4.17 Land Subsidence, Sinkhole, and Karst

4.17.1 Hazard Profile

Karst is the term used to refer to landscapes dominated by limestone and similar soluble carbonate rocks. Acidic groundwater and rainfall dissolves the surrounding carbonate rocks creating sinkholes. Sinkholes are classified as natural depressions of the land surface. Areas with large amounts of karst are characterized by the presence of sinkholes, sinking streams, springs, caves, and solution valleys (Weary and Doctor 2014). Human activities can expedite cavity formation in these susceptible materials and trigger their collapse, as well as the collapse of pre-existing subsurface cavities. Sinkholes are a frequent occurrence in areas underlain by calcareous carbonate formations, especially limestone and dolomite. Areas of abundant sinkholes are referred to as karst topography.

Land subsidence is the lowering of surface elevations due to changes made underground. It involves either the sudden collapse of the ground to form a depression or the slow subsidence or compaction of the sediments near the Earth's surface. It often occurs in regions with mildly acidic groundwater and the geology is dominated by limestone, dolostone, marble, or gypsum. Land subsidence is often due to natural processes: the dissolution of carbonate rocks (limestones) beneath the surface. In addition, human activity, such as fluid withdrawal (e.g. pumping of water, oil, or gas) from underground reservoirs, can cause land subsidence. Because the fluid withdrawal related subsidence usually destroys small areas, this plan update focuses on the carbonate substances related land subsidence which usually impacts massive areas.

Karst Aquifers

An aquifer is a subsurface layer or zone of porous and permeable rock, or porous and permeable unconsolidated sediments (e.g., sand or gravel), that has groundwater in its openings. Water in karst regions typically moves from sinkholes--where it is diverted from surface to subsurface pathways--to subterranean passages, and back to surface water at the spring outlet. Aquifers in karst regions can hold tremendous quantities of water because of the very large size of the openings that are commonly present in the limestone (e.g. cave passageways that are completely flooded with water).

4.17.1.1 Geographic Location/Extent

The distribution of mature surface karst landscapes are primarily dependent on the presence of soluble rocks at or near the land surface and mean annual precipitation above approximately 30 inches. In the United States, the formation of underground cavities can form and catastrophic sinkholes can occur. These rock types are evaporites (salt, gypsum, and anhydrite) and carbonates (limestone and dolomite). In the Eastern U.S., most karst features, such as sinkholes, occur in carbonate (limestone and dolomite) rocks. Figure 4-160 shows Karst distributions in Virginia where certain rock types are susceptible to dissolution in water. [86] It depicts areas containing rock types that, under a very broad definition, have developed or have the potential for developing karst features.

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[86] Weary and Doctor. 2014. https://dx.doi.org/10.3133/ofr20141156. The map data was compiled from the USGS karst map and database, and the USGS Groundwater Atlas of the United States.

In Virginia, the most dominant karst region is the Valley and Ridge Province in the western third of the state. Smaller karst areas also occur in the Piedmont, Cumberland Plateau, and Coastal Plain provinces. At least 29 counties contain significant karst terrain in western Virginia. Although the karst landscape is not prevalent in the Piedmont region where the CVPDC area is located, the western edge of the region is immediately adjacent to the edge of the Valley and Ridge Province. Soluble carbonate rock units susceptible to karst development include primarily limestone and dolomites, which are chiefly distributed throughout the Valley and Ridge Province. Smaller carbonate areas, consisting of limestone, dolomite, and marble, occur in the Piedmont region as well, primarily along the northern boundary of Appomattox County and Campbell County (Figure 4-161).

