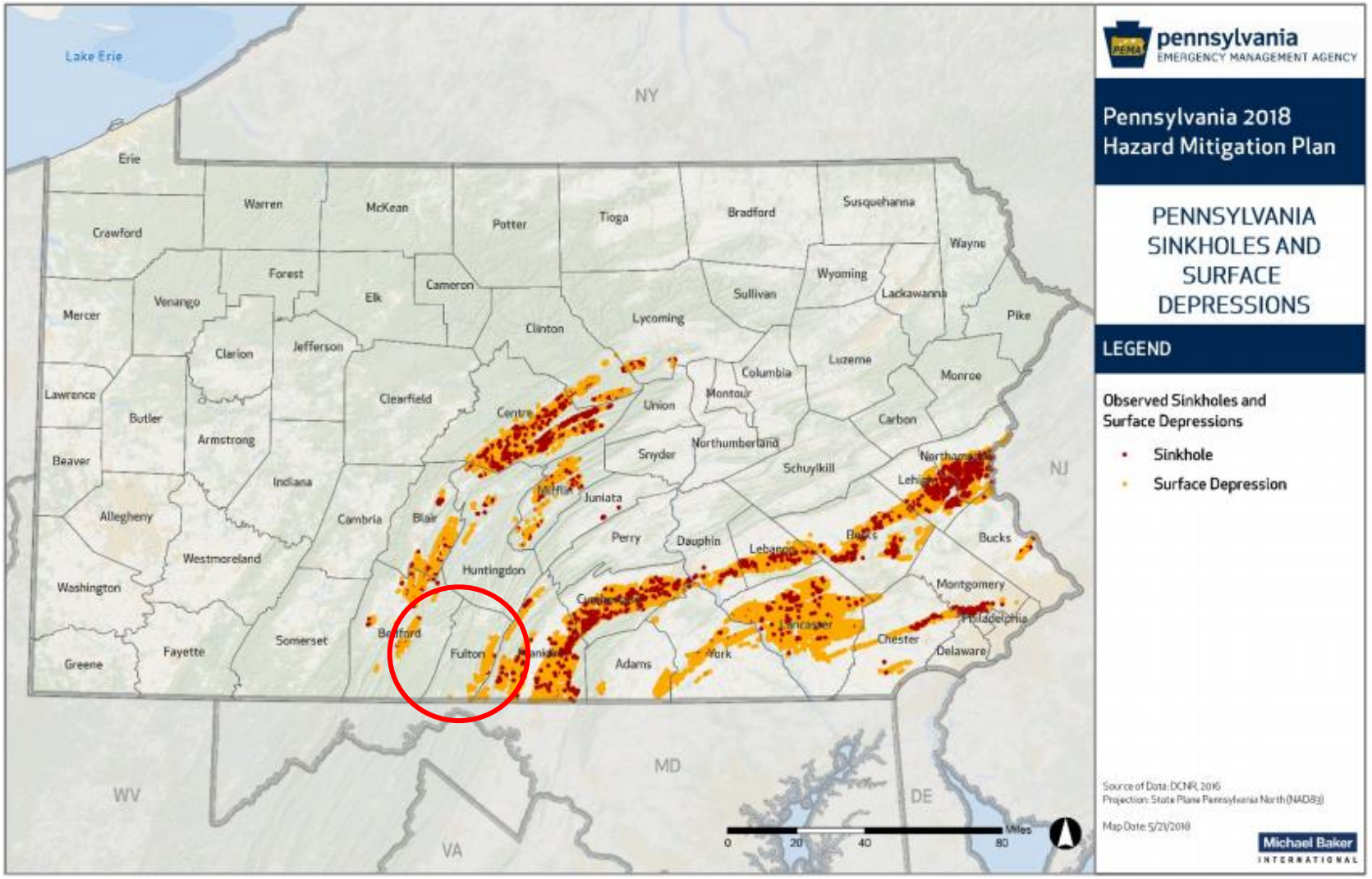
Approximately 17.7 percent of Fulton County (77.58 square miles) is underlain by carbonate bedrock (e.g., limestone). Fulton County has a very low susceptibility to sinkholes and subsidence attributable to abandoned underground mines; however, surface mines are present throughout the County.