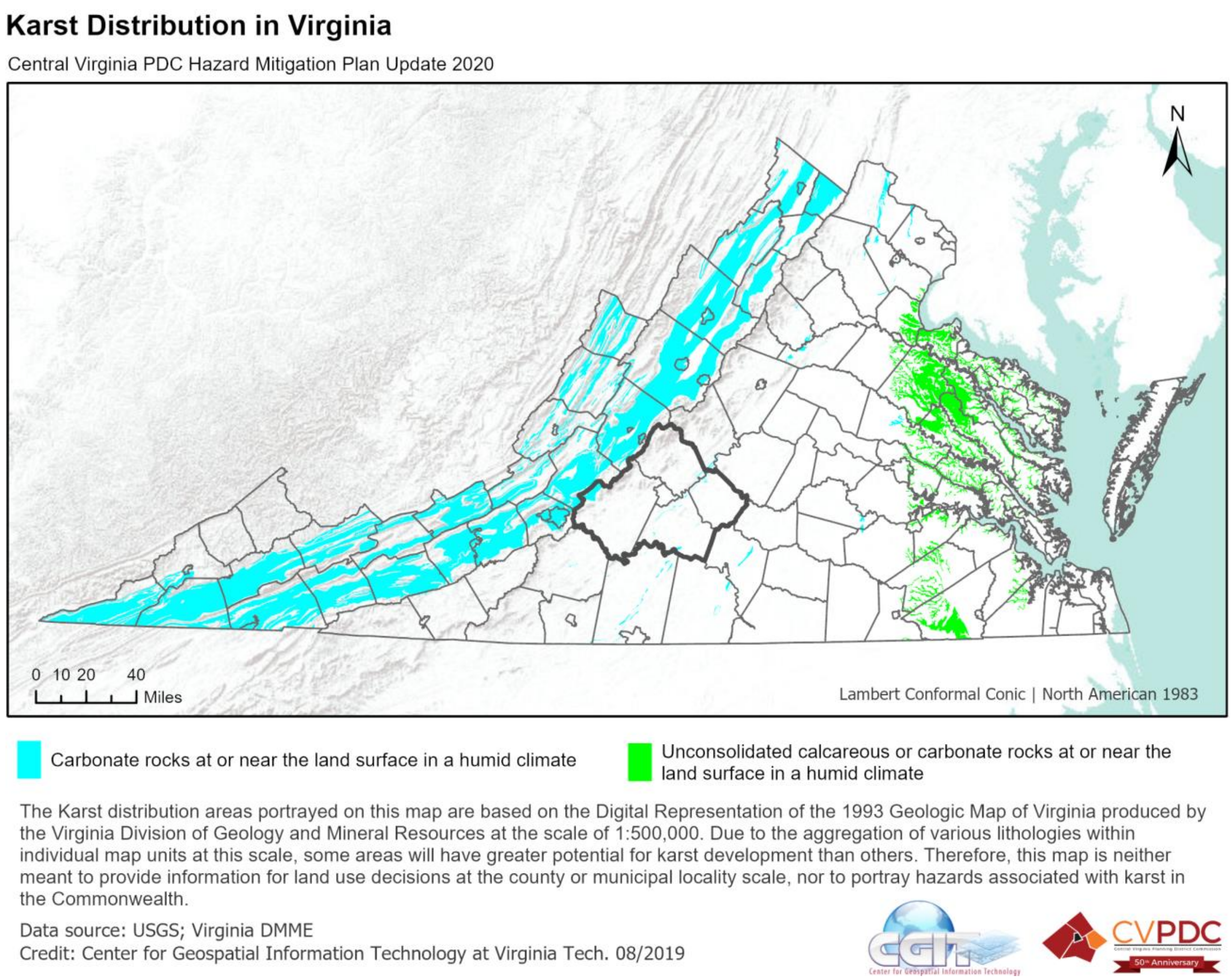

Figure 4-160 Karst distribution in Virginia

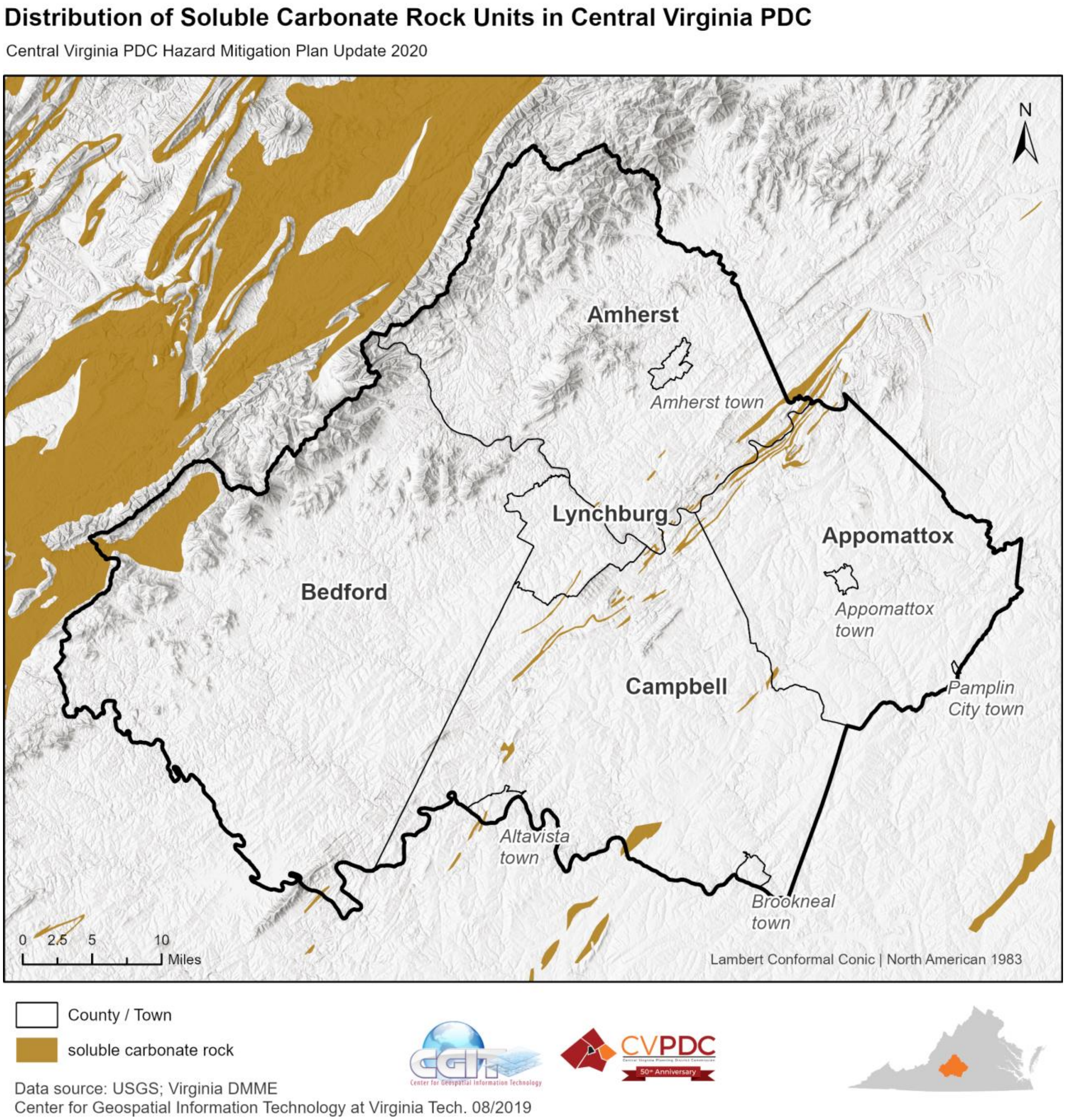

Figure 4-161 Distribution of Soluble carbonate rock units in CVPDC Area

4.17.1.2 Previous Occurrence

According to the Virginia State Hazard Mitigation Plan, there have been no Federal Declared Disasters or National Centers for Environmental Information recorded events for karst related events, either in the CVPDC area or in the Commonwealth. Land subsidence and sinkholes are very site-specific. There is no comprehensive long-term record of past events in Virginia.

4.17.1.3 Relationship to Other Hazards

Figure 4-162 shows the interrelationship (causation, concurrence, *etc.*) between this hazard and other hazards discussed in this plan update.

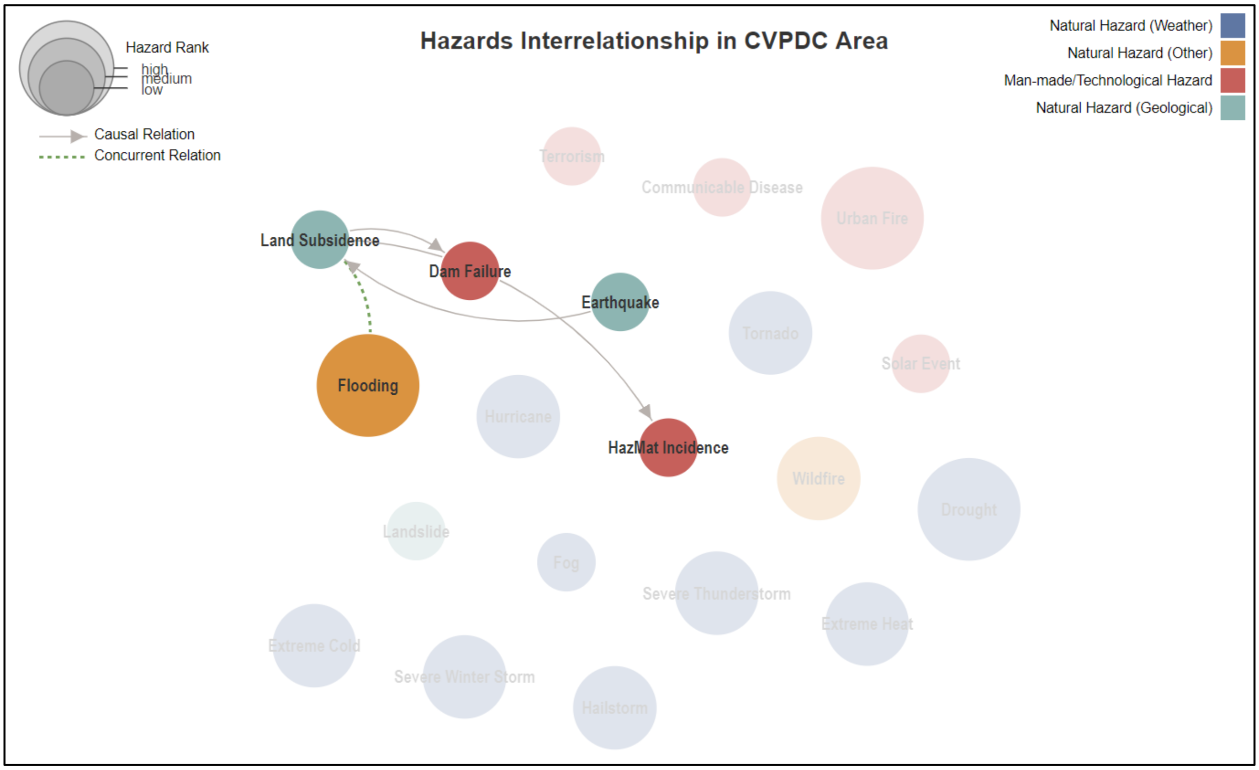

Figure 4-162 Hazards interrelationship

4.17.2 Impact and Vulnerability

In Virginia, the principal area affected by land subsidence or sinkholes is the Valley and Ridge Province, an extensive karst terrain underlain by limestone and dolomite, but the narrow marble belts in the Piedmont and some shelly beds in the Coastal Plain are also pocketed with sinkholes. Figure 4-163 presents potential risk areas for the Commonwealth of Virginia. These areas are broadly defined and mapped with a general understanding of karst hazard risks. According to Figure 4-160, a majority of the karst regions near the CVPDC area follow Interstate 81.