Figure 4.3.9-1 highlights the areas of Pennsylvania subject to natural subsidence caused by the presence of limestone bedrock; Figure 4.3.9-2 more specifically illustrates the carbonate bedrock, abandoned mine areas, and digitized mine areas across Fulton County. The following municipalities have identified near-surface limestone within Fulton County:

- Ayr Township
- Bethel Township
- Dublin Township
- McConnellsburg Borough
- Thompson Township
- Todd Township

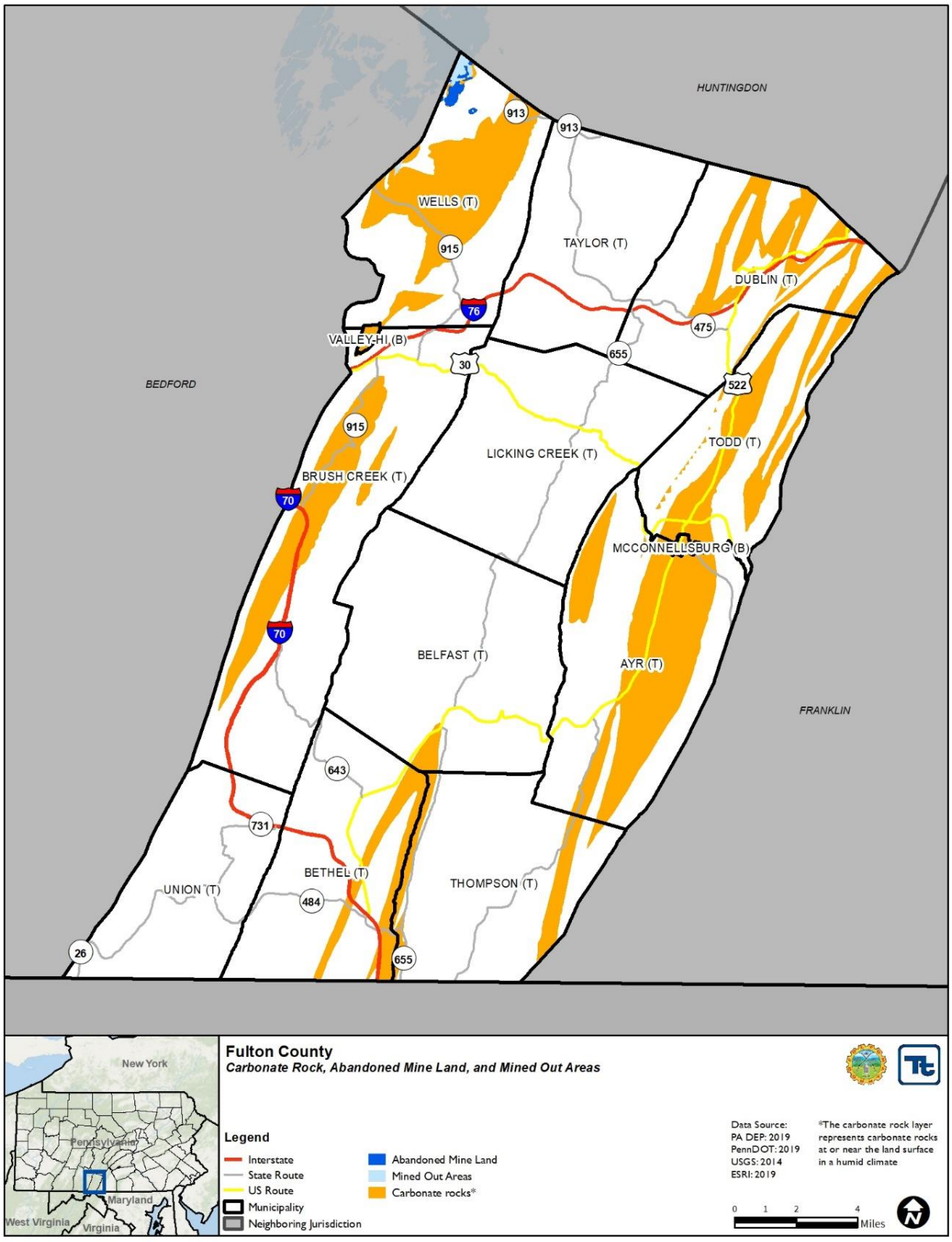
Fulton County has a very low susceptibility to sinkholes and subsidence attributable to abandoned mines; however, this does not mean such an event cannot occur. Figure 4.3.9-2 shows the approximate location of abandoned mine land problem areas created by past coal mining. Information illustrated in Figure 4.3.9-2 is based on a subset of data contained in the Office of Surface Mining Reclamation and Enforcement (OSMRE) Abandoned Mine Land (AML) Inventory. The AML Inventory data from July 2019 show 18 abandoned surface mines, 5 spoil areas, and 1 subsidence area within Fulton County (Pennsylvania Department of Environmental Protection [PADEP] 2019).