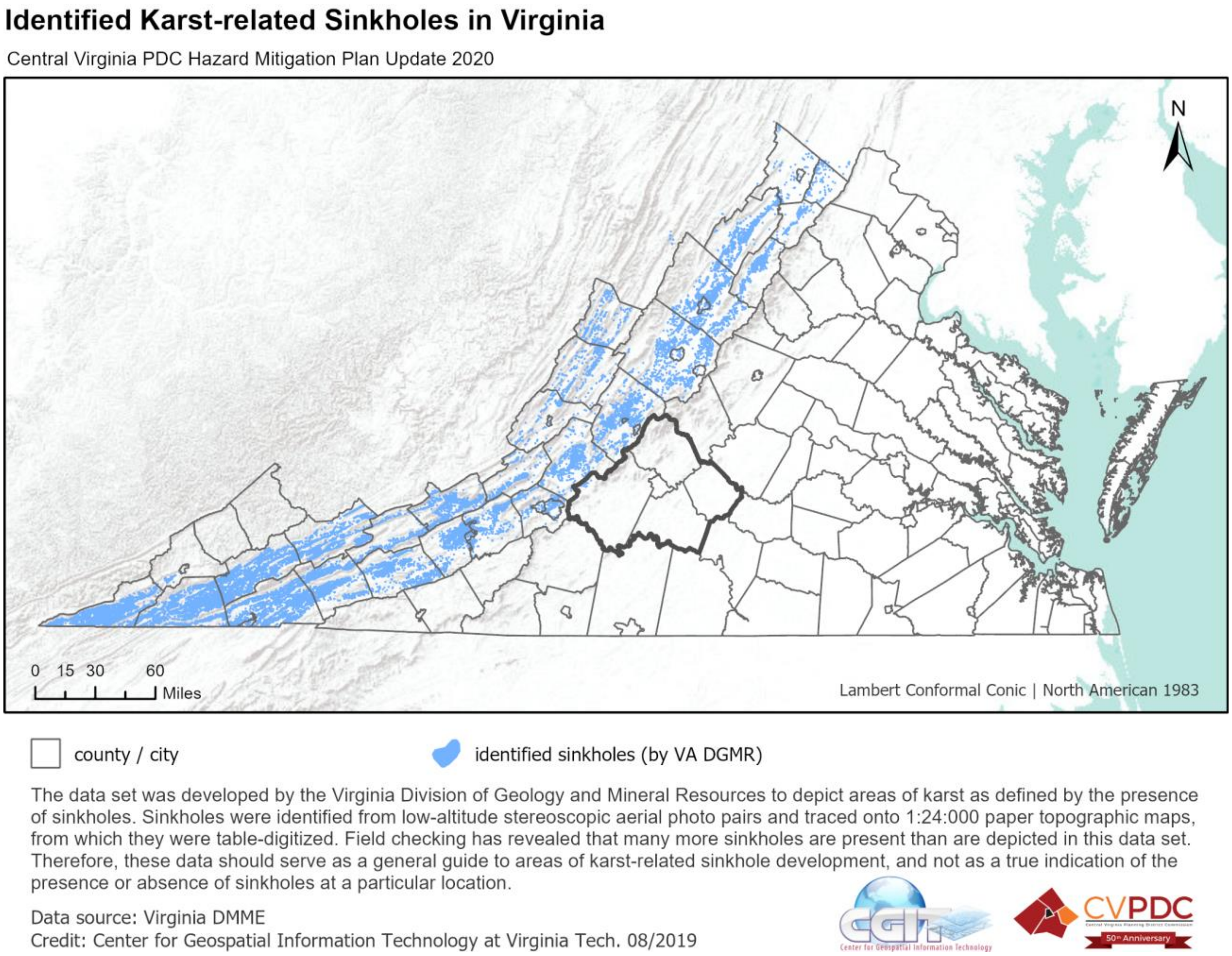

Figure 4-163 Identified Karst-related Sinkholes in Virginia. (Source: Virginia DMME)

4.17.2.1 Groundwater Supply

Sinkhole formation is a principal event associated with karst terrain. Although sinkholes are relatively uncommon events in the CVPDC area, they are still of particular concern because they serve as conduits between surface water and groundwater. This interaction can lead to rapid transport of surface pollutants introduced by various means such as urban runoff and use of sinkholes as trash dumps. The underground drainage system can also be blocked by erosion and sedimentation from construction sites and other human activities. In the United States, approximately 20 percent of the land surface is karst and roughly 43 percent of all groundwater withdrawals for public supply in the year 2000 came from karst aquifers.[87] Because so many people rely on groundwater (and wells) for drinking water, it is critical to protect the purity of groundwater, especially in environmentally sensitive karst terrain.

[87] Molly A. Maupin and Nancy L. Barber. Estimated withdrawals from principal aquifers in the United States, 2000. https://pubs.er.usgs.gov/publication/cir1279

4.17.2.2 Flooding and Pollution

There are two additional problems besides collapse that can result from the existence or formation of sinkholes: flooding and pollution.