Figure 4.3.9-1. Inventoried Sinkholes and Surface Depressions in Pennsylvania



Source: PEMA 2018 (highlight added)

Figure 4.3.9-2. Abandoned Mine Lands, Mined Out Areas, and Carbonate Rock in Fulton County



While fewer karst features have been mapped in existing urban areas, human activity can often be the cause of a subsidence area or sinkhole. Leaking water pipes or structures that convey stormwater runoff may also result in areas of subsidence, as the water dissolves substantial amounts of rock over time. In some cases, construction, land grading, or earth-moving activities that cause changes in stormwater flow can trigger sinkhole events. Subsidence or sinkhole events may occur during mining activities, especially in areas where the cover of a mine is thin, or in areas where bedrock is not necessarily conducive to their formation. In their article titled "Sinkholes are Bad," authors Piggott and Eynon indicated that sinkhole development normally occurs where the interval to the ground surface is less than three to five times the thickness of the extracted seam, and the maximum interval is up to ten times the thickness of the extracted seam. Subsurface (i.e., underground) extraction of materials such as oil, gas, coal, metal ores (i.e., copper, iron, and zinc), clay, shale, limestone, or water may result in slow-moving or abrupt shifts in the ground surface (Piggott and Eynon 1978).

4.3.9.2 Range of Magnitude

Based on the geologic formations underlying parts of Fulton 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. Abrupt subsidence and sinkhole events can cause severe damage in urban environments; gradual events can be addressed before significant damage occurs. 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.

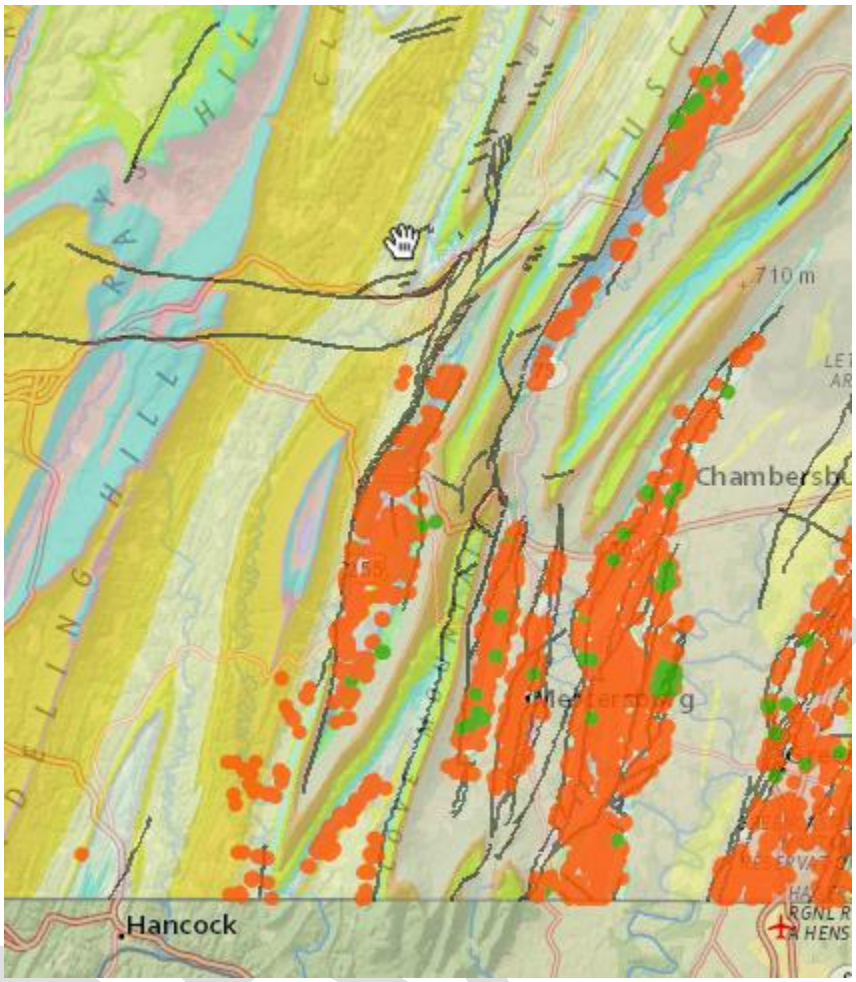
Sinkholes also may have negative effects on local groundwater. Groundwater in limestone and other similar carbonate rock formations can be easily polluted, because water moves readily from the earth's surface down through solution cavities and fractures, thus undergoing very little filtration. Contaminants of concern include sewage, fertilizers, herbicides, pesticides, and industrial products.