> ***Abandoned Coal Mines***
>
> *Areas over underground mine workings are also susceptible to subsidence. According to the Abandoned Coal Mine Lands map by Virginia DMME, abandoned coal mines don't exist in the CVPDC area.*
>
> *https://www.dmme.virginia.gov/webmaps/aml/*

Sinkhole flooding can develop from a number of natural conditions; however, two man-made conditions are the most common causes in Virginia: *plugging* - backup of natural sinkhole drains by sediment - and *overwhelming runoff* - the overwhelming of natural sinkhole drains by increases in runoff due to artificial surfaces. Inadequate erosion control during construction can result in the plugging of natural sinkhole drains by sediment-laden runoff. The accompanying restriction of subsurface drainage causes an increase in ponding or flooding. Increased runoff from roads, parking lots, and structures is the most significant cause of sinkhole flooding. Much of the precipitation that would have percolated through a vegetated soil cover is introduced rapidly into surface and subsurface (input through sinkholes) drainage networks. Increases in runoff have been reported to range from 48 percent for areas of suburban housing to 153 percent or more for industrial or commercial areas. Such increases in runoff can exceed the drainage capacity of natural sinkhole drain and result in ponding or flooding. In severe cases, excessive runoff can overwhelm the capacity of the natural subsurface drainage systems of sinkholes, causing water to back-up and flood sinkholes up-system. [88]

Another major problem associated with sinkholes or karst topography is its impact on aquifers and potential for groundwater contamination. The greatest impact occurs when polluted surface waters enter karst aquifers. This problem is universal among all populated areas located in areas of karst. The groundwater problems associated with karst are accelerated with: (1) expanding urbanization, (2) misuse and improper disposal of environmentally hazardous chemicals, (3) shortage of suitable repositories for toxic waste (both household and industrial), and (4) ineffective public education on waste disposal and the sensitivity of the karstic groundwater system. [89]

The USGS recognizes four major impacts caused by land subsidence:

- 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
- Failure of well casings from forces generated by compaction of fine-grained materials in aquifer systems

Although land subsidence hazard in the CVPDC area is not ranked as high as it is in Virginia coastal regions, where low-lying topography are susceptible to sea-level rise, land subsidence does have the potential to negatively impact assets and residents in the area. Damage to infrastructure in the region, such as

[88] Virginia DMME - Sinkholes: https://www.dmme.virginia.gov/dgmr/pdf/sinkholes.pdf
[89] Ernst H. Kastning. An expert report on geologic hazards in the karst regions of Virginia and West Virginia. 2016. http://wp.vasierraclub.org/KastningReport.pdf

buildings, bridges, and pipelines, can be caused by relative groundwater rise or land settling. Storm and wastewater sewers in urban areas may be vulnerable because subsidence can alter the flow through the sewers, causing increased flooding and more frequent sewer discharge from overflows. Land subsidence can also increase flooding risk such as locations along James River. Land subsidence could alter the topographic gradient that drives the flow of the river and possibly contributing to the flooding.

In flat karst regions, landslide or rock failures could possibly occur along the walls of the valleys. In addition to the usual factors that influence slope movements, the presence of karst voids and conduits, and the deriving modality of water circulation may further influence rock failures.[90] Karst rocks like carbonate rocks and gypsum are especially failure-prone.[91] In addition to landslides and sinkholes, breakdown processes within caves are extremely common in karst, and may represent a geohazard even to the built-up environment, due to the possibility of void migration toward the surface.

4.17.3 Risk Assessment and Jurisdictional Analysis

Critical facilities and infrastructures at risk in karst terrain were identified using the map of known soluble carbonate rock units. Table 4-155 presents the names and locations of these facilities. Besides, several pipeline portions also transverse karst terrains: a portion of hazardous liquid pipeline line and a breakout tank in Montvale area in Bedford County and another portion near the boundary of Amherst County/Appomattox County; a portion of Transcontinental Gas pipeline near Long Island in Campbell County (Figure 4-164).