The worst-case scenario for sinkholes in Fulton County would be a series of large sinkholes opening in Ayr Township. Long swaths of the Township have near-surface limestone, making it vulnerable to sinkholes. This series of sinkholes could close roads, cause power outages, prevent the delivery of emergency services, and cause injuries or death to the Township's residents.

4.3.9.3 Past Occurrence

The Pennsylvania Department of Conservation and Natural Resources (PA DCNR) Interactive Map (Figure 4.3.9-3) shows dozens of sinkholes and hundreds of surface depressions in Fulton County (PA DCNR, n.d.).

Figure 4.3.9-3. Sinkholes and Surface Depressions in Fulton County



Source: PA DCNR, n.d.
Note: Sinkholes are shown with green dots; surface depressions are shown with orange dots.

Because large-scale or fast-moving subsidence events can trigger landslides, landslides can be an indication of a potentially greater or secondary hazard.

4.3.9.4 Future Occurrence

Although sinkhole occurrence will continue to be a possibility in Fulton County, the probability of a sinkhole or subsidence event is difficult to estimate because of the low number of previous events. Areas to monitor for future sinkhole and subsidence events based on their geologic bedrock are listed above in Section 4.3.9.1.

Potential losses caused by sinkhole formation are difficult to calculate for all existing buildings, critical facilities, and infrastructure, because the hazard area may affect so much of the County. However, the future occurrence of subsidence areas and sinkholes is considered *likely* as defined by the Risk Factor Methodology probability criteria (further discussed in Section 4.4).

4.3.9.5 Vulnerability Assessment

To understand risk, a community must evaluate the assets that are exposed or vulnerable in the identified hazard area. This section discusses the potential impact of the subsidence and sinkhole hazard on Fulton County in the following subsections:

- Impact on (1) life, health, and safety; (2) general building stock; (3) critical facilities; (4) economy; (5) environment; and (6) future growth and development
- Effect of climate change on vulnerability
- Further data collections that will assist understanding of this hazard over time

Approximately 17.7 percent of Fulton County (77.58 square miles) is underlain by carbonate bedrock. For the purposes of this planning effort, the area underlain by carbonate (limestone) bedrock is considered exposed to this hazard. Table 4.3.9-1 summarizes the municipalities potentially vulnerable to sinkholes and subsidence events based on the presence of carbonate bedrock.

Table 4.3.9-1. Municipalities Vulnerable to Sinkholes/Subsidence Events

Municipality	Carbonate Rock	Municipality	Carbonate Rock
Ayr Township	x	Taylor Township	
Belfast Township	x	Thompson Township	x
Bethel Township	x	Todd Township	x
Brush Creek Township	x	Union Township	
Dublin Township	x	Valley-Hi Borough	x
Licking Creek Township		Wells Township	x
McConnellsburg Borough	x		

Source: USGS 2014; PADEP 2014

Impact on Life, Health, and Safety

To estimate the number of individuals exposed to the hazard, the total population for each municipality was divided by the number of residential buildings to establish an average population per residential structure that intersects the carbonate bedrock area. Table 4.3.9-2 summarizes the Fulton County population exposed to this hazard by municipality (U.S. Census 2010). The 2010 U.S. Census data are also used to maintain consistency in data throughout vulnerability assessments throughout this hazard mitigation plan. (Note: Municipal boundaries do not align with the carbonate bedrock polygon in the spatial data, and these estimates are for planning purposes only.)

Table 4.3.9-2. Estimated Population Located over Carbonate Bedrock (U.S. Census 2010)

Municipalities	Total Population (2010 U.S. Census)	Estimated Population Exposed	Percent Total
Ayr Township	1,942	1,165	60.0%
Belfast Township	1,448	112	7.8%
Bethel Township	1,508	169	11.2%
Brush Creek Township	819	288	35.1%
Dublin Township	1,264	230	18.2%
Licking Creek Township	1,703	0	0.0%

Municipalities	Total Population (2010 U.S. Census)	Estimated Population Exposed	Percent Total
McConnellsburg Borough	1,220	1,208	99.0%
Taylor Township	1,118	0	0.0%
Thompson Township	1,098	75	6.9%
Todd Township	1,527	1,005	65.8%
Union Township	706	0	0.0%
Valley-Hi Borough	15	15	100.0%
Wells Township	477	454	95.1%
Fulton County	**14,845**	**4,721**	**31.8%**

Source: U.S. Census 2010; USGS 2014

Impact on General Building Stock

As noted above, no standard loss estimation models exist for the subsidence and sinkhole hazard. In general, the built environment located on limestone is exposed to this hazard. In an attempt to estimate the general building stock potentially vulnerable to this hazard, the associated building replacement values (buildings and contents) were determined for the identified U.S. Census blocks within the approximate hazard area. The County-provided spatial layer for building structures was also used to determine the number of structures located within the hazard area. Table 4.3.9-3 lists the replacement cost value (RCV) (structure and contents) of general building stock (GBS) and number of structures located within the defined hazard area.

Table 4.3.9-3. Estimated General Building Stock Located over Carbonate Bedrock

Municipality	Total Number of Buildings	Total RCV	Carbonate Bedrock Area			
			Number of Buildings	% of Total	RCV	% of Total
Ayr Township	1,139	$328,056,000	676	59.4%	$208,651,000	63.6%
Belfast Township	740	$181,485,000	54	7.3%	$6,676,000	3.7%
Bethel Township	853	$243,010,000	100	11.7%	$20,208,000	8.3%
Brush Creek Township	519	$110,481,000	180	34.7%	$55,560,000	50.3%
Dublin Township	697	$153,284,000	125	17.9%	$37,533,000	24.5%
Licking Creek Township	881	$203,625,000	0	0.0%	$0	0.0%
McConnellsburg Borough	538	$276,419,000	538	100.0%	$276,419,000	100.0%
Taylor Township	697	$141,644,000	0	0.0%	$0	0.0%
Thompson Township	572	$155,461,000	40	7.0%	$1,195,000	0.8%
Todd Township	858	$298,975,000	566	66.0%	$269,306,000	90.1%
Union Township	421	$106,265,000	0	0.0%	$0	0.0%
Valley-Hi Borough	29	$5,827,000	29	100.0%	$5,827,000	100.0%
Wells Township	292	$58,946,000	280	95.9%	$58,402,000	99.1%
Fulton County	**8,236**	**$2,263,478,000**	**2,588**	**31.4%**	**939,777,000**	**41.5%**

Source: HAZUS-MH v4.2; USGS 2014; Fulton County 2019
Notes: GBS = General building stock
RCV = Replacement cost value

Impact on Critical Facilities

A number of critical facilities and utility assets are located in the hazard area and are also exposed to subsidence and sinkholes. In addition to impacting buildings and facilities, subsidence can severely impact roads and infrastructure. Major roadways that serve the County include Interstate I-70, I-76; Routes US-30, US-522, and US-322; and multiple State Routes, including PA-475, PA-484, PA-655, PA-913, PA-915, and PA-928. These roadways are built in areas underlain by carbonate bedrock or underground coal mines. The following summarizes potential impacts to critical infrastructure:

- Roads—Access to major roads after a disaster is crucial to safety and to response operations. Depending on the size, events can block egress and ingress on roads, causing isolation for individual residents and potentially entire neighborhoods, traffic problems, and delays for transportation. These factors can result in economic losses for businesses.
- Bridges—Mass movements can knock out bridge abutments or significantly weaken the soil supporting them, making them hazardous for use.
- Power Lines—A subsidence event could trigger failure of the soil underneath a tower, causing it to collapse and ripping down the lines. Power and communication failures can create problems for vulnerable populations and businesses.