The risk and potential impacts of land subsidence depend on the type of subsidence that occurs (regional or localized, gradual or sudden) and the location in which the subsidence occurs. Potential damage and loss due to sinkholes or land subsidence is nearly impossible to assess because the nature of the damage is site- and event-specific.

4.17.4 Probability of Future of Occurrences

Given the report of small land subsidence/sinkhole in the CVPDC area is not uncommon in the news media, as well as the existence of karst landscape in the CVPDC area, it is certain that a future event will occur. However, the lack of long-term record of historical occurrences and comprehensive, readily available scientific studies make it difficult to predict probability of future occurrence, only that it is likely.

Table 4-155 Critical Facility and Infrastructure in Karst Terrain in CVPDC Area

Locality	Facility Name	Facility Type	Location	Coordinates
Amherst	Greif Packaging Containerboard Mill	HazMat Facility	861 Fibre Plant Rd	37.5107, -78.9101
Amherst	Greif Brothers Packaging Corporation - Riverville Mill Fire	Fire Stations	861 Fibre Plant Road	37.5120, -78.9083

[90] http://cdn.intechweb.org/pdfs/27974.pdf
[91] Rock Failures in karst: https://www.researchgate.net/publication/233731628_Rock_failures_in_karst

Locality	Facility Name	Facility Type	Location	Coordinates
	Brigade And Emergency Medical Services			
Amherst	Gas Facility	Gas Facility		37.4951, -79.0568
Bedford	Woodhaven Nursing Home	Nursing Home	13055 West Lynchburg/Salem Turnpike	37.3981, -79.7539
Bedford	Transmontaigne - Montvale Piedmont Terminal	HazMat Facility	11685 W Lynchburg Salem Tpke	37.3881, -79.7316
Bedford	Montvale Wastewater Treatment	Wastewater Treatment Plant	185 Little Patriot Dr	37.3719, -79.7094
Bedford	Montvale Volunteer Fire Department	Fire Stations	1271 Volunteer Road	37.3850, -79.7305
Bedford	Montvale Pump Station	Sewer Pump Station		37.3788, -79.7098
Bedford	Montvale Elementary	Schools	1 Little Patriot Drive	37.3759, -79.7084
Bedford	Buckeye Terminals, Llc - Roanoke Terminal	HazMat Facility	1070 Oil Terminal Rd	37.3842, -79.7342
Campbell	Water Tank	Water Storage Facility	Bedford Avenue	37.1135, -79.2989
Campbell	Virginia State Police Division 3 Area 20 - Lynchburg	Law Enforcement	1065-G Airport Road	37.3306, -79.2030
Campbell	Rt 622 Pump Station	Water Booster Pump Station	1610 Waterlick Rd, Lynchburg, Va 24501	37.3147, -79.2263
Campbell	Lynchburg Regional Airport Aircraft Rescue Fire Fighting	Fire Stations	984 Airport Road	37.3289, -79.2016
Campbell	Lyn-Dan Heights Volunteer Fire Department	Fire Stations	578 Lawyers Road	37.3127, -79.1953
Campbell	Leesville Estates Pump Station	Sewer Pump Station		37.3027, -79.2425
Campbell	Lawyers Road Pump Station	Sewer Pump Station		37.3138, -79.1947
Campbell	Flat Creek Pump Station	Sewer Pump Station		37.3096, -79.1830
Campbell	Altavista High	Schools	904 Bedford Avenue	37.1095,

Locality	Facility Name	Facility Type	Location	Coordinates
				-79.2953
Lynchburg	Sylvain Melloul International Hair Academy	College		37.3644, -79.1797
Lynchburg	Lynchburg City Emergency Communication Center	Emergency Operations Center	3621 Candlers Mountain Road	37.3638, -79.1720
Lynchburg	Liberty University Police Department	Law Enforcement	1971 University Boulevard	37.3581, -79.1757
Lynchburg	Electrical Substation	Electrical Substation		37.3617, -79.1798
Lynchburg	Davis Frost Inc	HazMat Facility	3420 Candlers Mountain Rd	37.3675, -79.1730
Lynchburg	C.R. Hudgins Plating, Inc.	HazMat Facility	3600 Candlers Mountain Rd	37.3639, -79.1721