A number of critical facilities and utility assets are located in the hazard area and are also exposed to subsidence and sinkholes. Table 4.3.9-4 summarizes the number of critical facilities that are located within the identified hazard area, as identified by participants in the Fulton County Hazard Mitigation Plan (HMP) planning process.

Table 4.3.9-4. Number of Critical Facilities Located in the Identified Hazard Area (Carbonate Bedrock)

Municipality	Facility Types																					
	Commercial	Communications	County Office	Dam	Day Care	DPW	EOC	Fire	Hazmat	Hospital	Library	Municipal Park	Police	Polling Station	Post Office	Potable Water	Power	School	Senior	Shelter	Substation	Wastewater
Ayr Township	1	0	0	1	0	0	0	0	3	0	0	1	0	1	1	0	0	0	0	1	6	1
Belfast Township	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
Bethel Township	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Brush Creek Township	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	2	1
Dublin Township	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Licking Creek Township	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
McConnellsburg Borough	0	2	4	0	0	0	1	2	1	0	1	1	0	0	1	1	0	0	2	0	9	0
Taylor Township	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thompson Township	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Todd Township	0	0	0	0	1	1	0	0	1	1	0	0	1	0	0	0	1	1	0	0	2	0
Union Township	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Valley-Hi Borough	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Wells Township	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	4	0
Fulton County	**1**	**4**	**4**	**3**	**1**	**1**	**1**	**2**	**5**	**1**	**1**	**5**	**1**	**1**	**4**	**3**	**2**	**1**	**2**	**1**	**26**	**2**

Source: USGS 2014; Fulton County 2019

Impact on the Economy

Subsidence and sinkholes can severely impact roads and infrastructure. As noted earlier, carbonate formations underlie almost 17.7 percent of the County. Major roadways that serve the County include Interstate I-70, I-76; Routes US-30, US-522; and multiple State Routes, including PA-475, PA-484, PA-655, PA-913, PA-915, and PA-928. Portions of each of these roadways are located in the identified subsidence and sinkhole hazard area. It is not possible to estimate potential future economic losses caused by subsidence and sinkhole events at this time.

Impact on the Environment

The presence of sinkholes can result in increased potential for groundwater contamination. Because of the porous nature of the areas in which they occur, sinkholes are sometimes used as instruments for enhancing groundwater recharge. However, if hazardous materials are spilled at a recharge point, groundwater can quickly be contaminated due to the lack of soil substrate that would normally slow migrating contaminants. Vegetation is usually damaged during abrupt subsidence events. However, regrowth takes place over time. Land subsidence can also result in more frequent and expansive flooding and changes in river canal and drain flow systems (PEMA 2018).

Future Growth and Development

Areas targeted for potential future growth and development in the next 5 to 10 years have been identified across the County at the municipal level and are described in Section 2.4 of this Plan. New development occurring within the identified hazard areas may be exposed to risks associated with the subsidence and sinkhole hazard.

Effect of Climate Change on Vulnerability

Climate is defined not simply as average temperature and precipitation, but also by the type, frequency, and intensity of weather events. Both globally and at the local level, climate change has the potential to alter the prevalence and severity of weather extremes (U.S. Environmental Protection Agency [EPA] 2006).

Climate change factors such as an extended growing season, higher temperatures, and the possibility of more intense and less frequent summer rainfall may lead to changes in water resource availability. As stated earlier in this profile, changes to the water balance of an area will cause sinkholes. Water-balance changes include over-withdrawal of groundwater, diverting surface water from a large area and to concentrate flow towards 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.

The potential effects of climate change on Fulton County's vulnerability to subsidence and sinkhole events will need to be considered as more information develops regarding regional climate change impacts.

Additional Data and Next Steps

While it is not possible to predict when and where the next event may take place, the Fulton County emergency services, including local fire and police departments, are well-equipped and prepared to respond to emergencies as they arise. The status of subsidence and sinkhole risk in Fulton County will continue to be monitored, and ongoing and new mitigation efforts will continue to be developed.