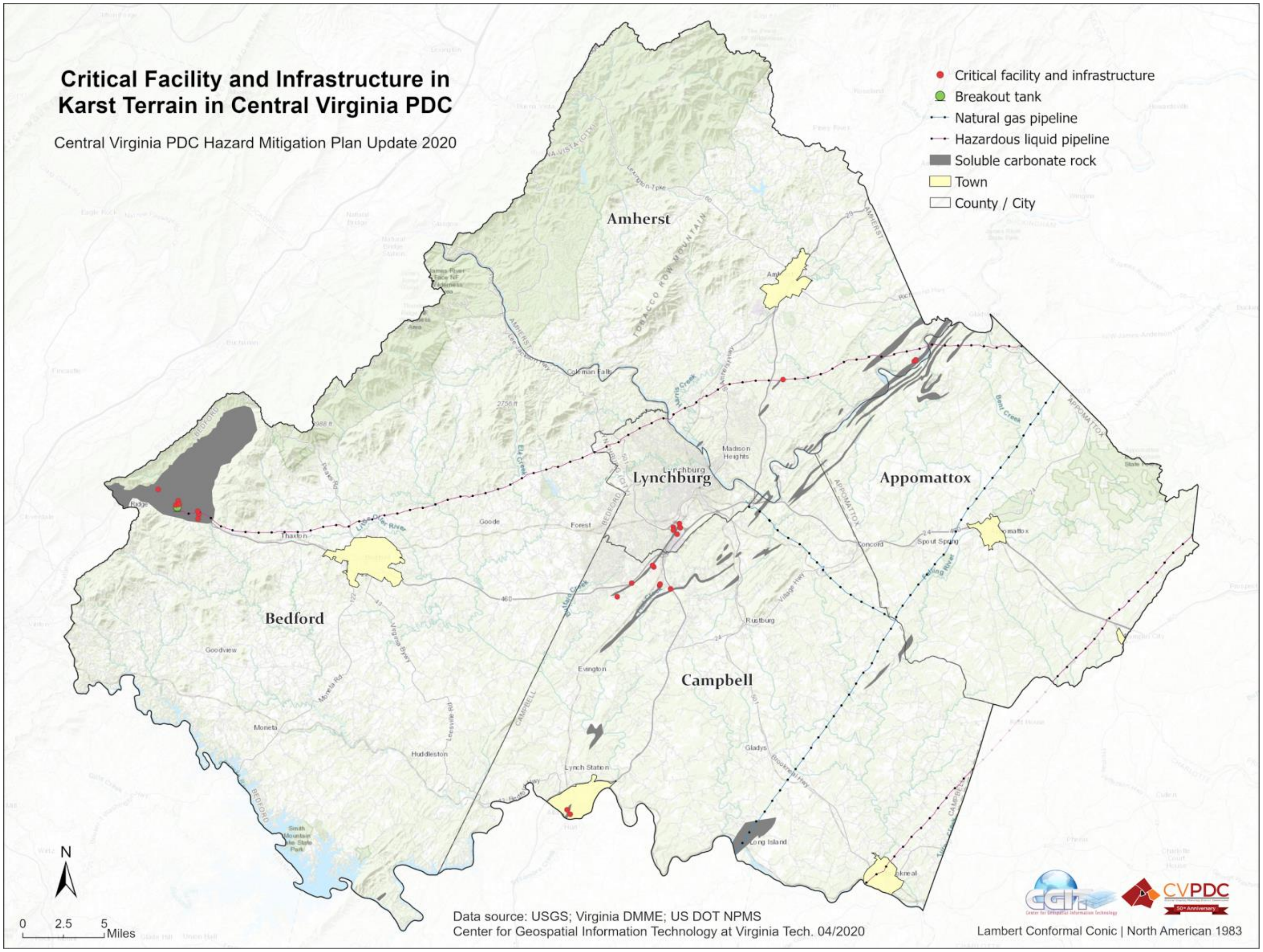

Figure 4-164 Critical Facility and Infrastructure in Karst Terrain in CVPDC Area

4.17.5 Reference

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